Project1: Design for manufacturability in composites

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Acknowledgement

I wish to thank Mr. Nachiket Thakur, DGM, PDDC, Mahindra Composites for his invaluable assistance and also mainly for involving me in this project work and lending me the opportunity of gaining invaluable knowledge from the field of composites. I also want to thank Mr. Tapan Basu, Sr. GM, Alternative Energy Vehicles, Mahindra for sharing loads of knowledge and thus helping me improve the design of the vehicle and sourcing me with other necessary information related to automobile and composites.

Objective

The objective of the project can be stated as follows

- To re-design and modify the vehicle concept to suite composite manufacturing process.
- Component level detailing according to the composite manufacturing process and materials

To re-design and modify the vehicle concept to suite composite manufacturing process:

The concept work of the vehicle was already done. The concept is an electric vehicle with the whole body to be manufactured using composite manufacturing techniques. So it required initially understanding the composite materials and composite manufacturing techniques. Also was the understanding of the various pros of this process and the various applications of the process in automobile sector

Component level detailing according to the composite manufacturing process and materials:

This included breaking down the final form of the vehicle into detailed individual components and providing all the amount of details related to the joinery and placement.

The final output of the project included a final 3D model data of the vehicle in any of the 3D modelling software, a BOM of the vehicle components along with weight and cost calculations and the exploded view of the components to understand the various positions of each component.

