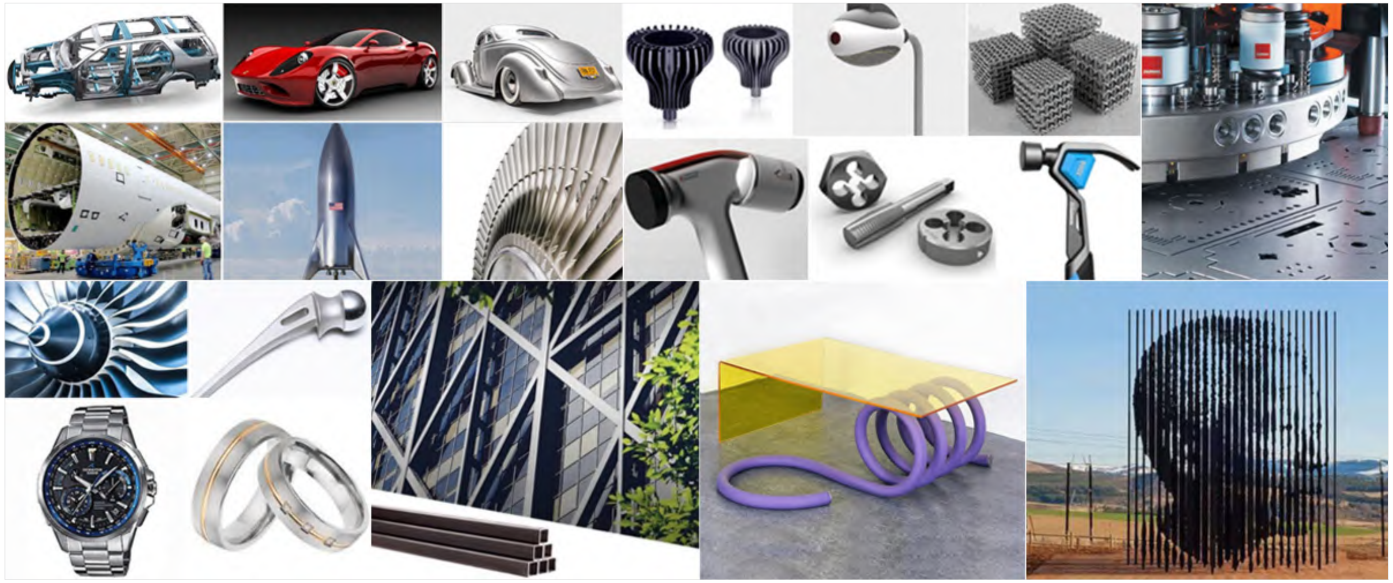
Design Course

Sheet Metal

Fabrication Technology in Product Design

by

Kishore Babu Kamatham



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Introduction

Chapter 1

Introduction

It is impossible not to notice one or more sheet metal objects at any given time in and around our work environments. From a hairpin, bottle cap, utensil, appliances to cars, airplanes, railway coaches, and many more, sheet metal's presence and association in everyday living is a fact of life. However, not much is known to everybody as to what goes behind before a sheet of metal turns into an object.

Sheet Metal, steel to a large extent, aluminium, stainless steel followed by titanium, brass, copper, exotic materials like gold and silver are present practically in every industry in some form or other. Sheet metals have more applications than virtually any other materials in the manufacturing industry. From cooking utensils to seatbelts, bridges to automobiles, cabinets to ornaments, these sheet metals are found as products everywhere.

The advantage of sheet metal is its higher strength-to-weight ratio. It is also strong and durable as compared to other contemporary materials like wood and plastic.

This document aims to briefly expose sheet metal fabrication technologies in product design to novices and professional design practitioners. It is aimed at explaining different types of materials and fabrication technologies that are commonly used. This study material also attempts to illustrate examples closely related to product design rather than general fabrication.

There is a misnomer that sheet metal in a general fabrication sense is crude and lacks finesse. Sheet metal offers much better scope than plastics in reaching out to customers quickly in wide appealing varieties.

1. Broad product areas using sheet metal

- Electrical, Electronics
- Automobile
- Furniture
- Domestic Utensils
- Exhibitions
- Signage
- Gifts, Novelty
- Packaging
- Construction
- Transportation, to name a few

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2. Examples of sheet metal products in everyday use – Mini to Mega

Engineering products are not inert. They do not lack the strength to evoke feelings. Every product we come across in everyday life has its own character. The efforts of engineers and designers ultimately culminate in a product is not that not only functional but also enjoyable to feel and even perplexing at times.

Small Instruments


Durable (Image source)


Cheap


Functional

Domestic Artifacts, Utensils, Appliances


Novel


Utility


Appropriate

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Housings and Enclosures


Economical


Protective (Image source)


Friendly

Furniture


Aesthetic (Image source)


Economical (Image source)


Different

Automobiles


Cost Effective (Image source)


Experimentative (Image source)


Evocative (Image source)

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Aerospace

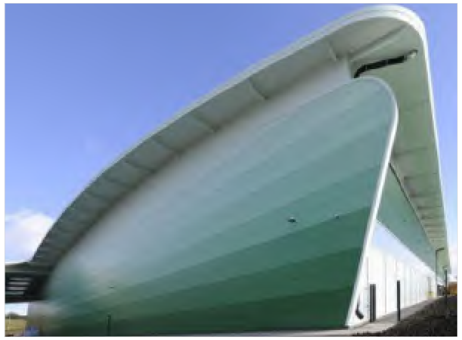

Large (Image source)


Unbeatable (Image source)


Long and Short

Construction


Modular (Image source)


Professional


Variety (Image source)

Art


Beautiful (Image source)


Strong (Image source)

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3. Manufacturing Methods
There are three types of productions involved in any manufacturing activity. They are,

• Mass Production
• Batch Production
• Custom Production

Mass Production


(Image source) (Image source)
Consumer Items small and big, are produced in large quantities

Mass production is where goods of the same type are produced in large quantities. In such cases, Capital Expenditure (CAPEX) on tooling is high. Operational Expenditure (OPEX), i.e., the production cost is low. Examples being automobile parts, Consumer goods, Utensils, Tools, etc. In mass production, manpower skill requirements are low.

Mass production involves moving the product part through a series of pre-determined stages continuously for processing and achieving a higher rate of production. This involves systematic planning in setting up the production line. The risk being, if there is a quality defect somewhere in the line, the entire line production of a production line is affected.

Batch Production

(Image source)
Predominantly industrial items, produced in batch quantities

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Batch production is where goods are produced in batches as per the given specification for each batch. CAPEX in batch production is low, and OPEX is medium. Examples are enclosures, cabinets, and the like. In batch production, the manpower skill requirements are medium level when large, medium-size products such as machine enclosures, electrical and electronic cabinets involving batch production, and sheet metal are the most preferred material for fabrication purposes.

In batch production, a group of product parts are made at one place and moved from one workplace to another workplace in a "batch." This method or production normally involves universal machines which are easily modified to process different components. One advantage of batch production is better quality control. Each batch is checked for quality before moving to the next stage. If there are quality issues, only a batch is affected by the entire lot.

Custom Production

(Image source)

(Image source)

One off item, produced to custom specifications

Custom Production or One of type involves just one or very few numbers produced mostly on highly customized specifications. Examples being Ship Bodies, Engineering Structures, Sculptures, and Handicrafts, etc. Custom production practically eliminates any kind of CAPEX but is high on OPEX. Manpower skill required is also high on the scale. There will be a lot of fluidity in the entire product building process. This requires continuous updating of information and change of plans.

Sheet metal is extensively used in any of these manufacturing methods. More than 60 % of raw materials in industrial production are sheet metal-based. Once the nuances of working with sheet metal are understood, it is left to the imagination of designers to explore endless interesting designs.

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3.1 Example of creative designs unique to Sheet Metal


(Image source)


(Image source)

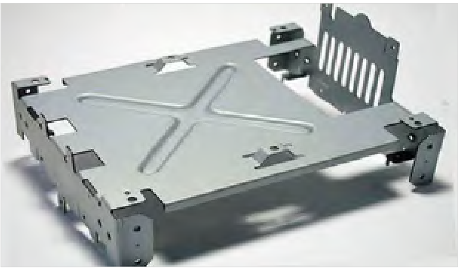
(RWTHAACHEN University).Tessellation techniques are well-made use of in this self-supporting structure.

Sheet metal processes such as intense strength characteristics, complex freeform architectural shapes can be conceived using modular elements which are interlinked, and the whole structure made self-supporting. The combination of tessellation and folding enables the generation of freeform structures using sheet metal.

4. Some practical examples

The global sheet metal market size was valued at USD 265.0 billion in 2018 and is projected to grow at a compound annual growth rate (CAGR) of 5% till 2025. Its versatility is such that it finds applications virtually in every conceivable manufacturing sector.

Equipment Chassis


(Image source)

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Sheet metal is an invaluable material in producing intricate shaped one-piece chassis for electronics housing. There is no other material that matches this kind of complexity in a cost-effective manner. Holders, clamps, tabs, and many other features are incorporated in this one-piece chassis part.

Aircraft Seat

(Image source)

Sheet metal is one material that possesses properties to strengthen itself with simple techniques. In this example, a simple embossing process is effectively used to strengthen the seating and backrest areas which otherwise would be flat surfaces prone to cambering and distortions.

Decking

(Image source)

Roof decks made out of sheet metal allow large spans without buckling with inbuilt provision to fix flooring material. They are used in flat, pitched, or arched roof systems. Besides, profiling allows easy underneath cable routing.

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Designer Stationery

(Image source)

Designer tableware is increasingly becoming popular in use. They are no more pricy because of their novelty. Due to volume production, the prices of such artifacts have become affordable and their use is widespread. The pen stand shown here has actually undergone through many precision manufacturing processes yet their prices are very low due to modern sheet metal processing techniques.

Storage Racks

(Image source)

Sheet metal possesses amazing strength characteristics. The items which were once used to be produced by heavy structural materials involving rigid welded joints are now produced in sheet steel and with flexible joints. With proper design considerations, they are capable of carrying large amounts of loads.

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Roofing Sheets

(Image source)

Sheet metal roofing sheets have replaced conventional roofing materials such as tiles, corrugated sheets many times over because they are cheaper and offer a lot of variety. They offer wide choices in different profiles and colours and coatings. Various components such as ridge caps, eave trims, etc., that are required in pre-engineered buildings are readily available in the market.

Automobile sector

(Image source)

About 50 to 55 % of automobile body components are made out of sheet metal. Sheet metal is the most preferred material in the auto sector as it offers required accuracy and forming technology which is essential and at cost-effective prices.

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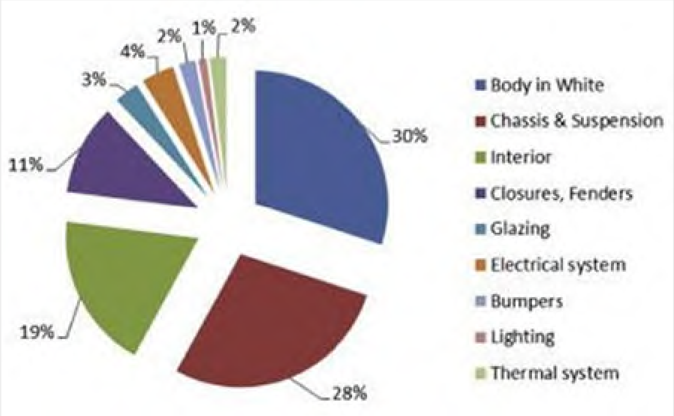
An example of share of sheet metal components in an automobile

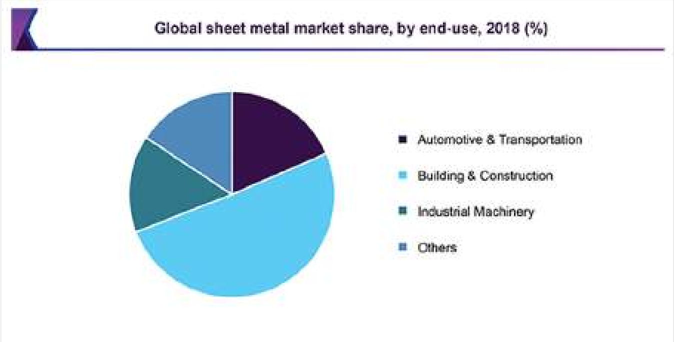


Weight ratio of various vehicle components
(Image source)

In an automobile, leaving aside the engine-related parts, the body, and its associated components have an important role in the weight of the vehicle. Nearly 50-60% percent of vehicle body components comprising of outer shell, chassis, and some interiors are all produced mainly using steel and aluminium.

These examples do not cover even a fraction of sheet metal applications. The applications are innumerable. The sheet metal market may be classified into steel, aluminum, and other metals such as tin, copper, and aluminum. Of these, steel accounts for the highest volume share of over 90%. On the other hand in terms of revenue aluminum accounts for the highest CGAR at about 9%.

4.1 Sheet metal market share



Grandviewresearch.com

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Overview of Sheet Metals

Chapter 2


Metals


Sheet Metal


Stainless Steel


Non-Ferrous Sheets


Copper


Brass


Bronze


Titanium


Tubes


The Design Element in Sheet Metal

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Metals

Metals are solid materials at room temperature. One exception is mercury which is also a metal. The density and melting points of metals are high. The typical characteristics metals exhibit and are made use of in manufacturing are:

- Hardness
- Ductility
- Malleability
- Thermal conductivity
- Electrical conductivity

Metals are sonorous which means they produce ringing sounds when hit with a hard object. They also possess a lustrous property that reflects light.

1. Hardness

Marteau Design (Image source)

Tool Steel Products (Image source)

Whistledesign

KA-BAR U.S. Army Knife 1219 (Image source)

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Resistance to wear and tear is directly proportional to the hardness of the material. Harder the material is, the longer its durability. Hardness represents the strength of a material.

Knowing metal hardness is important to understand the metal and to ensure part functionality. For example, a hammer made from low carbon steel may cost less but wears out much faster. A knife made from stainless steel will last much longer than the one made of mild steel.

Hardness Testing:

There are three main methods to measure the hardness of materials.
- **Scratch hardness**
- **Indentation Hardness**
- **Rebound Hardness**

Scratch Hardness:

Scratch Hardness Test (Image source)

The Scratch hardness test determines the hardness of a surface against scratches, friction, or abrasions. The test is conducted to measure the resistance to friction against a sharp object quantitatively. The resistance measurements are compared against standard scales. This test is commonly used to test the adherence quality of painting, powder coating processes.

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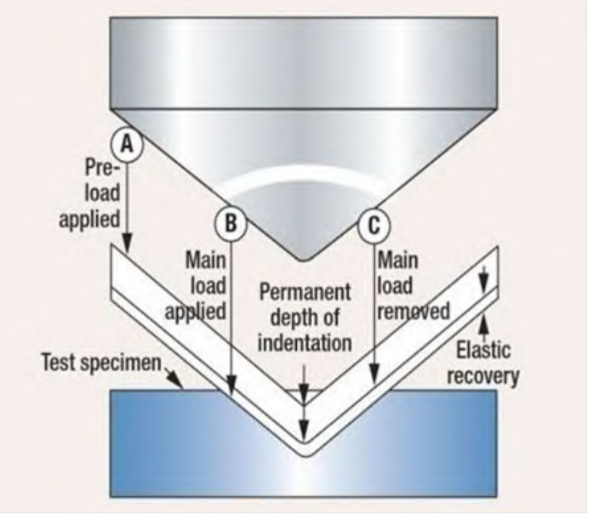
Indentation Hardness

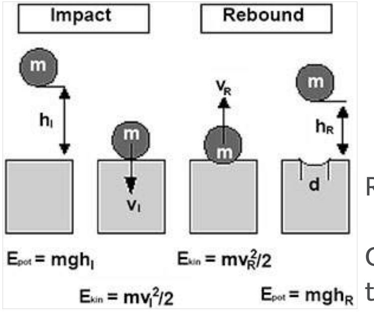


(Forge Magazine) Indentation Hardness Test (Image source)

The Indentation hardness test is to determine the hardness of the material against deformation. The level of indentation quantifies the hardness level. In practice, drop tests are conducted in product samples to test reliability after a fall from predetermined heights. We can understand the level of protection an enclosure cover or a packaging box offers to the hardware inside, which is meant to be protected.

Rebound Hardness:

It is a measure of the elasticity of the material. It measures the height of the bounce of an object under certain conditions. Indentation hardness tests are used to determine the hardness of a material to resist deformation. For example, electronic products are subjected to shock and bump tests to test the rigidity of electrical and mechanical connections.



Rebound Test (Image source)

Commonly adapted tests for measuring hardness tests are the Rockwell hardness test, Vickers Hardness test, and Brinell hardness test.

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2. Ductility

The ductility of a material is the ability to stretch under tensile stress. Understanding ductility properties helps to know how far the material can be stretched considerably without giving away. It is a measure of the deformation of a material under pulling pressure. It is the ductile property of the material that is observed in most of the sheet metal products involving processes such as wire forming, punch forming, shallow drawing, and so on.

Tensile Stress (Image source)

Ductility is a measure of material withstanding tensile stress

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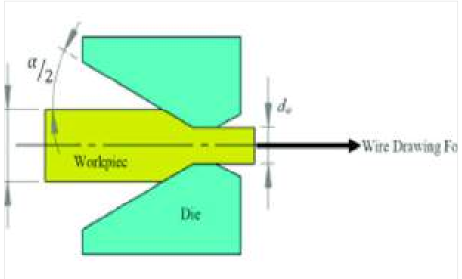
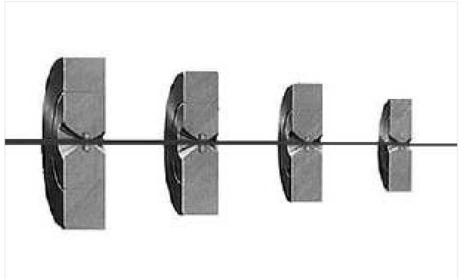


Ductility allows material to stretch down. (Image source)

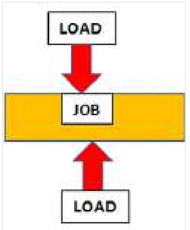

Progressive thinning of wire.


A wire drawing unit.

3. Malleability

Malleability is the ability of a material to deform under compressive stress. It means the material can be shaped to desired shapes by applying pressure. The malleability property of the material allows the conversion of thicker sheets into thin sheets by rolling or hammering. It is the ductile and malleable properties of sheet metals used in many production methods, mainly forming.


Compressive Stress (Image source)



Malleability is a measure of material withstanding compressive stress.

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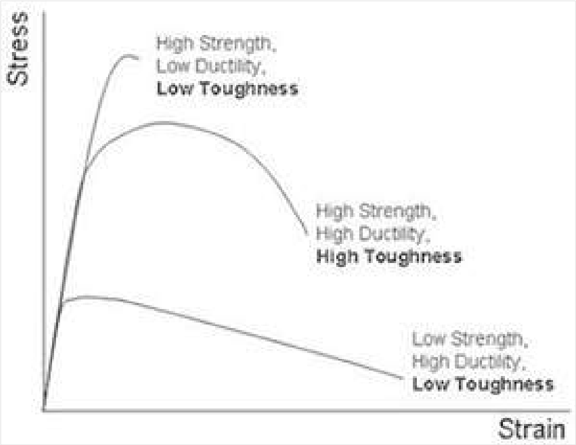
Rolled Sheet (Dean Norton.com.au) (Image source)


Stretched Tin (shubhamgarg.co.in) (Image source)


Compressed Dome (wallpaperflare.com) (Image source)

When subjected to tensile force, a ductile material gets stretched into longer shapes such as rods and wires without undergoing fracturing. When subjected to a compressive force, a malleable material gets deformed into thin sheets or forms new shapes. Both ductility and malleability are the two main characteristic properties of metals. Malleability combined with ductility allows materials to transform into different shaped components.

Relation between ductility and strength



Stress-Strain Diagram (Image source)

Too high or too low ductility is also not desirable.

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4. Electrical Conductivity

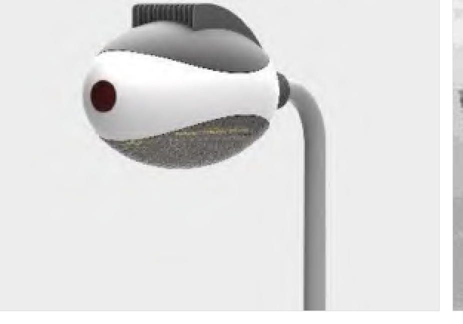

Twisted strand cable and Busbar.
(Image source)

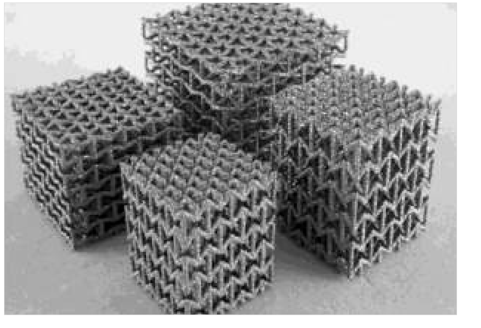

Shan power cable
(Image source)

Electrical conductivity is a measure of how well the conduction of electricity takes place inside the material. Lower the resistance of the material to allow electricity to pass, higher the rate of travel. Electrical and electronic products need the least electric resistant paths for the efficient function of the product. Almost all power electronics products will have bus bars for efficient conduction of electricity. Designers can make use of interesting patterns in arranging the bus bars.

5. Thermal Conductivity


Cast Heatsink.
(Image source)


Fabricated Heatsinks.


3D printed Heatsink.
(Image source)

Heat is a big deterrent for the proper function of electronics. Beyond a certain temperature, say 45 – 50 deg C, electronic components start displaying erratic behaviour. It is a must to dissipate thermal energy generated by electronic components as much and as faster possible for the reliability of the components and the product. Metals, in particular copper, aluminium have excellent thermal conductivity properties. Aluminium, in particular, is widely used in heat sink designs to dissipate away heat from electronic circuits. Generally, good electrical conductors are also good thermal conductors.

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Sheet Metal

When is a sheet called a sheet?

Extremely thin sheets are as small as microns are known as foils or leaves. Typically, 0.25 mm to 6 mm thick are known as sheets. When the thickness is over and above 6 mm, it is called a plate.

Sheet metal is a metal that is shaped into thin, flat pieces by hot and cold rolling industrial processes. It is one of the basic and commonly used forms of metalworking and can be processed into various shapes. Sheet metal is made out of flattening hot slabs of metal billets by way of running through a series of rollers that make them thinner and longer. The sheet is then cooled, rolled to desired thickness, and slit into sheets.

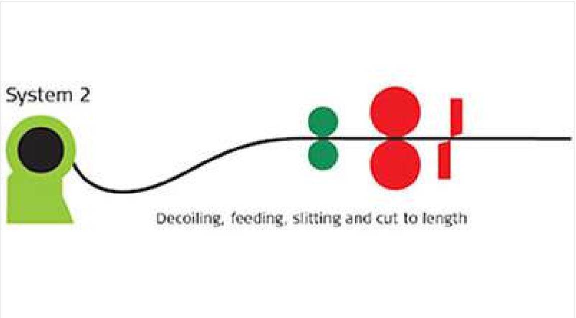
Sheet Metal Manufacturing


Billets.
(Image source)

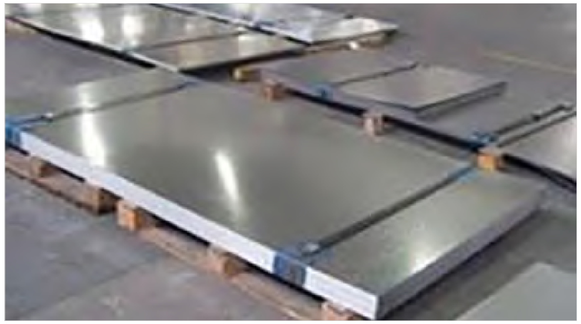

Flats.
(Image source)


Hot Rolling.


Coiling.
(Image source)



Decoiling.


Slit Sheets.
(Image source)

The de-coiled and slit sheets are the basic raw material for various manufacturing processes and finishing processes before emerging as a final product.

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Understanding Sheet Metal

Every professional knows sheet metal, the way it feels, the way it behaves; the only thing is the level of understanding. To beginners, it is stiff and rigid; to professionals, it is also organic in nature.

Sheet metal offers the best possible precision in the entire gamut of metal fabrication techniques. It easily surpasses hard fabrication technologies such as castings, rolled section fabrication, full welded fabrication.

The basic understanding of sheet metal – Cut and Bend

(Image Source)

The not so well understood sheet metal – Roll, Form, Press, Spin, and many other

(Image source)

Sheet metal is often understood at a very basic level in simple cut and bends methods; however, it also employs sophisticated techniques to bring out three-dimensional and curvy forms. Not limited to fabricating straightforward designs in industrial products, sheet metal is virtually found across all spectrums of products of everyday use such as utensils, domes, furniture structures, seats, automobiles and so, on. Besides consumer products, sheet metal is also used in shelters in the form of thin sheet structural elements.

Manufacturing Processes

There are very many manufacturing methods available to convert a sheet into a product. They vary from hand-crafted products made of handheld tools to highly mechanized industrial products. It is the quality and quantities of the products to be produced that decide the manufacturing processes.

The manufacturing processes are discussed in detail in chapter 3.

Finishes

Barring pre-coated sheets, sheet metal components need to be surface finished for protection and acceptance in the market. For example:

• Painting and Powder Coating gives appealing colours and surface finish.

• Anodising is the process of giving a decorative and protective oxide layer to aluminium.

• Galvanising is the process of zinc coating the steel sheets for corrosion resistance

• Tinning is the process of tin coating making steel sheets suitable for food cans

• Annealing is used to make metal sheets softer, thereby making them easier to bend and form

• Tempering is used to add hardness.

• Creation of surface textures on the surface by way of rolling add to the stiffness

The finishing processes are discussed in detail in chapter 6.

1. Types of Sheet Metal in general use

Sheets are ideal for machine fabrication, such as Punching, Bending, and Forming using the malleable and ductile characteristics of the sheet. On the other hand, plates offer much scope for very stiff and rigid product constructions such as trusses, bridges, storage tanks, etc.

The broad classification of sheet metals is

• Ferrous
• Non-Ferrous

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Ferrous Sheets

- Carbon Steel
- Alloy Steel
- Stainless Steel

Carbon steel sheets are the ones which we come across as widely used material in the industry. They are available as 'Hot Rolled' and 'Cold Rolled' from the mill. Hot rolled products are mainly plates with thickness varying from 6 mm to upwards of 30mm. Hot-rolled sheets are also available from 2 mm to 4 mm, but they are hard and less malleable.

Hot rolled steel involves heating the steel billets at high temperatures of about 1000 deg C, which is above its re-crystallization temperature and then rolled in this hot stage to the required dimensions to form plates. Hot rolled steel sheets are hard and tough. They are generally used in the construction industry in the form of plates, angles, and channels. They are well suited for welding technology.

Cold rolled steel is essentially hot rolled steel that undergoes further processing. The hot-rolled steel is further rolled in cold reduction mills, normally at room temperature, followed by annealing. Annealing is a heat treatment process to increase ductility and reduce the hardness of the steel. It is a process where the metal is exposed to above its re-crystallization temperature but below its melting temperature for a certain period of time and cooled down. During this process, internal stresses are relieved, and a new grain structure is realized. Annealing reduces hardness and increases malleability. Because of these additional processes, cold-rolled steel is more expensive than hot-rolled steel.

Cold-rolled sheets enable good control over fabrication tolerances, concentricity, and straightness when compared to hot-rolled sheets. Cold-rolled sheets provide a superior surface finish. They have low carbon content and are softer than hot-rolled sheets.

Rust

Researchgate.net
(Image source)

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One of the main problems in steel is that steel is susceptible to rust due to oxidation. This causes a reduction in the strength of the metal. But there are also proven solutions to prevent or minimize the damage due to rusting. For practical purposes, Carbon Steel sheets come in the following categories

• O- Ordinary steel (commercial quality close annealed cold rolled)

• D – Drawn steel (drawing quality close annealed cold rolled)

• DD – Deep Drawn steel (deep drawing close annealed cold rolled)

• EDD – Extra Deep Drawn steel (extra deep drawing non-aging close annealed cold rolled)

Ordinary quality is for general purpose fabricated products.
Drawn quality is for close-tolerance fabricated products.
Deep Drawn quality is for stretched material products.
Extra Deep Drawn quality is for deeply stretched material products.

Typical advantages and disadvantages of steel sheets.

Advantages	Disadvantages
High Strength to weight ratio	Susceptible to corrosion
Ductility and Malleability	Susceptible to fatigue
Stiffness	Susceptible to fracture
Suitable for all fabrication methods	Limited fire resistance
Allows onsite and off-site fabrication	High raw material cost

2. HRCA Steel Sheets


Girders using HRCA Plates.

Vehicle Frames.
(Image source)

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HRCA Outdoor Electric Panel Box.
(Image source)


HRCA Kiosk Panelling.
(Image source)

Hot rolled steel is best suited in applications where precise shapes, sizes, and tolerances are not important. Hot rolled steel sheets come with rough blue-grey surface colour and may have surface irregularities such as unevenness, roughness, and pits. The tolerance of the sheet thickness can be in the order of +/- 0.20 mm. Therefore, it requires more effort during pre-treatment before painting to obtain a smooth surface. Therefore, it is preferred to seek matt or textured surface finish during painting or powder coating partly to hide surface irregularities. HRCA sheets are advantageous where price matters more than precision. Some common uses of hot rolled steel are:

- Structures and Constructions
- Pipes and tubes
- Large vehicle frames
- Outdoor panel equipment
- Due to advances in technology, HRCA sheets to a limited extent are made available for drawing, even extra deep drawing purposes.

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https://www.dsource.in/course/sheet-metal/overview-sheet-metals/sheet-metal

Composition of elements in HRCA sheet grades								
IS 1079: 2009	Table 1 Chemical Composition (Clauses 6.1 and 6.2)							
Sl No.	Quality			Constituent, Percent, Max				
	Designation	Old Designation	Name	Carbon	Manganese	Phosphorus	Sulphur	Micro-Alloy
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
i)	HRO	(New)	Oridinary	0.25	1.70	0.05	0.045	---
ii)	HR1	O	Commercial	0.15	0.60	0.05	0.035	---
iii)	HR2	D	Drawing	0.10	0.45	0.040	0.035	---
iv)	HR3	DD	Deep Drawing	0.08	0.40	0.035	0.030	---
v)	HR4	EDD	Extra Deep Drawing	0.08	0.35	0.030	0.030	---
vi)	HR5	(New)	Micro-alloyed Duel Phase[1)]	0.16 0.16	1.6 2.0	0.020 0.05	0.020 0.02	0.20 0.15

(IS 1079: 2009)

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Commonly available HRCA Steel Sheets *(Ex:Bokaro Steels)*		
WIDTH mm	TH mm	LENGTH mm
900, 1000, 1250	2.0	2500,3000
1200, 1000, 1250	2.5	2500, 3000
1000	3.15	2500, 4000
1000, 1250, 1500	4.0	2500, 4000

Commonly available sizes of HRCA Steel Plate Sizes		
Discrete Plates		
WIDTH mm	TH mm	LENGTH mm
1500 To 4500	5.0 To 150	UPTO 40,000
1500 To 2500	5.0 To 25.0	TYP 2400

IS 1079– O,D,DD,EDD, typical examples being the manufacture of Chests, safes, cupboards, and other domestic and engineering items. This grade is used as a base material for general purposes and corrugated sheets, items in transportation bodies, and domestic appliances.

3. CRCA Steel Sheets

CRCA steel is an essentially hot rolled steel sheet with further processing in cold reduction mills and annealing ovens. Cold rolled steel sheets come with smooth blue-grey surface colour and will have practically no surface irregularities. The tolerance of the sheet thickness will be in the order of +/= 0.02 mm. Therefore, CRCA sheets are most widely used for the detail and definition they offer with very minimal deviation in mechanical properties. CRCAsheets are certainly the designer's choice for appearance. The surface finish of CRCA sheets will be smooth and requires fewer efforts during pre-treatment and painting.

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CRCA Sheets in Use

Over 60 percent of industrial, Commercial, and domestic products are made from cold-rolled steel.


Automobile.


Machine Body.
(Image source)


Equipment Housing.
(Image source)


Shelving.
(Image source)


Home Furniture.
(Image source)


Chair Seating.
(Image source)


Utensils.
(Image source)


Men's Ware.
(Image source)


Construction.
(Image source)

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Composition of elements in CRCA sheet grades

Sl No.	Quality		Constituent, Percent, Max			
	Designation	Name	Carbon	Manganese	Sulphur	Phosphorus
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	CR0	Hard	0.25	1.7	0.045	0.050
ii)	CR1	Commercial	0.15	0.60	0.040	0.050
iii)	CR2	Drawing	0.12	0.50	0.035	0.040
iv)	CR3	Deep Drawing	0.10	0.45	0.030	0.025
v)	CR4	Extra Deep Drawing Aluminium Killed (Non-ageing)	0.08	0.40	0.030	0.020
vi)	CR5	Extra Deep Drawing (Stabilized Interstitial Free)	0.06	0.25	0.020	0.020

(IS 513 2008)

The advantages of CRCA steel are:

- Precise and Accurate Dimensional Tolerances
- Good surface finish
- Improved mechanical & physical properties
- Improved draw-ability
- Good machinability

The disadvantages being:

- Less Corrosion Resistant
- Sensitive to the Moisture content

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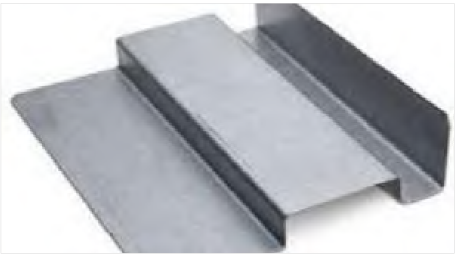
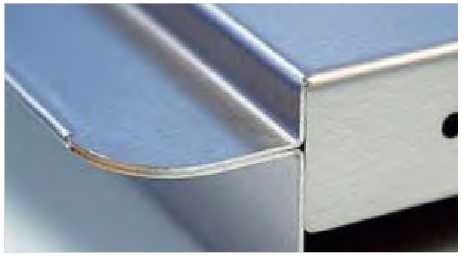
Although cold-rolled steel is more expensive than hot-rolled steel, the advantages make it useful for many applications. The finished products needless additional surface finishing to achieve a good result, as the surfaces are already smooth. Examples of cold rolled/cold drawn steel use include:

• Metal furniture
• Structural parts
• Home appliances
• Water heaters
• Metal containers
• Fan blades
• Frying pans
Computer cabinets

Common CRCA Steel Applications


Utensils.
(Image source)


Men's Ware.
(Image source)


Construction.
(Image source)

Cold Rolled Sheets are available in a wide range of strips as well as sheet forms. Different chemical compositions and modified mechanical properties are made available to suit specific Forming, Drawing applications.

Commonly used sizes of CRCA Sheets *(Bokaro Steels)*		
WIDTH mm	TH mm	LENGTH mm
450, 600, 900, 1250	0.3,0.5,0.6,1.0,1.2,1.5	2500
900, 1000, 1250	1.2,2.5,3.15	2500,3000

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4. Rust protected Sheets

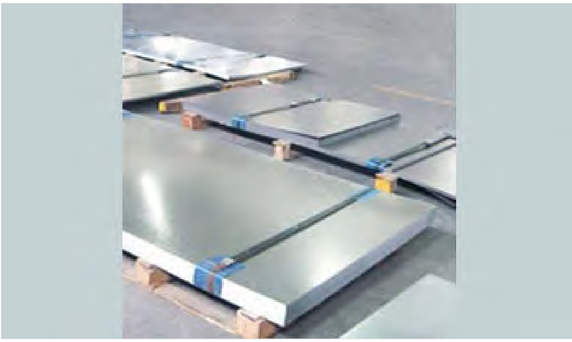
There are variations of sheets available with rust protective coatings.

Some of them are:

- Galvanized sheets
- Pre-coated sheets
- Plated sheets
- Speciality coated sheets

Galvanized Steel Sheets

Reular Spangle Sheets.
(Image source)



Zero Spangled Sheets.
(Image source)

There are two kinds of spangles for hot-dipped galvanized steels, one is regular spangles, and another is zero spangles.

The regular spangle is where the zinc layer coated is condensed under normal conditions after galvanizing, which is mainly used for general purposes. These are mainly used in building roofing and on applications occasion where there is less human direct contact.

Zero spangles are where the steel sheet has a very fine surface appearance after zinc coating, which has been applied through a special process. These sheets are used mainly in electronic equipment chassis and other such sensitive applications.

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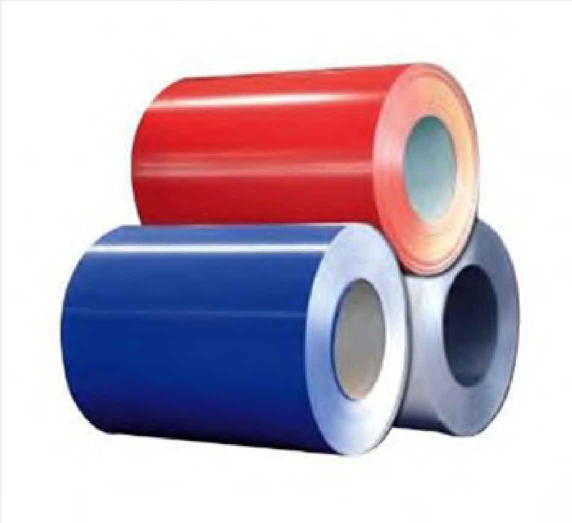
Galvalume Steel Sheets

Galvalume sheets are steel sheets that undergo the process of hot-dip of aluminium-zinc-silicon alloy coating. It differs from galvanized sheets because galvanizing is one hundred percent zinc coating, while galvanizing comprises 55% aluminium, 43.5% zinc, and 1.5% silicon. Over time galvalume tends to perform better than galvanizing.

Advantages of Galvalume Sheets
• Heat resistance - Withstands over 300 deg C.
• Thermal reflectivity – Thermal reflection is double as high as galvanized sheets.
• Corrosion resistance – High corrosion resistance due to high aluminium composition.
• Economy For a given weight of coating layer, galvalume offers triple the size of galvanized sheet.

Pre-Coated Steel Sheets


Colour coated sheet rolls.
(Image source)


Colour coated sheets as Roofing material.
(Image source)

CRCA sheets in thickness of 0.35 to 0. 55 mm are available in the pre-coated form. They are mainly used as roofing sheets and, to some extent, as cladding material. A pre-coated CRCA sheet is first given a zinc coating followed by a primer coat and a final surface coat. The pre-coated sheets are also available with integrated polyurethane foam as protection against heat. Pre Coated sheets are extensively used as roofing and in Pre Engineering Buildings (PEB).

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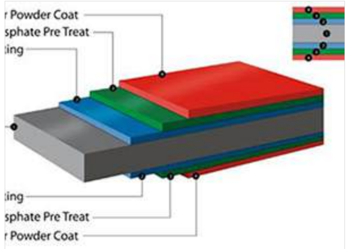
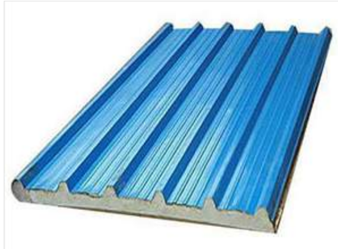

Pre Coated CRCA Sheet. (Image source)


Pre Coated CRCA Sheet with integrated PU Foam. (Image source)


Typical application of pre coated sheets in Pre-Engineered Buildings (PEB). (Image source)


Typical application of pre coated sheets in Pre-Engineered Buildings (PEB). (Image source)

Truss less Roofing

The strength of the steel sheet is such that it need not always have an engineered truss to support a roofing sheet in pre-engineered buildings. In a classic example, the physical properties of corrugated sheets are adequate to self-support it on the roof. The corrugations of the sheet act as ribs to strengthen the sheet. Corrugated sheets are rolled into curved shapes and fitted onto buildings. Truss less roofing is increasingly becoming popular where roof spans are not large.


Truss less Roof (Image Source)

Source:
https://www.dsource.in/course/sheet-metal/overview-sheet-metals/stainless-steel

Stainless Steel

Stainless steel differs from ordinary carbon steel by the amount of chromium present, which may vary from about 10% in the most common 304 grade to about 30% in high-end knife steel. Chromium increases the strength of the steel and the chromium oxide that is generated acts as protection to steel. It also contains various degrees of Carbon, Silicon, and Manganese.

Compared to other materials, stainless steel has strong mechanical properties offering resistance to heavy wear such as friction, abrasion, and impact.

Vegetable cutter blade.
(Image source)

Forged knife blade and the matching Handle.

Toilet Camode.
(Image source)

Wall Tiles.
(Image source)

Garden Chair.

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Source:
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Stainless Steel comes in surface finishes, from matt to bright and brushed. It is easy to clean therefore used in products such as utensils, kitchen equipment, and catering equipment. In architecture, stainless steel is used as wall tiles and garden furniture. It is used transport industry as toilet commodes, medical equipment, and the like. It has exceptional strength, as seen in the example of the garden chair shown above. It is interesting to note the folds and bends incorporated in the design to make the chair rigid and stable.

There are very many grades of Stainless Steel. The most common are :

• Grade 304 is most common for many applications.
• Grade 316 has high-temperature resistance and is used in industrial applications.
• Grade 410 is a heat treatable stainless steel, commonly used in cutlery.
• Grade 430 is a low-cost alternative to series 300's grades, used in appliances.

However, it may be that it is not entirely corrosion-proof. In certain circumstances, corrosion can happen. It is 'stain-less not 'stain impossible. In a normal environment, it is stainless. Stainless Steel is more expensive than ordinary carbon steel. Designers choose the material balancing cost vs. performance and life.

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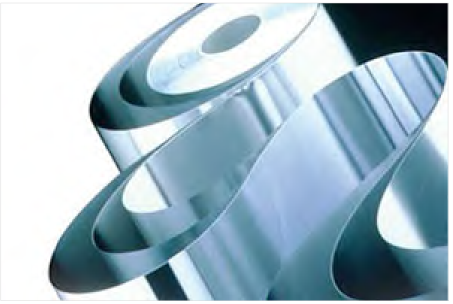
Non-Ferrous Sheets

1. Aluminium



(Image source)

Aluminium is a lightweight metal. It is soft and highly malleable and has a silvery-white appearance. Aluminium is a low-density metal with high thermal and electrical conductivity, non-magnetic and corrosion-resistant. Aluminium sheets are used in a large variety of products that include kitchenware, electrical enclosure parts, heat sinks, electrical transmission lines, aerospace components, and many others. Pure aluminium by itself is not very strong. It is often used as an alloy. Alloys with copper, manganese, magnesium, and silicon are lightweight and strong. They are preferred materials in the transportation and aerospace industries.

Aluminium is a good electrical conductor and is much used in electrical transmission lines. It is cheaper than copper weight-to-weight basis but acts as a much better conductor. Aluminium is used in vacuum metallization to give products high reflective coatings for both light and heat.

Aluminium – Foils to Sheets

Aluminium crystal structure has excellent plasticity, thus making it one of the best materials in metal forming industry.

The A can weighs less than 15 gms.
(Image source)

Micormeter Al foils in packaging.

A 0.3 mm Lithographic plate.
(Image source)

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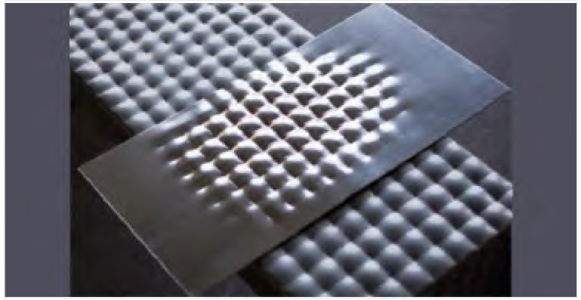
(Tim Tevi).
(Image source)


A Stool made from 2 mm aluminium sheet, using embossing to strengthen the sheet.

Thin aluminium foils as small as 6 mm are sandwiched in the paper, and plastic substrates are used for liquid packaging. Aluminium alloyed with magnesium and manganese gives the foil exceptional strength. A typical 30 CL beverage can weigh less than 15 grams. 0.3 mm thick aluminium sheets are used as lithographic plates with high strength, thermal stability, and fatigue resistance.

Physical and mechanical properties, when thoroughly understood and explored, aluminium offers interesting ways of working to the designer like no other material. Sheets as small as 2 mm or 3 mm, are used because of their plastic property, are explored to new innovative product developments.

Grades of Aluminium Sheets and Plates

Aluminium sheets are classified by series numbers and temper hardness.

Hrepresents a degree of hardening. Ranging from H1 to H9

T representing a type of tempering ranging from T1 to T10

XXXX A four-digit series number ranging from 1000 to 8000 representing purity, 1000 being the purest.

Grade 1100-H14 is commercially pure aluminium, highly chemical, and weather resistant. It is ductile enough for deep drawing and weldable but has low strength. It is commonly used in chemical processing equipment, light reflectors, and jewelry.

Grade 3003-H14 is stronger than 1100 while maintaining the same formability and low cost. It is corrosion-resistant and weldable. It is often used in stampings, spun and drawn parts, mailboxes, cabinets, tanks, and fan blades.

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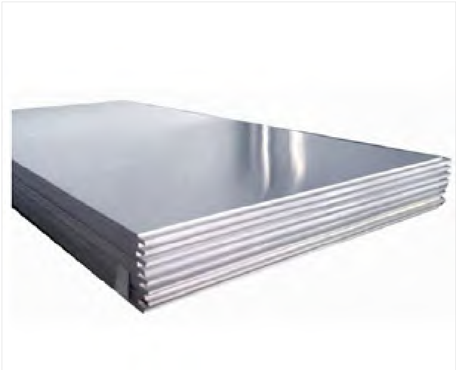
Grade 5052-H32 is much stronger than 3003 while still maintaining good formability. It maintains high corrosion resistance and weldability. Common applications include electronic chassis, tanks, and pressure vessels.

Grade 6061-T6 is a common heat-treated structural aluminium alloy. It is weldable, corrosion-resistant, and stronger than 5052, but not as formable. It loses some of its strength when welded.[5] It is used in modern aircraft structures.
(Wikipedia)

Aluminium Plates

Plain Sheets



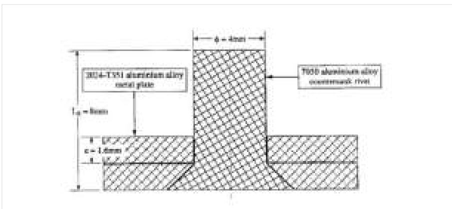
The A can weighs less than 15 gms.
(Image source)

Micormeter Al foils in packaging.
(Image source)

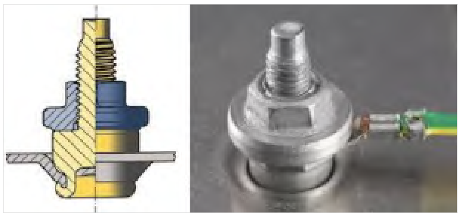
A 0.3 mm Lithographic plate.
(Image source)

Being a non-corrosive material, aluminium plates are ideally suited for outdoor wall paneling, cladding works. The rigidity and the fixing methods depend upon the thickness of the sheet.

Aluminium plates as Flats are used as Busbars for electrical conductivity purposes.



Countersunk riveting for panelling.



Reliable "Earthing/Grounding "connection in a metal plate. (Image source)

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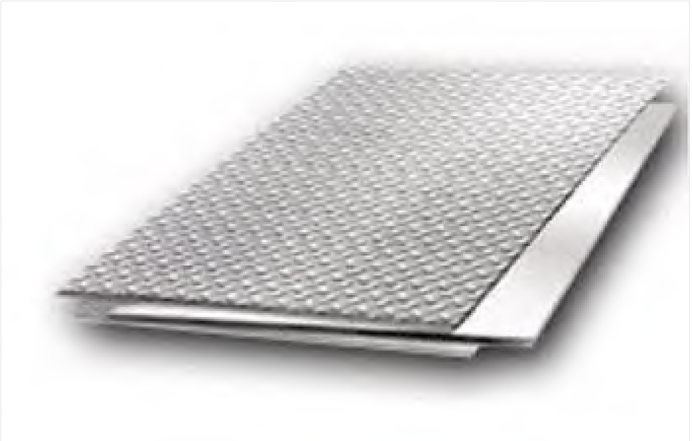
Chequered Sheets


Countersunk riveting for panelling.
(Image source)


Reliable "Earthing/Grounding "connection in a metal plate. (Image source)

Chequered sheets are used mainly as a flooring material because of their rigidity requiring fewer support structures underneath. As a flooring material, they are skid-proof and require less maintenance. They are also used as skirting panels, wall panels, and corner panels.


Tread Plate.
(Image source)


Guard Angle.

Wall Panel.
(Image source)

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Available Sizes of Aluminium Sheets		
Typical 5053 H32 H34		
WIDTH mm	TH mm	LENGTH mm
900, 1200	0.7, 0.9, 1.2, 2.0, 3.0, 4.0, 5.0, 6.0, 9.0, 10.0, 12.0	2400

A quick reference chart for a few aluminium grades

metalsupermarkets.com

GRADE	SUB	WELDABILITY			STRENGTH			FORMABILITY			MACHINABILITY		
	GRADE	EXCELLENT	GOOD	POOR	EXCELLENT	GOOD	POOR	EXCELLENT	GOOD	POOR	EXCELLENT	GOOD	POOR
1100		[yellow]						[yellow]				[green]	
2011				[red]			[red]		[green]		[yellow]		
2024				[red]					[green]				
3003		[yellow]						[yellow]					
5052			[green]						[green]				
6061			[green]						[green]				
6063			[green]						[green]	[red]			
7075				[red]									

Source:
https://www.dsource.in/course/sheet-metal/overview-sheet-metals/non-ferrous-sheets

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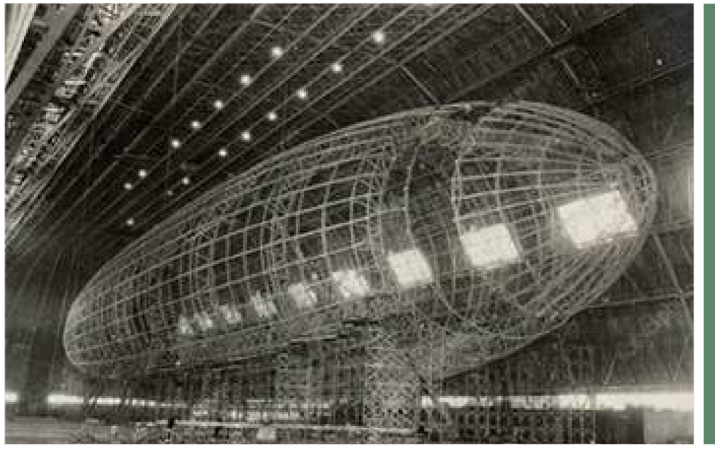
Duralumin

Duralumin possesses much higher strength than ordinary aluminium. Duralumin alloy consists of aluminium, copper, magnesium, manganese, and Zinc. Duralumin is a preferred material in aircraft body construction. It is also used in the construction of train coaches, pipelines, shipbuilding.

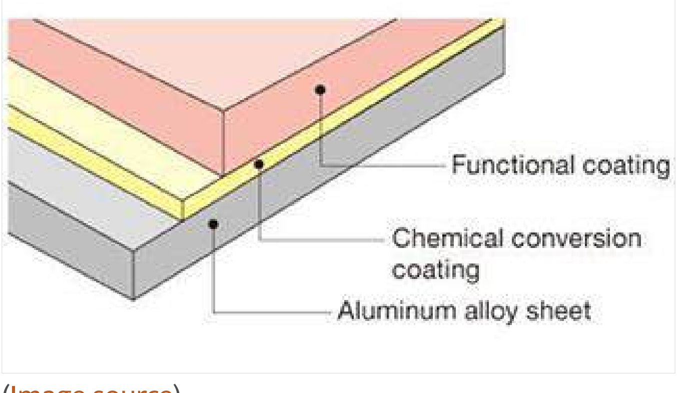


Duralumin in airship body construction.
(Image source)

Duralumin in a dome construction.
(Image source)

Pre-Coated Aluminium Sheets

In the case of pre-coated aluminium sheets, the coating material is different from that of CRCA sheets. Poly Vinyl Chloride (PVC) coating is what is given, which is highly durable.



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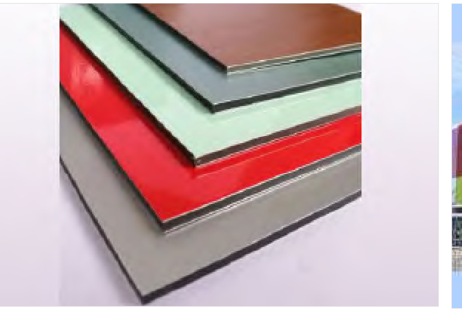
Aluminium Composite Panels

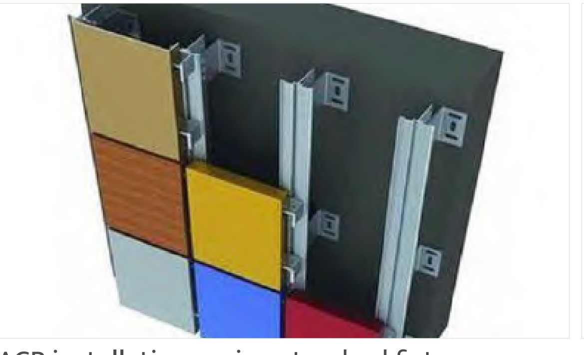
Aluminium Composite Panels are essentially sandwich panels. They are made of three layers: a low-density core and thin skin aluminium layers bonded to each side. Sandwich panels are used in applications where a combination of good structural rigidity and low weight is required. This results in increasing bending stiffness, with considerable weight reduction. The core may be a honeycomb or a solid filling.

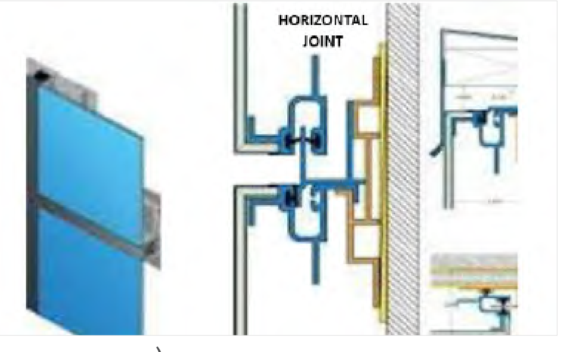
The main advantages of sandwich panels are thermal resistance and acoustic insulation, besides acting as attractive cladding materials.

Panel Structure of Sandwich.
(Image source)


ACP Sheets.
(Image source)


(Image source)


ACP installations using standard fixtures.
(Image source)



(Image source)

Available Sizes of ACP		
WIDTH mm	TH mm	LENGTH Mts
1220,1550,1800	1.0 to 6.0	6000

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Aluminium Anodised Sheets

(Image source)

Aluminium sheets also come as pre-anodized in different colours and finishes.

Anodising is the creation of aluminium oxide layer on the surface of aluminium by way of an electrochemical process. The coating is hard but not scratch-resistant. Good precautions must be taken while fabricating the sheet from damages and scratches. Many attractive colours can also be obtained in this process; however, the colours fade faster than other surface finishing techniques.

2. Steel Vs Aluminium

Steel is generally cheaper (per Kg) than aluminium. For a given component, the aluminium part will cost more because of the increase in the raw material price.

Corrosion Resistance

Aluminium's greatest advantage is that it is corrosion resistant without any further treatments because aluminium does not rust. Regular CRCA and HRCA sheets need to be given a protective coating against the formation of rust on the surface.

Strength and Malleability

Aluminium is more malleable and elastic than steel. Aluminium can create shapes that steel cannot, often forming deeper or more intricate parts. Especially for parts with deep and straight walls, aluminium is the material of choice. Steel is also ductile, but it has serious limitations when it comes to deep drawing or forming with respect to the formation of cracking and ruptures.

Strength and Weight

Despite being prone to corrosion, steel is harder than aluminium. Any grade of aluminium dent gets scratched more easily as compared to steel. The trade-off is strength vs. weight. Steel is 2.5 times denser than aluminium.

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Source:
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Copper

Copper sheets are made up of 99% pure copper. Bronze and brass are alloys of copper. Technically speaking, when the alloy is a mixture of copper and tin or leads, they are considered bronzes, while the mix of copper and Zinc are considered brasses. There are many varieties of alloys possible depending upon the chemical composition. Their names also vary accordingly, such as commercial bronze, cartridge brass, Muntz metal, nickel silver, etc. The colour of the metal also varies depending upon the composition.

Copper is a soft, malleable, and ductile metal with very high thermal and electrical conductivity. But it is not very strong or hard. Copper is cold workable. Its strength and hardness increase during the cold working process when impact forces cause the formation of elongated crystals.

Cookware.
(Image source)

Decorative Pot.
(Image source)

Electrical Lug.
(Image source)

Heat Exchanger.
(Image source)

Copper has a distinct colour and luster as compared to other metals. Pure copper is of orange-red colour and acquires a reddish tarnish because of cupric oxide formation when exposed to air.

After silver, copper is the immediate best metal in thermal and electrical conductivity. Therefore copper is used in electrical equipment such as motors and transformers in the form of wires and windings and in heat exchangers as heat sinks. This is because it conducts both heat and electricity very well.

Copper is also used in decorative art. Copper sheets are beaten to produce intricate patterns. Copper compounds are used as pigments that are used in paintings. Copper is used as a base metal for coverage applications of precious metals such as gold and silver in jewellery to improve their elasticity and hardness. Copper also processes an important medicinal property. It is very resistant to bacterial attacks.

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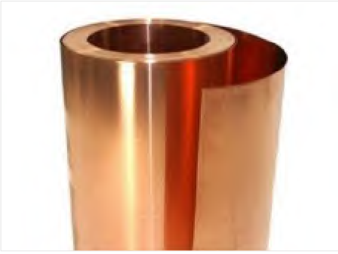
Rolls.


Plates.
(Image source)


Rods.
(Image source)


Profile Tubes.
(Image source)

Copper is available in standard Rolls, Plates, Profiles, Angles, and Channels. Copper is generally specified by hardness such as soft, half-hard, fully hard, and by weight, in grams per square meter. Example, 70 GSM, 75 GSM, 80 GSM,etc.,

Source:
https://www.dsource.in/course/sheet-metal/overview-sheet-metals/copper

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Source:
https://www.dsource.in/course/sheet-metal/overview-sheet-metals/brass

Brass


Brass artifacts. (Image source)


Musical instruments. (Image source)


Brass is a bearing class material. (Image source)


Brass is a bearing class material. (Image source)

Brass is an alloy of copper and Zinc. Their proportions may vary as per required electrical and mechanical characteristics and also have an effect on the shine of the metal. Its main properties include low melting points, easy workability, and durability. It has been traditionally used to make various types of utensils. Brass has low frictional property. This property coupled with corrosion-resistant property makes brass ideal to make products such as locks, hinges, bearings, and the like. The cold working properties of brass come to good use in the hand working of domestic and musical products.

Brass containing less than 40 percent zinc is malleable and can be cold worked. They are widely used in the manufacture of bolts and screws. Over 40 % of zinc brass is less ductile but stronger, suitable for producing goods such as bolts and handles that undergo wear and tear.

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https://www.dsource.in/course/sheet-metal/overview-sheet-metals/bronze

Bronze

Bronze is an alloy consisting primarily of copper, nearly 90 %, and the remaining comprising of aluminium, tin, zinc, and sometimes even non-metallic compounds such as arsenic, as may be required. These combinations produce a range of alloys to have properties such as stiffness, ductility, or machinability.


Bronze artefacts. (Image source)


Bronze is a bearing class material. (Image source)


Bronze is a bearing class material.


Bronze is a bearing class material. (Image source)

Bronze too has less frictional properties and is hence used to make bushes, plumbing fixtures, locks, and bearings.

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https://www.dsource.in/course/sheet-metal/overview-sheet-metals/titanium

Titanium

Titanium is a very durable metal for engineering applications. Its strength-to-weight ratio is very high. Titanium is equal to steel in strength but has much less density, about 40 % less in weight. It is an important alloying agent with metals such as aluminium, iron, and the like to produce low density and high strength alloys. It is, therefore, a much-preferred metal in the aerospace industry. It is also highly resistant to corrosion when exposed to the marine environment. Titanium has low electrical and thermal conductivity properties compared to other metals. But it is superconducting when cooled below its critical temperature.

Turbine Blades.
(Image source)

Hip Implant.
(Image source)

Watch Casing.
(Image source)

Jewellery.
(Image source)

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Titanium does not cause metallic allergies and has a unique texture. Therefore, it is widely used in jewellery, spectacle frames. Because of its hygienic properties, Titanium is used in medical applications such as hip replacement implants. A knife made out of Titanium retains its sharpness five times longer than that of a stainless steel knife.

Commercial Availability of Titanium		
Titanium is available in Rods, Flats and Strips.		
Standard available sizes:		
TYPE	Th mm	L mm
Rod	2-100	2500
Flat	2-100	2500
Strip	0.3	2500

Tubes

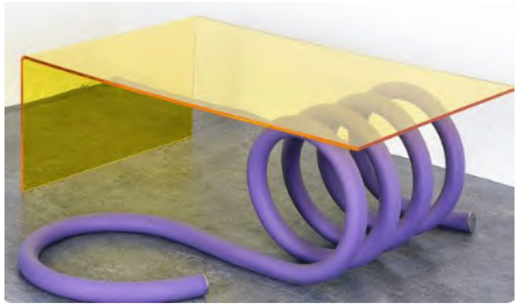
Tubes may be considered extensions of sheets by way of shape. They are essentially made from sheets by rolling to the shape and welded at the joint. Besides processing the characteristics of HRCA and CRCA sheets as discussed earlier, the mechanical characteristics of tubes increase tremendously because of the increase of bending moment of Inertia. “Strength to weight ratio is better for a hollow pipe than a solid rod.”

Difference Between Pipe and Tube

(Image source)

Pipes are always round-shaped, while tubes can be rectangular, square, or round. Pipes are specified with a nominal diameter which is the inside diameter, and a “schedule,” which means the wall thickness. Tubes are specified in terms of outside diameter if it is round, or the dimensions if square or rectangle, and the wall thickness. Generally, speaking pipes are meant for piping works to transfer fluids and gasses, while tubes are used in structural constructions. Both pipes and tubes may be seamless or welded. Both are available in the galvanized state.

A Façade constructed with Hollow section Tubes. (Image source)



A Designer Table.
(Image source)

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Typically available in sizes:			
PRODUCT	SIZE mm	TH mm	LENGTH Mts
Round Tube M.S Black	NB Dia 15 up to NB Dia 150	2.0 5.4	6.0 to 18.0
Round Tube Structural Purpose	NB Dia 15 up to NB Dia 350	2.0 12.0	6.0 to 18.0
Rectangular Hollow Section (RHS)	40*20 up to 240*120	1.2 8.0	6.0
Square hallow Section (SHS)	19*19 up to 180*180	1.4 8.0	6.0

An art installation using steel tubes. (Image source)

Tubular forms remain rigid without depending upon other support structural elements.

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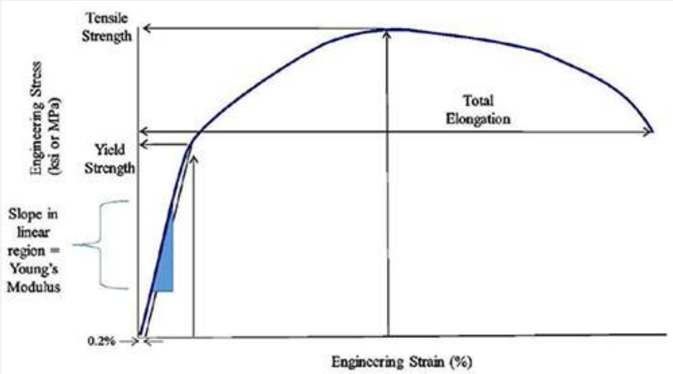
The Design Element in Sheet Metal

The following explanation though somewhat technical to a non-engineering student is useful to understand the science behind the physical properties of materials. This will help in converting a design idea into a practical solution.

The differences between stiffness and strength in metal:

• By Daniel J. Schaeffler



Stress Strain Diagram (Image source)

Strength

Strength is a measure of the stress that can be applied to a material before it permanently deforms (yield strength) or breaks (tensile strength). If the applied stress is less than the yield strength, the material returns to its original shape when the stress is removed. If the applied stress exceeds the yield strength, plastic or permanent deformation occurs, and the material can no longer return to its original shape once the load is removed when the applied stresses are higher than the material's tensile strength, the material cracks when forming.

Stiffness

Stiffness relates to how a component bends under load while still returning to its original shape once the load is removed. Since the component dimensions are unchanged after a load is removed, stiffness is associated with elastic deformation. The stiffness of a component is a function of both material and geometry.

Altering a flat surface geometry increases its rigidity. A piece of paper is flimsy, but putting a crease down its center makes it more rigid. Darts, beads, and ribs are shapes that can be added to parts to restrict flexing. On surface parts visible to the consumer, they are called feature lines or character lines, highlighted for their aesthetic benefits.

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Ribs are added to truck bed designs to help increase overall stiffness.
(Image source)

For instance, the panels that comprise a pickup truck bed shown above are mainly flat. Ribs are incorporated to help increase overall stiffness. However, the sheet metal needs to be sufficiently formable to accommodate the additional shapes. The truck bed panel ribs might not be very deep, but the metal needs to be stretched over short distances.

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Manufacturing Process

Chapter 3

Any kind of sheet metal fabrication essentially involves either removal or addition of material or changing the material into a different shape by way of applying compressive or tensile forces externally to obtain desired shapes. Manufacturing involves one or more of many metal manufacturing processes available that convert sheet metal into an object.

The raw material thickness of sheets can typically be classified as follows:

Foil	0.15 mm and less
Sheet	0.2 to 6.0 mm
Plate	6.0 mm and more

Strength

Barring very few, all metals available in sheet form, steel to gold, sheet form, Steel to Gold, are suitable for fabrication techniques available in the industry.

The basic three methods involved in sheet metal fabrication are:

- Material Removal
- Material Addition
- Material Forming

The important material removal methods are:

- Shearing / Cutting / Cropping
- Punching / Blanking / Piercing

The important material addition methods are:

- Welding
- Riveting
- Hemming
- Adhesion

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The important material forming methods are:

- Bending
- Pressing
- Drawing
- Rolling

The Important characteristics of metals in forming are:

- Elongation
- Grain Size and Direction
- Residual stresses
- Spring back
- Wrinkling
- Quality of sheared edges
- Surface condition of sheet


De Cambering


Metal 3D Printing

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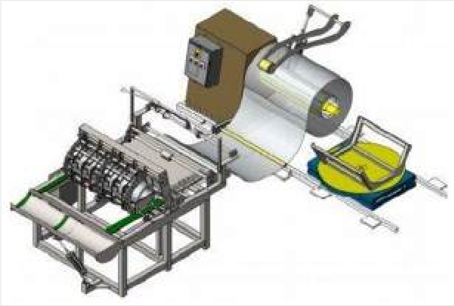
De Cambering

1. De Cambering


Steel Coils.
(Image source)


De cambering - IL Vita.


Sheet stalk.
(Image source)

Steel Sheets are delivered from the steel mill in roll form. For fabrication purposes, the roll has to be split into sheet form. If the sheet is slit from the coil without de cambering, it tends to form camber or warping. This will not only cause a considerable amount of inconvenience during fabrication but also affects the quality of the components. Decambering involves flattening or leveling the sheet to make it crisp straight before being made available to the fabrication industry.

2. Shearing

This is the very basic operation in sheet metal fabrication. This operation can be done using a simple hand shear to sophisticated automated machines.

Adapted in low quantity manufacturing, sometimes even without electricity, there are hand-operated and foot-operated machines available for the purpose. Metal shearing can be performed on sheet, strip, bar, plate, and even angles, bars can be cut to length. Many geometrical patterns can be produced by shearing sheets and plates.

The quality of the cutting edge of the sheet depends upon the quality of the shearing blade, the clearance between the top and bottom blades.

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Hand Shears

Hand operated mechanical shear - Upto 1.5 mm thick Mild Steel.
(Image source)

Powered hand shear - Upto 3.0 mm thick Mild Steel.
(Image source)

Foot Pedal Shear - Upto 4.0 mm thick Mild Steel.
(Image source)

Hand and foot-operated shears usually result in visible deformed or warped edges along the line of cut and will require a post-operation finish. Power-operated production machines have provisions to minimize warping.

Power Shears

Electric Power Shearing Machine - Upto 6.0 mm thick Mild Steel and Upto 1200 mm width.

Hydraulic Power Shearing Machine - Upto25.0 mm or more thick Mild Steel Upto 6000 mm width.
(Image source)

Shearing machines are normally called guillotine shears. Electric-powered machines are fast with a higher production rate than hydraulic shears. On the other hand, Hydraulic powered machines though a bit slower offer a better cut. The quality of shear ultimately is decided upon the sharpness of the blade, gap between upper and lower shearing blades. Power shears are equipped with "back Gauges' which are essential stoppers to stop the sheet when it is pushed ahead between the blades. Depending upon the quality of these stoppers, a sheet can be sheared to an accuracy of +/_ 0.1 mm of the desired cut size.

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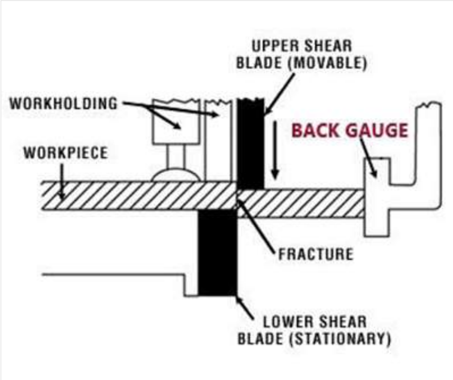
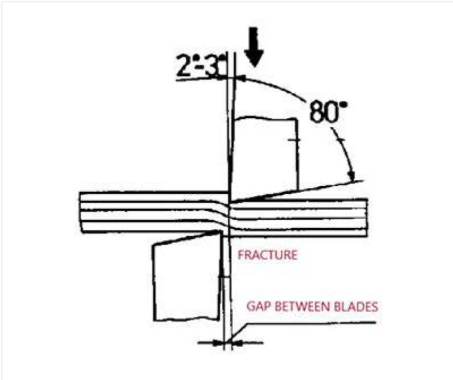
Shearing Process



Back Gauge to adjust the cut size. (Image source)

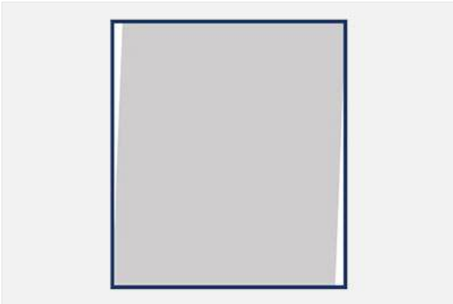


Gap between the Blades.

Shearing operation of a sheet is normally carried out between a lower fixed blade and an upper moving blade. During the shearing operation, the sheet first undergoes through plastic deformation then a fracture occurs and ultimately shear happens.

Typical Defect in Shearing Process


Camber - due to quality of sheet. (Image source)


Parallelogram - due to improper back gauge.

It is important to get a clean and straight edge to the sheet before proceeding to other operations. Poor quality edge will often lead to difficulties at later stages in alignments.

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3. Punching

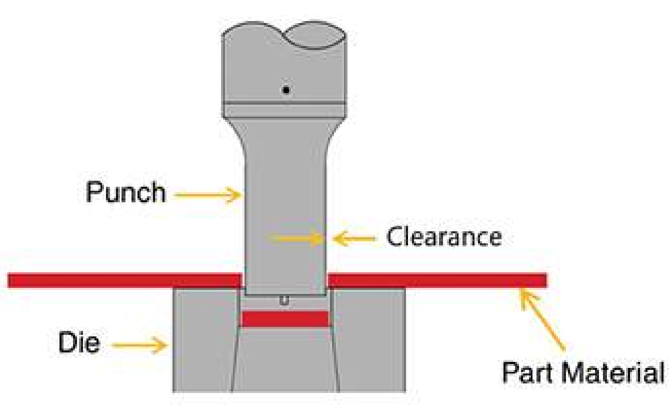
The next most used of all operations in sheet metal is Punching. Punching is done by way of using Presses either hand-operated or mainly power-operated presses in semi-precision to high precisions operations. Punching is done to create holes, hole patterns, cut outs, embossing, shearing, plunging to mention a few.

Sheets in the form of strips are generally used as feedstock in presses. As sophistication progress, CNC machines or even Press Brakes are used to perform punching operations.

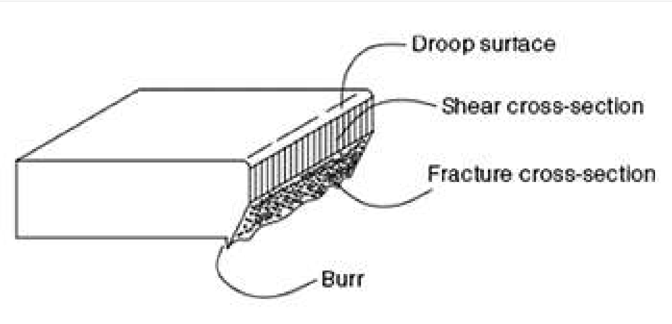
A punching operation requires a die and a punch. The sheet is inserted between the die and the punch and force are applied. The sheet then takes the shape of the clearance between the die and punch. The size and complexity of the punched piece depend upon the quality and precision of tools and tonnage of the presses. Punch removes material from the Blank with the support of a Die.

Hand operated Fly Press.
(Image source)

Power Press.
(Image source)



Punching Process.



Droops and Burrs.

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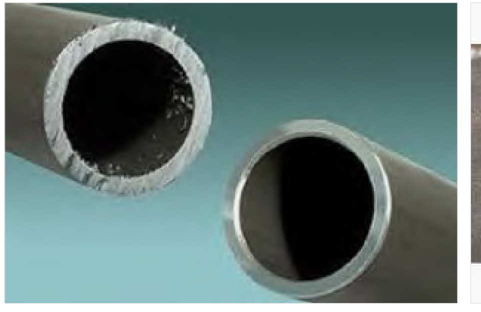
Droops and Burrs
When the sheet is punched, few things happen to the sheet. A droop forms above the shear cross-section, fracture happens below the shear cross-section and burr formation happens below. They can be controlled with the right type of tooling with respect to sheet thickness. Burrs are removed in post-processing by way of the sander and grinding.

Component Quality

All most of all sheared and punched parts will have edge burrs which require removal using grinding and sanding tools, abrasive sheets, or abrasive blasting. The quality of tools used in punching influence the quantum of post-processing. Small-time fabricators instead of using good-conditioned tools opt for more post-processing work resulting in more man-hours of work. In high production, rate works automated methods are used. It is advisable to minimize post-processing works.

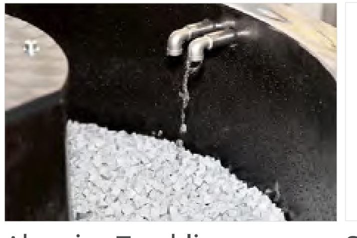

De burred parts- before, after.
(Image source)


De burred parts- before, after.


De burred parts- before, after.


Filing.
(Image source)


Abrasive pads.


Abrasive Tumbling.
(Image source)


Sanding.

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A good quality punched component depends mainly upon four components – The Die, the Punch, the Stripper, and the clearance between die and punch. Less the clearance between die and punch, better is the sharpness of punched component. Improper tooling results in more post-processing such as grinding and sanding of the edges of components adding to costs.

Nibbling

(Image source)

Nibbling is a process by which material is removed to form a cut by a series of overlapping strokes of the punch. It is a low-cost machine that can perform versatile operations. The nibbling machine operates the punch at a rapid rate of around 500 to 600 strokes per minute. Irregular contours can be cut conveniently. This process is often adapted to make prototypes and to produce a low quantity of parts. The limitations are the depth of the arbour which limits the length of the sheet to be placed on the machine and the size of the tools. Large size punches and dies are generally not used and the thickness of the sheet is limited to 6mm mild steel.

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4. CNC Punching

Computer Numerically Controlled (CNC) machines have virtually replaced traditional power presses for punching sheet metal. They are now central and foremost to the sheet metal fabrication industry. A CNC turret punch press contains a rotating turret that can hold a number of punches, some as many as 36 punches in the upper arbour of the machine. A die cavity is incorporated in the bed of the machine where the desired punch in the turret aligns with the die as per the program. There are varieties of machines with a varying number of tools in the turret, speed, and force. The CAD software optimises the layout of the sheet for maximum utilization. **CNC punching process** is a cheaper alternative to laser cutting in comparison with price and quality.

CNC Punching Machine.
(Image source)

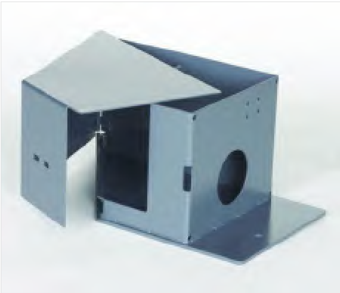

The turret over the sheet.
(Image source)

CNC Punching can be done on all sheet thicknesses available in the market. It is however advisable to keep the thickness under 6 mm.


CNC Punched part.


Different Hole patterns.


Different punch operations without removing the sheet from machine.
(Image source)


High Precision is the name of the game with CNC operations.
(Image source)

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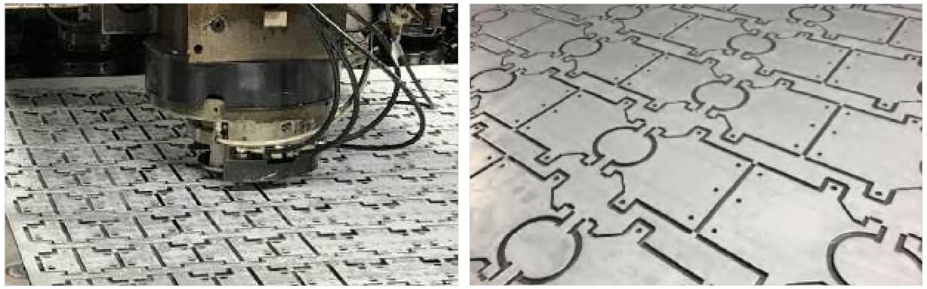
Another important feature of the CNC punch press is that it can generate 3D profiles such as dimples, knockouts which are not possible in other high-tech cutting machines like water jet or laser cut machines. Cutting machines are plain cutting machines while punch press is also a pressing machine.

Design is also about minimal wastage of raw materials. Nesting is a very useful operation in the CNC punching process.


Nesting.

Nesting is the process where multiple components can be arranged closely to minimize wastage of the sheet.
Tips:

• Hole diameter should be minimum the wall thickness of the sheet
• Plunged forms from the parent sheet metal with tapped holes can save money while replacing threaded inserts.
• Toy tags can be used to aid the assembly of small lightweight parts instead of screws
• CNC punching job works are charged based on machine time usage in hours.

5. CNC Laser Cutting

CNC laser cutting is like CNC press punching except that the machine uses a laser beam to cut the sheet instead of punches and dies. The programming, nesting is all like in a punching machine, except that the process of cutting is different. Instead of a cutting tool, a high-energy laser beam generates heat sufficient enough to burn through the sheet. Depending upon the programme the laser beam moves along the determined path and cuts the material to the desired shape. Laser cutting is suitable for a wide range of materials, including metal, plastic, wood, glass, and paper. Complex and intricate parts can be produced without any mechanical tooling.

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Laser Process.
(Image source)

Laser cutting in process.
(Image source)

An Example.

One main advantage of laser cutting over punching is that curved lines are better defined and cleanly finished because there are no serrations formed as in the case of punch and die-cutting. The cutting width of the laser is as small as 0.02 mm and the dimensional accuracy of cutting is in the range of +/_ 0.01 mm.