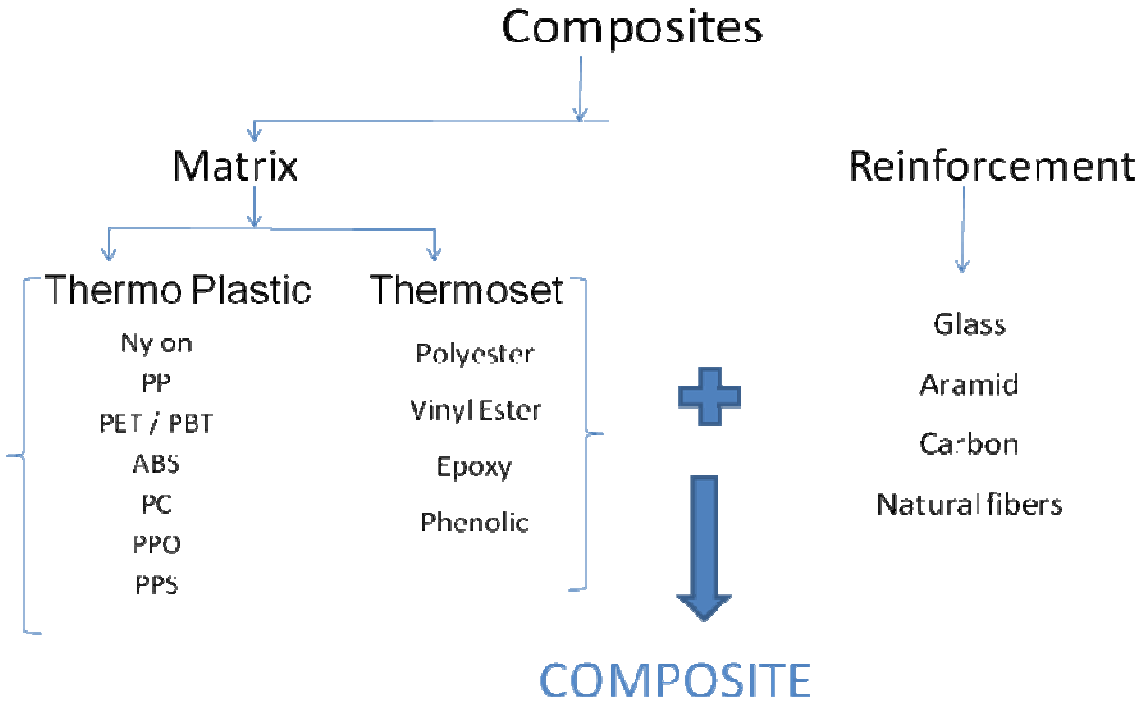
Introduction to Mahindra Composites

Mahindra Composites, formerly Siro Plast Ltd., is a branch of the Mahindra Systech, which is a part of the various business sectors of Mahindra Group. Mahindra Systech consists of various manufacturing units as MUSCO, Mahindra stampings, Mahindra castings, etc. Basically established by M&M in 1982 with SICOM and the commercial production of SMC/ DMC compound and component started off from 1989 and the RTM and hand lay-up production started off from 1999. Mahindra composites consists of a two plants the head quarters at Pune which is a 3.5 acres plot and also houses Compression Molding shop and the Concept and Engineering Services division while the other being the Mangaon plot which is a 15 acres plot housing various plants of SMC & DMC Compounding, Compression Molding shop, Hand Lay up Shop, RTM Shop, Painting Shop and Prototyping Shop.

The design activities undertaken by Mahindra Composites consist of Product Concept Designing, Prototyping and Mold Development. There are also various research works going on to optimize the production and quality standards of the products being produced at Mahindra composites and also several in house projects which also accounts this current project. There are a range of products that the firm has come up with for various business sectors as Automotive Sector Electrical & Switchgear, Farm Equipment Sector, Railways, Medical Equipments and Defense Equipments. Their customers list includes GE (USA), L&T, Siemens, TVS electronics, AVIA, Mahindra and Mahindra, Bajaj Auto, TATA motors, TVS, etc. There are also several awards and recognition gained for these products one of which consists of JEC Innovation Award, Transportation which has been awarded for the front fender designed for the TVS three wheeler which is a single piece composite product.

Introduction to composites

Composites, as a material, are a special form of plastics where a combination of two or more materials such as fibre as a reinforcement, and matrix material as binder , resulting in a material with properties superior to that of the constituting materials. Generally heat and pressure are used to shape and cure the mixture to achieve a finished part.



The matrix materials being used are general plastics, either thermoset as PE, vinyl ester, epoxy, etc or thermoplastics as PP, PET, ABS, PC, PPS, etc. which are mixed with resins as carbon, glass, aramid or natural fibres. Sometimes there is also addition of curing agents, also known as hardener, it acts as a catalyst and enhances in the curing process also hardening the final product.

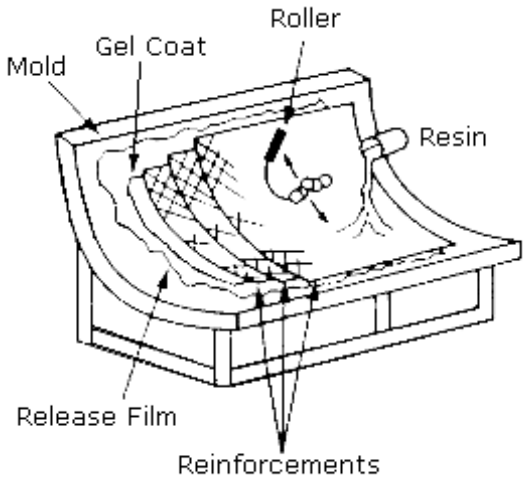
There are various composite manufacturing techniques depending upon the type of output and the type of quality required from the desired product. These manufacturing techniques are as follows:

- Hand layup / spray up
- Vacuum bag / autoclave moulding
- Compression molding
- Glass matt thermoplastic (GMT)
- Resin infusion moulding (RIM)
- Resin transfer moulding (RTM)

- Injection moulding
- Filament winding
- Pultrusion
- Thermoforming

Few of the basic manufacturing techniques are explained as below.

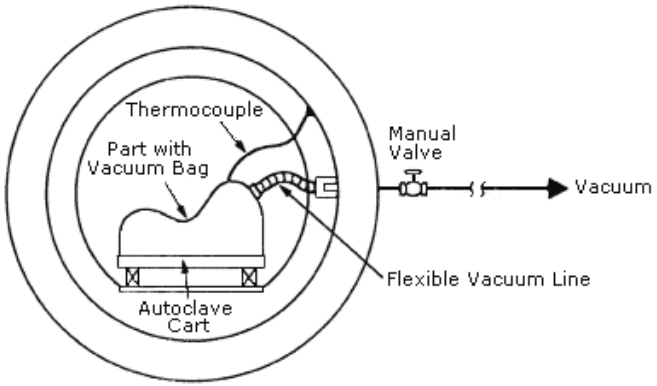
Hand layup/ sprayup: This is basically an open mould process where several layers of the resin and the binder. These layers are later pressurized using a roller for laying the layers properly over each other. Spray up method is similar to the hand layup process but the layering is done with the help of a spraying gun.