On the other hand, laser cutting demands high power consumption and the beam is delicate to handle. There is a limitation in cutting thick materials and materials like reflective materials Also, good care is required when metals like copper, cobalt, manganese are made to cut.

CNC laser cutting job works are charged based on the length of the laser cut carried out in mm.

6. CNC Water Jet Cutting

Water jet cutting machines use a high-powered water jet usually mixed with coarse powdered abrasive materials capable of cutting a wide variety of materials. A beam of water is ejected from the machine nozzle cutting through the material with a jet of a speed of over 700 m/s. Abrasive materials such as aluminium oxide are mixed with water at the end of the discharge nozzle. The mixture discharged at high speeds cuts through the materials.

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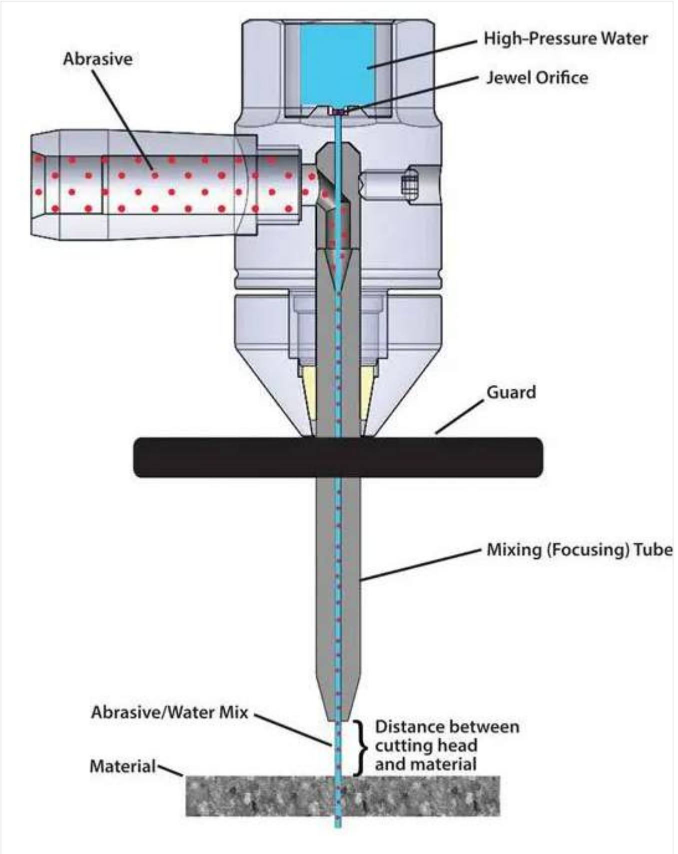
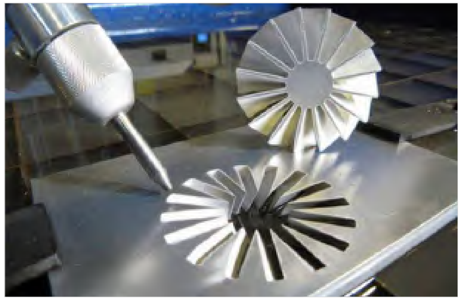


Water Jet cutting process.
(Image source)

Water Jet cutting in progress.
(Image source)

3 Axis cutting machine.
(Image source)



5 Axis cuting machine.
(Image source)

Garnets.
(Image source)

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Water jet cutting is the preferred method when the materials being cut are sensitive to the high temperatures generated by other methods. The width of the cut can be as small as 0.50 mm and the dimensional accuracy is about 0.15 mm. Water jet cutting is more effective as compared to laser cutting of punching in cutting thicker materials. There are 3 axis and 5 axis machines also available for intricate 3-dimensional profile cutting. Laser cutting and water jet cutting are both high-tech, highly accurate forms of sheet metal fabrication. However, laser cutting costs less than waterjet cutting.

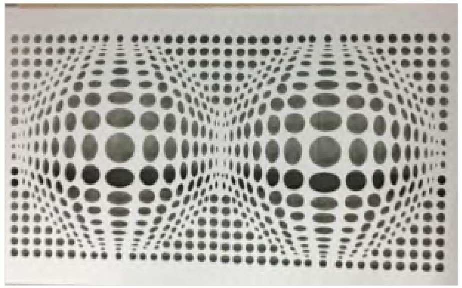
Laser: 500 to 1200 mm per minute, up to .01 mm tolerance
Waterjet: 100 to 500 mm per minute, up to 0.15 mm tolerance

7. CNC Routing

CNC routers conduct milling operations. There are both benchtop and floor-standing industrial versions available. Almost all materials metal to plastic to leather can be routed using CNC routers. CNC routers. However, they are mainly used in the sign industry to route graphic patterns on aluminium and aluminium composite panel sheets. Modern routers can accommodate up to 2000 mm wide sheets with the length being not a constraint.


Bench Top CNC Engaver / Router.


Industrial CNC Router.
(Image source)


CNC Routing on Aluminium sheets.
(Image source)

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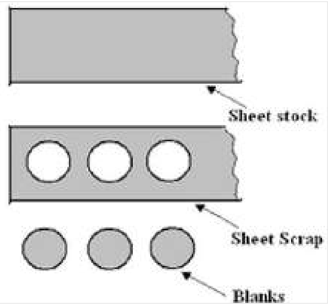
CNC Routing job works are charged based on the length of the cut carried out in mm.

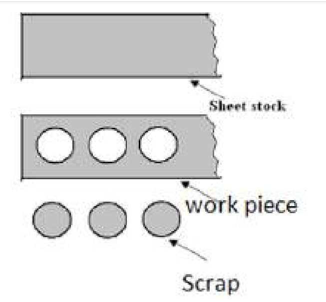
Comparison of CNC Punching, Laser, Water Jet and Routing processes (nes solutions)

Parameter	Water Jet	Laser	Punch	Router
Accuracy mm	+/_ 0.1	+/_ 0.025	+/_ 0.05	+/_ 0.5 – 1.0
Thickness mm (General)	75.00	M.S < 6.00	M.S up to 3.00 Al up to 6.00	up to 25.00 for wood Up to 3.00 for Al
Cutting Speed Mts /Min	6-30.0	30-60.0	0-50.0	5-20.0
Edge Quality	Excellent	Excellent	Fair	Fair
Heat Effected Zone	No	Yes	No	No
Material Distortion	No	Yes	Some	Yes
Others	Versatile Materials	Limited to Nonreflective	Many Tool operations	V Grooves possible

8. Blanking

Blanking is a process during which a metal workpiece is removed from the primary metal strip or sheet when it is punched. The material that is removed is the blank.





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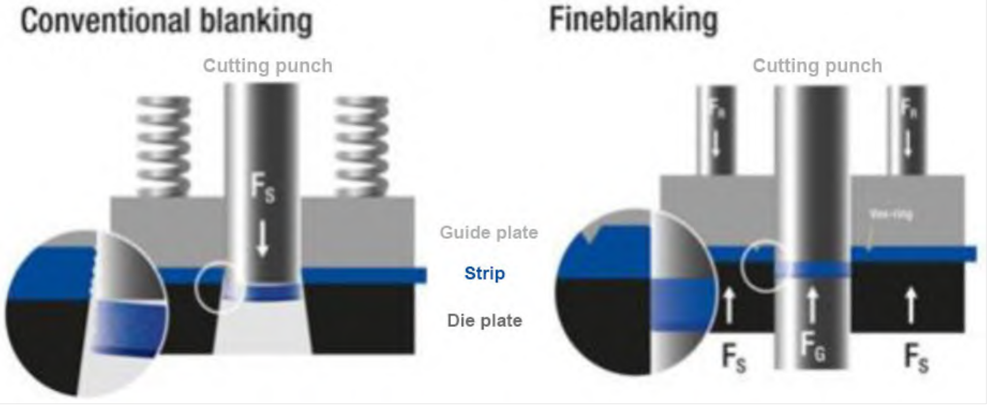
Punching Vs Blanking
- In blanking, removed material is the desired component
- In punching, removed material is scrap

9. Fine Blanking



Fine blanking applies pressure on the job from both sides.
(Image source)

(Image source)

Examples.

Fine blanking is where the component under blanking is subjected to an equal amount of pressure from both the die and punch. As compared to the normal blanking process, fine blanking provides excellent definition, flatness, and excellent edge quality. A remarkable feature of fine blanking is that shearing happens with practically no fracture zone. Under ideal conditions, very close tolerances between +/- 0.01–0.05 mm are possible, in fine blanking depending on the base material thickness, tensile strength, and the quality of the tooling.

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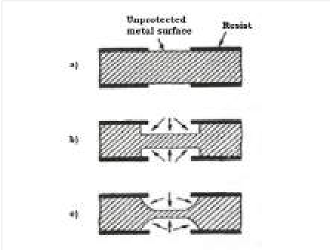
10. Chemical Blanking



Chemical blanking.


Very thin blanked materials.

Chemical blanking process is adapted to produce machined features on thin sheets and foils. The material is actually etched out by a chemical process. In some sense, it is chemical milling. Certain micro components like very thin gears, levers are done by chemical blanking.

Chemical Blanking consists of four main operations:

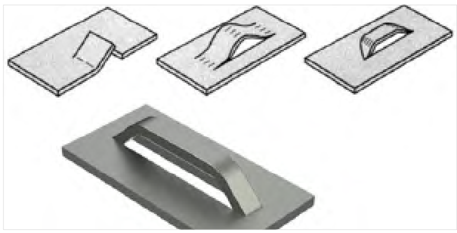
- **Cleaning**
Surface preparation

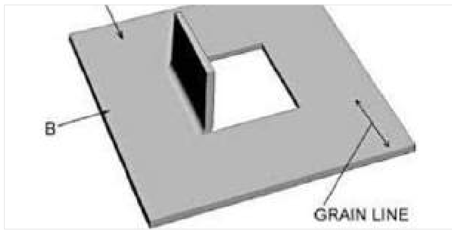
- **Masking**
Mask the areas to retain

- **Etching**
Etch out the unwanted areas

- **De Masking**
Remove the mask to expose the part

Chemical etching or milling is also done to produce shallow cavities with complex profiles on the surface of metal sheets and plates. The depth of material removed can be as deep as 10 mm.



Pierce and Plunge - To produce in-built hooks and Handles.
(Image source)



Pierce and bend - To produce integrated bends.

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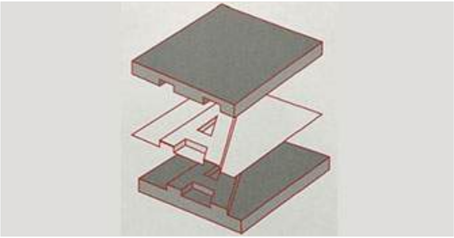
Lancing is a process wherein the material from a sheet is sheared and expanded further to form a profile in the same stroke. There is no loss of material but only a modification carried out in the sheet with the parent material still attached to the slit material. Lancing process is used to make ventilating louvers, tabs, bridges, flanges, and the like. Lancing is recommended to be done along the grain lines of the sheet.

12. Embossing

Embossing.


Embossing.

Embossing.
(Image source)

Embossing is used to create raised or sunken reliefs in ductile sheet metal. This can be done either by pressing the sheet between a die and punch or by passing through rollers with the etched patterns. Roller embossing gives a high rate of production. Embossing is sometimes combined with foil stamping to create decorative 3D effects. Embossing is usually limited to a maximum of 4 to 5 mm in depth.

13. Coining

Coining as the name implies is used to produce coins, buttons, badges, etc., It is a kind of precision cold forging process wherein the material is tightly compressed between two dies using a good amount of force. The surface of the material is subjected to such high stress that it induces plastic flow on the surface to produce finer definitions. The surface of the sheet is subjected to work hark hardening. Coining ensures very close tolerances, smoother surfaces, and practically no tapered edges.

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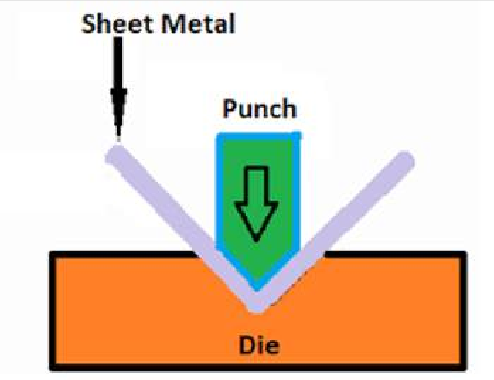
14. Bending

Bending is the most widely used operation in sheet metal fabrication. The machine that carries out sheet bending operation is called a "Press Brake". For small size manual bending "Fly Press" is used. Press brake also comes with a manual or CNC-controlled back gauge that allows positioning the bend line accurately.

Hand operated Fly Presses are available with tonnage up to 5 T.
(Image source)

Powered Press Brakes are available with tonnage up to 100 T.
(Image source)

Bending Process



Bending Process.

Different types of Punches and Dies.
(Image source)

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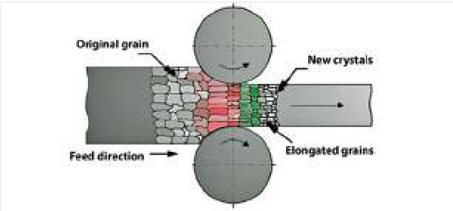
Vertical punch bending.

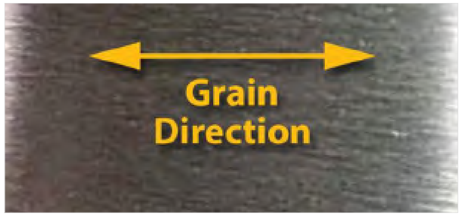

Horizontal punch bending.
(Image source)

The sheet is placed on a "Die" with a 'V" groove and the "Punch" applies downward pressure on the sheet above the die groove causing the sheet to bend. The bending process can be vertical or horizontal. The sharpness of the bend depends upon the groove width, sheet thickness, and the force applied. However, one hundred percent sharp bends are practically impossible due to the thickness of the sheet and in turn, their bending factors involved.

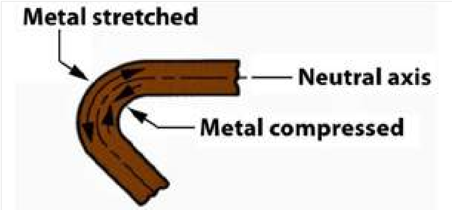
Bend Quality



Embossing.



Embossing.



Embossing.
(Image source)

Metal sheets have grain directions. These are formed at the time of manufacturing the sheet when the sheet is rolled and the grains elongate due to pressure in the direction of rolling. During the bending process the sheet contracts inside due to compressive forces and expands on the outside due to tensile forces. The bend line should preferably be perpendicular to the line of grain flow. While it may not always be possible, at least important bend lines should follow this guideline. The type of grain has also some influence on the bending force to be applied.

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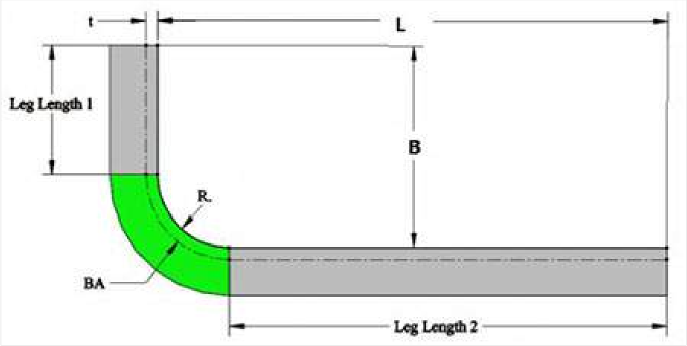
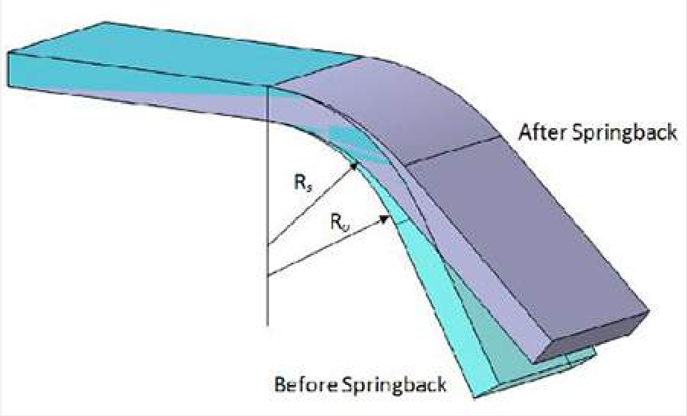
Precision



Given proper bending allowance to the sheet length, it is possible to derive bend lengths (shown as L and H in the figure) within +/_ 0.1 mm accuracy.
(Image source)

Once appropriate preparations are taken care of before bending, it is amazing to notice the quality of bends and the precision of corner joints. With proper tolerances, the joint appears almost seamless.

Spring Back



(Image Source)

When a sheet is bent with a stroke of the punch and when the punch is withdrawn, invariably the sheet springs back a little. On the shop floor, the press brake operator applies some allowance known as "spring back allowance" to compensate for the deviation. If bending is carried out little more than theoretical normal, the sheet springs back to the desired dimension. This practice is more of a trial and error method. The spring-back effect may vary from batch to batch of materials as well cold rolled or hot rolled sheets.

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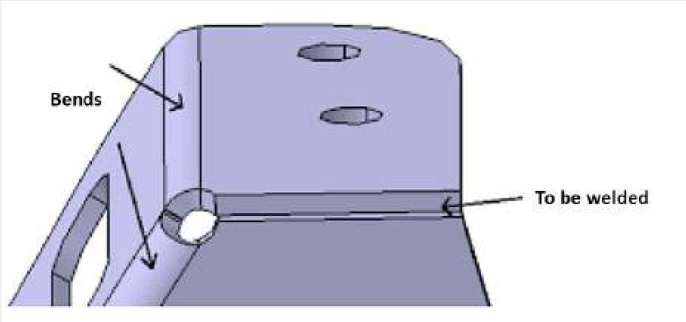
Corner Reliefs



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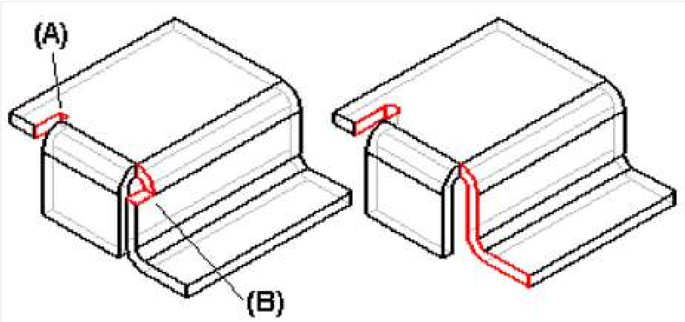
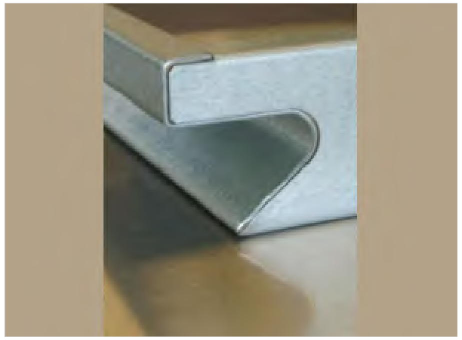


(Image source)

When a part is folded to form a three folded structure, as shown above, a corner relief hole is important for a sharp and undistorted corner joint. Without this hole, there will be interference of material from the three sides and tend to form a bulge. Also, the sheet tends to develop some stresses and tear even when two adjacent bends meet each other. In general, a minimum bend relief is equal to the material thickness plus the inside bend radius.

Corner Detailing


Typical corner welding.
(Image source)


Alternate corner detailing B and C.


Alternate corner detailing B and C.
(Image source)

In a simple tray-type bending the vertical gap between two adjacent folds in the corner always is an irritant. If it is filled with weld seam, the subsequent griding makes an appearance not very appealing, if not filled the gap may not be uniform. Unsupported vertical edges tend to show some buckle. To overcome this problem, flange material is made to firmly sit on the adjacent sheet edge as shown in fig B or corner bends are incorporated as shown in fig C.

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An interesting example

Manually bent flaps along the slots.
(Image source)

Another example of slots to assist bending with less force.
(Image source)

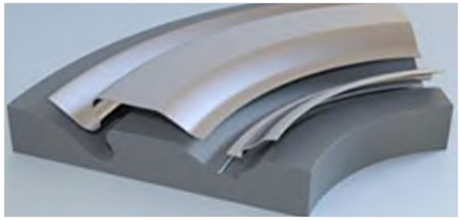
An example of bending a sheet metal part without a bending machine. Slots can be cut at the bending line to selectively weaken the material. The tabs can then be bent manually using a plier or even folded by hand. Since the slots weaken the material, such practices are not suitable for load-bearing, but suitable for small prototype enclosures.

15. Forming

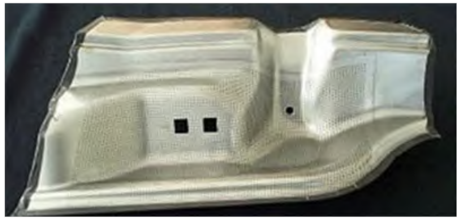
Forming is essentially causing deformation to the sheet metal by applying pressure to derive curvy or other intricate shapes. Almost all forming operations are cold working, which means they are not heat softened but worked on using the ductility properties of the sheet.

Bending and Forming
Bending and Forming are two different operations where the sheet metal is bent along an axis. When the axis of bent is a straight line then it is called bending and when the axis of bend is curved it is known as forming. The common feature between these two operations is that there is plastic deformation only near the axis of a bend.

Bending.



Curved Forming.
(Image source)



Deep Drawing.

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16. Deep Drawing

Deep drawing is one of the most widely used processes in sheet metal forming. It is widely used in the automobile industry to produce large auto body parts, in domestic products to produce kitchen sinks vessels with large depths, one side closed-end-tubes, etc. Deep drawing preferably requires softer and stretchable materials such as aluminium, copper, brass, while stainless of particular grades are also used with higher forces. Deep drawing occurs under both tensile and compressive conditions and is generally carried out in stages.



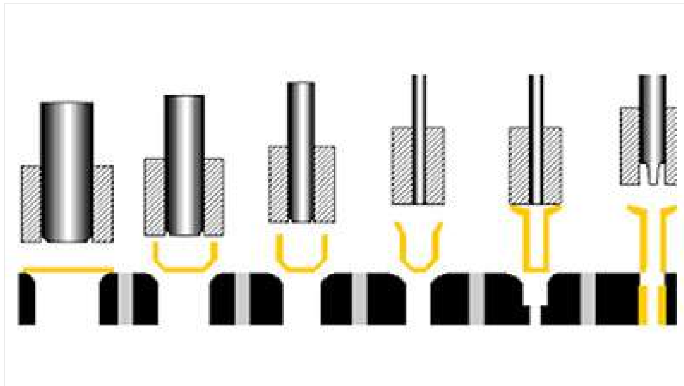

(Image source)

(Image source)

Examples of Deep drawn products.

Deep Drawing Process

Progressive Deep Drawing Process.
(Image source)


Progressive Deep Drawing Process.
(Image source)

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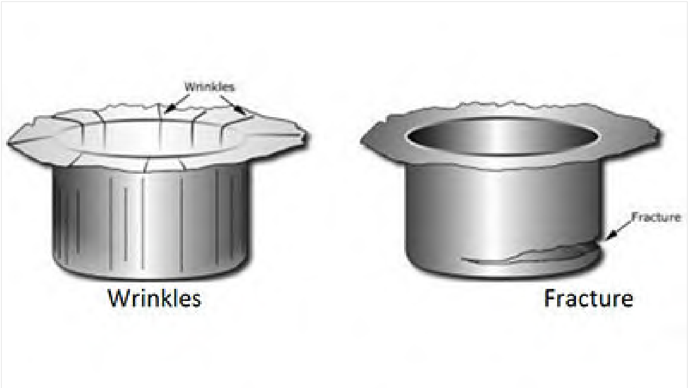
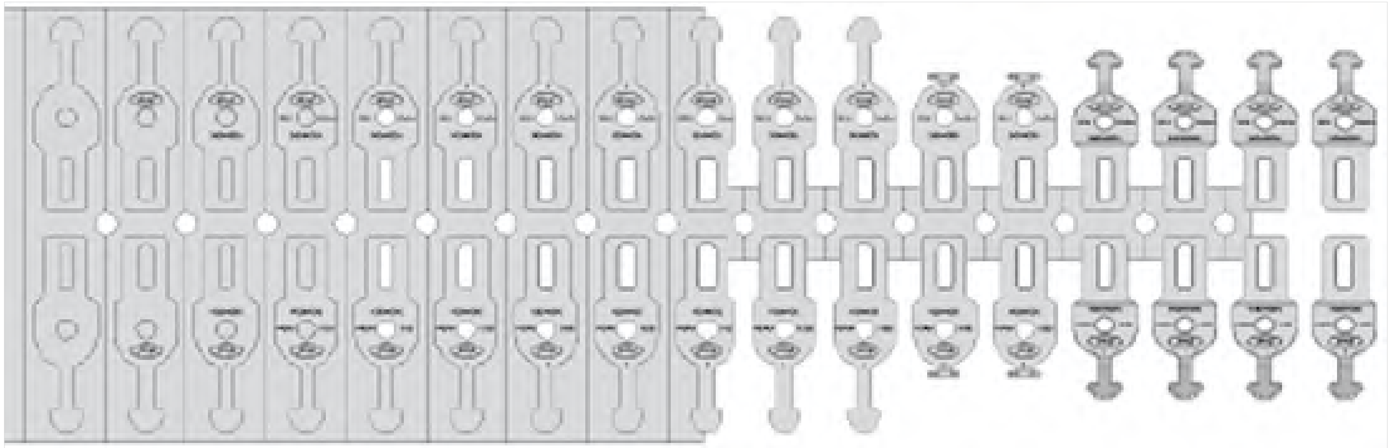
Deep drawn part before trimming.
(Image source)



Possible defects in deep drawing.

During deep drawing, work hardening takes place on the material. Therefore deep drawn products are considerably stronger.

17. Stamping



Progressive Die Stamping.

Stamping is adapted in the high rate production of small-sized components such as lugs, terminal strips. Stamping may involve a single punching method or a combination of punching processes such as press punching, blanking, bending, coining, embossing, flanging, etc.,

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18. Spin Forming

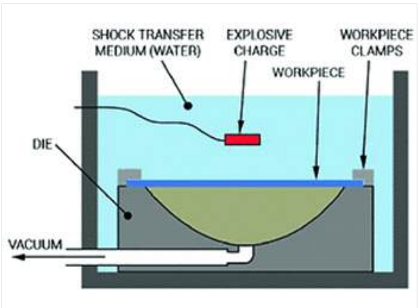
Spin Forming process.
(Image source)

Components formed out of spinning.
(Image source)

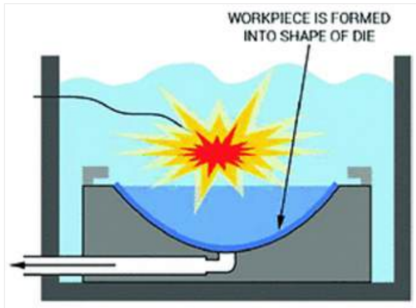
The spinning process is a process by which a disc or tube of metal is rotated at high speed against a mandrel of the desired shape and formed into an axially symmetric part. Spinning process does not involve material removal but essentially involves press forming over an existing shape. Commercial applications include nose cones, gas cylinder parts, kitchen utensils, etc.,

19. Explosive Forming

Explosive forming is a technique in which explosive charges are used instead of a punch to form the component against a cavity. Explosive forming offers interesting and unique possibilities where conventional methods cannot be applied such as one-off-large-sized components, or when very high pressures are required in a very short span of time.



Spin Forming process.
Examples of Explosive Forming
(Image source)



Components formed out of spinning.

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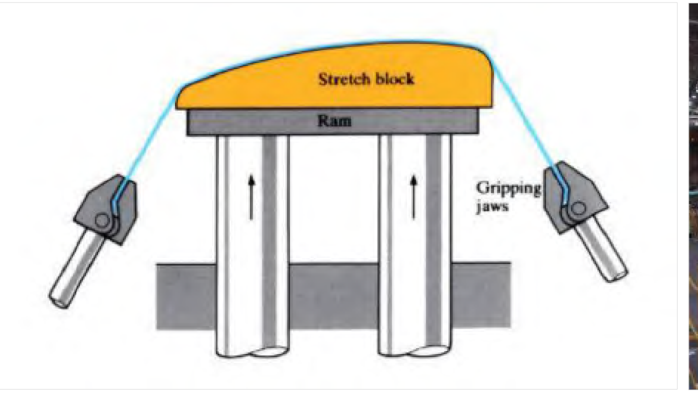
Rocket Cone.
(Image source)

Complex geometry.
(Image source)

Large size corner cladding.
(Image source)

Sheet sizes of more than 10 sq. mt, various types of metal sheets of varying thicknesses some upto 100 mm have been successfully formed by explosive forming.

20. Stretch Forming



Aircraft fuselage by stretch forming.
(Image source)

Aircraft fuselage by stretch forming.
(Image source)

In the stretch forming method, the sheet is stretched and bent simultaneously over a block to form large contoured components.

The sheet is firmly gripped at the ends by gripping jaws and placed over the stretch block. The block which has the desired curved contour is moved upwards to deform the long sheet. Any ductile sheet can be formed by this method, but normally aluminium alloy sheets are used to form large parts like aircraft fuselage cladding. Stretch forming as can be understood is limited to one side countered curvature only but not dual axis forming like bowls.

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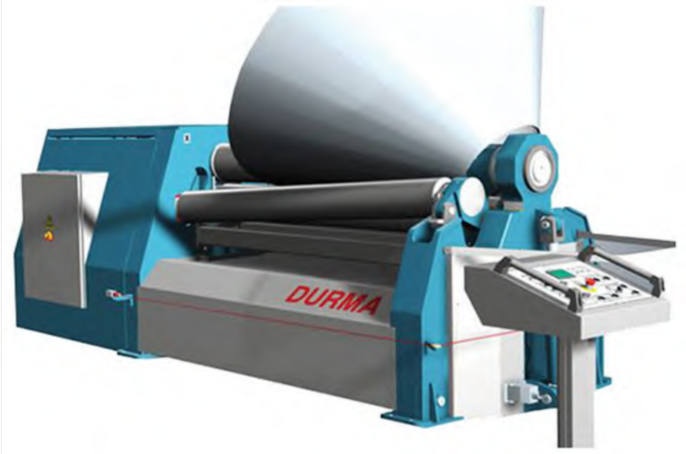
21. Rolling/Rollforming

Rolling is the process of inducing curvature in sheets. In rolling the sheets are rolled between a set of rollers into cylindrical or any curved shapes. Rolling of sheets with varying radii is also possible. The number of rollers typically varies from three sets to seven sets depending upon the accuracy required. There are simple manually operated machines to CNC controlled power machines are available. In these machines, not only sheets but profiles such as flats rods can also be rolled. The rollers in such cases will have grooves to accommodate the profile of the stock to be rolled.

Ducts .
(Image source)



Conical Roll Forming.
(Image source)

Hand operated rolling machine.

Power operated rolling machine Rolling.

Machine for bars and profiles.

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Rolling

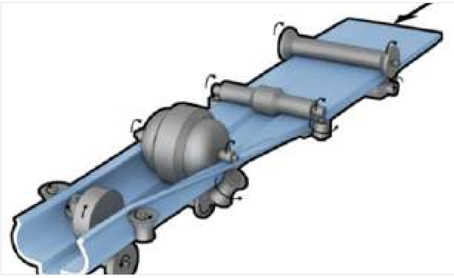
Sheet rolling plays a very important role not just in simple products like storage tanks and troughs but in complex products such as ship hull fabrication.


(Image source)

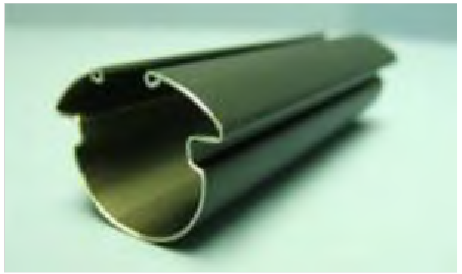

(Image source)

Rolling when done with proper engineering allows precision joinery to the closest possible tolerances. There can be no other way to form radii in sheets of high thickness and large sizes as possible with the rolling process.

Rollforming


Hand operated rolling machine. (Image source)


Power operated rolling machine Rolling. (Image source)


Machine for bars and profiles. (Image source)

Roll forming is a continuous process that converts a sheet by passing through a series of rollers into complex profiles. It is economical than press brake operations to produce components in large quantities. Since the raw material stock is normally a coil, there is no limitation on the length of the part other than handling issues. Almost all ferrous and non-ferrous materials such as steel, stainless steel, aluminium, and special alloys can be rollformed. Since it is a continuous line process, secondary operations such as painting, powder coating, galvanizing even mechanical operations like holes, hemming, knockouts can be integrated within the production line making it a very cost-effective process. The number of rollers sets in roll forming typically varies from three to nine. The higher the sets, the more intricate are the profile of the derived component.

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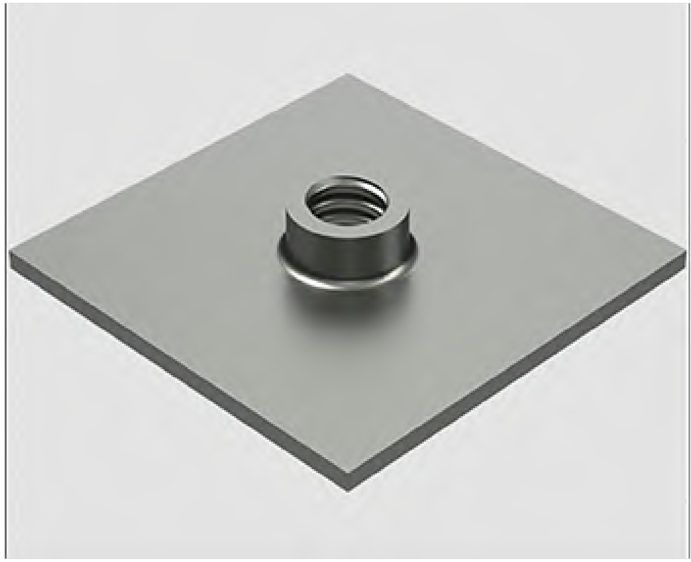
22. Plunge and Tap


(Image source)


(Image source)

Screws require threading to lock themselves in. Plunging operation allows part of the parent material to squeeze out and with enough wall thickness to permit threading by way of tapping.

Plunge and Tap accommodate screws without any nut. The basic material of the sheet is made to Stretch down without tearing to make allowance for tapping. This process is generally limited up to M5 size screws.

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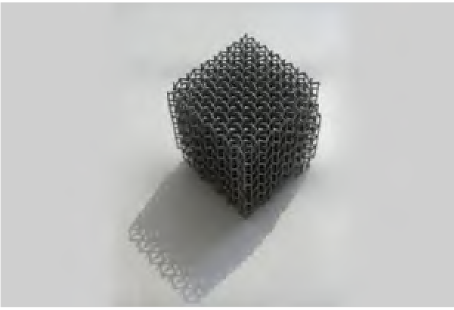
Metal 3D Printing


(Image source)


(Image source)


(Image source)

Examples of 3D Metal Printing

While 3D printing is not truly a part of sheet metal processes in the context of this book, it is not out of the way to learn something about this process as additive manufacturing which is known as 3D printing as it is bound to replace many conventional metalworking processes soon.

Metal 3D printing is considered the apex of all 3D printing. Metal 3D Printing is a laser-based technology that uses powdered metals. **DMLS** (direct metal laser sintering), **SLM** (selective laser melting), and **EBM** (electron beam melting) methods are commonly used methods of printing. Like Laser Sintering, a high-powered laser selectively binds together particles on the powder bed while the machine distributes even layers of metallic powder. Support structures are automatically generated and built simultaneously in the same material and are later manually removed. Once complete, the part undergoes heat treatment.

Printing Process

A 3D Metal Printing Machine (Image source)

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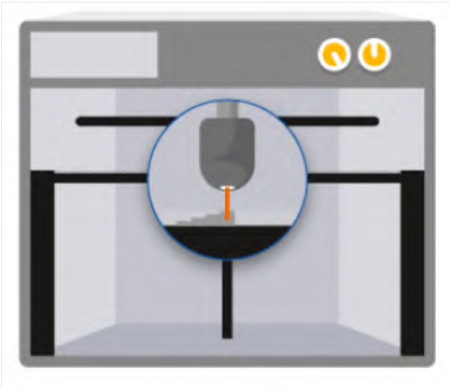
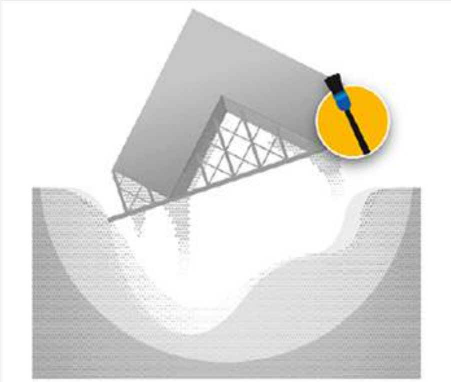
CAD Model.
(Image source)


Laser impinging.
(Image source)


Powder layer replinishment.
(Image source)


Power Removal.
(Image source)


Part Removal.
(Image source)


Heat Treatment.
(Image source)

Issues in 3D Metal Printing

3D printing however is not without its problems. Lot of preparatory work goes into the work. Much attention needs to be given to the CAD model to avoid possible problematic issues. Some of the problem areas are as follows:

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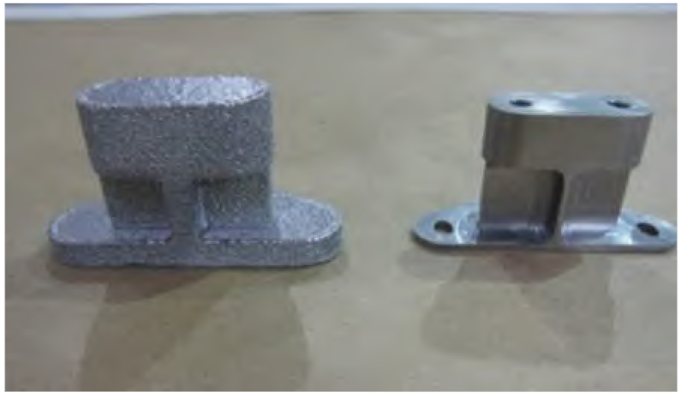
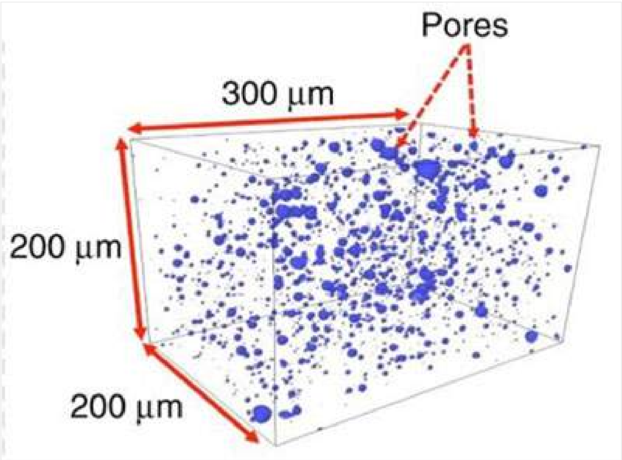
Issues in 3D Metal Printing



An example of surface finish before and after machining. (Image courtesy NASA)

Surface finish quality is most often rough and requires post-printing operations like machining. There is a trade-off involved between surface finish and cost.

Porosity



Courtesy: (3printr.com)

Porous cavities may occur due to certain gas formations or due to process anomalies during printing. It is important to control the quality of the powder, laser spot size, and intensity to avoid pores. Also, powder density and porosity are interrelated. A good printed part should at least have 90 % density.