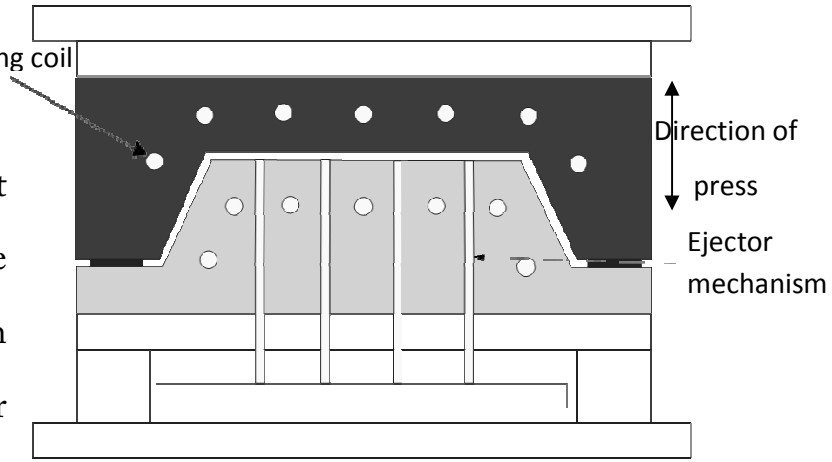
This process results in single side finish products and the time required for getting the final product is high but requires less tooling cost. Due to the presence of direct exposure of the resin with humans these processes are not generally preferred. This process is preferred for small

scale production or for general prototyping.

Vacuum bag/ Autoclave molding: The process is carried in the presence of a vacuum. The layers are placed inside a plastic bag where the later vacuum is generated to shape the layers according to the mould. Later heat is applied for curing. The result of this process is high quality moldings without any air bubbles and good inner surface finish. Controlled curing conditions improve quality and consistency and also results into a more rapid cure with faster turn round of moulds

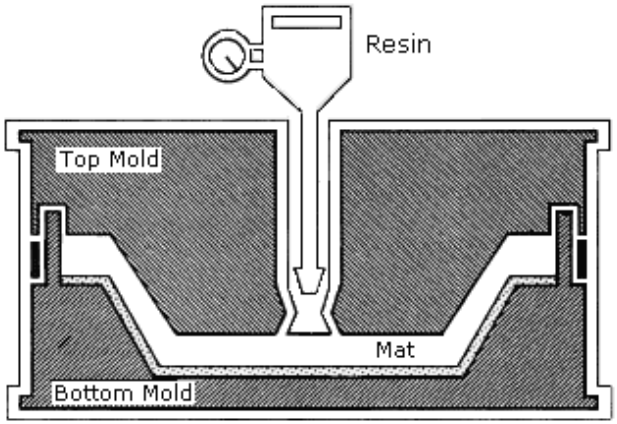


Compression molding process: The process basically consists of applying pressure on to the raw materials. It requires metal mold due to the application of high pressure and thus the final product has both side good surface finish along with good strength. The raw material can be SMC or DMC which are placed over the mold and the press is closed

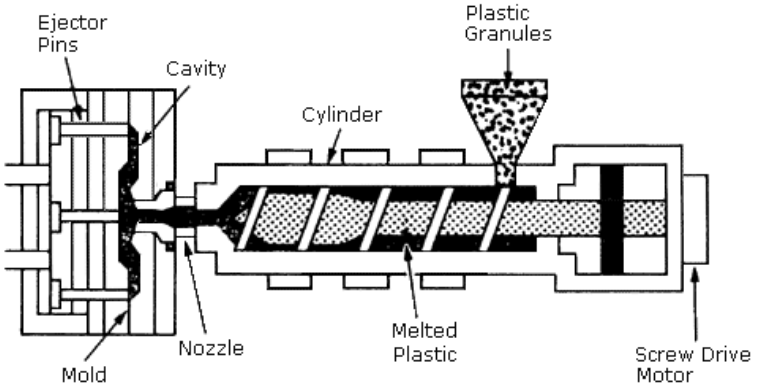


later with the application of high pressure and temperature. The molds are heated to 140 to 160˚C and pressures of 50 to 150 bars applied. Production rates of 200 parts per day possible with this process.

Resin Transfer Molding (RTM): Resin Transfer Molding process is preferred when parts with two smooth surfaces are required at low pressure. The basic reinforcement fibre is placed initially in the mold. The catalyzed resin mixture is pumped into the mold cavity which is later cured under heat and pressure basically to shorten the curing time. The process requires high energy consumption and high amount of ventilation. Also high quantity production is not possible in this process.

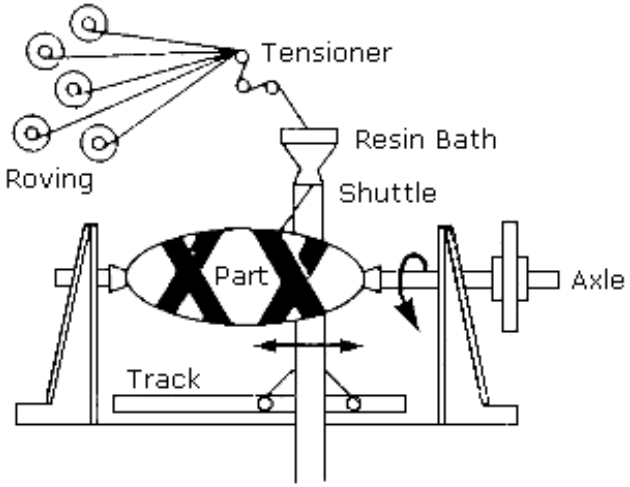


Injection molding: The charge of the material is fed through the hopper into the cylinder. This charge is passed through a heated screw type barrel conveyer where the charge gets melted and later is passed into the mold through a nozzle. This process is best for large



scale series production due to the possibility of automation of the process and high production rates. The temperature maintained for this process is around 160°C and the pressure maintained is around 150 to 200 bars.

Filament winding: In this process continuous fibre reinforcement materials are drawn through a container of resin mixture and formed onto a rotating mandrel to achieve the desired shape. This is later cured in an oven. This process is generally preferred for producing high performance hollow symmetrical products.



Advantages of composites

The usage of composite materials and manufacturing techniques are advantages in various forms. These are explained as follows:

Strength to weight ratio: Composites exhibit a higher strength to weight ratio than steel or aluminium and can be engineered to provide a wide range of tensile, flexural and impact strength properties. For example, a composite's strength per unit density is roughly two times that of aluminium and four times that of steel.

Corrosion resistance: Composites are corrosion resistant to most chemicals, do not suffer from electrolysis and incorporate long-term benefits such as weather ability and UV stability.

NVH compliance: The material provides internal damping to the vibrations moving along the fibres thus reducing the vibrations also has good noise transparency and also leads in reduction in harness.

FST compliance: The material provides good fire resistant property with good compliance in smoke and toxicity thus satisfying the FST regulations.

Surface finish: The product finally obtained can have high surface finish depending on the type and quality of the molds and working parameters making it possible to achieve near class-A surface finish with simple fabrications.

Complex organic shapes: Due to the flexibility of the material and the method of manufacturing it, achieving complex organic shapes with good strength is easier.

Components: Due to the flexibility in achieving organic shapes the no. of total components required for making the complex shapes reduces thus also reducing the time and cost of assembling

Dent resistance: Due to the fibrous structure the material provides high amount of resistance to any force and preventing formation of dents.

Applications of composites in automobile sector

Earlier composite materials was being used in small scale applications as small coverings or basically in low grade as temporary hard tops for soft/open top vehicles e.g. auto rickshaws. But the most extensive use of the composite materials was being done in the racing sector with the use of carbon fibre for making the body structure of the racing cars for example the Formula 1 cars.