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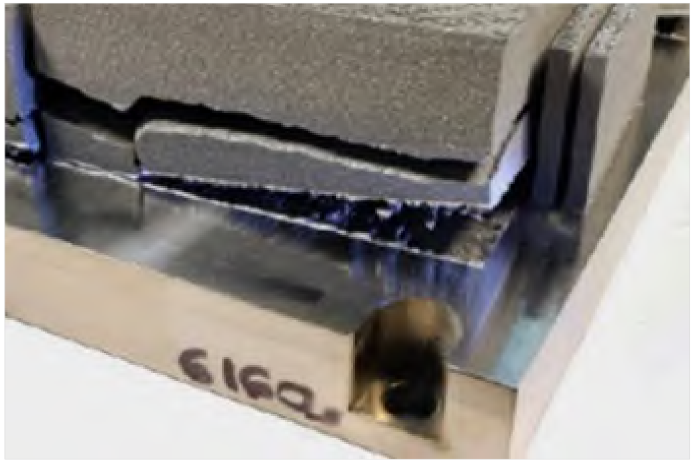
Residual Stresses



Residual Stress defects.
(Image source)


Cracking.

(Image courtesy of Albert To and University of Pittsburgh's Swanson School of Engineering.)
Residual stresses may occur due to expansion and contraction as a result of heating and cooling of the part while printing. This may lead to defects such as warpage or cracking of the substrate material during the solidification process. The quantum of energy applied also plays a role.

Warpage

Image courtesy of the Center for Additive Manufacturing and Logistics at North Carolina State University.
(Image source)

Thermal stresses induced in support structures or varying thicknesses can cause warpage to the component. To prevent warpage, it's necessary to place the ideal number of support structures in the right locations.

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https://www.dsource.in/course/sheet-metal/manufacturing-process/metal-3d-printing

Delamination

Image courtesy of International Materials Reviews. (Image source)

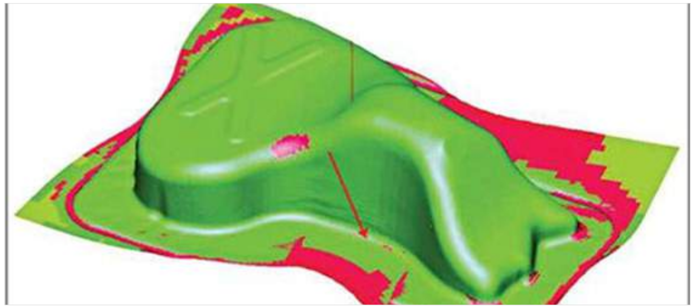
The cost of 3D printing is typically calculated as the cost of the powder used plus the machine time per hour. The machine time per hour price may vary from INR 2000 to 5000 depending upon the machine.

Few things to consider in 3D metal printing:

Wall Thickness - Maintain minimum wall thickness recommended by powder manufacturers.
Slits and gaps - Too narrow slits in the component tend to close.
Bridges - Inadequately supported bridges tend to collapse.
Hole Diameter - Maintain minimum hole diameters.
Overhangs - Cantilever projections, overhangs to have minimum recommended lengths.

1. Virtual Manufacturing

Excerpts from an article authored by Prof P P Date, Dept of Mech Engg, IIT-Bombay



CAD Model and actual componenti

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Given the increasing complexity of part geometries, together with ever-expanding options from the availability of a spectrum of materials and processes, getting the part ‘first time right’ appears to be a difficult proposition, unless modern techniques of simulation are used. Simulation software has been continuously incorporating these advancements into their database to predict the strains and the potential locations of failure in the part being formed. Virtual manufacturing will take the centre stage soon, since one can get a feel for how close the formed part would be, to the geometry intended by the designer.

Virtual manufacturing of sheet metal parts will have to account for the variations introduced by the inevitable variations in material properties, tool wear, tool deflection under load, and some inconsistency in spring back. While different stakeholders are working on the consistency of the final product quality, each of the above-mentioned factors will continue to bring in an element of uncertainty since the interaction material variations with almost every major parameter (like product geometry, tool design and tool geometry, sheet thickness, etc) impacts the final characteristics of the sheet metal part. Unless variations in material properties are curtailed, generous tolerances will have to be assigned to the dimensions and the philosophy of functional build will have to be adopted.

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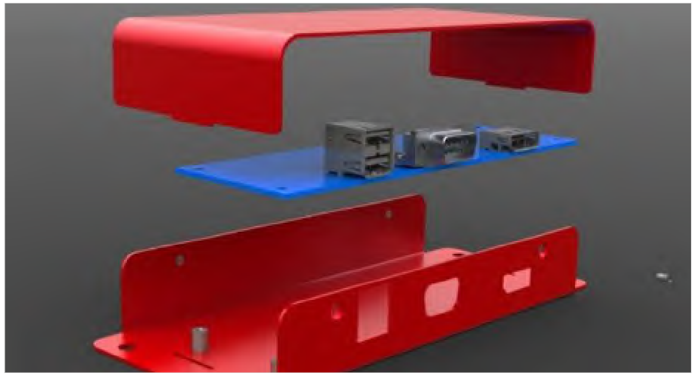
Sheet Metal Joinery

Chapter 4

Very few stand-alone sheet metal components are used as a final product by themselves. Usually, a final product appears after joining one or more parts in a sheet metal product assembly. They may be fixed permanently or temporarily. A good amount of detailing goes before the realization of a final product. A flawless mating of two parts begins at a conceptual level. An innocuous hinge may have involved in-depth work with respect to matings and tolerances.

A frequently used product may have a number of parts and joints which must be durable.These may be permanent or non-permanent whose choice depends upon the nature and function of the final product. Two parts may be fixed permanently together either in a rigid way or in a flexible manner. This chapter takes a review of these aspects.

An aircraft wing asembly.
(Image source)



An electronic product assembly.
(Image source)

Permanent Joints

A permanent joint is one wherein the joined parts can be separated by only destructive methods.

Types of permanent joints are:
- Welding
- Brazing
- Rivetting
- Flaring
- Seaming, Hemming

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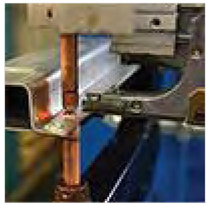
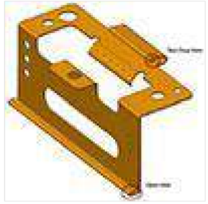
Welding


Riveting


Flaring


Hemming and Seaming


Non-Permanent Joints


Nuts


Washers


Hole Tolerances and Aesthetics


The Power of Sheet Meal Design

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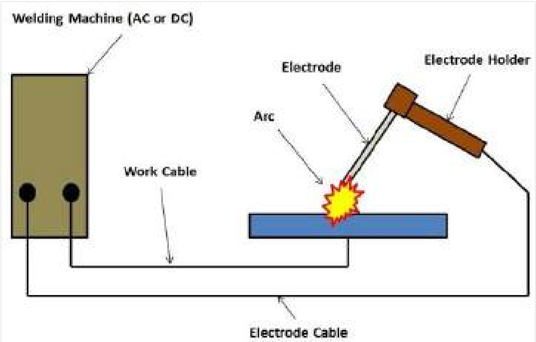
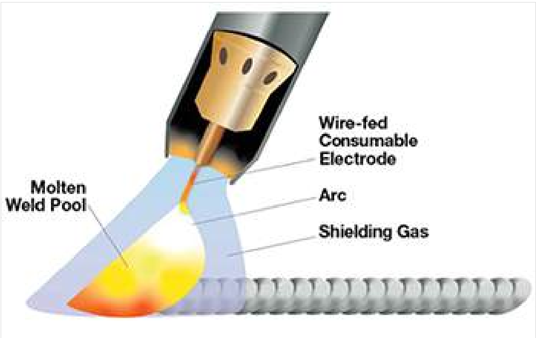
Welding

Welding is a fusion process. The heat applied to the pieces to be joined will during will melt the metals to a fluidic state and fusion takes place. If the process is done correctly, the fused metal is as good as a homogeneous one. The strength of a weld is such that under tensile stress, rupture can only take place nearly at the ultimate tensile strength of the original metal. For instance, one single weld bead drop of about 6 mm diameter will easily hold more than 100 kg of weight in tension.



(Image source)

The basic arc welding which is also called Shielded Metal Arc Welding (SMAW) uses an electrode whose material is compatible with the base metals to be welded. This strikes an arc between the metal and the electrode to melt the metals to the fusion point. The core of the electrode also acts as the filler material. Oxidation of metal is the biggest problem in the welding process as oxidation causes lumps which weakens the joint. In arc welding, the electrode has a coating that generates gases during welding that offers protection against oxidation.



MIG welding process.

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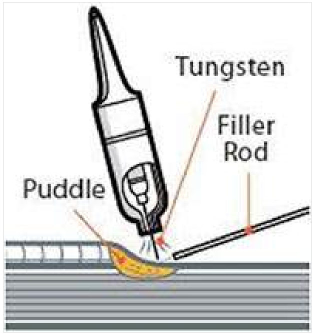
Gas Metal Arc Welding (GMAW) which is also known as MIG welding is a continuous wire welding process using a wire-fed electrode where a shielding gas around the electrode tip ensures protection to weld pool against oxidation. A variation of MIG welding is MAG (Metal active gas welding). In MIG welding the shielding gas is an inert one such as Argon or Helium, meaning the gas does not participate in the fusion. In MAG welding the shielding gas is an active one such as CO2, meaning the gas actively participates in infusion. MIG welding is preferred welding for aluminium while MAG welding is preferred welding for steel. The shielding gas also impacts the behaviour of the weld pool, regarding the penetration and mechanical properties of the welded joint.


Typical MIG welding machine

Normal arc welding is not recommended to weld sheet metal parts as it is likely to burn the sheet because of high temperature besides allowing oxidation resulting in lumps and poor welds. Most often inert gas welding such as Co2 is adapted because of the gas shield at the weld point which protects the weld from oxidation. The thin wire electrode used helps in controlling the temperature better than in arc welding. Argon arc welding is used for stainless steel and aluminium sheets welding using stainless steel electrodes and aluminium alloy electrodes respectively.

TIG Welding



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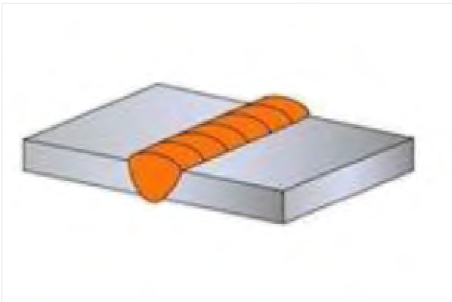
TIG (Tungsten Inert Gas) welding involves a Tungsten electrode that supplies the current for welding. The filler rod is dipped into a molten puddle for the pieces to join. This is the most popular welding method for thin metals. TIG welding is especially used for nonferrous materials such as aluminium, copper, and bronze. TIG welding is more versatile in the sense that it can be used to weld many types of metals and alloys including steel.

TIG welding requires more skill than MIG welding because the operator has to use both hands while welding. TIG welding gives a cleaner weld joint appearance than MIG welding. It is however little more expensive.

2. Types of Arc Welding

The primary types of welding the sheets together are **"Butt","Lap","Tee","Corner"and "Edge"** joint weldings.

Butt Joint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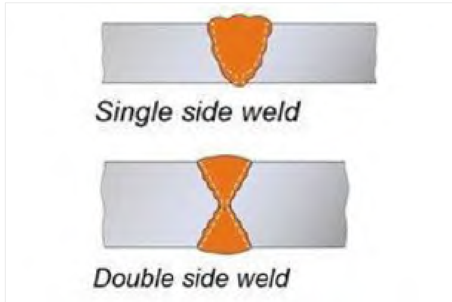

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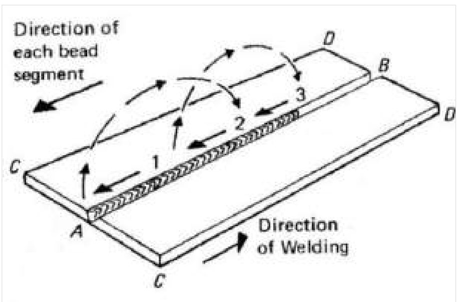

Skip and hop.


Butt weld in progress.
(Image source)

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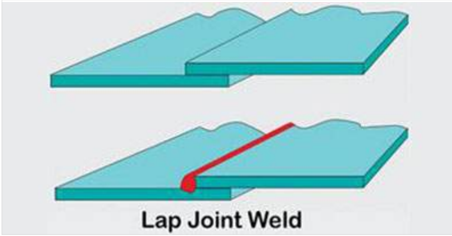
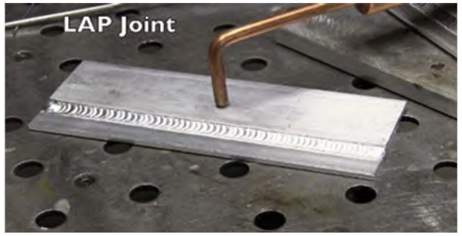
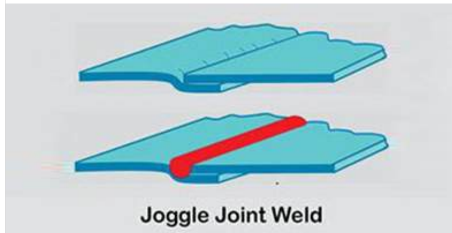
A butt joint is called when two workpieces are held together in the same plane and joined by a weld along their edges. In order to avoid distortions, welding is carried out in segments skipping and hopping along and in the opposite direction of the weld line. Metal sheets of over 3.00 thicknesses are generally employed for butt joints.

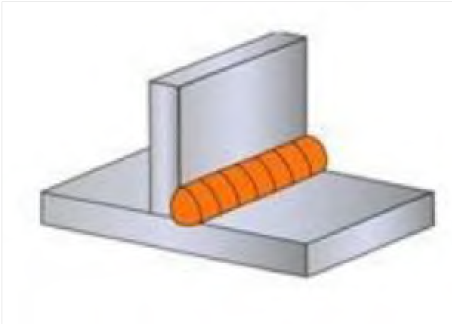






A lap joint is called when a part of a sheet is made to rest on another sheet and joined by a weld along the edge and on the surface of the sheets. A Joggle joint is when one of the pieces is pressed along the edge to accommodate the thickness of another sheet.

Tee Joint


(Image source)

(Image source)


T Butt welding in a structural frame.
(Image source)

A T- joint is called when the edge of one workpiece meets the surface of another workpiece in a perpendicular manner with material on both sides of the edge. The weld which is carried out along the joint of the sheets perpendicular to each other is known as fillet weld.

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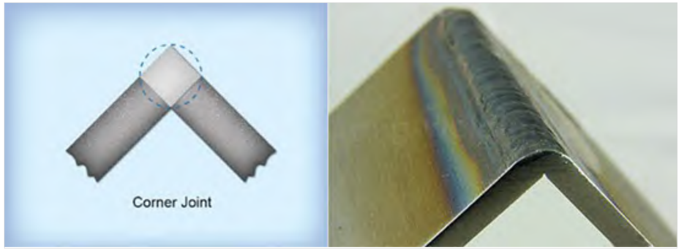
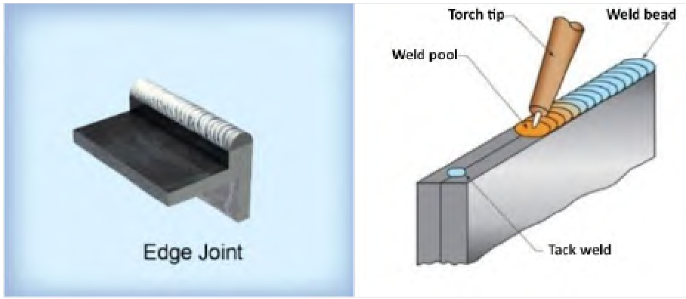
Corner Joint



(Image source)

When the edges of two pieces are perpendicular to each other and one piece's edge aligns with the other piece's surface, it is referred to as a corner joint. Common corner joints are edge to edge, flush corner, and half overlap, each with its own benefits.

Edge Joint



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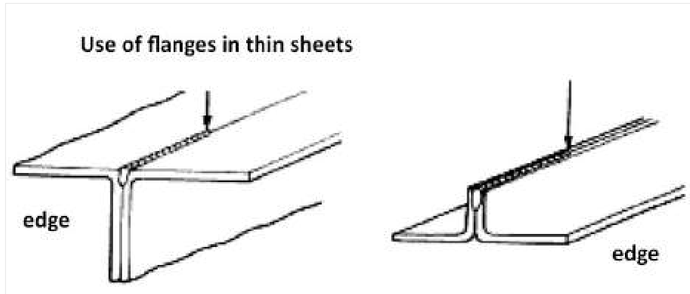

(Image source)

An edge joint is when two edges of weld pieces are adjacent and in parallel planes with each other. The weld does not penetrate completely through the joint thickness so it should not be used in high stress or pressure situations. In thin sheet metals, a flange is created, and welding is done either at the edge of the flange or in between the flanges.

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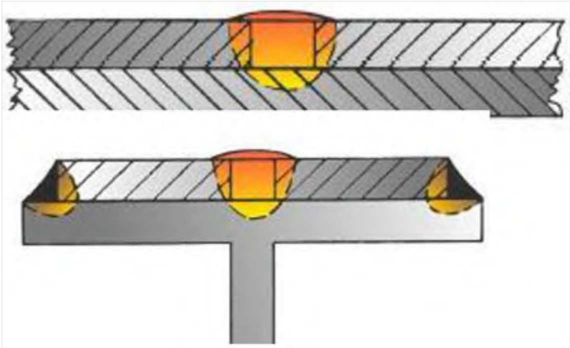
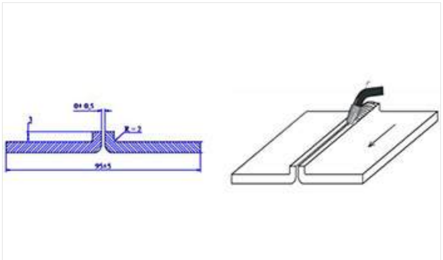
Plug Welding



(Image source)

A plug weld is used to join two pieces by welding through a hole in one of them to secure a bond and fill the hole with weld metal.

Joint Design in Sheet Metal
Butt joint weld for sheet metal is difficult and not advisable. If required edges may be folded a little and weld. A component should be designed in such a way as to increase metal thickness by way of a fold and carry out minimum possible welding. Consider if a tack weld may be sufficient instead of a full weld.



Butt welding of thin sheets.
(Image source)

Folded sheet and joggled welding.

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(Image source)


(Image source)


(Image source)

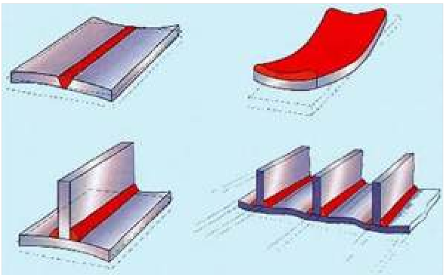
Defects in Welding

Porosity


(Image source)

Porosity occurs when gas bubbles are trapped within the weld. It is most common in normal arc welding. Proper temperature control and shielding against oxidation help prevent porosity.

Distortion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Steel sheet welding is a skilled process. Welding of sheets 0.5 to 2.00 mm thick generally involves high precision techniques. Warp and camber occur if proper care is not taken. Product design should keep in mind the distortions caused by the weld heat to the component and make allowances as required. When welding thin metal, the main objective is to avoid warping, burn-through, and excessive heat-affected zones while still ensuring the weld has enough mechanical strength for the application.

To counter distortion, camber, and stresses due to heat.,skip welding is a technique employed. Heat dissipation is another method.

Heat Management


Skip welding. Skip and weld (Image source)

The normal method of the welding process is first to hold the job in position firmly and tack welds (a spot of weld) at regular intervals applied along the desired weld length. After ascertaining the rightness of relative positions of pieces with respect to angles and straightness, full welding is carried out. Here Jigs and fixtures play an important role in holding the job in the position. Welding without holding the pice riding in place will lead to a very unacceptable end result. Even a spot of tack weld will make the job very rigid and distorted. It may be possible to knock off the weld bead and reweld but only at the cost of appearance.

The strength of the weld also depends upon the number of passes the welding torch makes along the line of welding. This in turn depends upon the thickness of the sheets as to how many passes are required.

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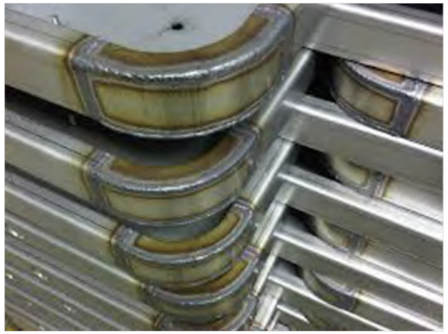
Corner Joints

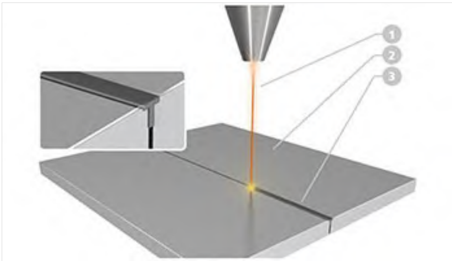
Direct corner edge welding.
(Image source)



Corner strap welding.
(Image source)

Quite often corners of a sheet metal component such as a tray as shown need corner welding. If the corner finish is aesthetically important it is better to introduce a corner strap instead of direct edge welding.

Laser Welding



Laser Beam Laser weld quality.
(Image source)

Work Piece.

Weld Seam.
(Image source)

Laser welding technology is a modern welding solution. A laser beam is highly focused and very intense. The impinged area of the beam receives energy ten times more than conventional arc welding. The beam can melt or evaporate all most any material. In butt welding, unlike other welding processes where weld material forms a bulge along with the electrode travel, laser welding creates a narrow and deep weld groove. This is because the surface of the metal where the laser beam touches evaporates because of the high-intensity heat.

Laser welding produces visibly smooth surfaces. It also reduces many post-weld operations such as grinding and sanding. The weld quality and productivity are much better in laser welding as compared to other conventional methods.

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There are three types of laser welding which is in general use:

1. Fibre Lasers
Fibre Lasers are more versatile. The size of the materials to weld varies from very small to very thick. They are also relatively cheaper.

2. Nd: YAG Pulsed Lasers
These are a kind of doped synthetic crystal material lasers that are mainly used for spot welding. The size of the spot can be varied to suit particular applications such as deep spot or seam welding.

3. Continuous Wave Lasers
Continuous-wave lasers emit continuous laser beams with controlled heat input. These are ideal for high-speed welding because of the constant beam.

Though initial expenditure is more to install laser welding set up, it pays well as compared to MIG/MAG welding in large-scale production.

Stainless Steel Welding

Heat control is very important in SS welding. (Image source)

The main grades of stainless steel for welding purposes are 300 series and 200 series. The most popular austenitic stainless steel is grade 304. The filler material to be used for welding must be compatible with the base metal for a good weld joint. It is also important to monitor the temperature of both. The temperature of weld material and base material must be controlled properly to ensure good performance of the joint. While MIG, MAG welding is also used in welding stainless steel, TIG welding is the preferred choice.

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In stainless steel, welding surface protection is of utmost importance because stainless steel is very sensitive to the presence of carbon. The presence of co2 gas or residues of carbon on the work table or tools can react adversely with stainless steel under welding. Also, stainless steel is very unforgiving in hiding mistakes. Every scratch, discoloration, and blemishes are more pronounced than in MIG/MAG welding.

Colours in the weld bead mean oxide formation which affects corrosion resistance. The colours vary from chrome to gold to deep purple. The darker the colour more is the oxidation. Oxidation on the surface is acceptable but below the surface, porosity occurs.

Aluminium Welding

(Image source)

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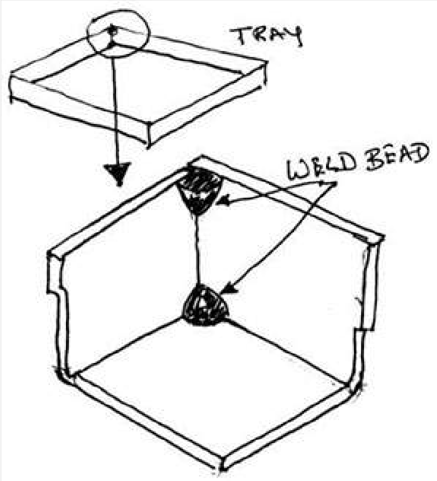
Aluminium has always a coat of oxide present on the surface which acts as a barrier for quality welds. This oxide melts at a much higher temperature than aluminium itself. It is, therefore necessary to remove the oxide coat either by chemical or mechanical means. Aluminium has high thermal conductivity and a low melting point. While this is useful for quick solidification of the weld, it is advisable to dissipate the heat quickly. The solidified weld bead's volume is much lower than the volume of the molten weld bead, therefore distorting during the time of shrinking. It is also important that the welding is carried out at a faster rate and with some heat dissipation methods. The most popular method adapted in aluminium welding is gas tungsten arc welding or TIG welding followed by gas metal arc welding or MIG welding.

Tip



While fabricating components such as panels and trays explore if inside corners can be welded rather than outside corners. This will eliminate grinding and sanding on the outside to ensure a clean appearance.

3. Resistance Welding

Resistance welding is a metal fusion welding technique where the materials to be joined are heated by electrical resistance and fused together with some pressure. Resistance welding is employed to join parts of steel, aluminium copper, bronze, and the like where electrical conduction is ensured. Spot welding, seam welding, projection welding processes are all form part of resistance welding techniques.

Spot Welding
Spot welding is when a spot of a weld is created between two sheet metal parts by resistance welding to fuse together the parts.

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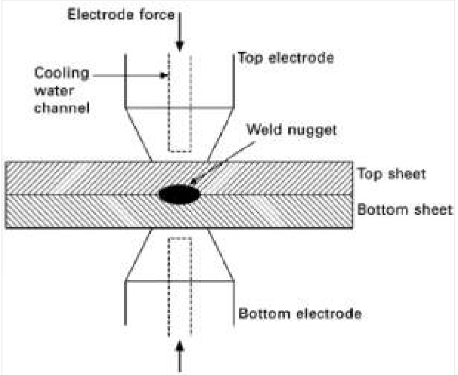


Welding process.
(Image source)

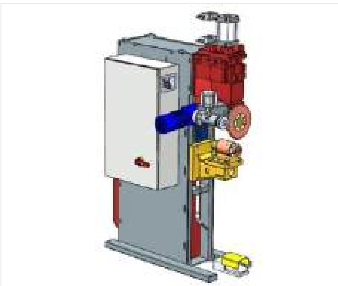
Floor standing Spot Welder.
(Image source)

Portable Spot welder.
(Image source)

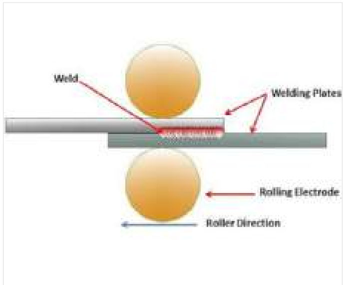
Extensive use of spot welding in automobile bodies.

Resistance welded automobile door.
(Image source)

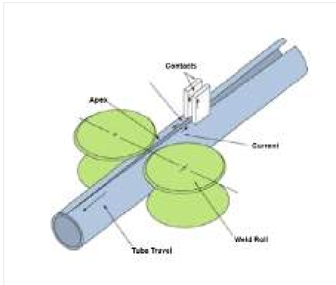
Seam Welding



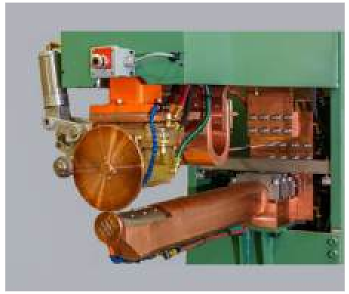
Seam Welder.
(Image source)



Seam welding of sheets.
(Image source)



Pipe formation by seam welding. (Image source)



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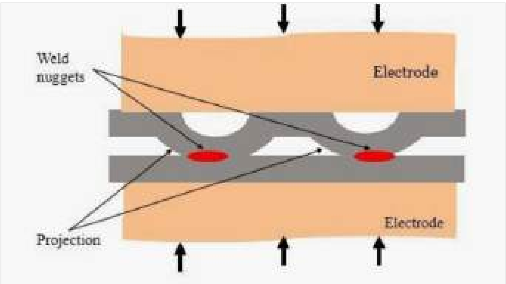
Seam welded Drums.
(Image source)


Seam welded tube.
(Image source)

Seam welding may be inferred as continuous spot welding in which a roller-type electrode is used to flow current through workpieces for continuous welding. A high ampere current is made to pass through the set of rollers which moves the sheets forward to be joined. This will create a continuous weld joint that can be air-tight.

Projection Welding



Projection welding process.
(Image source)


The nuts on the wheel hub are projection welded.

Projection welding process is a type of resistance welding. Projection welding requires studs to be placed on the metals to be welded. The shape of such studs can be button types, cone types, or spherical types depending upon the thickness of the materials to be fused.'

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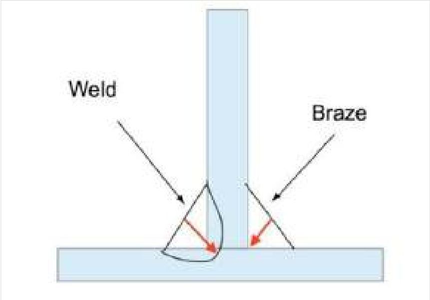
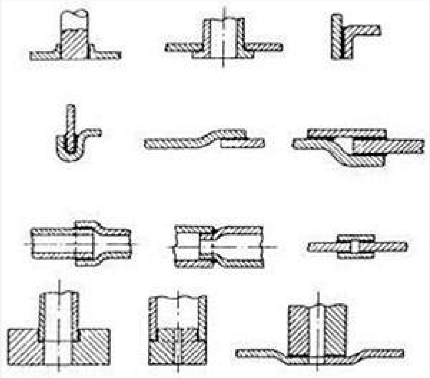
4. Brazing



Brazing does not percolate into metal. (Image source)


A cleanly finished brazed component. (Image source)


Suitable Joint Designs for Brazing.
Image courtesy: Handbook of Brazing and Soldering
(Image source)

Like in welding brazing uses a filler rod to apply molten material onto work-pieces. Brazing differs from welding in that the temperature is far lower allowing better dimensional control. Brazing does not melt the base metal. The important aspect of brazing is the joint design. Many types of joint designs are possible to enable different choices.

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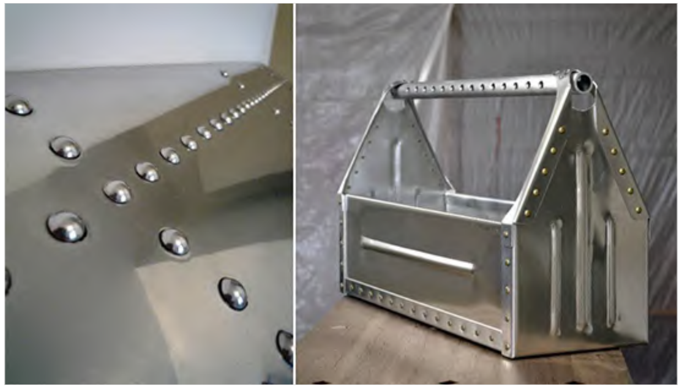
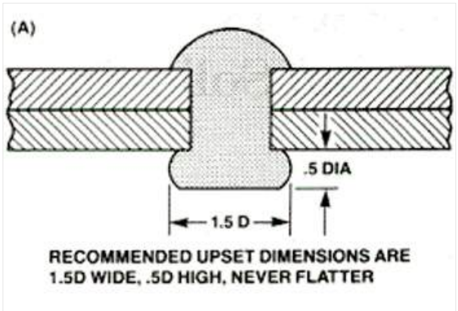
Source:
https://www.dsource.in/course/sheet-metal/sheet-metal-joinery/riveting

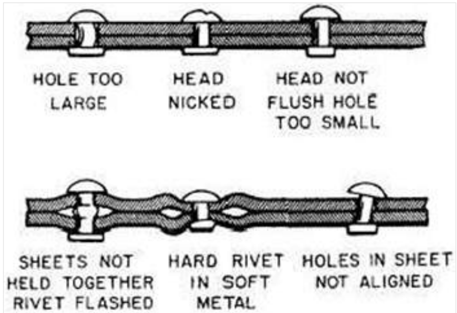
Riveting


(Image source)

Riveting is a cold process where the force applied causes deformation of a portion of the rivet. The deformed portion forms a bulge and holds firmly the workpieces together like a fastener. Rivets have various designs of the head at one end and they can be solid or hollow. The riveting process required good hole tolerances, positional accuracy and the right type of rivet material. Improperly planned riveting leads to distortion of sheets and other surface blemishes.



Standard upset dimensions.



Typical mistakes in riveting.
(Image source)

1. Blind Rivet
The term Blind rivet comes from the fact that only one side of the workpiece is seen when they are applied. Using predrilled holes two pieces can be fastened together without having to look at the other side. Blind rivets are ideally suited where normal rivets or other joints are not possible. Another advantage is that they are tamper-proof unless destructive forces are applied.

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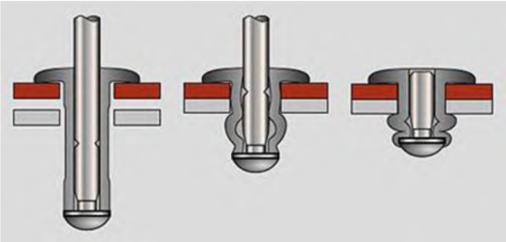
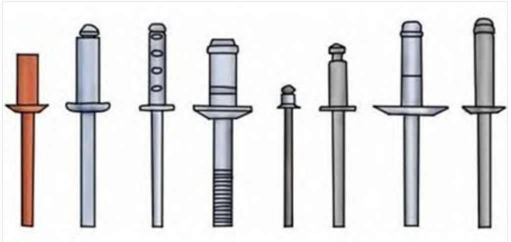
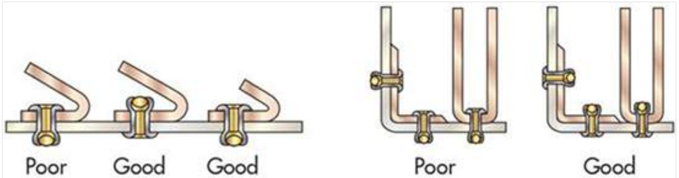
A blind river comprises two parts, the rivet body, and a mandrel. The rivet held by an installation tool is then inserted into the matching holes of two sheets. When the installation tool is triggered, the mandrel pulls the head of the rivet into the blind side of the rivet causing it to bulge and get trapped. The excess length of the mandrel breaks off at a pre-determined break-load. The result is securely held workpieces.


Blind riveting sequence.


Different heads of blind rivets.
(Image source)

Component Design
It is very important to plan a blind riveting position in advance while designing a component for the purpose. Easy access to the process is important. Factors such as joint strength, joint thickness, materials, hole size, and head style must be considered before selecting a blind rivet.



Predetermine the access to blind rivet locations

As with solid rivets, blind rivets should not be positioned too close to the edge of a joint subjected to structural loading. The centreline of the rivet hole should be at least equal to the diameter of the rivet.

2. Captive Nuts


Clinch Nut.
(Image source)


Rivet Nut.
(Image source)

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Source:
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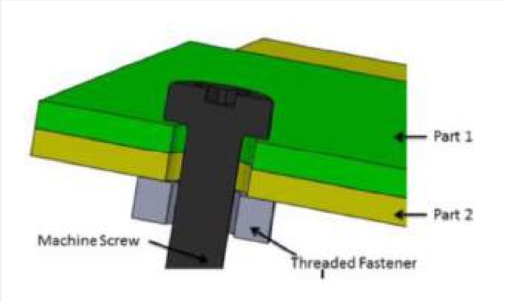
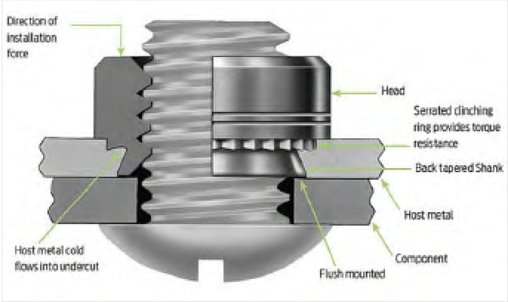
Normally, a screw and a threaded nut are used in securing two sheets together. At times the location of the nut may not be accessible to fix the screw. In such cases, as in the case of blind rivets, clinch nuts or rivet nuts are used for the purpose. These fasteners will have knurling under the head. As in the case of rivets when compression takes place, the corresponding thickening of the midsection forces the knurling 'eat' into the sheet, and clinching takes place. Thus the nuts are securely kept in place permanently.

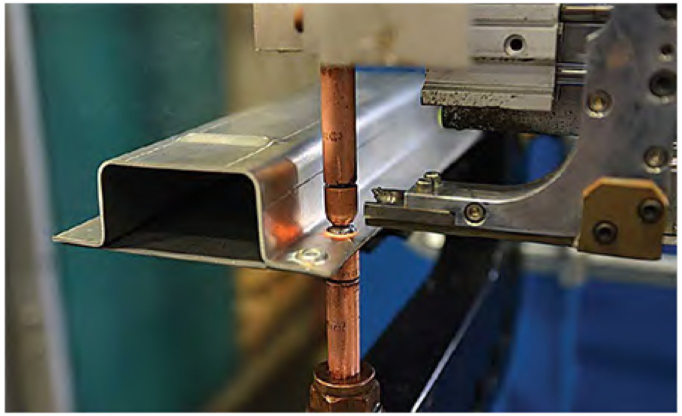


Clinch nuts and rivet nuts are clinched or rivetted to part 2 to replace conventional threaded nut.



Clinch nut nomincalture.
(Image source)

3. Revit Cum Spot Welding



Rivet cum Spot weld
Arconic Fastenin Sys (Image source)

A hollow rivet may also be spot welded for specific purposes. As can be seen in the picture the sub-assembly is spot welded with hollow rivets. This enables the sub-assembly to get fixed to any other part of the main assemblies with suitable fasteners through the hole available in the rivet.

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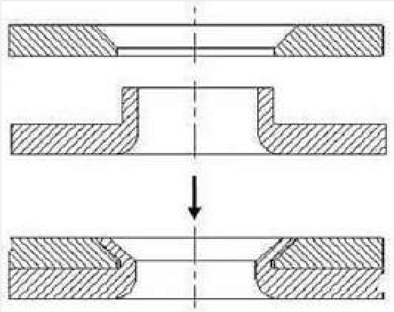
Flaring


Flaring.


Flaring Tool.
(Image source)

Flaring is the process by which two sheet parts are tightly held together by expanding and squeezing the material of one part into the countersunk space of another part. It is a form of revetting where the rivet is nothing but the integral material of one of the parts. Flaring is recommended mainly to arrest lateral movement of the parts.

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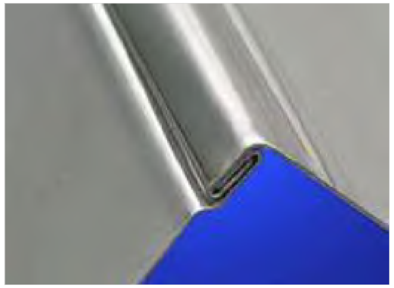
Source:
https://www.dsource.in/course/sheet-metal/sheet-metal-joinery/hemming-and-seaming

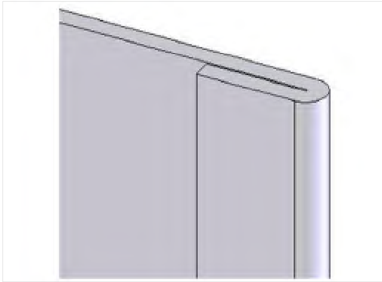
Hemming and Seaming

Hemming and seaming are two similar metalworking processes in which a sheet metal edge is rolled over onto itself. Hemming is the process in which the edge is rolled flush to itself, while a seam joins the edges of two materials.