There had been other applications of composite materials in auto sector as the body panels of heavy trucks and modern vehicles where organic shapes can be made easily and also as the load carrying members as these cannot be easily dented or broken due to its fibrous inner structure and high strength to weight ratio. These are also replacing sheet metal panels due to its cheap tooling costs and lighter weights. Also most of the auto sector companies are eyeing on this unique and cheap material as a replacement for sheet metal due to the limited resource and ever increasing cost of sheet metal in the global market. Due to the achievement of flexibility in form and high strength to weight ratio

these are already being used in most of the heavy duty regions in automotive sector and also new applications, due to its durability and toughness, as military vehicles and ammunitions are being brought up as in one of the cases armoured vehicles are being made from composite materials.

There are also extensive works going on to make the usability of composite materials in high temperature regions to extend the usage of the materials in the exhaust manifolds of high performance vehicles where real high temperatures has to be sustained. Other applications as oil sump where corrosion is a major problem in case of metals, valve covers, floorings, engine hoods, NVH covers for various SUV's and LCV's etc are also being manufactured from composite materials.

Existing Product Study

To continue with the designing phase after understanding the composite material I had to understand various existing products either being manufactured using composite manufacturing process or which are compact mobile vehicles, either three wheeled or seating two people.

This study was necessary to understand the form, technique of assembling or detailing of the various components and also a few of the technical data as the type of suspension, drive train, etc.

The products selected were:

Aptera

Aptera, a three wheeled hybrid vehicle made out of composite material i.e. carbon fibre provides attaining organic and aerodynamic shapes easliy. Organic shapes being maintained in all the components as the windows, doors and headlamps.

Cree SAM

Cree SAM, a three wheeled vehicle, basically carrying overall elongated spherical shape. This provides the model a compact feel. Provision is provided along the corner to accommodate the simple headlamps. Gull wing type doors provide interesting element and an ease for ingress and egress. Interesting elements as vents provided in the front serving function of cooling.

Nmg sparrow

NmG-1 is a single seater, three wheeled all electric vehicle which hs been registered as a motorcycle. The overall form of the vehicle is spherical and maintains a curvy profile all over the vehicle dimensions. Various elements as the window, dicky also carring the same theme of curvy lines. Bright

colours being used for the vehicle. Power provided to the rear single wheel via a belt drive from the rear mounted motor. Monoshock suspension provided at the rear.

Lumeneo Smera

Lumeneo Smera, a four wheeled all electric vehicle capable of manoeuring like a motorcycle.The layout of seating is tandem where the driver and the passenger seats one behind the other. Interesting details given in the vehicle enhancing the form which also works as a functional element for the vehicle. Single large door provided on both sides of the vehicle for easy ingres and egres. Further detailing as small luggage parcel at the rear providing enough room for small bags.

Data Carried

From the above products studied, Lumeneo Smera was considered as a benchmark for developing the vehicle but with simple mechanisms and layout to fix the vehicle for the given constraints of economy and ease in manufacturing. Basic points as a carry over of the theme on all the elements, making use of the flexbility in shape of the material to a greatest extent for providing any amount of functional elements/details. Seating provided is tandem for better utilization of space and to keep the width of the vehicle minimum for easy manueovarablility in urban conditions.

Initial input

The concept to be worked on has been worked upon to a stage where the basic configuration of the vehicle was already finalized. The final vehicle to be designed is supposed to be powered by an electric motor powered by a set of batteries. The structure of the various main components as the load floor and a rough body shell was done and basically acted as a bench mark for further designing. Also was finalized was the layout of seating of the driver and the passenger. The process selected for manufacturing of the various body panels was SMC as it provides high volume production at a cheaper cost, both side surface finish is possible, is also easy to paint and is also light in weight. The panels to be detailed out should suite the manufacturing process as well as should be good in form too. The panels are supposed to be assembled by bonding them onto each other so some form of provision was to be provided for the same purpose.