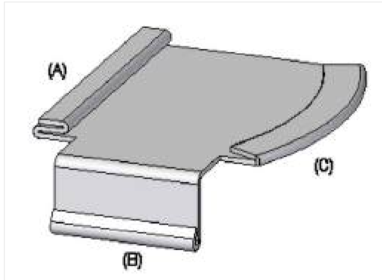
1. Hemming



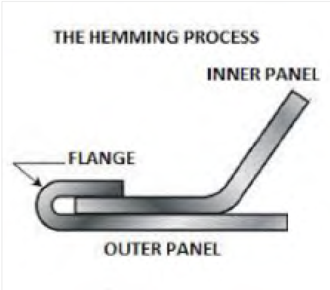
Straight Hem.
(Image source)



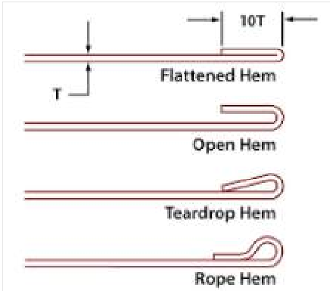
(Image source)



Contour hemming.
(Image source)

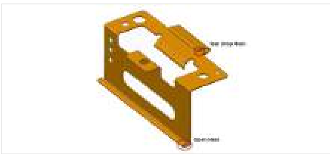


Hem detail.
(Image source)



Types of Hemming.
(Image source)

Hemmed component example.
(Image source)



Hemming on an automobile part.

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The accuracy of the hemming operation is particularly important since it affects the appearance of the surface and surface quality. Improperly done hemming causes dimensional variations and material deformations such as wrinkles in the flange.

Hemming ensures better edge stiffness to a sheet. Hemming also helps in creating a smooth surface to touch instead of a sharp edge typical of sheets.

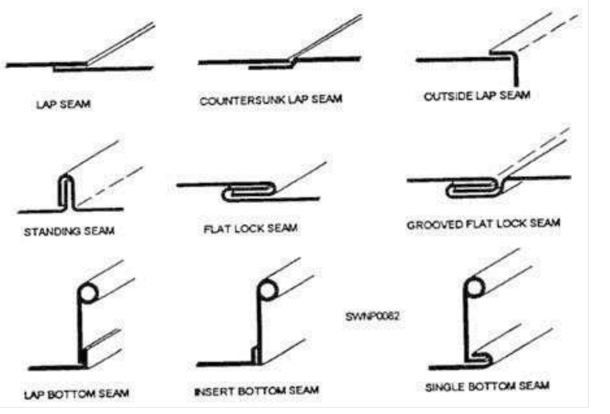
2. Seaming

Hand Seamer.
(Image source)

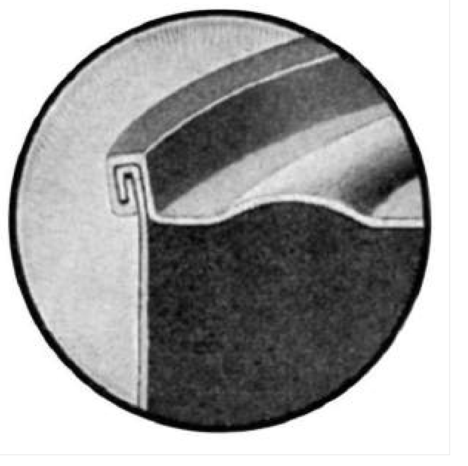
Desktop Seamer.

Seamed Roofing Sheets

Seaming is when two partly hemmed edges are joined together to form a seal. Seams are commonly used in the food industry on canned goods. Seams are also used to seam two roofing sheets together in the building industry.



Types of Seams.
(Image source)



Seaming forms a hermitical seal between the body and cover of a can.
(Image source)

Source:
https://www.dsource.in/course/sheet-metal/sheet-metal-joinery/non-permanent-joints

Non-Permanent Joints

Fasteners

Bolts Screws Nuts Washers


Bolt
(Image source)


Screw
(Image source)

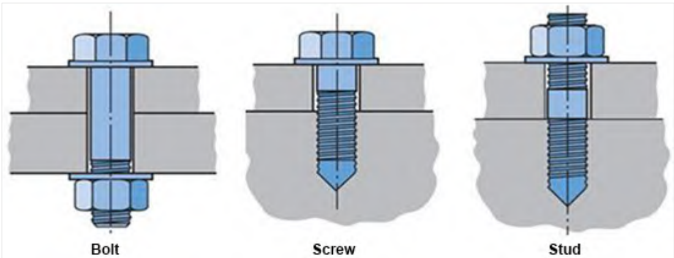

Nut
(Image source)


Washer
(Image source)

Fasteners are used to create non-permanent joints between parts. There are two types of fasteners generally used in the fabrication industry – threaded fasteners and general fasteners.

Threaded Fasteners

Threaded fasteners are the principal devices used for assembling components and they are usually grouped into three main categories as shown in the figure:



(Image source)

Difference between bolt and screw:
• **Bolts:** A bolt has a head on one end and threads on the other end and it is paired with a nut.
• **Screws:** Screws have a head on one end and threads on the other end and usually have longer threads than bolts. They are made available with heads of different types.

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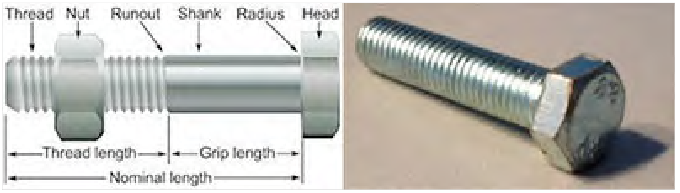
• **Studs:** A stud is a rod that is threaded on both ends and joins two mating parts. A nut may be used on one end.

1. Bolts

Bolts are less used in sheet metal applications. However, it is appropriate to review some pertinent information.

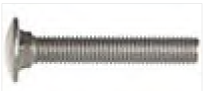


Structural Bolt
(Image source)

Hex Head Bolts

Hex tap bolts, hex cap screws, trim head hex cap screws, and hex serrated flange bolts fall under this category. They share a hexagonal head and are driven with a wrench.

Carriage Bolts



(Image source)

Also known as a "coach" bolt, has a domed or countersunk head. The square section under the head grips into the part being fastened preventing the bolt from turning when the nut is tightened.

Shoulder Bolt

(Image source)

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Shoulder bolts are machine screws with a shoulder between the thread of the screw and the head of the part. Once installed, the non-threaded portion extends out of the surface of the application site, allowing the bolts to act as dowels or shafts for moving parts.

Anchor Bolts

(Image source)

Anchor bolts also known as expansion bolts are used for grouting purposes, for example, to rigidly fix an assembled cabinet or a frame to the ground in a secured manner. They are first driven into the ground and made to stay in place tightly by way of expansion sleeve.

J Bolts

(Image source)

J-bolts are J-shaped fasteners, threaded on the straight side. They are often used in structural applications like securing parts to foundations or other rigid parts. The bent end hooks around the support.

U Bolts

(Image source)

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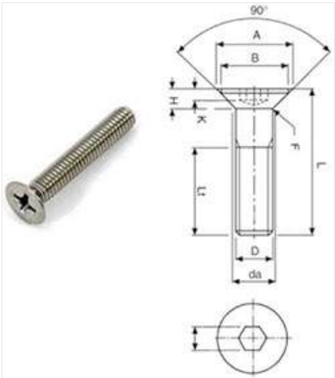
U-bolts have primarily been used to support pipework. A U-bolt would be described by the size of pipe it was supporting. U-bolts are also used to hold ropes together.

2. Screws

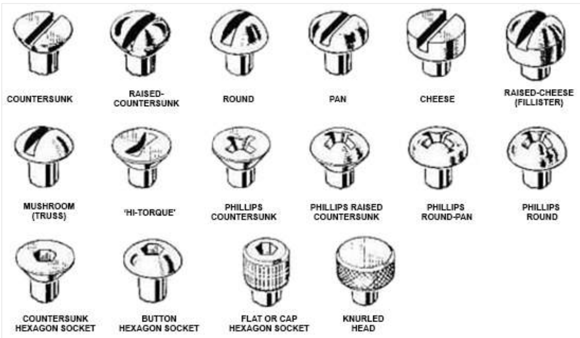
Screws are the most widely used fasteners in the sheet metal industry. There are a wide variety of screws available to suit different applications.

Anatomy of Screw



Example CSK Screw.

Machine Screws
Machine screws have rolled threads means the threads are precise in pitches and tolerances. They come in a coarse thread, which means they have 1 thread per mm, and in fine thread, they have1.25 threads per mm. Machine screws come with different types of heads.



(Image source)

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The most common types of machine screw head shapes are pan-head, cheese head, countersunk, button head, socket head, and Phillips head. While screws require a regular screwdriver to tighten, the socket head needs an Allen key, and phillips head needs a star screwdriver Countersunk screws are used when the screw needs to be flush with the surface. Set screws and grub screws are headless.

How to specify a Screw?

(Image source)

Example : CH M8 x 20

the description means...

CH = Screwhead type (Cheese Head)

M = Metric thread designation

8 = Nominal diameter, in mm

20 = Length, in mm

Datasheets of screws give elaborate and precise information about all fasteners. It is easy to incorporate the same in designs and documentation to facilitate tolerances and hole diameters.

3. Screw / Bolt Hole Tolerances

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Clearance Hole Tolerance Table

Bolt or Scre Diameter	Close Fit			Medium Fit			Free Fit		
	Clearance Hole		Position Tolerance	Clearance Hole		Position Tolerance	Clearance Hole		Position Tolerance
	Min Dia	Max Dia		Min Dia	Max Dia		Min Dia	Max Dia	
1.5	1.7	1.8	0.08	1.8	1.94	0.16	2.0	2.25	0.35
2.0	2.2	2.3		2.4	2.54		2.6	2.85	
2.5	2.7	2.8	0.16	2.9	3.04	0.35	3.1	3.3	0.55
3.0	3.2	3.32		3.4	3.58		3.6	3.9	
4.0	4.3	4.42	0.25	4.5	4.68	0.4	4.8	5.1	0.7
5.0	5.3	5.42		5.5	5.68		5.8	6.1	
6.0	6.4	6.55		6.6	6.82	0.55	7.0	7.36	0.9
7.0	7.4	7.55	0.35	7.6	7.82		8.0	8.36	
8.0	8.4	8.55		9.0	9.22	0.9	10.0	10.36	1.8
10.0	10.5	10.68	0.4	11.0	11.27		12.0	12.43	
12.0	13.0	13.18		14.0	14.27		15.0	15.43	
14.0	15.0	15.18		16.0	16.27		17.0	17.43	2.8
16.0	17.0	17.18		18.0	18.27		19.0	19.52	
18.0	19.0	19.21		20.0	20.33	1.8	21.0	21.52	
20.0	21.0	21.21		22.0	22.33		24.0	24.52	
22.0	23.0	23.21		24.0	24.33		26.0	26.52	3.5
24.0	25.0	25.21	0.9	26.0	26.33		28.0	28.52	
27.0	28.0	28.21		30.0	30.33		32.0	32.62	
30.0	31.0	31.25		33.0	33.39		35.0	35.62	4.5
33.0	34.0	34.25		36.0	36.39		38.0	38.62	
36.0	37.0	37.25		39.0	39.39	2.8	42.0	42.62	
39.0	40.0	40.25		42.0	42.39		45.0	45.62	5.5
42.0	43.0	43.25		45.0	45.39		48.0	48.62	
45.0	46.0	46.25		48.0	48.39		52.0	52.74	6.0
48.0	50.0	50.25	1.8	52.0	52.46	3.5	56.0	56.74	7.0
52.0	54.0	54.3		56.0	56.46		62.0	62.74	9.0

Dim in mm (Image source)

4. Self-Drilling / Tapping Screws

Self-tapping screws enable the elimination of nuts in joining two sheet metal parts. They are effective in keeping parts together under compression. A recommended pilot hole is drilled in the bottom sheet metal part and a through-hole in the top part. The self-tapping screw plunge through the bottom part creating a thread or two to enable taught fixing. The number of threads depends upon the sheet thickness.

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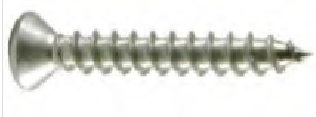
Where the material which accommodated the self-tapping screw is porous, a standard fiber "gland" is inserted to plug the hole as well to accommodate the screw.


Self Drilling Screws.
(Image source)


Sheet Metal Screws.
(Image source)


Gland/Wall plug.

Clinched Studs and Standoffs



(Image source)



(Image source)

Clinched studs and standoffs are meant to clinch into the sheet and stay firm. They are very useful for joining sheets and parts together so long as the pulling forces are not very high. Self-clinching fasteners stay permanently in thin ductile metal sheets by being pressed into place in a properly sized drilled or punched hole and by applying sufficient squeezing force. The force applied causes displaced sheet material to cold flow into the annular recess in the shank, permanently locking the fastener in place. Serrations, knurling in the fastener prevent the fastener from rotating in the metal when applying tightening torque. As compared to clinched nuts clinched studs have less footprint to enable placed closer to the edge of the sheet without causing the edge of the sheet to bulge. They can be mounted in sheets as thin as 0.8 mm. Clinch studs are used widely to stack PCBs using spacers in the electronic industry.

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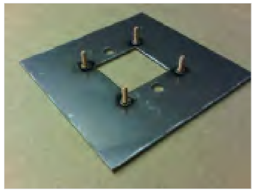
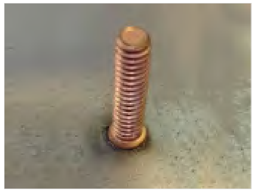
5. Resistance Welded Standoffs


Instead of clinching, this type of stanoffs are resistance welded to supporting sheet.


Welded threaded Studs.

Stud Gun. (Image source)


Copper Stud for grounding. (Image source)

Instead of clinching, these type of standoffs are resistance welded to supporting sheet. There are stud guns available that can weld the standoff by triggering.

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Nuts

The main purpose of the nut is to allow the maximum amount of torque and grip for a given size to tighten against a part. Nuts are graded with compatible bolts or screws.

Following are the most commonly used nuts:


Hex Nut.
(Image source)


Lock Nut or Jam Nut.
(Image source)


Cap Nut.
(Image source)


Castle Nut.
(Image source)


Coupling Nut.
(Image source)


Flange Serrated Nut.
(Image source)


K. Nut.
(Image source)


Square Nut T.
(Image source)


T Nut.


Shear Nut.
(Image source)


Wing Nut.
(Image source)


Knurled Thumb Nut.
(Image source)


Nylon Insert Nut.
(Image source)


T Nut.
(Image source)

The most commonly used nut is the six-faced Hexagonal nut. A jam nut is the second nut that is used to keep the first nut locked in place. A cap nut is used to protect the threads of the screw it covers. A castellated nut, also called a castle or slotted nut is used to insert a cotter pin from preventing the nut to rotate. A coupling nut is used for joining two male threads. A flange nut has a wide flange at one end which acts as an integrated washer. The serrated flange nut grips the part being tightened. A k-nut has an attached free-spinning lock washer. Square nuts provide a greater surface contact area and are typically mated with square head bolts. Wingnuts are threaded nuts with wings on each side of the body allowing for easy manual turning operation. Shear nuts are cone-shaped nuts with a hexagonal top. Once maximum torque is reached the hex head snaps off leaving behind a protective cone nut that cannot be easily removed. A knurled thumb nut has a rounded but knurled outside surface which facilitates tightening by hand. A nylon insert lock nut is internally threaded with a nylon insert to prevent loosening from vibration. A t-nut is used to pierce into the material and be flush with the surface.

1. Captive Nuts

These are the types of nuts kept in captivity either permanently or in a removable way.


Swage Nut.
(Image source)


Rivet Nut.
(Image source)


Weld Nut.
(Image source)


Cage Nut.
(Image source)

A Swage nut or clinch nut is used to clinch to a sheet to provide threading. Rivet nut has serrations and is riveted t the sheet, weld nuts are welded to sheets. Cage nuts come with housing which will be clipped onto a square slot provided in a sheet.

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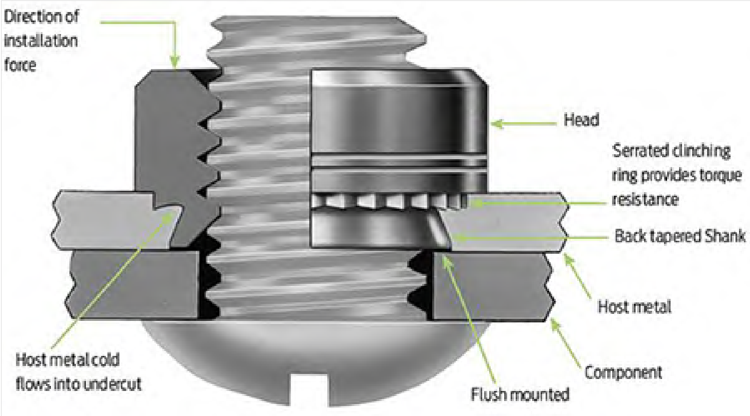
Clinch Nut



Clinching process in a clinch nut (Image source)

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Washers

The primary purpose of washers is to distribute the load evenly. They are most often kept between the screw head and the sheet surface or between a nut and the sheet surface to be tightened. Another purpose is to retain the screw in a vertical position with compressive force because screw threads may cut into sheet edge if there is lateral movement of the screw while tightening. Washers may also be used as spacers to fill the gap between the screw head and sheet surface if required.

Some of the commonly used washers are as follows:


Flat Washer.
(Image source)


Cup Washer.
(Image source)

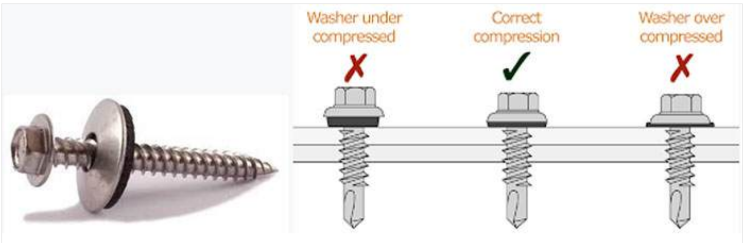

Curved Washer.
(Image source)


Split Washer/Spring Washer.
(Image source)


Toothed Washer / Serrated Washer.
(Image source)


Tab Washer.
(Image source)


Gromet Washer.



Damping washer
(Image source)

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Plain Washers or flat washers are the most commonly used washers to distribute the load evenly onto the mating surface. The Cup washer has a slightly conical shape which provides an axial force when deformed. A curved washer is curved in only one direction, enabling four-point contacts under pressure. Spring washers have a helix shape and allow the thread to be tightened by the nut in one direction only. Further, the raised edge bites into the underside of the bolt or nut and the part that it is bolted to, thus resisting turning. A serrated washer has radial serrations which bite into softer material to cause a locking washer effect. They also provide effective bonding with electrical grounding components. A tab washer is a locking washer with a side tab that can be bent into place against a nut. A Grommet washer has multiple sharp teeth integrated within a cup washer. These teeth dig into softer materials and remain in place even if the fastener is withdrawn. Damping washers have softer materials to act as dampers against vibrations as well to prevent seepage of liquids.

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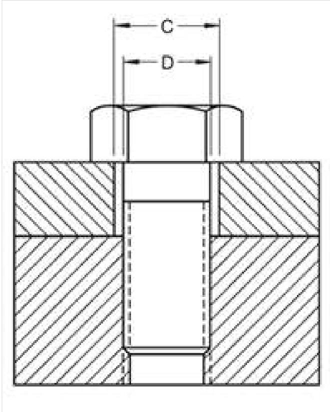
Source:
https://www.dsource.in/course/sheet-metal/sheet-metal-joinery/hole-tolerances-and-aesthetics

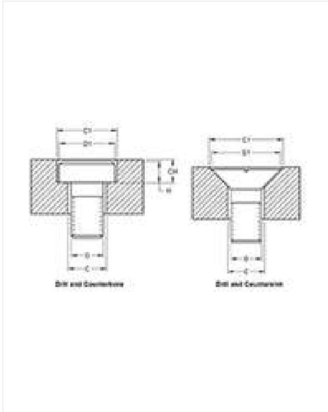
Hole Tolerances and Aesthetics

- **Aesthetics in conception**
- **Aesthetics in realization**

Tolerances are required to ensure that parts, and their fasteners, fit together within specification.



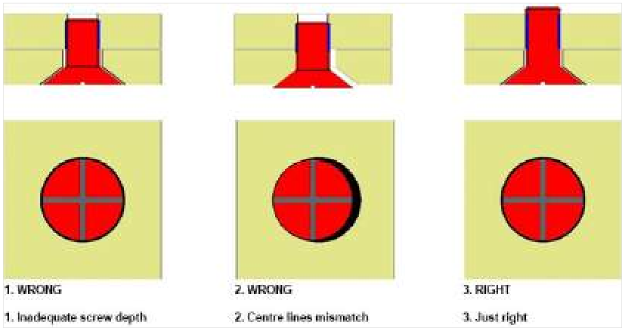
Bolt Clearance.
(Image source)



Screw clearance.
(Image source)

Tolerances are an inseparable part of fabrication. However well the choice of fixing methods is chosen, badly executed detail can undermine the intentions. We often come across badly fitted screws exposing unwanted areas, inadequate or over projected screws inviting frowned looks from prospective customers. Designers would do well in understanding the nuances involved in such details. Tolerances deserve the respect they need.

Example of a typical countersunk screw.



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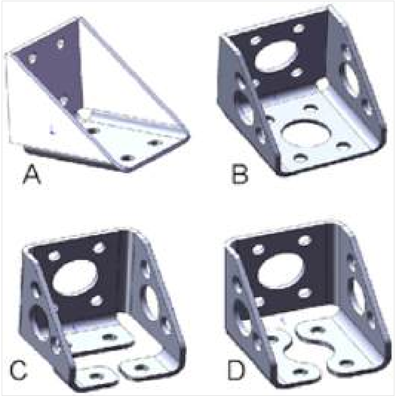
The Power of Sheet Meal Design

(Grant Hagedorn in Fabricator) Images courtesy of TRUMPF Inc.

Redesigning the bracket eliminates welding and, to varying degrees, eases overall manufacturing.



(Image source)

Simple designs are not always the most cost-effective to manufacture. In the below, Design A shows a seemingly simple bracket. Found throughout manufacturing, the design requires two vertical welds to attach the backplate. Its workflow is as follows: laser, press brake, welding, finishing, and then assembly and shipping.

Design B shows the bracket redesigned with flat tops to ease bending, but the welds are still there. Design C has no welds and requires five bends, three of which are performed simultaneously. Design D also removes the welds and requires only four bends, and the first two again can be formed at the same time. So, in both C and D designs, the brake ram would cycle just three times. It is all a matter of the designer understanding shop floor practices properly.

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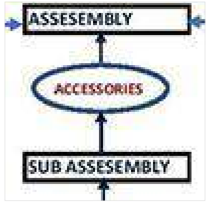
Sheet Metal Assembly

Chapter 5

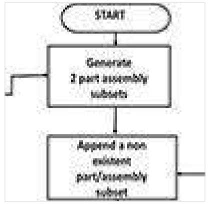

Introduction


Role of Sheet Metal in Industrial Products



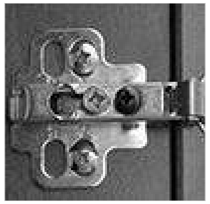
Sheet Metal Assembly


Asembly Considerations



Assembly Sequence


Assembly Categories


Accessories for Assembly


Fixtures


Panelling


Alignments

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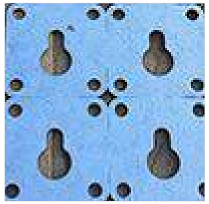
Corner Joints


Assembly Methods

Mechanical Fastening

Handling

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https://www.dsource.in/course/sheet-metals/sheet-metal-assembly/introduction

Introduction

An assembly is coming together of various sub-assemblies to manifest into a final usable product. Sub-assemblies in turn may have two or more parts coming together to form a sub-assembly. For a final assembly to manifest certain joining elements come into the picture. There are many such elements, maybe called accessories or support systems, some specific, custom-built, and some off-the-shelf components such as fasteners.

The market size of India's metal forming sector during 2016-2017 was 2,450 crore with a market share of around 25 percent. The metal forming industry is expected to grow at a CAGR (Compound Annual Growth Rate) of around 15 percent year on year.

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Role of Sheet Metal in Industrial Products

A brief review of the role of sheet metal in industrial and consumer products

Industrial Electronics


(Image source)


(Image source)

Industrial electronics form a major part of sheet metal consumption in the industry. In industrial electronics user experience (UX) considerations are limited. The emphasis is on the perfect fitting of electronics into the housing with remarkably close tolerances. A Printed Circuit Board is expected to jack in with the mating connector within the tolerance of +/_ 0.01 mm. Sheet metal design allows this. Design for **access** is one of the main important factors in industrial electronic products.

Medical Electronics

(Image source)

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In medical electronics, human factor engineering plays a crucial role. The human interacting elements such as displays, and controls need to be emphasized predominantly for quick access and easy understanding and offer a soothing appearance. Sheet metal design plays a strong and fail-proof supporting role. Often some integration with plastic parts is common in medical products. Design for **reach** is one of the main important factors in medical electronic products.

Consumer Electronics



(Image source)

In consumer electronics "Appearance" takes the predominant role. Sheet metal is well manipulated to achieve this objective. Most often sheet metal design considers assembly with plastic parts. The surface finish is given the highest importance. Parts are designed to function with ease and durability. Maintenance is not of high priority. Design for **attention** is one of the important factors in consumer electronic products.

Kitchen Products


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While the function of the product is the primary criteria, visible "Design' is the main guidance in consumer product design and all other factors become secondary. Sales because of visible design is the guiding factor. Sheet metal helps produce durable products which is of high importance in consumer products. There is also less consideration for maintenance, but more importance is given to the availability of spare parts and ease with which parts can be replaced in the unorganized sector. Design for **appeal** is one of the important factors in consumer products.

Interior and Public Products

(Image source)

The advantage of sheet metal in public products is that one-off production is possible. In many cases, the manufacturing of products is possible with not very sophisticated infrastructure. High tolerances are not considered as they are expected to be produced with a limited range of machines or even at craftsman levels. Design for **low-end machinery** is one of the important factors in these products.

Architecture

(Image source)

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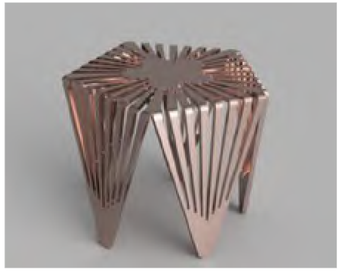
Structural sheet metal fabrication refers to metalworking done to produce items as part of the building process. Large-scale sheet metal fabrication projects create the metal components used by shops, manufacturers, buildings, and skyscrapers. Metal siding, structural framing studs, roofing, and load-bearing fall into this category. The precision quality of sheet metal comes to good use here. Modularity and durability are achieved with ease using sheet metal. Design for **modularity and ease of assembly** are the main important factors in architectural products.

Sheet Metal in Furniture



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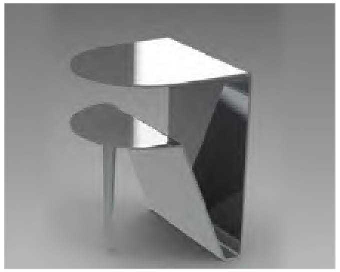

(Image source)

This segment offers creative exploration to the maximum. Variety in design is of prime consideration. Sheet metal offers Custom and batch production possibilities. The emphasis is on easy assembly with very few or no fasteners. High tolerances are not of great concern. **Design for marketability** is one of the important factors in these products.

Sheet Metal in Auto Industry

(Image source)

(Image source)

Sheet Forming enables achieve striking appeal. There is a considerable amount of planning and preparations are involved in auto body parts because they are highly tooled intensive. Accordingly, the design calls for close tolerances and detailing to produce parts with no blemishes. Design for **semi automatic or fully automatic** quick assembly is one of the important factors in the auto industry.

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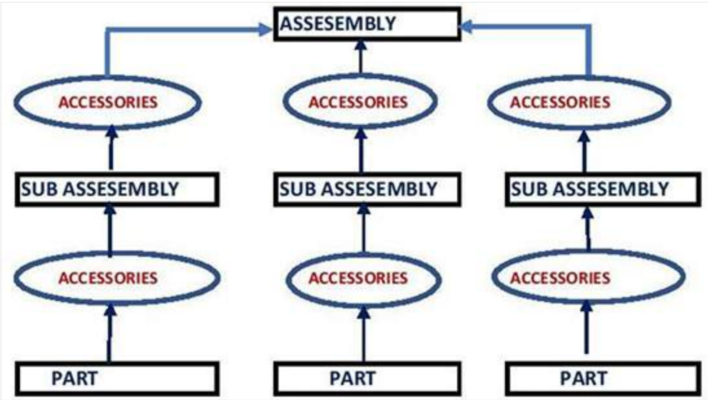
Sheet Metal Assembly

It needs to be understood that a final product emerges after the due assembly of various parts or sub-assemblies. It is important to give due consideration in design that everything has a place and everything is in its place. Assembly design is a subject by itself.

Organization Chart

An assembly is like an organizational chart. A few parts were puts together to make a sub-assembly. Few sub-assemblies make a final assembly. At the commencement of design, it would be extremely useful to visualize a structure diagram of this kind for two reasons. Firstly, the distribution of work and therefore the evaluation of the work becomes easy at all working levels. Secondly, it becomes easier to evaluate the mating compatibilities and initiate corrections, if necessary. The ultimate idea is a zero-defect product.

This kind of organization chart is universally adapted everywhere from project management to product management. Only the name of the chart may change but the essence is the same., In the present context, the chart is as shown below.



Product Structure diagram

Accessories mean joining elements such as rivets, weld, fasteners, hinges, etc.

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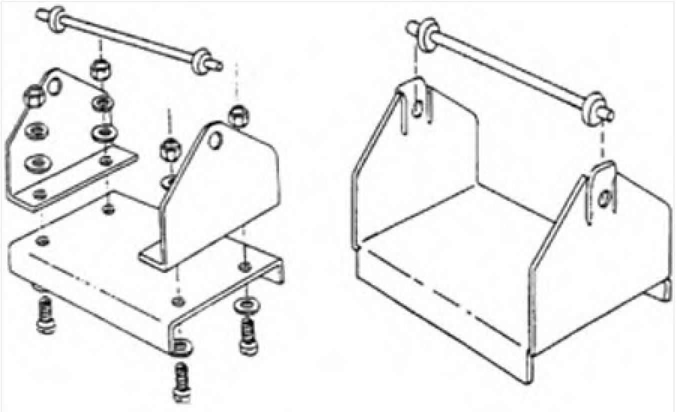
Asembly Considerations

Fewer parts make a good assembly. While designing products, it is essential to conduct an analysis of product structure. It will be helpful and save money to eliminate surplus parts. One can combine parts by functionality by removing redundancy.

An assembly has to store, sorting, position, adjust and join operations. Lesser the components better are control over quality and efficiency. This is where design for manufacturing and assembly comes into the picture. Understanding DFMA and following using simple principles will go a long way in the outcome of a good product. In some products cost of assembly and overheads may exceed the bill of materials and production costs. In such cases, the cost benefits are substantial if the product is designed keeping in mind assembly easiness.

Design for Excellence by James G. Bralla, Mcgraw-Hillan is an extremely helpful book.

Reduce the Part Count



The design efficiency is increased by over 30 %.
(Image source)

The design on the left has 24 parts while on the right has 2 parts. The improved design has also reduced the manufacturing processes to the barest minimum and has just one assembly step.

The two main factors that affect the assembly cost of a product are the number of parts to be assembled and the ease with which the parts can be handled. A product with fewer parts will cost less to assemble. Thus, the best method to reduce assembly costs is to reduce the number of parts in the assembly.

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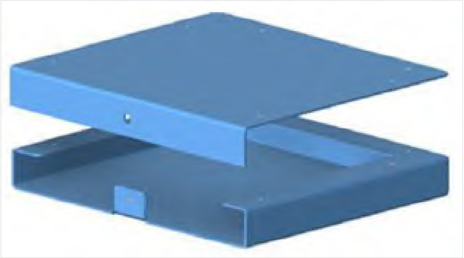
The part reduction can be accomplished by eliminating redundant parts, combining two or more parts into one. For example, screws and washers may be eliminated by adapting press or snap-fits to join two components. Choosing the right type of fasteners for the right purpose and minimizing the variety of fasteners also help in reducing the assembly time and cost.

Simplify Assembly

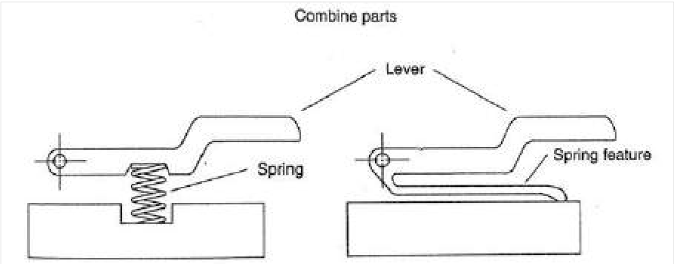


Locating a part to the correct position takes time and effort. In this example, a snap-fit is incorporated to locate and align the top cover with the bottom cover. This eliminates a screw fastener at the indented area and minimizes the total number of fasteners.

Boothroyd & Dewhurst and Lucas Methodologies suggest categorizing parts as "A" essential and "B" Target for designing out. Where design efficiency is (A/A+B) X 100 %. In sheet metal assemblies, Parts may be considered as 'A" category and fasteners may be considered as "B" category. But within an assembly, some parts may become "B" as well-targeted for designing out.

Integrate

Most often it is possible to integrate functions of two parts into one. Understanding of material properties comes to good use.



By incorporating the spring function in the lever, the need for a separate coiled spring is eliminated.
From James G. Bralla. Design for excellence, Mcgraw-Hill (Image source)

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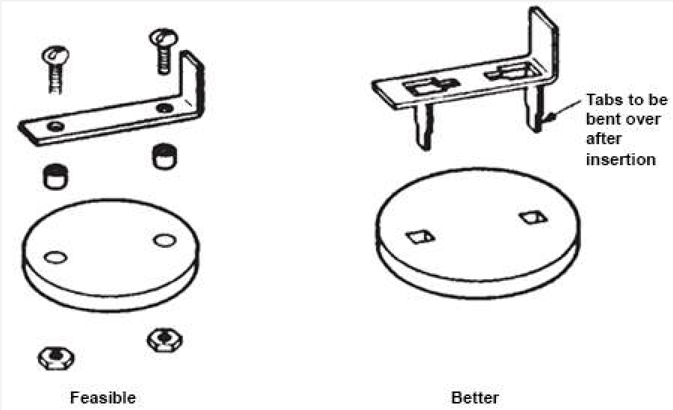
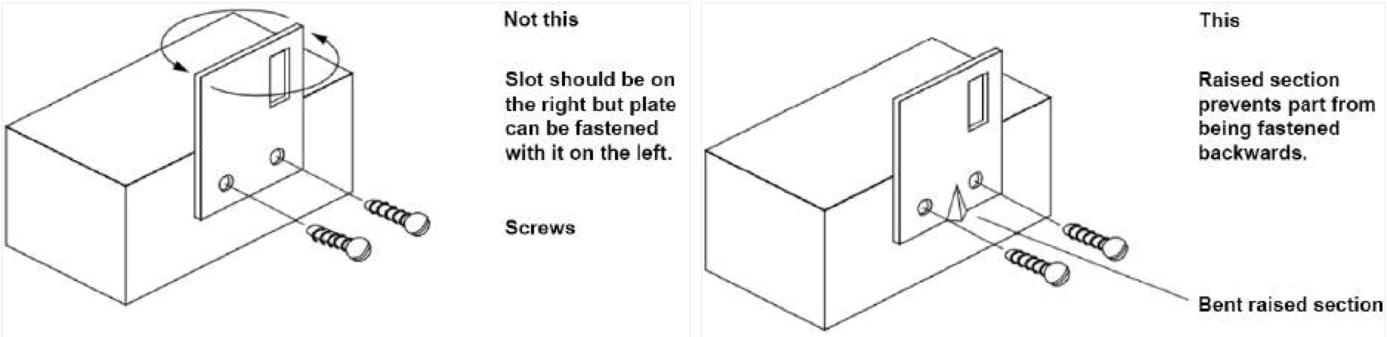
Innovate



From James G. Bralla. Design for excellence, Mcgraw-Hill
(Image source)

Consider the use of snap fits. Screw-type and other separate fasteners can be replaced with integral snap-fit elements, tabs, or catches. These can be incorporated in many parts such as guides, bearings, covers, etc.

Polarize



(Image source)

One of the phenomenons one comes across in assemblies is the right orientation of the part. Design parts in such a way that parts are constrained to locate in the desired orientation.

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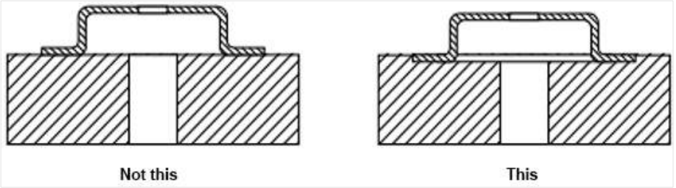
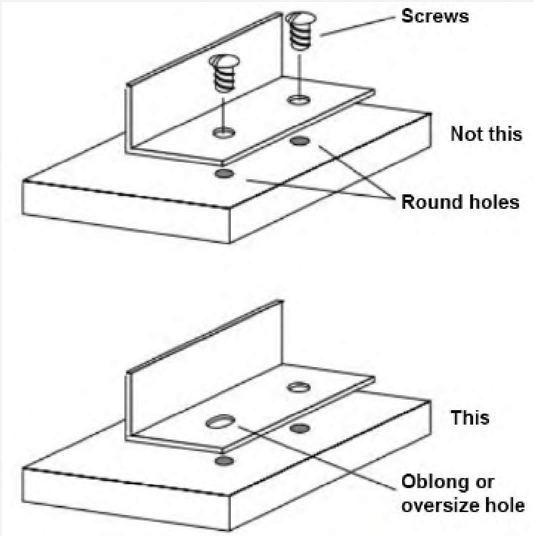
Ease of Location



Designing for Self-alignment of parts must be considered whenever possible.
(Image source)

Ease of Alignment



(Image source)

Inserting fasteners should be made easy without much effort. Components with tapered ends make alignments easier with matching tapered receptacles.

When there is no need for accurate assembly of two parts, make provisions to facilitate quick assembly. In the example on the right, oblong holes in the bracket facilitate quick assembly with the bottom plate.

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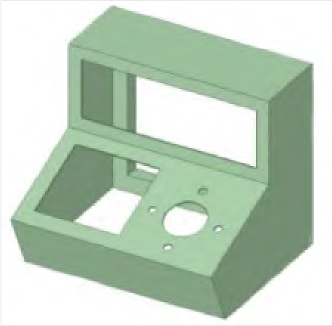
Ease of Fabrication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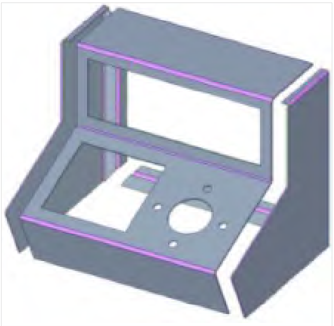
(Image source)

Product designers conceive an enclosure design based on component layout, customer's requirements such as available space, floor standing, or tabletop, etc., He need not necessarily be a sheet metal shop floor specialist with a thorough understanding of machine limitations. For example, the developed sheet dimension of the image shown exceeds available sheet lengths which can be accommodated in the machine. On the other hand, the shopfloor engineer converts the same concepts into a practical solution as shown on the right. The product is split into three parts and welded together for ease of manufacturing. It will be useful to give sufficient thought to the aspects of ease of handling, ease of manufacturing at the design stage.

Fastening Methods

It is important to give particular attention to the type of fasteners required because each one serves a specific function. Also, every fastener has a preferred installation process. It is also important to consider the materials, coatings of the fasteners. Quality versus cost must be weighed properly. Preplanning at the design stage instead of the assembly stage makes a lot of difference.

Besides nuts and screws, there are a wide variety of methods for the purposes of assembly. Screws, nuts, washers, clips, adhesives and sealants, eyebolts, rod ends, straps, gaskets and seals, hinges, levers, handles, pins, spacers, standoffs, springs are all part of the final assembly process. It is important not to miss any detail, however trivial at the design stage.

Welding at the assembly stage cannot be totally ruled out but is to be avoided as far as possible.

Source:
https://www.dsource.in/course/sheet-metals/sheet-metal-assembly/assembly-sequence

Assembly Sequence

As discussed previously, understanding the product structure is especially important. Putting together of parts becomes sub-assemblies and putting together sub-assemblies becomes final assembly. There are so many paths one can choose to achieve this but the most cost-effective one is what must be found in each case. The optimal plan of assembly significantly influences the product cost.

Here again, the analysis of product structure comes to good use. The levels of sub-assemblies and the parts within the sub-assembly are analyzed thoroughly to decide an optimal assembly sequence. There are many analytical methods available to decide on the optimal assembly path.

When choosing a product assembly following things must be considered

- Materials
- Production Volume
- Capital Expenditure
Costs
- Time

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Source:
https://www.dsource.in/course/sheet-metals/sheet-metal-assembly/assembly-categories

Assembly Categories

Sheet metal assemblies may be divided into four categories.

- Large
- Medium
- Small
- Micro

1. Large Size Assemblies

Sequence of Assembly


(Image source)

Large-sized assemblies call for a stationary job and moving tools and personnel around the job. In large assemblies once assembled, removal of parts after a while is a difficult and tedious task. Therefore sequencing of assembly procedures and identification tags for parts is very important. Jigs and Fixtures, Sequence of assembly, Access to men is of prime importance. Periodic quality checks are essential in order to avoid reworks which is expensive and time-consuming.

Large assemblies are generally custom design-oriented, one-off builds, or in low quantities.

Sheet Sizes


(Image source)

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Design should take into account available sheet sizes when large parts are involved. It is necessary to split a large-sized part into modular sub-assemblies for easier fabrication as well for easy integration to the main assembly.

Where large plain areas in an inexpensive product are involved, it is appropriate to consider natural stiffening by way of a bend against warping.

Human Factors

Design should keep in mind convenience in assembly and reach. The acts of reaching a location, the ease of looking at a location are important. The use of scaffoldings, work platforms may be considered for easy assembly.

If the job has to be mobile, Palettes with wheels are helpful in moving the job from one station to another.

Further, in large assemblies, it is necessary to provide lifting eyebolts at the top of the product to enable lifting by cranes.

Robotic Assembly

Robotic assembly in the continuous production of products such as automobiles may be of use in reducing human errors and fatigue. Because sheet metal offers extremely close tolerances in production, it is easier to adapt robotic assembly methods in moving apart with close tolerances.

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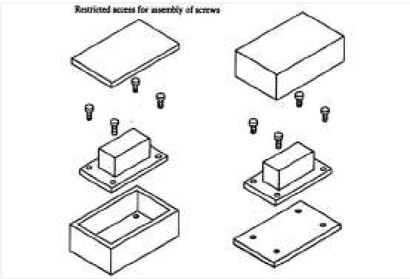
2. Medium Size Assemblies

Workstations

Proper Workstation design is important for the assembly of products. Workplace design has a bearing on the productivity of workers. Optimal placement of tools, fixtures, and parts integrating human factors in work station design within the available space are the key factors.

Medium-sized assemblies call for moving the job from one workstation to another station in stages. Each station will attend to a particular sequence of assembly. Each station will have its dedicated jigs and fixtures and tools for assembly. Quality checks are carried out as required after a few stations.

Access



Design for Assembly-James. G. Bralla
(Image source)

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Product design should keep in mind access to assembly areas at the workstation level. Blind spots, uncomfortable reaches should be avoided. It will be useful to minimize the variety of fasteners to save on inventory costs as well as part counts.

3. Small Size Assemblies

(Image source)

(Image source)

Small size assemblies call for specialized handling tools. When scaling down the products and parts, it is rather difficult to realize when the limitations in comfortable manual handling of parts and components. It may be necessary to have mechanical arms; grippers etc., to move the parts into close proximity of the assembly person's vision and reach. Human sight resolution is important. In electronic assemblies in particular there will be requirements of anti-static mats, gloves, and even ionized air.

The workstation design for small-size assemblies considers the hand reach of the assembly worker without moving around and adequate lighting.

4. Micro Assemblies

In micro assemblies, there are considerations of feeding, manipulation, and insertion techniques.

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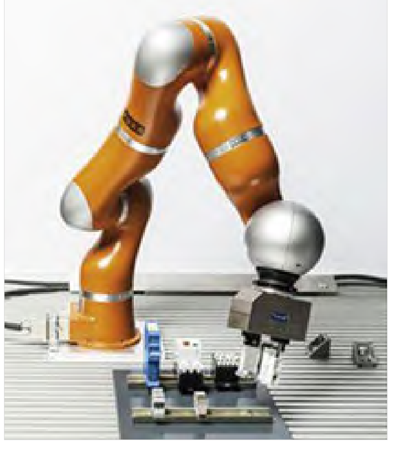
A typical watch part may involve a sheet metal part less than say 5 mm in size. A fixing screw can be as small as M 0.8mm. These require special attention in terms of assembly tooling and techniques. Workstation's micro assemblies call for bright lighting and viewing aids like magnifying glasses, computer monitors.

Robotic Assemblies



Robotic assembly techniques are increasingly becoming important in micro-assembly methods. Unlike human hands, robots use suction pads, grippers, claws, etc., for this purpose. It is, therefore necessary to design the component for assembly to facilitate robotic use.

Innovative collaborative robots use sensory capabilities to reach the specified areas. Product design must make provisions for such areas.

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Accessories for Assembly

The main elements that make an assembly happen are Fasteners, support systems, Locks, Latches, Hinges, Handles, Knobs, Gaskets and Seals, Cable management systems in case of electronic equipment, and many such elements. Out of this, we had reviewed fasteners in the earlier chapter "Sheet Metal Joinery". Let us briefly review the others in this chapter before looking into the methods of assembly.

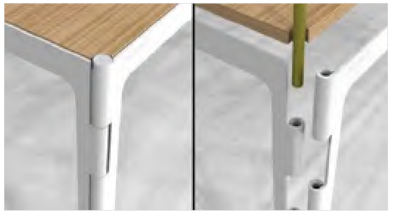
Some of the accessories in assemblies are as follows:

1. Hinges

A hinge is a mechanical bearing that connects two parts and allows rotation relative to each other along a common fixed axis. In sheet metal technology hinges can be inbuilt or off-shelf hinges can be used.

Pin Hinges

Pin hinge.



A pin hinge creative application in assembling the legs of a table. (Image source)

Pin hinges are used when the second rotating part is not fixed rigidly to the hinge. Pin hinges enable easy insertion of one part into another.

But Hinge

(Image source)

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A butt hinge has two rectangular leaves with knuckles in the middle, joined by a pin. It is the most common hinge used on doors, the standard choice for light doors. Ball-bearing butt hinges are more durable and last longer. Spring-loaded butt hinges (also called self-closing butt hinges) contain a spring that automatically closes a door.

Hinges with metallic inserts and Studs

Concealed Hinge


Custom fabricated hinge.


Standard concealed hinges. (Image source)


A concealed hinge in assemby. (Image source)


A concealed hinge in assemby. (Image source)

Concealed hinges are used where they cannot be seen from outside. They provide a smooth, uninterrupted appearance that is aesthetically pleasing. Also, because they cannot be tampered with from the outside, they provide security.

Knife Hinge/Pivot Hinge


Panel Board Hinges. (Image source)


Panel Board Hinges. (Image source)

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Panel Board Hinges.
(Image source)


Barrel Hinge.
(Image source)

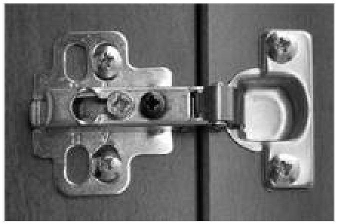

Piano hinge.
(Image source)

Hinges or pivot hinges may open fully or may have stops to restrict the movement. These are often used in doors to be fixed to a cabinet. Only the pivot point is visible after installation.

Panel Board hinges are very economical, used extensively in Panel Boards. Barrel hinges are useful when axial loads are less. They are fixed to the edge of the panel's piano hinge, also known as a continuous hinge that tends to span the entire length of a door or a lid continuously. Piano hinges are easy to install, are very affordable, and are extremely durable. The disadvantage is the maintenance as they tend to easily accumulate dust and grime.

Spring Hinges


Spring hinge.


Spring loaded hinge.
(Image source)

Spring hinges are self-closing hinges. A spring mechanism in the barrel allows the hinges to automatically close a door. A spring-loaded hinge makes it possible to lock the door in a fully open or fully closed position.

Things to consider in designing a hinge

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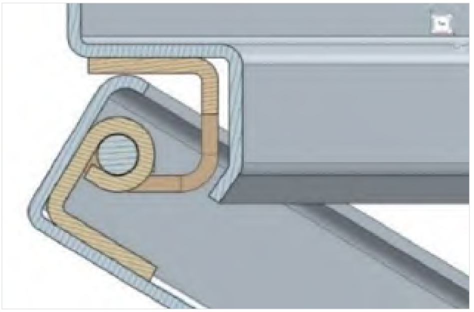


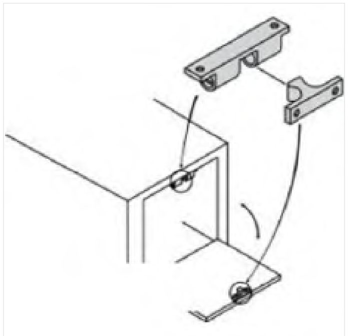
When designing a concealed hinge, the often-encountered problem is an interference of the panel with respect to hinge pin location. Much study and care are needed to avoid interference. It is a tight balance between pivot location versus panel thickness.

2. Latches / Locks

Ball and Roller Catches

Custom fabricated hinge.

Standard concealed hinges. (Image source)



A concealed hinge in assemby. (Image source)

A concealed hinge in assemby. (Image source)

Ball and roller catches are widely used in domestic shelving applications. They are durable and long-lasting . Most often these types of catches use non-ferrous materials to prevent rusting. The applied force required to detach a mating part depends upon the compressive force of the spring which applies pressure on the ball.

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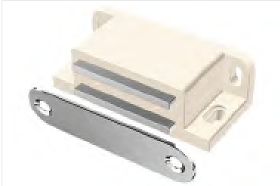
Magnetic Latch


(Image source)


(Image source)


(Image source)

One advantage of mag latch is that magnets as thin as the sheet itself are available for easy concealing and be flush with the sheet. Excessive contact pressure between the magnet and mating part is detrimental to the purpose. Effects of Jarring caused while applying excessive pull force are not good for the durability of parts besides being uncomfortable.

3. Slides


Heavy duty slides.
(Image source)


Undermount slides.
(Image source)


Soft closing slides.
(Image source)

There are many varieties of slides available commercially. Heavy duty to light duty, self-locking, self-closing, push to open etc., Slides are widely used to access serviceable parts and sub-assemblies.


A 19" Sub Rack mounted on slides. Facilitates access to back panel wiring and Components.
(Image source)


A Medical Cart uses "push to open" slides to open the drawers, eliminating protruding handles.


A Medical Cart uses "push to open" slides to open the drawers, eliminating protruding handles.

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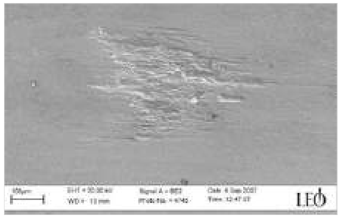
Galling


Galled Threads.


Galled sheet surface (Courtesy : leo)

Galling is a form of wear caused by adhesion between sliding surfaces caused by friction. It tears into metal and causes slipping between two sliding surfaces. Galling commonly happens between two metal surfaces that are in sliding contact with each other. It is especially common where there is inadequate lubrication between the surfaces. Aluminium galls very easily, whereas hardened steel resistant to galling. Some of the ways to prevent galling are to use slides or incorporate embossed dimples between the sliding parts.

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Fixtures

(Image source)

Fixtures are the work holding devices, which hold, support, and locate the job. Fixtures are important in assemblies to locate parts in their correct locations to assemble with other parts with accuracy. They are used to locate repetitive parts within tolerances to save labor and time. Besides helping the insertion of fasteners, minor welds can also be carried out with mating parts without distortions.

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Panelling

Enclosures and Panelling

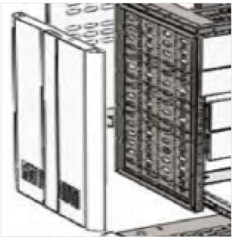
The task of assembling an enclosure is by panel joining. Side panels, rear panels, lids, floors, and brackets are all joined to make a simple enclosure frame. Once the enclosure is complete, doors are mounted and held in place with hinges. These hinges are commonly installed with fasteners, such as screws, but can be welded into place. To allow for the opening and closing of the enclosure door, a handle or latch is also installed.

Typical Enclosure

The selection of fastening and access hardware will also have an impact on other design criteria, such as speed of assembly, cost, functionality, and aesthetics -- even "design for disassembly" needed for the maintenance of the enclosure, or when the product has reached the end of its lifecycle. All these design requirements will have an impact on the final product and will influence the fastening and access hardware selection. Most sheet metal enclosures, be it electrical, electronics, domestic cupboards are constructed using panels. Panels of different sizes are arranged in desired configuration and assembled either by welding in case of permanent method or using fasteners for easy dismantling purposes.


A Final Product.


A Final Product.


Hooked on side panel.

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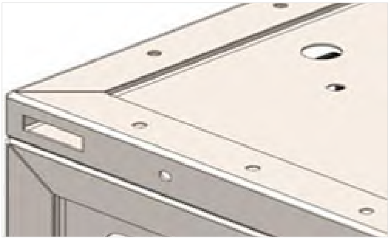
Alignments



One can create a framework using five numbers of folded panels.

A simple basic panel typically has four corner notchings and eigh bending operations. A panel invariably involves a corner joint that requires welding and is finished by sanding and grinding resulting in a corner joint.

The accuracy of bending the sheet decides the quality of joints between the panels. It is possible to maintain the sizes of panels within an accuracy of +/_ 0.1 mm easily with machines available in the industry. At the design stage, it must be taken into account to provide relief holes to accommodate the screwdriver to fix the panels together.

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Corner Joints

(Image source)

In panel construction, if visible from the outside, the most often encountered problem is clean corner joints. A miter joint is the most widely practiced joint because it is the fastest way. A welded corner joint always has a problem in finishing by painting or powder coating. Therefore such detailing is often used in "non-critical appearance" applications. Such as internal structures, large size panellings where the joint becomes insignificant in view of overall appearance.

Miter Joint

Often, when there are radii involved in both horizontal and vertical planes, an add-on corner piece is the most sought-after option. Here the skill of alignment and joint coverage in welding is very important. There are other practices for undistorted corner joints are shown as below.

Add on corner piece.
(Image source)

Side Flap with no Corner joint.
(Image source)

Corner radii with no corner joint.
(Image source)

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Assembly Methods

Assembly without Fasteners

Fasteners cost money. Fasteners contribute to the increase of Bill of Materials (BOM) besides inventory costs. It is possible in sheet metal product design to assemble parts without fasteners.

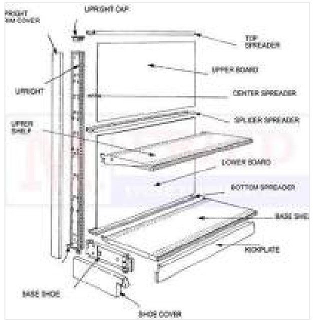

(Image source)


(Image source)

Assembly with Inbuilt Hooks (Image Courtesy: Pelican Shelving)

One wonderful property of sheet metal is its rigidity yet at the same time flexible enough for easy assembly. Here we observe a shelf that can be installed to a rear bracket without fasteners. Notice the upper lip in the rear bracket to facilitate hooking.

Assembly with Tongue and Groove



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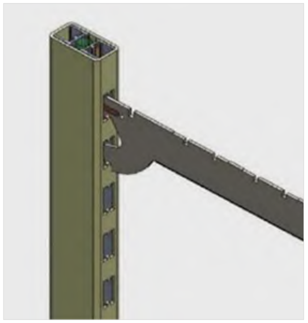
(Image source)

Tongue and Groove detail (Image Courtesy: piterest)

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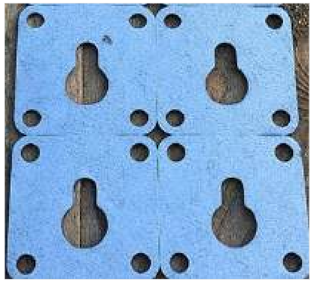
It is very convenient to adapt tongue and groove joints for detaching sheet metal parts from one another using tongue and groove systems. A tongue designed at the end of a component gets inserted into a groove of another component with a slight play. The width of the tongue should be sufficient enough to firmly sit in the groove but not allow too much play.

Use of Studs, Keyholes

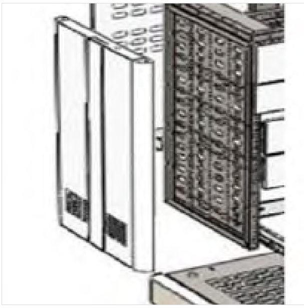
Studs and keyholes can be provided in the panels at mating places to enable hooking one panel to the other. The studs may be a simple stud welded to the panel or a clinch stud that can be clinched to the sheet bending into a panel.

Standard Keyhole clinch Studs.

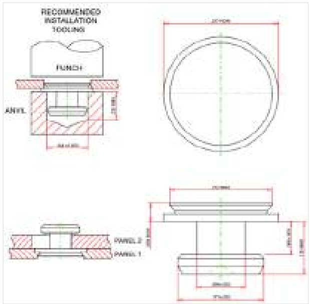


keyhole in the chassis. Panels are hooked on to chassis for easy removal. (Image source)

Standard Keyhole clinch Studs.



keyhole in the chassis. Panels are hooked on to chassis for easy removal



Typical engineering details of a keyhole joining fastener - Courtesy: Penn Engineering

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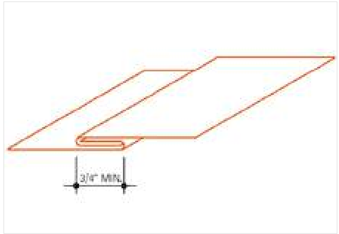
Assembly Using Hemming

Hemming is one of the best ways to join two sheet metal parts without fasteners. This process needs to be adapted in joining two sheet metal parts into a sub-assembly before assembling of internal components.

Hemmed parts.
(Image source)



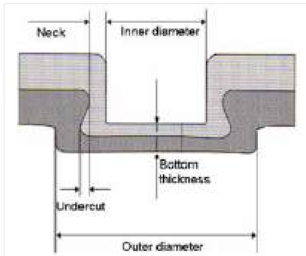
Minimum hemming area.

Assembly Using Clinching

Clinching joint is a sheet metal operation to permanently join two sheets together This method can be used to join two flat areas of sheets using the cold heading method. It creates a button type between two or three types of sheets.

It is a cost-effective process of joining sheets of metal without the sparks, fumes, and potential material damage that can be caused by spot welding. Basically, this quick and easy metal fastening method does not create heat or require pre-drilled holes.

Clinching Joint.
(Image source)



(Image source)

Clinched assembly.

Assembly using Snap Fits

Spring force can be used to fasten parts together. The figures below illustrate the type of fastening effect that can be achieved with spring-type holding devices. The assembly operation requires only that the spring or spring-like receptacles be snapped into place.

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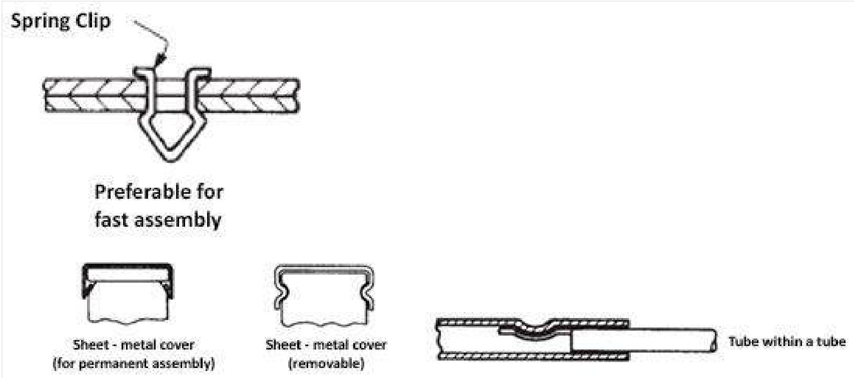
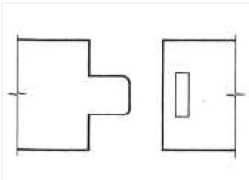


Examples of snap fits (Courtesy : DFA by James. R. Bralla)

Assembly using Tabs
(Image Courtesy: Stephen Mraz)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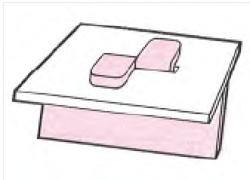
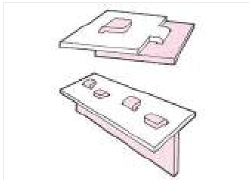
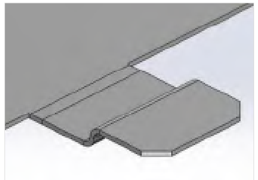
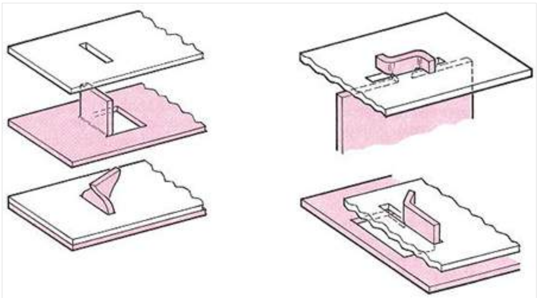

Tongue and slot.
(Image source)


Floded tab.
(Image source)


Types of tabs.

Tabs or tongues are formed by punching operation in one of the parts. The mating part will have a corresponding slot that is slightly larger than the tab for easy insertion. The tab is then folded at 90 deg and pressed onto the mating part to form the joint. Tabs can vary in size and shape for appearance and make assembly easier.



Tabs can also be twisted instead of folding. (Image source)

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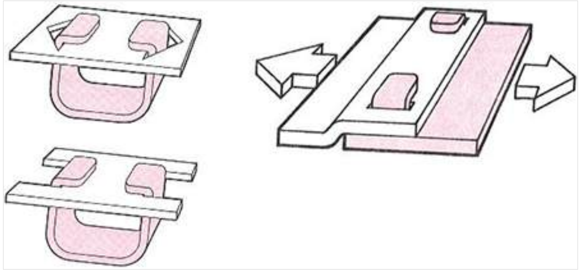
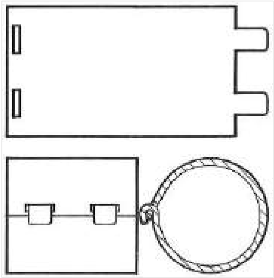
Slot Shapes



(Image source)

Slots need always be rectangular shapes. They can be triangular or even notches. Joint strength can be increased by folding the tabs in opposite directions.

Self-Locking Tabs



(Image source)

Assembly does not always involve two or more parts. The same part can be joined to itself, one end to another, by folding tabs. This image shows how a tube can be formed using tabs.

Redundant Tabs

(Image source)

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Tabs are sometimes used as redundant details. They may be used if required by bending and aligning or tearing them if not required.

Assembly using Hinges

There are many types of hinges available to suit individual applications. Hinges have to be chosen keeping in mind primarily the weight of the part and frequency of use and ease of assembly. If a door has to be removed completely, say for servicing of a cabinet, spring-loaded pin hinges or pivot hinges are most appropriate. Large size products such as control panels, Consoles may need piano hinges to support heavy rotating doors.

Example of the extruded hinge as shown here with no need for a pin to create the hinge. In this example, the gear also offers good torque facilitating a tight turn for the flap.

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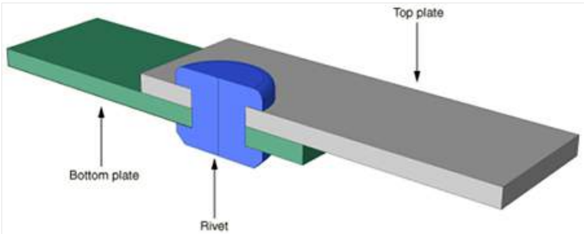
Mechanical Fastening

Mechanical fastening of two sheet metal parts is assembled by way of Bolts, Screws, Rivets, adhesives. Welding in the final assembly process is not advisable. Bolt fastening is less used than screw fastening because generally low-stress values are involved between sheet joints. Bolts are used when thick plates are involved when high compressive or tensile forces are prevalent between two sub-assemblies, or when a large product assembly is to be lifted by hooks, etc.,

Mechanical fastening of two sheet metal components should preferably consider snapping fits, press fits, hooks, etc, over riveting or screwing to minimize costs and time.

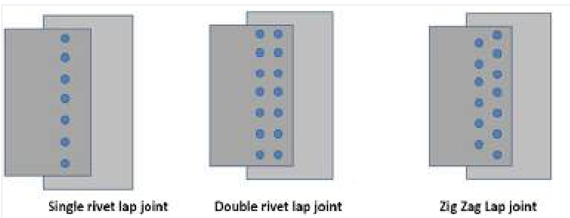
1. Assembly using Rivets



Riveting is adapted and preferred over screwing when high shear forces prevail between two parts. Riveting is also cost-effective.

Riveting Patterns

- single riveted lap joint
- double riveted lap joint
- single-strap butt joint
- double-strap butt joint



(nsnsm riveted joints)
(Image source)

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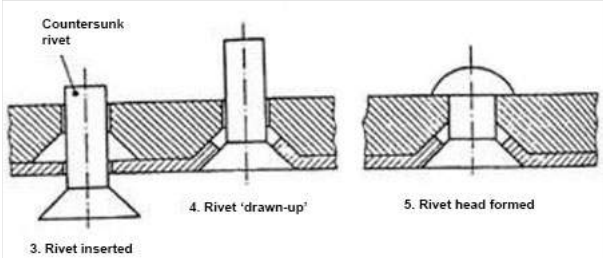
The recommended edge distance from the sheet edge is twice the diameter of the rivet. The overlap dimension of two sheets under riveting is four times the diameter of the rivet.

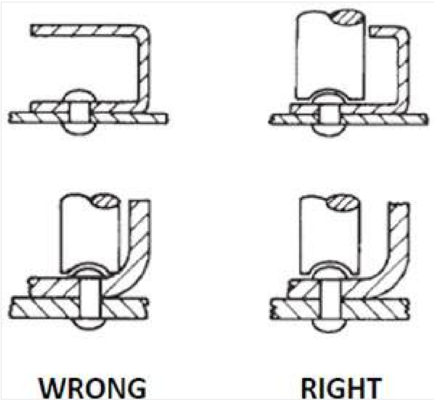
Riveting thin sheets to thick sheets



(Image source)

When a thin sheet must be riveted to a thick sheet, the thick sheet will have a countersunk bore and the thin sheet a normal hole. The countersunk rivet is then placed in position and a rivet head is formed on the other side.

Access to Rivets



While designing the component for riveting it must be noted that clearance distance to the rivet spot should be taken into account not just for the rivet head diameter but to the rivet clinching tool diameter.

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Pop Riveting

Pop Rivets.
(Image source)

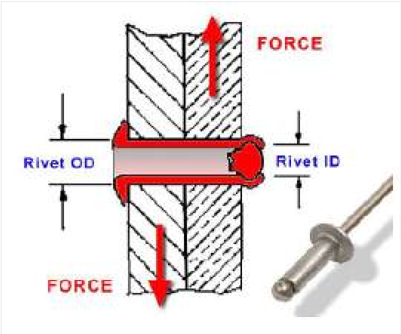
Rivet Gun.
(Image source)

Pop Rivets and Rivet Gun

Pop rivets are the preferred choice over solid rivets for general riveting. They are available in diameters 2·4 mm, 3·2 mm, 4 mm, and 4·8 m for joining thicknesses up to 12 mm.

Pop rivets are limited to light-duty, usually thin sheet metal. They are available in aluminium, steel, stainless steel, and brass materials. Pop rivets give the advantage of conducting the assembly with access from one side only. Once the holes are properly aligned it is very convenient to do riveting.

Pop rivets being used to join the sheets.
(Image source)



Pop-rivet after forming between the two sheets.
(Image source)

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Source:
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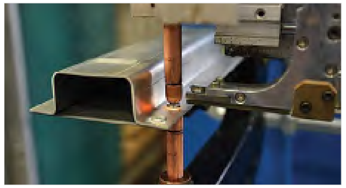
A pop riveted corner assembly.
(Image source)


A sub-assembly done entirely with rivets.
(Image source)

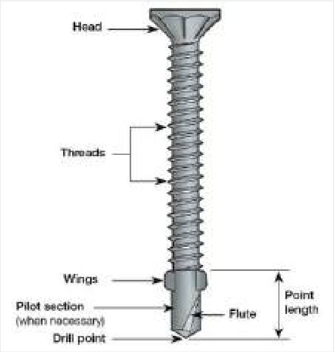

Resistance welding of pop rivet.
(Image source)

It is particularly advantageous to construct sub-assemblies with pre-coated sheets using pop rivets. It saves a lot of expenditure to use rivets instead of screws. They are also more effective against shock and vibration.

2. Assembly using Screws

Traditional threaded fasteners are still the highest volume as detachable fasteners. They enable easy serviceability and disassembly, and quick removal of various components and sub-assemblies. Fastening by screws is by far the most prevalent in assemblies. Screws offer a wide variety of choices and they are much easier to adapt at shop floor level.


(Image source)



(Image source)

Manufacturers always look towards reducing product costs. One thing that is constantly looked at is to reduce sheet thicknesses. For example, one can notice a considerable reduction in the thickness of appliances over a period of time. What used to be 0.8 mm thick washing machine housing has come down to 0.5 mm. What used to be a 3 mm thick aluminium cooker material is now at 2.0 mm. This is possible due to increased strength characteristics vs thickness. However, joining thinner sheets together is a tricky issue. Welding causes distortions, tapping into the sheet does not give adequate threading, normal fasteners are expensive. Self-tapping screws are useful in such cases. There are screws that can do the required bit of plunging and further carry out threading.

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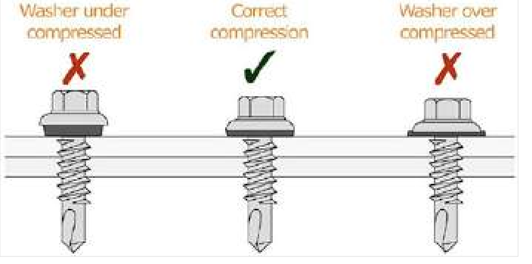
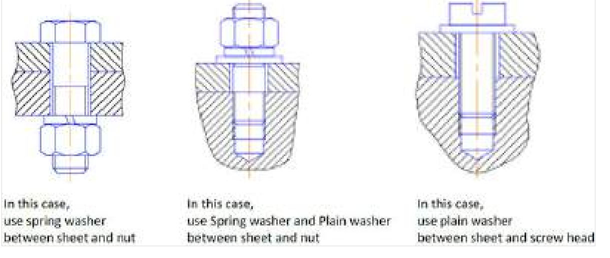
There are two basic types in this type of fasteners. Self-tapping screws and self-drilling screws. A self-tapping screw requires a pilot hole slightly smaller than the screw diameter. When inserted into this pilot hole and driven, a self tapping screw cuts the threads. A self drilling screw does not require a pilot hole. It drills into the material and then continues creating threads.

There are a few factors to be taken into account when designing for self-tapping screws. Incorrect flute length leads to jamming of the screw because the flute does not complete the drilling. The drill bit material should be harder than the material to be drilled. Too small or too large drill tips cause loosening of materials under fixing.



Self-tapping screws with inbuilt washers in the roofing industry. Optimal torque is important to derive maximum benefit from the washer.
(Image source)

Application of washers



3. Assembly with Specialized Fasteners

As for steel sheets, manufacturers tend to use cold-rolled, fully galvanized, hot-dip galvanized, hot-dip aluminized and organic-coated steel sheets more often to reduce raw material costs. These higher-strength steel grades allow engineers to use thinner appliance walls with desired strength. However thinner sheets cost more than thicker sheets, but the higher costs of high-strength steels are well compensated by weight savings and correspondingly lower logistics costs.

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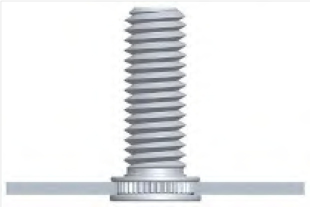
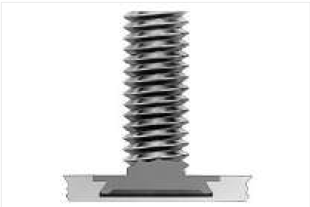
The necessity of using thinner sheets has resulted in the development of specialized fasteners too and a wide variety of such fasteners is now available to suit different applications.

Concealed Head Studs





(Image source) (Image source)

These studs ensure permanent mounting in metal sheets as thin as 1.60mm. The fastener head is locked securely in a blind, milled hole and is able to handle substantial loads. The concealed-head feature allows the side of the sheet opposite installation to remain smooth.

Penetrator

There are specialized fasteners for specific applications. Penetrator is one such example. If two sheets are to be fastened with a screw and nut, and if a cable must pass through the middle of the screw ensuring waterproof seal, penetrators are used. Provision is made to apply sealants at entry and exit holes of the shank.

A penetrator is a screw with a hole running all through the shank of the screw. This will enable elements like cables and wires to pass through the hole the chamfer provided at the entry and exit of the shank allows potting (sealing with resin) thus making it a leak-proof joint. Such fasteners are widely used in electronic products designed for marine environments.

Penetrators.

Cables.

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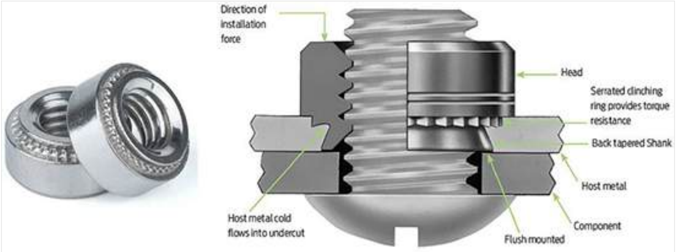
Use of clinch nuts and studs

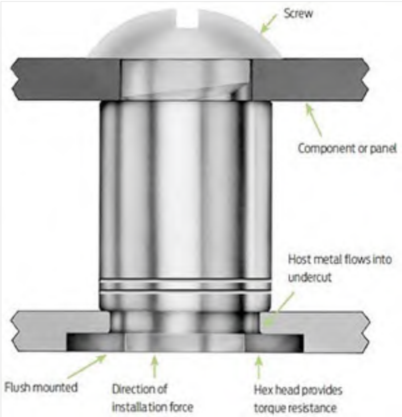
Clinch Nuts



(Image source)

Self-clinching nuts are very popular in the sheet metal industry for joining parts. These nuts have serrated clinching rings or ribs which get embedded into the sheet when squeezed with sufficient force. They become a permanent part of the metal and cantnot be removed unless destructive forces are employed to remove the nut. Self-clinching fastener nuts have strong internal threads than conventional milled screw threads.

Clinch Studs



(Image source)

Clinch studs are similar to clinch nuts but they provide more height than a nut. Thus, it will also act as a spacer.

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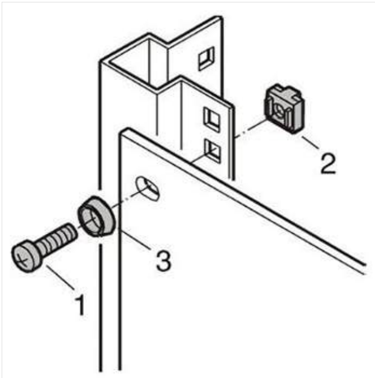
Captive Nuts



(Image source) (Image source)

There are varieties of captive nuts available in the market. These are normally square nuts held in a captive holder or a bracket. The nut will have some play within the bracket to allow for mating tolerance of the incoming screw. It is necessary to have the play because the mating is blind. The captive nut is snapped in place into the desired member to be fastened and the screw is fixed blind without much discomfort because of the play allowed by the nut. They vary from M6 to M12 as standards.



(Image source)

The captive nuts are held in place as shown in the slots punched in a frame. The mating panel will have corresponding matching holes or slots.

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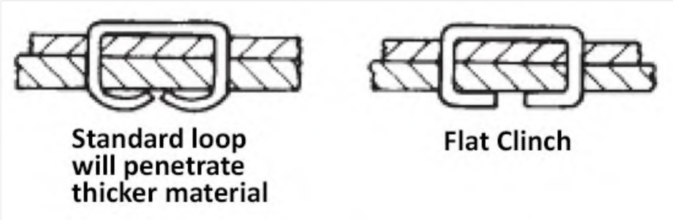
Spacers

Spacers are generally used to cover unwanted gaps. Spacers, as shown in the figure, can also be used to increase the area of contacts.

A metallic flat spacer is used to increase the area of contact for better conductivity of electricity.

4. Stitching



Stitching examples

Stitching is also a method to join sheets together. Stitching is recommended when sheet thicknesses to be joined are low and when the product is subjected to high vibrations.

5. Assembly using Welding

Welding may be done at assembly stages, but they have limitations. Welding causes distortion, therefore, it is necessary to be very careful when fabricated sub-assemblies are subjected to high heat. After welding, there may be areas that are inaccessible which are prone to surface degradation and may require protective coatings. An element of rigidity comes into place.

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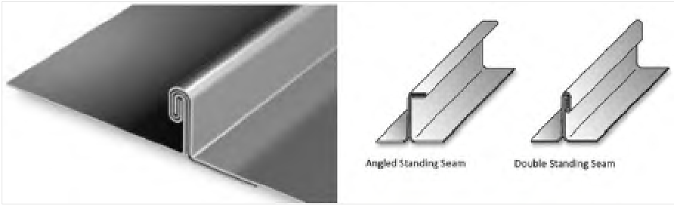
Sheet Metal fixing in Roofing Industry

Metal Sheets are commonly used for non-structural purposes. The basic purpose is to protect from external elements such as rain and wind and to provide an aesthetically appealing finish. In roofing sheet fixing and wall cladding, there are methods available other than screw fixing.

Standing Seam Method



(Image source)

Standing seam method is one of the most reliable systems. It provides a folded connection between two sheets at the edges. The sheets are hemmed into each other and seamed continuously.

Snap Lock Method

Snap lock seam feature a 40 mm leg height and a continuous interlock for improved structural performance and wind resistance. A concealed fastener clip system allows for thermal expansion/contraction while providing extraordinary hold-down strength.

(Image source)

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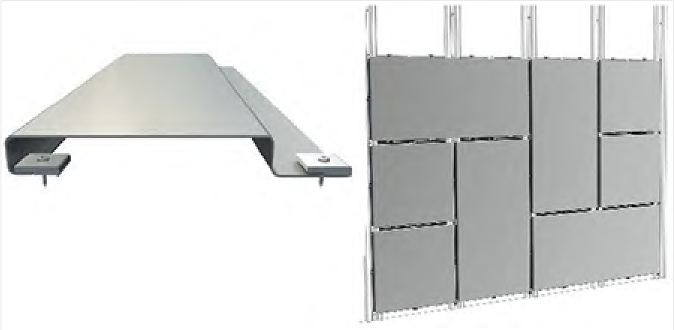
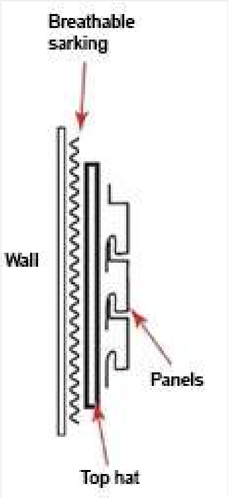
Cassette Method



This is one of the most popular wall cladding methods. Ideal for large cladding areas, the open-jointed cassette system can be used with large panels up to 13 feet in length. The cassettes are bent and fixed with invisible clips, usually to an aluminum framework.