Understanding

The basic points of considerations to be made before designing were:

- The product should look fresh, should be sleek and cute.
- Economy or final cost of the vehicle was a big consideration
- Optimum utilization of interior space was also an important point
- Ease in manufacturing was one of the main purpose of designing

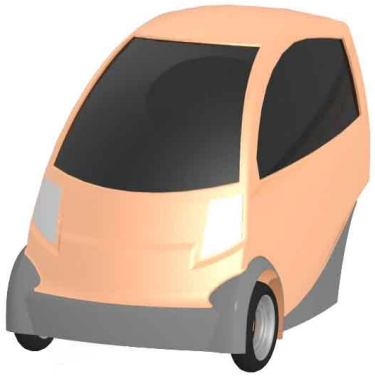
Design Process

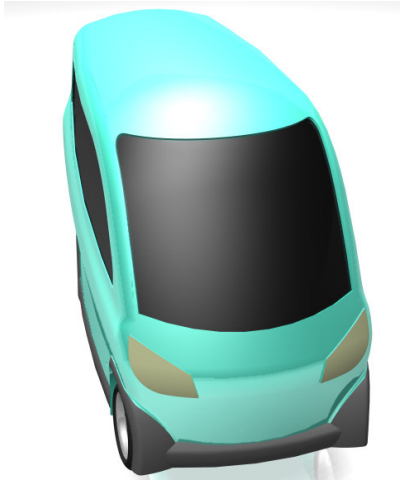
The design process basically is consisted of

- Modifying the basic rough form of the existing concept,
- Design and developing the load floor of the vehicle,
- Design and development of the final 3d form of the vehicle and
- Breaking down the external body into smaller components
- Detailing each component according to manufacturing
- Design and development of the interiors

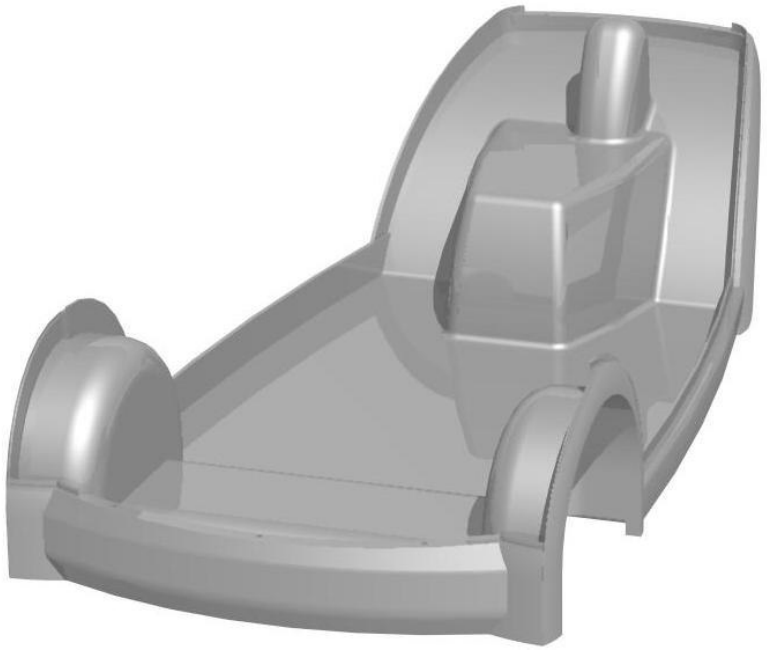
Modifying the basic form of existing concept:

To start with the design process initial form of the vehicle had to be decided. This required exploration of the existing form for the vehicle and modifying it to give the required characteristics to it. Various exploratory sketches were made with different variation in the elements making the vehicle look according to the requirements as specified earlier. To clear out the complexity in the sleek vehicle basic 3D form of the vehicle had to be made in modeling software (few of the models are shown besides). Once the basic form of the vehicle was finalized the final sketch of the vehicle was prepared.