Interlocking Method



The Interlocking Panel system is a wall cladding system involving laying interlocking panels on a metal frame-work. The panels are simply connected by the use of an interlocking groove giving the elegant appearance of a recessed joint.

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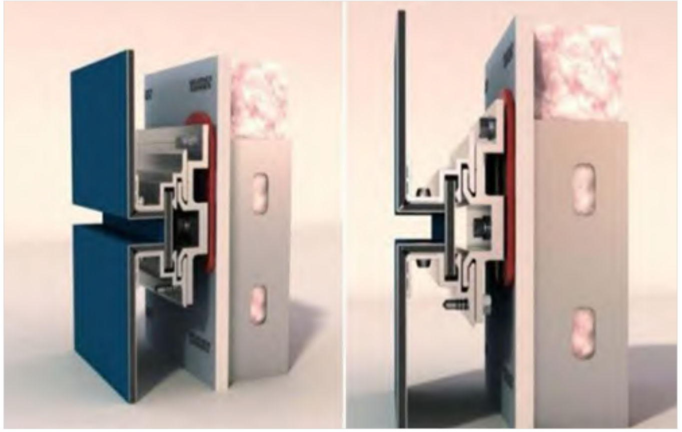
Aluminium Composite Panel Fixing



(Image source)

Aluminium Composite Panels are sandwich panels comprising a foam material sandwiched between two sheets of 0.3 mm aluminium sheets. They are widely used as building cladding material. Special extrusions are available to build a support a framework and use custom fixtures. Sheets are fastened with concealed screws.

9. Assembly using Adhesives

Adhesives join objects together by strong surface attraction. Adhesives may be one best solution to join together sheet metal surfaces when tensile or shear forces are not involved. Adhesives are relatively cheaper compared to mechanical fasteners and they also resist corrosion better. There are single compound and two compound adhesives available in liquid or semi-liquid forms.
However adhesives need to be cured to reach their maximum strength values and this is done by applying heat, pressure, or both and time curing. Adhesives also have the ability to fill minute gaps such as pores between the surfaces.

Adhesives are preferred methods when there are constraints about weight the final assembly of products when the appearance of the product is marred by the presence of fasteners. Adhesives help in the reduction of vibrations and rattling. The limitations are extreme variations in joint temperature and high tensile stresses.

Types of Adhesives

Anaerobic adhesives are one compound solution that cure in the absence of air and are best for applications of metal to metal contacts.

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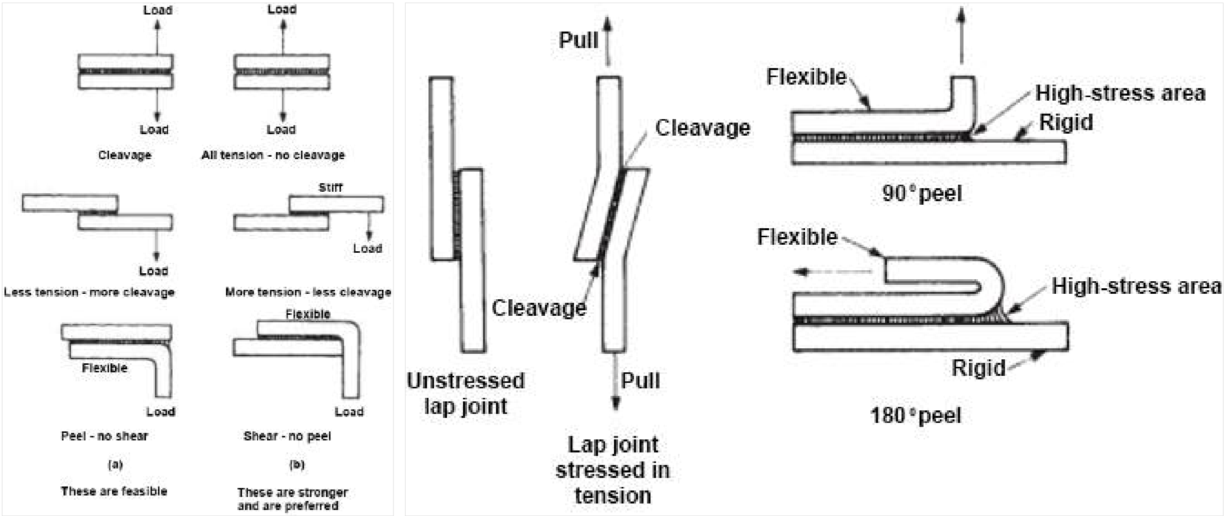
These are used as thread lockers in fastener fixing. Acrylics and epoxies form strong bonds with good temperature resistance and reasonably good structural strengths. Cyanoacrylate adhesives perform well in shear conditions. Modified silicone adhesives are UV cured and form very thin invisible joints.

Thermoset adhesives are two compound adhesives and are most common. They are polymeric resins that are cured with the addition of catalysts and by using pressure, heat, or heat and pressure. They offer high strength and gap-filling ability. Polyester and epoxy-based resins are low cost and widely used. Polyamide adhesives are expensive but they can withstand high temperatures as high as 500 deg C.

Design for adhesives

Thorough surface cleaning is very important in adhesive bonding. Dirt, oxides between the surfaces prevent proper adhesion. Solvents may be used for cleaning. Thin application o adhesives are better than thick layers. Thick layers tend to develop cracks.



Adhesive joints (Courtesy)
(Image source)

Design the joints for shear, tension, and compression, not cleavage or peel. Adhesive bonds resist shear, tensile, and compressive forces better than cleavage or peel. The width of the joint overlap is more important than its length.

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Assembly with dissimilar material parts

Methods of Integration / Joining

Most often plastic parts are joined to metal parts by snap fits, regular fastening using screws clinch nuts, adhesives, and heat riveting of plastic parts. Metal parts such as brass and copper are joined to steel parts by way of welding, brazing, and riveting.

(Image source)

Brazing is one very common method to join copper, brass parts to steel parts.

It is often seen that most assemblies comprise of combining a primary sheet metal part with other dissimilar or non-metallic parts. In such cases, designers must pay good attention to material properties such as coefficient of expansions, contractions, and the right fits and tolerances. Inadequate attention may part function and durability, more so in products which are of regular use.

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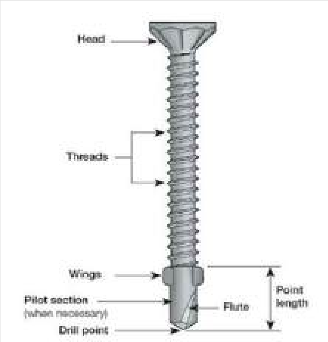
This lid is only six months old. Yet grime formation is clearly noticeable. The assembly detail of the plastic knob with the stainless steel lid is apparently not quite correct. The radii of the lid and knob have to be properly matched and a firm compressive grip between the two parts is needed.

Combining plastic components with sheet metal parts has become a necessity to reduce the overall part weight. With the increasing use of plastics, typical passenger automobile body weights have come down by over 20 %. Plastic to metal applications can be found in very many industrial areas such as telecom, electronics, aerospace, consumer durables. However, it is important to know what plastic is better suited in what applications.

Shears with plastic grip (Brac-Werke AG).
(Image source)



Plastic and metal parts integration in an automobile door (LAN Excess).
(Image source)

For large volume productions, thermoplastics are injected onto or into metal components for seamless integration using high-pressure injection moulding machines.

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Handling

As the size of the product becomes large, handling starts becoming an issue. Product has to move from stage to stage during production, during assembly, during packing, and transportation. While it is easier to handle small and medium-sized products, it is difficult to handle large size products smoothly not only due to the bulk but also due to weight. The designer has to keep this in mind in the initial stages while designing the product. The aim is to protect the product from scratches, dents, moisture, fungi, drops, falling offs, and so on.

Hooks

(Image source)

Large size products make use of inbuilt Hooks, trolleys, pallets, etc., Provision must be made for them.

Pallettes

(Image source)

Standars Palette Size.

Mid-sized products use Handles, Conveyors, Mini Pallets, etc., Provision has to be made in the product by way of appropriate legs, hold up areas etc.

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Trolleys

Ribs give stiffness to the barrel. But then, they are also designed as an easy demarkation area to hold the barrel and also to prevent slippage of the product.

Handles

Handles in many products are an integral part of product design. If not provision must be made to insert a handle.

A detail to accommodate a Handle.
(Image source)

Handle itself is an interesting sheet metal product.
(Image source)

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Sheet Metal Finishes

Chapter 6


Natural Finishes


Organic Coatings


Fillers


Painting

Types of Paints


Coating Application Types


Common Paint Problems


Powder Coating


Test Standards for Paint and Powder Coated products


Plating

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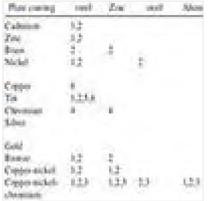
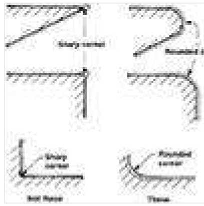
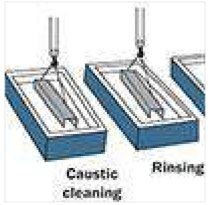


Commonly Used Basic Materials and Plating Metals



Design Considerations in Part Design for Plating



Hot Dip Galvanizing

Anodizing

Vacuum Metallization

Chemical Etching

Protective Films

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Natural Finishes


Brushed Stainless Steel. (Image source)


Brushed Copper Sheet.


Galvanized Steel. (Image source)


Anodized Aluminium. (Image source)


Brushes and abrasive wheels are used for natural finishes.

If the item is made of stainless steel, it probably will not need a coating to protect it from corrosion. Usual techniques for stainless natural finishes are brushed bright, satin, and mirror finish. Similarly, metals like aluminium, brass, copper, depending on the situation may or may not require coatings for protection. Different types of natural finishes can be obtained by creating grains on the surface, brushing, and buffing. Aluminium may be anodized in colours.

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Organic Coatings

Organic coatings act as a protective barrier against corrosion and oxidation. These coatings are applied to the surface of sheets for protection from oxidation and rusting as well as for appearance. Organic coatings are chemically inert and impermeable. Organic coatings can be paint or powder-based. Painting is relatively a simpler process as compared to powder coating. But solvent-based paints emit volatile compounds while powder coating does not emit such compounds. Powder coating can be more durable than paint. The sequence in which the painting or powder coating process is carried out is as follows.

Surface Preparation
Application
Protection

1. Surface Preparation

This is an area most ignored and given less priority. Blemishes on the metal surface will be damaging to the applied finish and sometimes they even appear magnified after finishing. Therefore, thorough surface preparation is the key to good finish and longevity. Then the desired finish is given by way of painting, powder coating, plating, or some other chemical processes. Normally a protective layer is given over the finished surface.

Sheet metal or for that matter any material surface needs surface preparation before being carried on to be given desired finishes. There are set procedures for surface preparation, but it also is an activity requiring good manual skills.

The surface may have dents, crests, rust, or other deformities. They need to be addressed and removed to move the job to the next stage of finishing.

2. Mechanical Cleaning

The surface of the parts must first be cleaned mechanically. It can be simple wiping with a clean cloth if the surface is without blemishes or it may require the use of mechanical aids such as steel wool, abrasive papers, and brushes and wire brushes to remove dirt, rust, and caked foreign material. Non-metallic bristles provide milder abrasive action. Heavy wire brushes provide strong action. The parts are wiped clean with solvents after mechanical cleaning.

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Abrasive papers and brushes. (Image source)

For large size parts and production line quantities abrasive blasting is adapted. This involves bombarding the part with high-velocity abrasive materials such as sand, aluminium oxide, silicon carbide, plastic granules, steel balls, etc., all depending upon the level of scales and corrosion on the surface of the metal part.


Sand Blasting.
(Image source)


Shot Blasting.
(Image source)

The quality of a paint coat or plating surface is directly proportional to the thoroughness of the surface finish.

3. Chemical Cleaning

After proper mechanical surface cleaning, the next step is to give a conversion coating to the surface of the substrate. Conversion coatings involve changes to the chemistry of the metal itself. They can be used to provide corrosion resistance, enhanced appearance, or act as a primer coat for paint.

Pre-Treatment process for steel sheet products

Seven Tank Process
A "7-tank process" is a process where parts are immersed in **seven** tanks sequentially. Normally, a zinc phosphating process is done in 7 steps while the simpler iron phosphating **pre-treatment** process is done in 3 steps or sometimes 5 steps.

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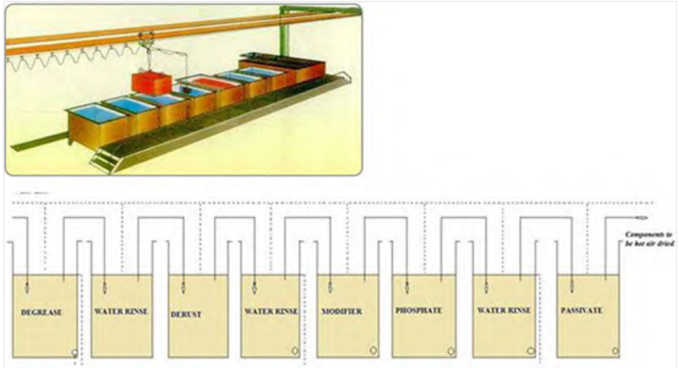
The steps are as follows:

• De Greasing
• Rinsing
• De Rusting
• Rinsing
• Phosphating
• Rinsing
• Sealing



(Image source)

The seven tank pretreatment line

1. Degreasing - Alkaline degreasing for 5-7 minutes at about 70 deg C to remove oils and grease.

2. Water Rinsing - Water rinsing for removal of traces of alkaline.

3. Derusting - Acid derusting normally by diluted sulphuric acid derivate solution for 5- 15 minutes at room temperature to remove rust.

4. Water Rinsing - Water rinsing to remove traces of acid. Any traces will cause rusting on steel parts.

5. Phosphae Conversion - Coating of zinc phosphate or Iron phosphate for 5-15 minutes depending upon temperature up to 70 deg C, onto the metal surface to an extent of 80 – 100 microns.

6. Water Rinsing

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A car body under pre treatment.


A mini PLC controlled 7 tank process.
(Image source)

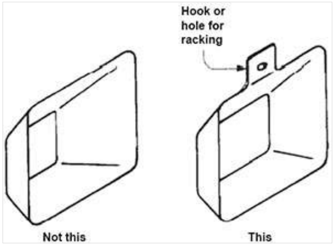
7. Passivation - Passivation to remove any embedded contaminants and return the part to its original corrosion specifications.

3 in1 Solutions


(Image source)

There are also inexpensive 3 in 1 solutions available mainly for steel and iron surface cleaning. These contain a mixture of alkaline, acidic and phosphate compounds which form iron phosphate coating on the surface. The metal surface was wiped clean with these solutions. These are adequate in many small production operations provided the process is done with due care.

Design Consideration



Example

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The design of components should permit the flow of cleaning solutions to reach all corners. They also need to be designed for hanging to a hook so that the component is not held manually. There are areas such as crevices, folds, hems, etc., where cleaning solutions may get trapped. While it is not entirely possible to avoid such mechanical details, care must be taken to minimize entrapments or make provisions for draining out the solutions.

Pre-Treatment process for non-ferrous products

Chromate Conversion Coatings

Chromate conversion coatings are obtained by chemical reaction with the substrate to form chromate film over the surface. The coating adheres to the metal at a molecular level and hence good binding. It creates an iridescent yellow-green film that resists corrosion, can be used as a primer for paint and retains electrical conductivity. The process can be by dipping or spraying.

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Fillers

Post-pre-treatment and prior to painting or powder coating, the surface may have to be treated with filler materials to cover dents and deformities.

Putty

Putty or spot putty is the main material used for filling the dents. It is a kind of cementing material containing a mix of calcium carbonate powder and linseed oil. There is a variety of putty available in the market for this purpose.

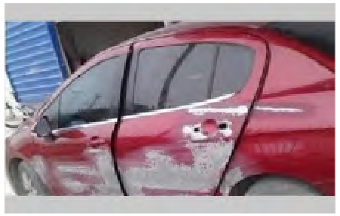
For mild scratches and dents, polyester-based putty is used. It is a one-part compound filler good for many applications except in extreme high-temperature environments.

For deep gashes, metal putty is used. They are normally two compound fillers with polyester or epoxy bases. They are mixed with compounds of metals such as steel, aluminium, or bronze. Putty can be diluted using recommended thinners and is applied with putty blades.

Application of putty with blade. (Image source)

Application of putty with blade.


Orbital Sander.


Polyester putty application on auto body.
(Image source)

Once the compound is cured putty becomes extremely hard and can be rubbed, sanded, or even machined.

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Source:
https://www.dsource.in/course/sheet-metal/sheet-metal-finishes/painting

Painting

Painting is the most versatile application of the final finish on the product. Painting offers advantages such as the availability of many colours and the ability to mix different colours to obtain desired shades. There are paints available in metallic shades and even to give textures. There are specific formulations available for indoor and outdoor applications. There are also electrostatic type paints available for better adhesion and to minimize wastage in spray painting.

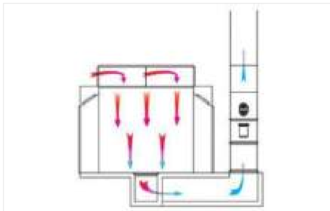
Basic Infrastructure in Painting, powder coating

Water wash sparay booth.
(Image source)

Portable sparay system.
(Image source)

Mobile spray system.
(Image source)

Professional Paint Booth.
(Image source)



Schematic diagram of paint booth working.
(Image source)

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Source:
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Types of Paints

- Air Cured
- Oven Cured

1. Air Cured Paints

(Image source)

All paints barring very few are to be mixed with recommended thinners either for brush applications or spray applications. The right viscosity gives the right application and the right optimization of cost. Curing involves open-air drying or oven drying and hardening of paint. Drying enables the evaporation of the mixed solvents and hardening involves hardening of the main polymer base to give a solid appearance. Air-cured paints are available as both slow drying and fast drying.

Acrylic Paints
Acrylic paints are water-based quick drying paints. They constitute organic or inorganic pigments suspended in acrylic polymer emulsion. Post drying acrylic paint becomes water-resistant. The paint film is flexible in the sense that it withstands some amount of warping of the substrate surface. Acrylic paints are generally not meant for large quantity applications but are more suitable for small-sized hand applications.

NC Paints
Nitro Cellulose-based paints are volatile and quick drying. They are mainly used for auto body re paintings, prototypes, and quick-drying works. These types of paints are also available in aerosol cans for ready use.

Enamel Paints
Enamel paints are air dry-paints well suited for outdoor applications. Enamel paints constitute certain metallic oxides such as zinc, iron, or lead with polyester or epoxy resins used as binders. They are slow-drying paints and gives an opaque and high gloss appearance after drying.

2. Oven Cured Paints

Oven cured paints are industrial paints cured through the heated air that is circulated in the drying ovens. This is generally done by having a heating chamber where the air is heated, and circulated inside the curing oven chambers by means of fans. On the other hand, heating and curing are also done by a series of infrared or ultraviolet lamps arranged inside the ovens.

Polyester based Paints
Polyester paint is a three-component paint that utilizes resins, catalysts, and accelerants. They have a high percentage of solid pigment contents in the paint offering better mechanical and chemical strength.

Polyurethane based Paints
Polyurethane paints are known for their hardness, chemical resistance, and high abrasion resistance. They essentially constitute PolyIsoCynate based polymers. Polyurethanes come in either a mono-component or bi-component product.

Polyester has around 95% solid content, Polyurethane has around 60% solid content. Because polyester has a much higher solid content than polyurethane, polyester's surface Is stronger. However, polyurethane is more flexible than polyester making it suitable for applications where flexibility is important. Both polyester and polyurethane are UV stabilized.

3. Others

There are also other methods of painting processes such a vapour cured, and ultraviolet rays cured, though these are not of frequent use.

Vapour cure process makes use of the substrate exposed to vapours generated in a closed chamber to cure the paint coat.

The UV cure process makes use of the substrate exposed to UV lamps for a particular duration to cure the paint.

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Source:
https://www.dsource.in/course/sheet-metal/sheet-metal-finishes/coating-application-types

Coating Application Types

The generally known paint application procedures are :

- Brush application
- Spray application
- Electrostatic spray application
- Brush Application

Spray Application
Spray gun will have a chamber to store the paint. Air at some pressure is delivered to the nozzle of the gun from an air compressor. Paint and air are mixed at the nozzle point in the spray gun and sprayed onto the component. There are many combinations of the mixture of paint and air to obtain different desired effects. The air intake may be low volume and high pressure or high volume and low pressure as is required. Added to this the design spray gun nozzle varies to produce different spray patterns.

Airless Spray
This method uses paint under high pressure at about 500 to 6,500 psi. The airless spray system is more portable, produces a higher film build, and cuts overspray considerably.

Electrostatic Spraying
The differences between this and air spraying are that the electrostatic gun has an electrode at the nozzle and the object to be painted is grounded. The charged paint is attracted to the grounded object. The advantages are a reduction in overspray requiring less pressure. Paint is forced to travel towards the object because of the nature of electrical conductivity. This nature also allows a wrap-around effect in the sense the paint spry travels around and applies to the object though not within the direct sight of a spray gun.

The disadvantage being only one coat is possible because the first layer acts as an insulator. Some non-conductive materials too can be painted.

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Source:
https://www.dsource.in/course/sheet-metal/sheet-metal-finishes/common-paint-problems

Common Paint Problems

Many problems occur due to improper following of set procedures. A good quality paint surface depends upon the right use of following:

- Type of thinners
- Viscosity of paint
- Atomization of Paint
- Operator skill
- Curing Time

Some common problems are as below:

Blistering

(Image source)

Lifting of the paint film from the underlying surface, which appears as paint bubbles or paint blisters in the mixture, is usually caused by heat, moisture, or excessive moisture in the paint mixture.

Chipping

Surface impact, primer without sealing before applying topcoat, exposure to harsh conditions, Component "A" and Component "B" not uniformly mixed, a coating applied over a previously cracked finish or unstable substrate, excessive total film thickness.

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Delamination

(Image source)

Contaminated surface, metal conditioner, and/or appropriate primer was not used, the insufficient flash-off time between coats, poor quality sanding, incorrect film build-too heavy, incorrect Spray Technique, a coating applied too dry or too heavy, insufficient flash off time between coats (and or between primer and topcoat).

Mottling

Improper equipment - a type of gun, size of the nozzle, improper gun settings, Incorrect spray technique, Holding spray gun too close to surface, Uneven spray pattern, Application too heavy Wrong thinner/reducer for shop temperature, Component "A" and Component "B" not thoroughly mixed.

Orange Peel

(Image source)

Viscosity too high Gun air pressure too low (causing lack of atomization), Primer or sealer applied not smooth Wrong thinner/reducer, Incorrect spray technique, Holding gun too far from the surface, the Wrong amount of thinner or reducer used - not enough, Poor quality sanding.

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Source:
https://www.dsource.in/course/sheet-metal/sheet-metal-finishes/powder-coating

Powder Coating


(Image source)

Powder coatings are essentially based on electrostatic technology. This application method uses a spray gun, which applies an electrostatic charge to the powder particles, which when sprayed attracted to the grounded part. After the spray of powder, the parts are cured in an oven where with the addition of heat the coating chemically is cured and becomes a strong layer of film. Powder coatings can also be applied to non-metallic substrates such as plastics and medium-density fibreboard (MDF). Sometimes a powder coating is applied during a fluidized bed application. Preheated parts are dipped in a hopper of fluidizing powder and the coating melts and flows out on the part.


High Gloss Poder Coat finish.
(Image source)


Metallic finish.
(Image source)


Chrome Effect.
(Image source)


PU Textured powder coat.


Polyester epoxy matt powder coat. (Image source)

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Source:
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1. Epoxy Powders

Epoxy-based coatings are good for chemical resistance, wear and tear and provide great corrosion protection. However, epoxy coatings are susceptible to ultraviolet rays instability. Therefore they are not best suited for outdoor applications.

2. Polyester Powders

The two most widely used types of powder coatings are polyester and Urethane polyester. They provide excellent wear resistance and outdoor durability. Polyester Urethane also provides good chemical resistance. They are mainly used in automobile industries.

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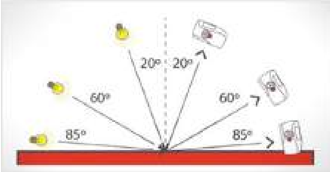
Source:
https://www.dsource.in/course/sheet-metal/sheet-metal-finishes/test-standards-paint-and-powder-coated-products

Test Standards for Paint and Powder Coated products

1. Gloss Test (ASTM D523)

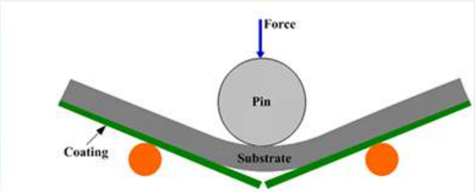
Gloss test meter.
(Image source)



Measurements from different angles.
(Image source)

Gloss is associated with the capacity of a surface to reflect more light in directions close to the specular than in others. It refers to surface shininess. Measured gloss ratings by this test method are obtained by comparing the specular reflectance from the specimen to that from a black glass standard. Other visual aspects of surface appearance include the distinctness of reflected images, reflection haze, and texture. The specular gloss measurement is performed for the light reflected from the sample surface. The angle of reflection at different angles is measured in Gloss Units (GU) and matched against standards. High gloss is measured at 20 deg. Universal measurement at 60 deg and low gloss is measured at 85 deg.

2. Adhesion Tests
Bend Adhesion Test (ASTM D522)



(Image source)

The sample is subjected to 180 degrees bend against a roller of a specified diameter. The sample is observed for cracks or any other defects at the peak edge of the bend.

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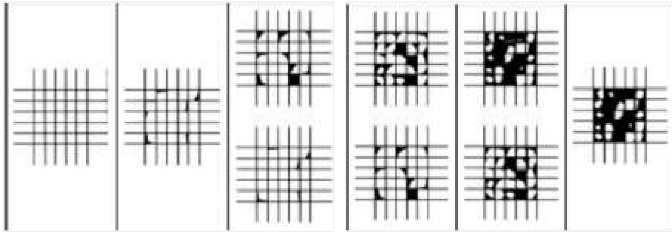
3. Crosscut hatch Hardness Test (ASTM D3363)


(Image source)


(Image source)

Surface of cross-cut area from which flaking has occurred. (Example for 6 parallel cuts)	None					Greater than 65%
Classification	5	4	3	2	1	0

(Image source)

A cross-hatch pattern is created on the sample with a sharp knife, the grid size being 3 mm apart. An adhesive tape is firmly stuck on the sample and peeled of vigorously. Depending upon the amount of peel off or detachment of paint flakes the adhesion quality can be determined on a scale of ISO Class 0B to 5B, 0 being a fail and 5 being excellent.

4. Chemical Resistance Test (ASTM D1308)


(Image source)

Resistance to various liquids used in the home is an important characteristic of organic finishes. These test methods provide how the relative performance of coating systems may be evaluated.

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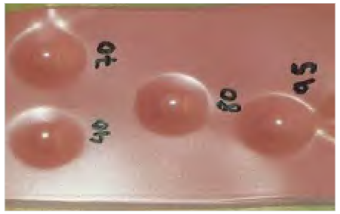
5. Impact Test (ASTM D2794)

Coatings attached to substrates are subjected to damaging impacts during the manufacture of articles and their use in service. In its use over many years, this test method for impact resistance has been found to be useful in predicting the performance of organic coatings for their ability to resist cracking caused by impacts. This test is performed to know the values of deformation, Impact resistance, and impact Strength.


Impact Tester.
(Image source)



A tested sample.

A steel ball of specified mass is dropped from varying heights onto the sample and checked for visual damages such as cracks, peelings, flexibility, etc., Different methods are used for a different types of coatings.

6. Salt Spray Corrosion Test (ASTM B117)


(Image source)
ASTM B117 test


(Image source)

The salt spray test is a popular corrosion test method, used to check corrosion resistance of materials and surface coatings. The solution typically used is Sodium Chloride solution with a concentration of 50+/_ gm/L. The standard test duration is for 72 hours.

ASTM B117 is the test conducted to visually find and measure the corrosion resistance of metals, surface coatings.

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Source:
https://www.dsource.in/course/sheet-metal/sheet-metal-finishes/plating

Plating

Electroplating involves electrolytic deposition of one metal onto another, to improve its appearance and resistance to wear or corrosion. Almost any substrate, ferrous or nonferrous, can be plated. zinc, copper, silver, gold, cadmium, chromium, nickel, and tin are common plating materials. Materials such as hot-rolled carbon steel will appear rough and often dull after plating.

Cold-rolled carbon steel, which typically has a higher-quality surface, generally will require less preparation for equivalent results.

Luster is one of the main objectives in plating. It is a function of the smoothness of the surface to be plated. Brasses, Copper, Gold Silver plating give a very high luster.


(Image source)

Products with high luster.

Common Plating Processes

1. Zinc Plating
Zinc plating is common in the automotive industry. Zinc deposition resists oxidation and corrosion well. Zinc plating is often associated with the galvanizing process. E electroplating of zinc is often called electro-galvanization.

2. Nickel Plating
Nickel plating is a popular plating metal, especially because it's useful in electroless plating. Nickel plating is used to coat household products such as doorknobs, cutlery, and shower fixtures for enhanced appeal and wear resistance.

3. Chrome Plating
Chromium plating is mainly used for decorative purposes but can also improve corrosion and friction resistance. Nickel chrome plating is done in items like furniture and automotive trim products. Iron and steel are r common substrates of chrome plating.

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4. Gold Plating
Gold is valued for its high resistance to oxidation and electrical conductivity. Gold plating is done to impart these characteristics on metals such as copper and silver. Gold plating is often used for jewellery decoration and for improving the conductivity of electronics parts such as conductivity tracks in PCBs and electrical connectors.

5. Silver Plating
Silver plating essentially does what gold does but serves as the most cost-effective solution as compared to gold. It is done in plating applications that call for decorative appeal and improved electrical conductivity. Copper is the most used substrate for silver plating.

6. Copper Plating
Copper is another popular plating metal for applications that require high conductivity and cost-efficiency. Copper plating also serves the purpose of base coating to support other subsequent coatings.

7. Cadmium Plating
Cadmium plating improves paint adhesion, corrosion resistance and has a lubricating characteristic. Due to this property, cadmium plating offers better wear resistance with minimal plating thickness. Cadmium plating is well used in military and aerospace applications.

8. Tin Plating
Tin plating is used mainly where non-toxicity, high ductility, and good solderability are required. These characteristics make tin plates advantageous in the electronics industry and food processing industry. Tin plating is commonly used on non-ferrous metals such as copper and nickel. Many ferrous metals can also be tin-plated.

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Source:
https://www.dsource.in/course/sheet-metal/sheet-metal-finishes/commonly-used-basic-materials-and-plating-metals

Commonly Used Basic Materials and Plating Metals

	Basis Material										
Plare Coating	Carbon Steel	Zine	Stainless Steel	Aluminum	Copper	Brass	Nylon	Polyphenylene Oxide	Polyphenylene	Bronze	Alloy Steels
Cadmium	1,2										1,2
Zine	1,2										1,2
Brass	2	2			2						2
Nickel	1,2		2		1,2	1,2				2	1,2
Copper	6										6
Tin	1,2,5,6				6	6					1,2,5,6
Chromium	4	4									4
Silver					2	2				2	
Gold					2	2				2	
Bronze	1,2	2			1,2						1,2
Copper-nickel	1,2	1,2					2	2	2		
Copper-nickel-chromium	1,2,3	1,2,3	2,3	1,2,3	1,2,3	1,2,3	2,3,4	2,3	2,3,4	2,3	1,2,3

*1 = corrosion protection; 2 = apperance; 3 = Iarnish resistance; 4 = physical properties; 5 = in-process protection; 6 = simplication of subsequent processing.

(Reproduced from Design for assembly, James Bralla)

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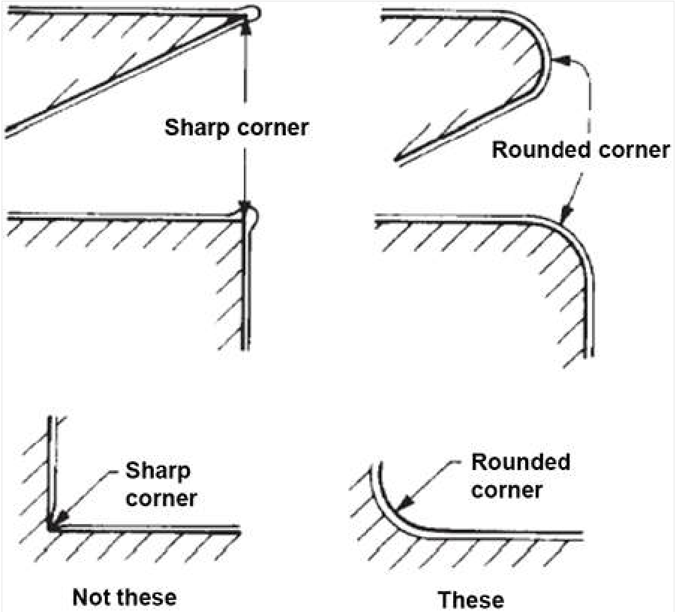
Design Considerations in Part Design for Plating

In plating, External sharp corners receive excess plating deposit, whereas sharp internal corners receive insufficient deposit; large radii promote a more uniform plating thickness.



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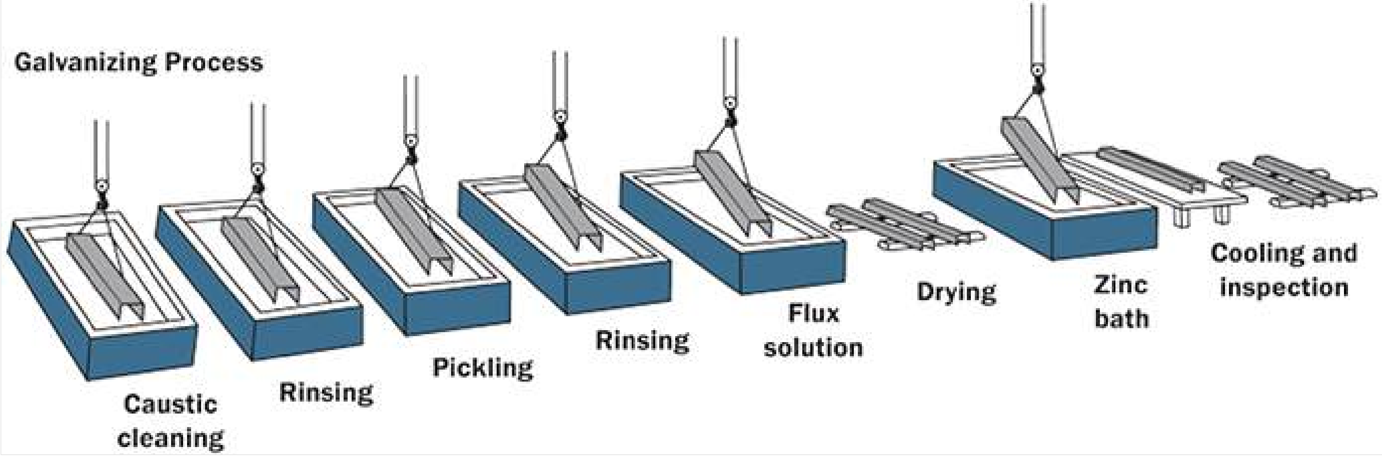
Hot Dip Galvanizing



(Image source)

Hot-dip galvanizing (HDG) is the process of giving a coat of galvanic coating to steel parts. by immersing in a bath of molten zinc at about 450 deg C. While it is mainly used for higher thickness materials such as angles, channels poles, etc., sheets from 3 mm upwards too can be galvanized. Below 3 mm the sheet will warp due to the heat. Zinc, aluminium, tin, lead, and lead alloyed with 10 to 20 percent in are commonly used for hot-dip coatings.

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Source:
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Anodizing

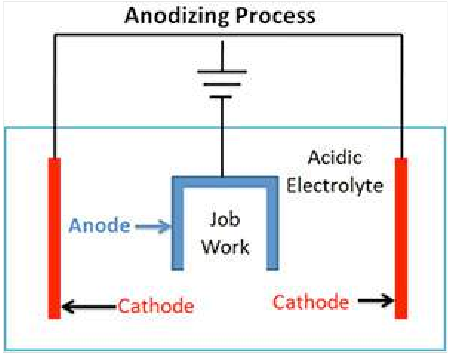
Anodizing is an electrochemical process that converts the metal surface into a decorative, durable, corrosion-resistant, **anodic oxide** finish. Aluminium is ideally suited to anodizing, although other nonferrous metals, such as magnesium and titanium, also can be anodized.

Anodizing, used mostly on aluminium and zinc, is an electrochemical process that deposits an oxide coating on the surface of the metal, which provides a certain amount of corrosion resistance and can be dyed in brilliant colours. Plain anodizing is widely used for aluminium extrusions and decorative parts. Hard anodizing is used for cookware.


Exmples of anodised parts. (Image source)


Aluminium Chassis.


Hard anodized cookrware. (Image source)



(Image source)

Generally speaking anodizing costs less than powder coating or painting. Due to the translucent property of anodizing, it gives aluminium a deeper, richer metallic appearance than many other organic coatings. Anodising is much better for aluminium, especially in high-traffic areas where a coating is prone to abrasive cleaners and other forms of physical abuse. Anodised aluminium metals cannot chip, peel, blister, or flake. This is because the coating is part of the metal itself.

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Hard anodized aluminium is used in a variety of cookware. The process keeps the metal from reacting with acidic foods and provides a hard, smooth surface that is very durable. Aluminium conducts heat well and is a less expensive metal.

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Source:
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Vacuum Metallization

Vacuum metalizing is a process in which thin coatings of metal compounds are deposited on workpiece surfaces in a vacuum chamber. Parts are normally pre-coated before metalizing and a protective layer is applied. Electronic components such as capacitors, integrated circuits, contacts, and photoconductors utilize vacuum coatings. Vacuum metallization is used for bright and lustrous effects in products such as automobile light reflectors and other applications such as optical glasses.

Vacuum metalization applications (Image source)

Typical examples of coating on different substrates.

Coating material	Function	Coating thickness, mil	Substrate Material
Aluminum	Decorative	0.001–0.005	Metal
Aluminum	Reflective	0.5	Glass
Aluminum	Protective	0.5	Steel
Aluminium	Decorative	0.5	Aluminium
Cadmium	Protective	0.5	Steel

Aluminium is widely used for vacuum coating. It vaporizes easily at less vacuum pressure. Many other metals can be used for vacuum coating depending upon their volatility and vacuum coating ability.

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Source:
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Chemical Etching

Chemical etching is meant for very close tolerances of etching to obtain desired aesthetic design appearance. It is also a cost-effective etching process that achieves exacting tolerances. It is versatile to explore interesting variations in product design.


Precision Micro (Image source)

Etching is the process where strong acids or other chemicals are used to cut into the metal surface and unprotected parts which are done by way of masking to create designs in incised metal surface to create designs. Most metal surfaces can be chemically etched.

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Protective Films


(Image source)

Protective coatings are commonly used to protect paint and powder-coated surfaces, anodized and plated surfaces.

There are transparent coatings that offer protection film over the painted surfaces and will give attractive shine. Further, they Prevent deterioration, corrosion, and tarnishing of the paint coats. Good quality protective films are flexible enough to resist cracking and peeling.

Varnish

(Image source)

Varnish is mainly meant of wooden surfaces and a very durable because it contains a higher ratio of solids. It is an excellent protective coating for outdoor applications such as exterior doors, boats, beach chairs, etc.,

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Lacquer

(Image source)

Lacquer provides a gloss finish often used on many products. It is extremely durable and resistant to damage. however, over time lacquer can be become and susceptible to scratches. Discoloured it can begin to discolour and become scratched. The common finish terminology varies from least shiny to most shiny flat, matte, egg-shell, satin, semi-gloss, and high gloss.

Polyurethane Coat

(Image source)

Water-based polyurethane is popular because of its low odour and low toxicity. It goes on clear without adding a slight colour that oil-based versions can, and it dries much faster. Water-based polyurethane won't hold up well to heat and chemicals. It's good for bookcases, desks, side tables and picture frames — anything that won't be exposed to extremes. Oil-based polyurethane is slightly more durable than water-based, especially when it comes to handling heat, so a kitchen table is a good candidate.

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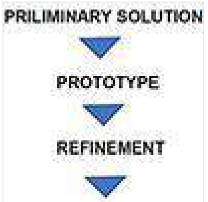
Design Methodology

Chapter 7



The Design Process


Design Brief


Preliminary Design

Design Alternatives

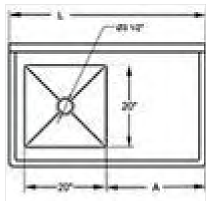

Raw Materials


Manufacturing Methods


3D Printing


Human Factors


Aesthetic Considerations


Working Drawings

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Prototype


Design Refinement


Detailing


Evaluation


Engineering Documentation


CAD / CAM Computer-aided Design and Manufacturing


Production


Finishes


Scrap

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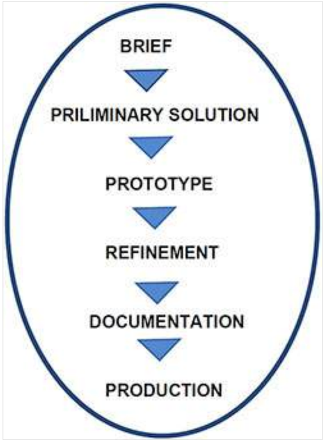
The Design Process

The realization of a product starts with design. The design methodology is an organized approach for the most optimal and cost-effective results. The methodology broadly follows the following sequence:



Design Goals

Design at best should be simple. Any design can be implemented at any cost. But that should not be the design goal. It must be easy to implement. It must be easy to understand and easy to process. Design must be simple. The fewer the parts simpler the product is.

Design must take standardization into account. Standardize available materials, processes, hardware. Design with right tolerances. Too close tolerances cost money. Evaluate the utility of each tolerance. Design should offer minimal operations, for example, two operations may be combined into one.

Design should optimize Operational Expenditure (OPEX) and Capital Expenditure (CAPEX). Choose what is right for the product. No overdesigning, no under designing.

While attempting to design a sheet metal product the design engineer must review many factors that affect the design process. Planning is important. Planning saves much time.

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Sheet Metal
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Source:
https://www.dsource.in/course/sheet-metals/design-metodology/design-brief

Design Brief

The design process begins with a product Brief. The brief is expected to be concise and clear. The brief makes it known available resources to the designer as to what infrastructure is available and the expected product cost. The brief also makes it known the constraints within which the design must be carried out. For example, the designer should know whether the work could include both Fabrication and Forming or should it be limited to either one of them. The designer should know for whom the product is aimed at so that design thinking can be narrowed down to fewer variables.

Design Brief is expected to clarify all that is to be clarified about the product. To name a few:

- Industrial Product or Consumer Product
- Batch production or mass production
- Life expectancy
- Standards to follow

These have bearings on the type of materials and processes to be chosen and the cost of production.

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Source:
https://www.dsource.in/course/sheet-metals/design-metodology/preliminary-design

Preliminary Design

Often a final design does not materialize in the first instance. It starts with basic idea generations and is carried forward for a detailed design and engineering at a later stage. At the forefront of preliminary designs is concept generation.

The preliminary design or basic design bridges the gap between conceptual ideas and the detailed design. Preliminary designs are necessary particularly in cases where the level of conceptualization achieved during ideation is not sufficient for a full evaluation. The preliminary design builds the basic platform on which further progress is made. They form the foundations based on the product brief and within the parameters of available resources.

The general guidelines to generate basic ideas may be based on the following:

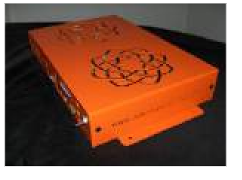
• Based on the component layout in the case of electronic and electrical enclosures,
• Based on industrial design visualizations in the case of automobiles, "Form" related concepts
• Based on the economy of weight and volume in case of aircrafts
• Based on space constraints in case of a public product
• Based on product price in case of consumer products and toys etc.,

1. Component Layout

Designs based on component layouts follow the adage "Form follows Function". The enclosure is conceived around the component layout. Minor changes can be made from a human engineering point of view.

a. Layout based on functionality

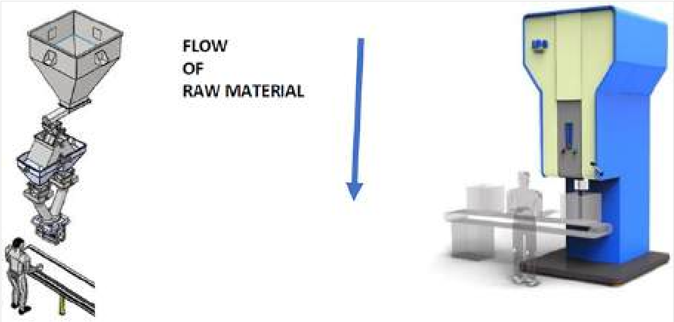




(Image source)

Simple fabrication is adapted in most industrial electronic products. Aesthetic aspects are limited to superficial embellishments such as the punched design shown in the picture at right which also acts as ventilation slots.

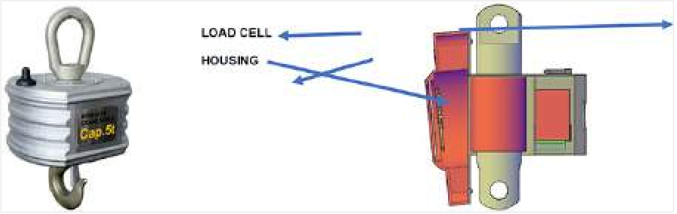
b. Layout based on Functional Flow



Bag and Weigh Machine (IPA, Bangalore)

In this example, product design has followed the component layout. The chute height has been modified to suit the operator's convenience.

c. Layout based on order of priority



In this case, loadcell is the most important part and is required to be centrally balanced. All other parts such as electronics, batteries are accommodated around the primary element.

d. Layout based on Visual Appeal

There are products sold mainly on visual appeal. It is the primary driving element in design. Industrial design explores this potential fully to promote the product.

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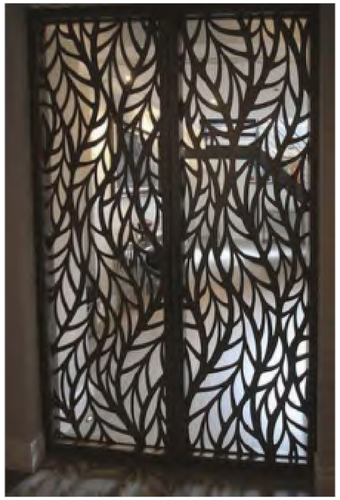
Staircase with perforated Metal steps.
(Image source)



Laser cut seet steel door panels.
(Image source)

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Source:
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Design Alternatives

The success of the completed design depends on the selection of appropriate concept alternatives. A mismatch between customer’s needs, product, and the process cause loss of quality, delays, and added costs. Changes made early in the design process are less costly than those made during detailed design and later stages. Unattended design defects in conceptual design are expensive to correct in the detailed design stage. Therefore design alternates at the conceptual stage are important.

Example 1

Weighing Scale alternatedesign concepts built around the primary component which is the loadcell

Example 2


Medical Carts (Wellness, Bangalore)

It is always good to have alternate ideas using different fabrication and joining techniques. Ultimately it is the user acceptance and the end price of the product that matters. In this example of medical carts, exploration of ideas results in a better-suited design for sheet metal as shown on the right without changing the inner component layout.

There is always more than one way of doing things. Each of these ways must be studied to decide on the most optimal and cost-effective way of realizing the product. It must be remembered that the apparent least complex path need not necessarily be the most desired path.

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Raw Materials


(Image source)


(Image source)

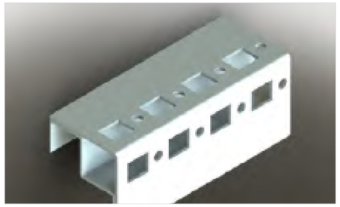
Product manufacturing starts with the choice of raw material. Raw materials comprise about 60 % of the typical product cost. The remaining are manufacturing costs and overheads. The raw material is the very essence of the product and any reduction in the cost without compromising the quality will benefit the product in the competitive market. The raw material choice depends upon the structural strength required, process complexity, and the final finish. Consider high strength low thickness sheets wherever possible. For components where a natural finish is sought, design the process to protect the natural finish from damages due to processes and handling. In such cases design parts with less mobility from workstation to workstation.

1. Strength

Sheet metal processes surprisingly high strength. Like in structural angles and channels in steel, thin metals also can be bent into profiles with good structural strength characteristics. For example, the whole weight of an aircraft with a full load is entirely carried out by aluminium alloy structures.


A geodesic dome structure. (Image source)


An aircraft fuselage structure. (Image source)




(Image source)

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Thin metal profiles are also widely used in structural frames for electronic enclosures and architectural frameworks. Thick metal profiles are used in architectural applications. The all-around material is steel. The kitchenware material is stainless steel. The light and durable material is aluminium. The high-strength materials are titanium. One can refer to a wide variety of materials and their grades that are available.

While choosing the sheets for fabrication or forming the following factors must be checked
- Flatness
- Bow
- Buckle
- Creases
- Structural Streaks
- Blisters
- Stains
- Corrosion Marks
- Dents
- Damaged Edges

2. Typical grades of sheets and their applications


Stainless steel grade SS 303 / 304. (Image source)


Aluminium Grade 3003/3004. (Image source)


Deep Draw, SS 200 series.


SS 316. (Image source)

Machine Housing, HRCA/ CRCA sheets. (Image source)

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Panel Boards, CRCA Grade O.


Different grade of steel in automobile body. (Image source)


CRCA D grade. (Image source)


Toy, Alloy aluminium. (Image source)


Toy, CRCA DD grade. (Image source)


Perforated CRCA sheets CRCA O grade. (Image source)


Rolled CR sheets O grade. (Image source)

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Source:
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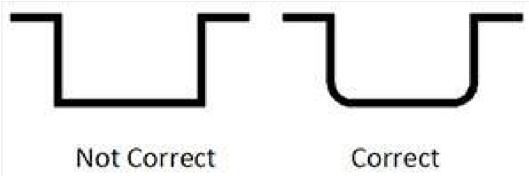
Manufacturing Methods

In sheet metal, there are only two processes often used. **Fabrication and Forming**. The designer at a broad level should know available manufacturing methods keeping in mind the production quantities. For low volume production CAPEX should preferably be avoided. Wherever possible, parts must be designed using general-purpose tooling rather than specialized tools.

1. Small Size Fabricated Parts

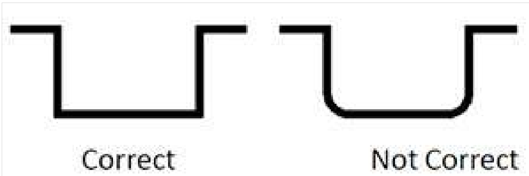
Capital Expenditure (CAPEX) vs Volume

Example: High Volume Production



Investment on Forming Tool is justified.

Example: Low Volume Production



Investment in Forming Tool is not justified.

The manufacturing methods for fabrication and forming vary widely depending upon the size and complexity of parts. There is a wide range of machinery from simple manually operated fly presses to totally computerized machines to perform required duties. The designer in consultation with the production specialist should decide on the manufacturing options available to suit the design.

Sheet metal using an established CNC industry may not particularly be good for small parts. It may be expensive. However, in countries like India, there are many micro-scale industries that can cater to such requirements with makeshift tools and equipment. They may be adapted to test prototypes though compromising on tolerances a bit. A manually operated fly press without electric power can surprisingly generate many interesting parts.

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Hand operated fly Press. (Image source)


Punched components using fly press. (Image source)


Bending by Fly Press. (Image source)


Medium complex component by fly press. (Image source)


A cabinet of this kind is easily done on a fly press.

2. Large Size fabricated Parts


(Image source)

Large size fabricated parts however are made joining together different parts made by different methods into one part. Welding is more often used in large part fabrication although riveting and screwing are also frequently used. A designer must design the components keeping in mind the joints and the method of joinery. A designer should make provision for jigs and fixtures locations in consultation with production personnel and as to how to handle the part during and post-manufacturing.

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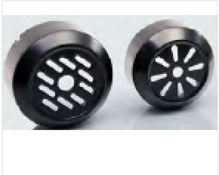
3. Small Size Formed Parts

Simple forming operation by fly Press.
(Image source)

Here again, simple forming operations can be achieved on manually operated power presses with makeshift tools. Tool designers can produce low-cost limited-use tools. They are useful to test joinery and to develop prototypes. Medium-sized power presses and CNC tooling can opt for precision production.

4. Medium Size Formed Parts

Medium capacity Power Press.



Parts using medium capacity Power Presses.
(Image source)

Design of a cooking stove using formed components on medium capacity press.

5. Large Size Formed Parts

Large formed parts need large machinery and expensive tooling. It is a capital expenditure process and demands high volumes to justify such expenditure. But once properly proven tooling is in place tens of thousands of parts can be produced. The cost of tooling will be amortized over the number of parts produced.

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A 2000 Ton press used for an auto body part forming.
(Image source)

Source:
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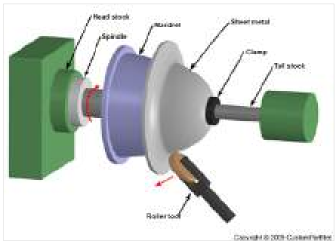
6. Other Manufacturing Methods

We have reviewed manufacturing processes in detail in "Chapter 3. Sheet Metal Manufacturing processes". There are other processes available for the designer to opt for appropriate manufacturing methods. Designers must finally balance between quality, time, and cost.

Roll Forming.



Spin Forming.
(Image source)

3D Printing

Designers may consider the use of 3D metal printing when possible and fits into the budget. 3D printing is particularly useful in prototype development or even small quantity production. Complex parts can be produced without the need for tooling. While the cost of 3D-printed metal is high at present, the prices are bound to come down in due course. The 3D printing process is bound to make many convention manufacturing methods obsolete.


(Image source)

Selective Laser Melting (SLM) and Direct Metal Laser Sintering (DMLS) are two metal additive manufacturing processes that belong to the powder bed fusion 3D printing family. SLM produces parts from a **single metal**, while DMLS produces parts from **metal alloys**. Both SLM and DMLS are used in industrial applications to create end-use engineering products.

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Source:
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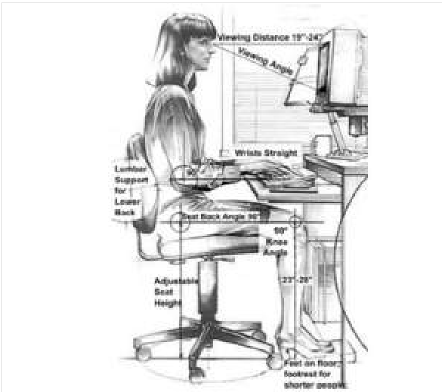
Human Factors

Human factors and ergonomics are the application of psychological and physiological principles to the engineering and design of products, processes, and systems. The goal of human factors is to reduce human error, increase productivity, and enhance safety and comfort with a specific focus on the interaction between man and the machine. Human factors engineering is a combination of numerous disciplines such as psychology, physiology, anthropometry, interaction design, user experience, user interface, engineering, and biomechanics. In essence, it is about adapting the machine to man.
(Wikipedia)



Human factors engineering considerations in product design.
(Image source)

Human factors design principles can be obtained from many sources. The ISO specifies ergonomic design principles in several of its standards. ISO 6385 (Ergonomic principles in the design of work systems): "establishes the fundamental principles of ergonomics as basic guidelines for the design of work systems" ISO 6385 defines a number of general principles for the design of work systems in various work situations.

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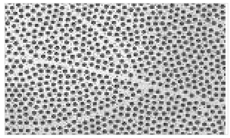
Source:
https://www.dsource.in/course/sheet-metals/design-metodology/aesthetic-considerations

Aesthetic Considerations

Aesthetic considerations cannot be ignored at a component level and at the final product level. Aesthetics play a very important role in the acceptance of a product. Designers should constantly strive to introduce an element of aesthetics at all levels. This sensitivity rewards well in acceptance of the product at different levels. The sense of aesthetics can be felt at a simple joint level to overall product appearance. Right product conception is the beginning of aesthetic appeal. Simplicity adds to aesthetic appeal. Application of tolerances adds to aesthetics. Application of right surface finishes adds to aesthetics. Ultimately, workmanship adds to aesthetics. On the other hand, overdone aesthetic treatment can have a repulsing effect too.

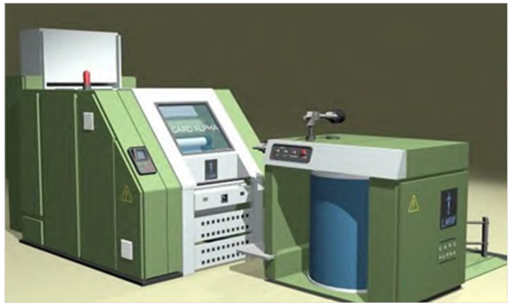

Form as aesthetic element. (Image source)


Colour and surface finish as aesthetic elements. (Image source)


Perforations as aesthetic element. (Image source)


Surface finish as aesthetic element. (Image source)


Over done aesthetic attempts do not really help. (Image source)


Identity as aesthetic element ((Chandran K. P.)

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When there are two machines working in tandem on the shop floor, it will be good to consider giving a family identity. The identity may be with similar shapes and colour schemes. This kind of treatment adds to the attraction. Each area of product application has its own demand for colours and finishes to appeal to the the end-user. The subject of colour and its applications are so vast it is better to consult specialists in taking a decision. In industrial products, however, certain colour standards are established to be neutral and not to distract the operator in stressful work environments.

Source:
https://www.dsource.in/course/sheet-metals/design-metodology/aesthetic-considerations

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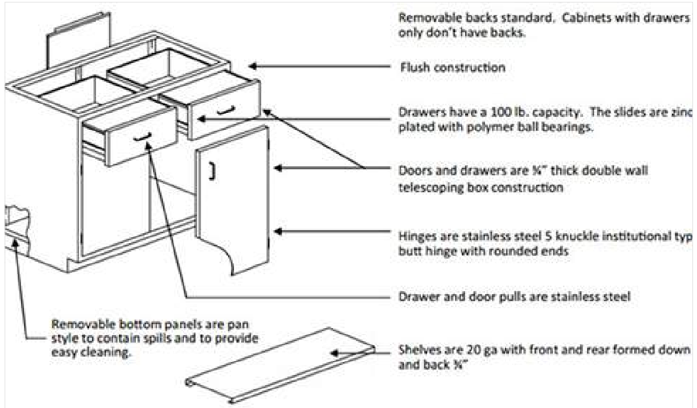
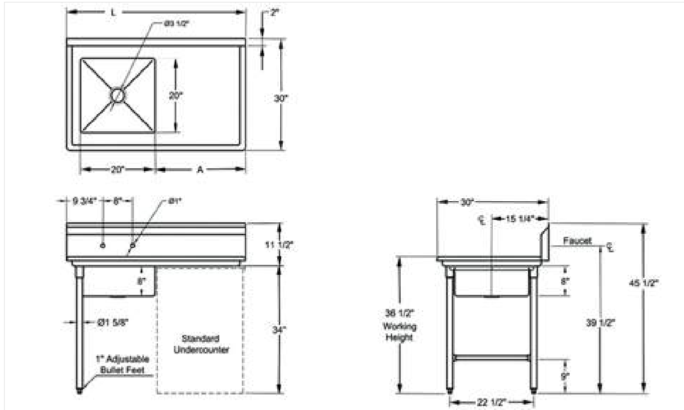
Source:
https://www.dsource.in/course/sheet-metals/design-metodology/working-drawings

Working Drawings

Working drawings are meant for first-level prototype realization. The notes in working drawings need not be very specific. The purpose is to realize a prototype for evaluation as quickly as possible. It is acceptable to leave certain issues to the shop floor personnel's discretion. This way new inputs may also arise for later refinement and final documentation. Similarly, it is not necessary to define close tolerances in working drawings. Loose tolerances are good enough at this stage.





Often as-built drawings are made after the completion of prototypes for review and corrections before final documentation is initiated.

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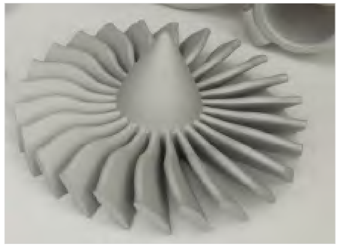
Prototype

A prototype is a rough draft of a part for testing and further development before actual manufacturing. Prototypes can be low-cost fabricated or simulated using different techniques or even handcrafted.

Sheet metal fabricated prototypes.

Sheet metal fabricated prototypes.
(Image source)

Extruded prototype.
(Image source)



3D printed prototype.
(Image source)

In some situations, designers may also create plastic prototypes for parts that will eventually be manufactured in metal. It is not very important if the part does not possess the structural qualities of the intended final part when it is only for visual evaluation.

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Source:
https://www.dsource.in/course/sheet-metals/design-metodology/design-refinement

Design Refinement

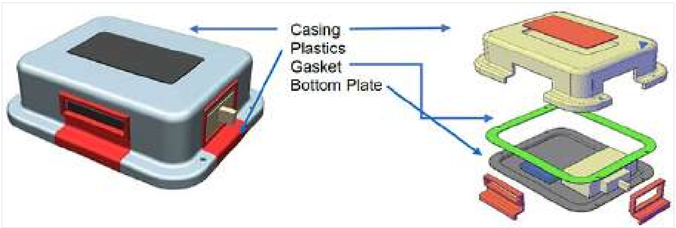
Refinement means addressing the factors earlier noted but not addressed and anomalies not corrected. Refinement makes the design production worthy. Refinement is a process that is beyond simulation and ends with documentation.

There are three distinct functions in the product realization chain -product design, process design, and process execution. The interface between these three functions is also critically analyzed.

Example: Electronic Enclosure

Original Prototype

The electronic components are in place on a single PCB with an output connector on one side and a power switch on the other side. The product has mandatory projecting flanges with holes to connect to a panel. The other customer requirement is it must be drizzle proof if not watertight. The prototype fabricated box served the purpose well to demonstrate the successful function to the customer.



Example of Refinement: Redesigned and refined final design with the same inside components.

A deep-drawn casing that mates with a bottom plate are the design refinement. Electronics are fitted to the bottom plate aligning with the mating connector. The cut-out slots for the connector and the power switch are snap-fitted with a moulded plastic component to make the enclosure drizzle-proof. The panel fixing flanges are integrated with the casing.

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Following are some of the factors to be considered while in the process of refining a design:

1. Check Access

(Wellness, Bangalore)

Design should allow components of the product to be assembled in a particular sequence. The product may have to be opened for service and maintenance at periodic intervals. Cutouts for doors, hatch doors, portholes, etc., must be planned in advance at the right places. Many times we observe anomalies after full assembly such as deviations from optimal positions. In such cases provision must be made for necessary hardware such as special tools to access parts.

2. Review Hardware
There are many kinds of knobs, wheels, handles, stoppers; gaskets, and so on of different sizes and designs that come into the picture to complete the product. It is important to refer to actual technical data sheets to properly incorporate such elements. After works and patchworks should be avoided.

3. Explore Repeatability of Parts
It is useful to design parts for repeatability. One can plan to use the same parts and the fixing mechanisms to suit a family of products. This helps in saving time and effort, reduces inventory costs, and further helps to establish product identity.

Family of products using common parts

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4. Explore Modularity

Modular sheet metal components are in use for identity as well.

Modularity is the degree to which a system's components may be removed and recombined to give the benefit of flexibility and variety in use.

Modularity is particularly important in product design. It allows easy replacement. It reduces inventory costs. It also helps in generating new product concepts using a particular module.

5. Optimization
There are many variables in the whole path of design to manufacturing. They are primarily materials, manufacturing processes, direct and indirect labour, and capital expenditure. The interrelationships are complex. They must be carefully balanced by exploring alternates in optimizing the design during the detailing phase.

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Detailing

Detailing is the most involving phase in the design process. It consumes much time and effort, coupled with documentation is popularly known in design parlance as donkey work, meaning drudgery. But then it is the most essential part of the whole process.

During the phase of the detailed design process, the design engineer has to specify clearly the size, shape, material, tolerances, manufacturing information, and other pertinent information that will allow their design to be realized. There are many areas where critical observations are needed. This phase also involves questioning and reviewing various design parameters.

Size and Shape - Should the part be made bigger, smaller, solid, or hollow? Should the shape be different?

Materials - Which material to be used and why? Which grade of sheets? Material selection has an influence on weight, cost, manufacturability, reliability, etc.

Joinery - What is the mechanism of joining parts together? If the joinery is weak it has an effect on reliability, robustness, safety, and many others.

Manufacturing Processes - Are there better methods of making the part better and cheaper?

User Experience - What will be the user experience? Can it be made more comfortable to use?

Sustainability - Does the product have an adverse effect on the environment?

Maintenance - Has the design taken care of maintenance aspects? How easily can the part be removed and replaced in a short time? Is preventative maintenance required? Is it better to make a more durable part at a higher cost to eliminate recurring maintenance costs?

Life - When does the product become redundant? Are the materials recyclables? Are the materials used are hazardous?

1. Mating of Parts

The most essential part of the design engineering process is to ensure that parts mate with each other to become sub-assemblies with ease and the sub-assemblies mate with each other with ease to become final assembly.

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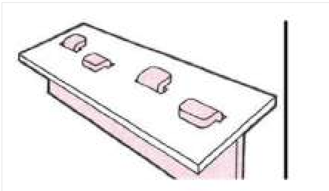
The number of parts in a product may vary from just two numbers in a simple product to many in a complex product. It is absolutely necessary to divide the product structure into modules, sub-modules and down to the last part in order to assess ease of mating of parts in a systematic way. Tolerances, type of fixing methods, type of assembly tools, jigs, and fixtures all matters. It is a critical phase where close interaction is required between designer, engineer, and shop floor personnel.

Parts mating with each other.

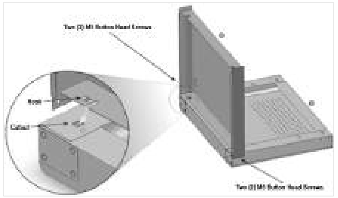
Corner detailing.

2. Joinery
• Minimize joints
• Minimize fasteners

As discussed earlier minimal number of parts and minimal use of fasteners are essential parts of a good design. One can think of the use of tabs, snap fits, press fits, or any other creative means to minimize joins and fasteners to save assembly time and costs thereof.



Use of tabs.



Use of hooks.

An example of a product which is assembled without fasteners.

Joinery Detail.
(Image source)

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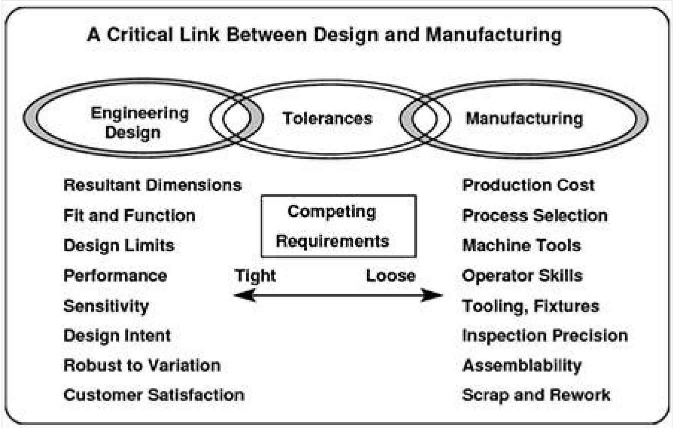
3. Tolerances



(Image source)

Work out realistic tolerances. There is no need to suggest close tolerances everywhere. For example, there is a difference between +/- 0.5 mm vs +0.5 /- 1.0 mm which will have a bearing on the chain of events ultimately leading to the final cost.

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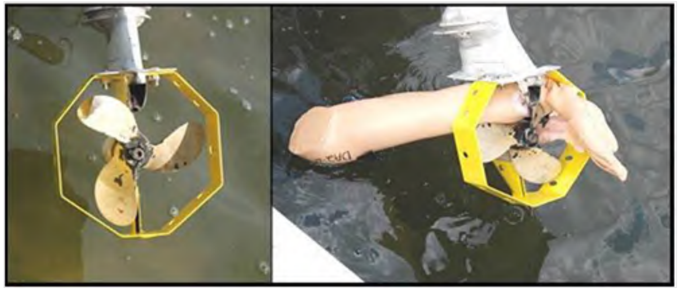
Evaluation



Testing of ring-type guard design showed significant entrapment issues.
Design Research Engineering
(Image source)

Product evaluation is essential to assert the soundness and effectiveness of the design. Product evaluation is the process of assessing the intended product's functionality, usability, to identify and remove design or manufacturing defects.

There are different stages methods of evaluation. Depending upon the nature of the product at what stage evaluations are to be done will be decided. They may be a general evaluation at the design and manufacturing stages or a critical evaluation at the time of prototype testing. Questionnaires, creation of weightage points to evaluate different functional and operational parameters are used in the evaluation process. The questionnaires may seek feedback on aspects such as functionality, feasibility, user-friendliness, durability etc.,

Usability

- Is the product design approach correct?
- Is the product usable?
- Is the product meeting the design brief?
- How close is the design to the brief?
- Is the product meeting the customer's expectations?

Credibility

- Is the product safe to use?
- Is the product safe from copyright issues?
- Is the product following applicable standards?

Feasibility

- Is the product technically feasible?
- Is CAPEX justifiable?
- Is the product competitive?

Durability

- Is the product durable?
- Are the parts easy to change?
- Is the product amicable to change?
- Is the product easy to change?

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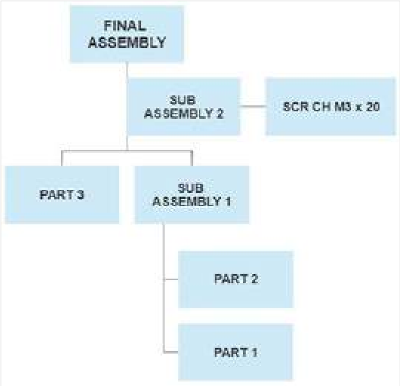
Engineering Documentation

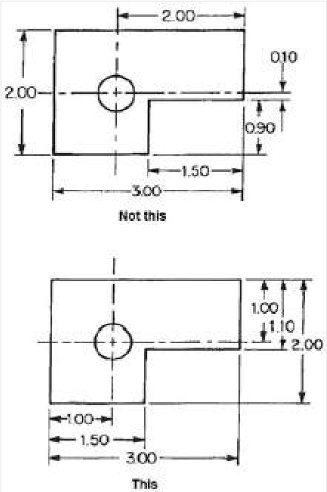
1. Product Structure



The product structure must be clear when it comes to final engineering documentation. The drawings and other documentation must follow the product structure. Nothing should be missed. At the highest level of the structure, a simple screw is given equal importance as is given to the final assembly. Without this simple screw, the final assembly is not complete.

The documentation conforms to the product structure diagram.

2. Dimensioning



Dimensioning for sheet metal punching, bending operations follow the datum rule.

Dimensions should be from one datum line rather than from a variety of points to simplify tooling and gauging and avoid overlap of tolerances.

3. Standards

Technical documentation involves the preparation of drawings, manuals, literature, etc., conforming to defined standards. There are well-defined ISO standards for various activities. It is well-advised to follow known standards for conformity.

For example, ISO 8887-1:2017 specifies the requirements for the preparation, content, and structure of Technical Product Documentation (TPD) for the cycles of manufacturing, assembling, disassembling, and end-of-life processing of products.

1S0128-30:2001 gives Indian standards for technical drawings, general principles of presentation.

IS 800 gives a code of practice for general construction in steel.

4. BOM/BOQ

Bill of Quantities (BOQ) and Bill Of Materials (BOM) help project managers and vendors in understanding the part requirements associated with the product.

BOM is related to the list of sub-assemblies, parts, specifications of raw materials. It is hierarchical in nature with the top-level representing the finished product which may be a sub-assembly or a completed item.

BOQ lists the quantities required to fabricate the product. BOQ is used mainly for tendering purposes. The quantities may be measured in number, area, volume, weight, or time. Preparation of BOQ means that the design is complete, and specifications have been prepared.

BOM and BOQ both are closely interrelated.

Typical BOM Format

Typical BOQ Format

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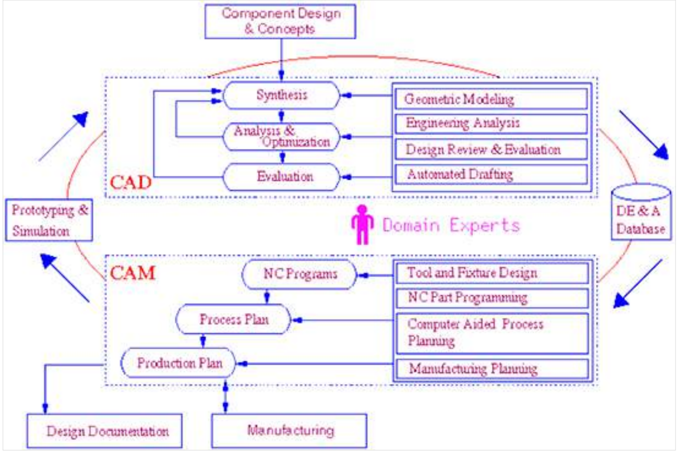
CAD / CAM Computer-aided Design and Manufacturing

CAD/CAM applications are used to both design a product and program manufacturing processes, specifically for CNC machines. CAM software uses the models and assemblies created in CAD software to generate tool paths that drive machine tools to turn designs into physical parts. CAD/CAM software is used to design and manufacture prototypes, finished parts, and production runs.



A normative concurrent design and engineering process

CAD CAM Packages

There has been tremendous progress to make use of CAD/CAM software in small and medium scale industries. There is affordable software available for the lower end of the industries. It is now an inevitable transition from conventional manual systems to computerized systems in the sheet metal industry.

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Example: Amada Software Solution, Software covers the entire manufacturing path for sheet metal fabrication. (Amada)

It is well-advised to choose appropriate CAD software to manufacture sheet metal components. Most sheet metal fabrication operations on CNC machines involve cutting, punching, bending, and dimple and boss creations. Many also use general-purpose CNC machines for prototype development, one-off or small batch productions. Designers should visualize the part in CAD models and try to understand how to optimize the sheet sizes, generate punch and bend sequences, how to avoid dimples and bosses that do not conflict with punch tools and bending tools.

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Production

As discussed earlier the equipment of a sheet metal shop varies widely depending upon the size of the product and production quantities. The layouts also vary accordingly. A reasonably equipped sheet metal fabrication shop should have at least the following:

Primary Section

- Sheet stalkers
- Power Shearing Machine, 2.5 Mt length, Hand Shears
- CNC Turret Punch Press, 24 stations, Power Presses- 20T,60 T, Fly Presses

Secondary Section

- CNC Press brake 2.5 Mt length, Hydraulic press brake. 2.5 Mt, Folding machine 1.2 Mt
- Notching Machine, Clinching machine, Riveting machine, Hand Riveting equipment
- Work Benches 2Mt length, Fitter Hand Tool Sets,

Integration Section

- CO2 Welding, TIG Welding, Arc Welding, Spot welding, Resistance welding
- Welding Tables, Welding Jigs
- Deburring, Grinding, Sanding
- Inspection Tables, Inspection Tools

Finishing Section

- 7 Tank Pre-treatment
- Conveyorized Spray painting, Powder Coating booths
- Effluent Treatment Systems
- Plating Systems

Assembly Section

- Assembly tables
- Assembly Documents
- Assembly jigs

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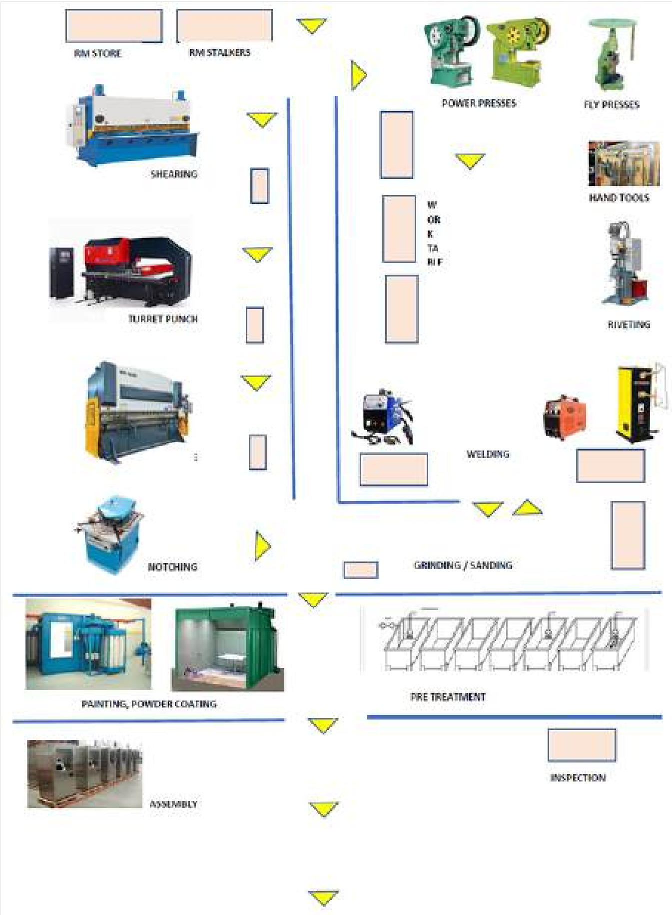
- Pneumatic Screwdrivers
- Cleaning Systems

Dispatch Section

- Packing
- Dispatch Documents
- Jib Crane or other lifting equipment



TYPICAL LAYOUT OF A SHEET METAL FABRICATION SHOP. MACHINES CAN BE MORE THAN ONE.

Production should be planned based on firm BOM and BOQ along with formatted final drawings, not as-built drawings

Sheet Metal production initiation generally comprises of:

- Work Order Generation
- Production Flow path creation
- Man, and machine time planning
- Quality manual generation
- Inspection manual generation
- Dispatch document generation

The production begins with these documents. There must be periodic in-process quality checks and final quality checks before the product is certified for dispatch.

Finishes

We have reviewed in detail about the finishing processes for sheet metal products in chapter 6.

What is required in consultation with the marketing people or as per the customer specification is the decision as to what is to be specified in the documents.

1. Types

Natural
Organic

2. Standards

Some of the Indian Standards fop saint applications and other miscellaneous information are as follows:

3. Colour Specification

IS 137 – Specification for ready mixed paint, brushing, matt or eggshell flat, finishing as required.

Indian Standards for paints, compositions, miscellaneous.

IS 15489 – Paint, Plastic emulsion - Specification.

IS 1477 - Code of practice for painting Ferrous materials.

IS 14246 - Code of pre-painted galvanized sheets.

IS 2074 – Ready-mixed paint, air drying, red oxide, zinc chrome, priming.

4. Texture specification - Munsell textured colour samples.

5. Gloss Specification

Full Gloss: 70–90%, Semi-Gloss: 41–69%, Satin: 26–40%, Sheen: 15–25%, Eggshell: 10–15%, Matte: <10%.

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6. Test Specifications

IS 101-1-3; 3-1;3-3 – Methods of sampling and test for paints, varnishes, and related products, Part 1 tests on liquid paints.

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Scrap

(Rajat Kapoor, President, Cosmos Green FZE)

(Image source)

Finally, there is something one needs to be aware of is about the scrap generated out of sheet metal fabrication industry. Metal scrap contribute substantially to environment pollution and degradation. Metal recycling awareness, unlike plastic and paper, is low in India. Nevertheless, the recycling of metals is as important to improve the environment as recycling paper, plastic, and other commonly recycled materials.

Recycling metal helps in preserving natural resources including water and energy. As of now, the consumption of metal scrap in India every year is about 25 million tonnes. Only 20 percent of metal is recycled out of the metal that is produced and used in the country. According to data released by FICCI, recycling ferrous metal in India can lower emissions by a whopping 59%. Likewise, as per FICCI, the recycling of steel waste, can lower water pollution by 76% and trim down pollutants in the air by 86%.

Let us preserve the `earth'

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