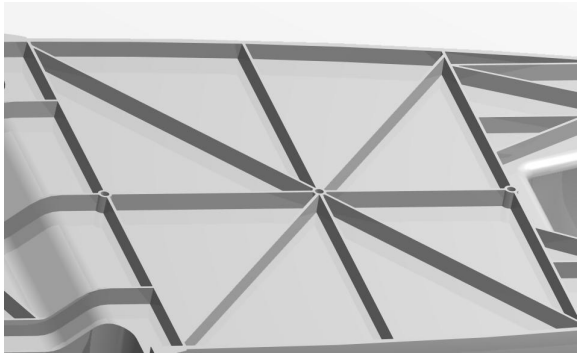




Design and development of the load floor:

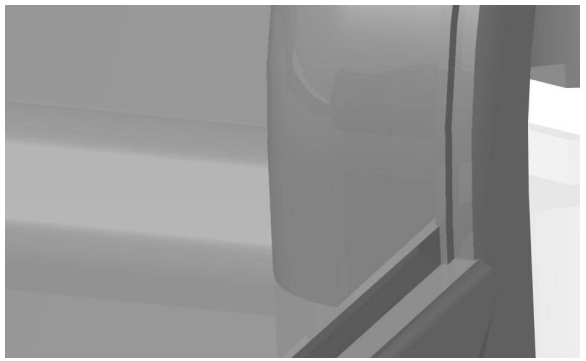


Later, the design and development of the load floor had to be worked on. The basic layout of the load floor was finalized initially but more detailing of the load floor had to be done. There were various requirements that the load floor design had to fulfill. The load floor had to sustain loading in various forms as direct load of the vehicle and the occupants and several other components, torsion load due to the dynamic motion of the vehicle, also it had to provide excess surface around the top edges to provide area for pasting the exterior panels onto the load floor. It also had to form a barrier for the doors so as to prevent it from getting inside. The engine/motor and other parts as the suspension, etc. had to be fixed onto the load floor so it had to take provision for placement.

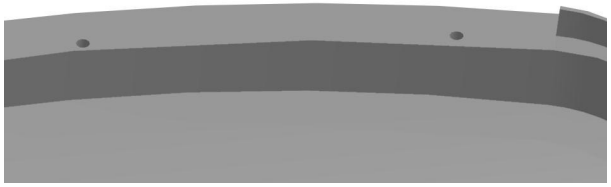


Ribbing below the load floor

And the important point to be kept in mind was to keep the weight of the vehicle optimally low. The load floor is to be manufactured by compression molding process to achieve good dimensional stability and also for both side surface finish. After making the basic 3d model various details as flanges, space or a bump for placing the motor and also the suspension were provided. Step by step each major as well as minor detailing was brought about suiting the manufacturing process. Considering the loading condition and weight an optimum thickness of the load floor was decided and further strengthened using ribs on the lower portion of the load floor.



Flanges for constraining the door movement



Provision for bolting front and rear panels onto load floor

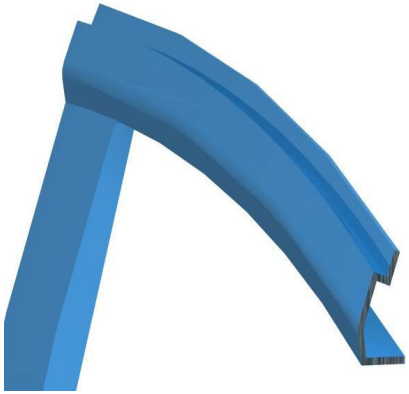
Design and development of the final 3d form:

After finalization of the load floor design the final form of the vehicle was made in the 3D CAD software and a few options were made with the earlier finalized form. Once the form of the vehicle was finalized the second objective of the project or second phase of the project had to be started with the detailing of each component requiring breaking off the whole structure into individual components for ease in manufacturing. After successfully breaking down to individual components, the way of bonding each component on other had to be decided. Also few provisions had to be made available to easily paste the various individual components with each other. These components are also to be manufactured by compression molding process for its high volume production possibility and also for the both side surface finish. Regarding the doors, the doors to be provided are suicide doors with access just from the left, the doors on the right are fixed or rather donot have hinges and are

The final 3D form

bonded. The suicide doors are being used for ease in ingress and egress and also with the absence of b-pillar the access area is made large. Due to the absence of b-pillar, the locking of the door is done at the top and bottom portions with a linkage provided to keep the doors locked. The doors are hinged on to a frame present both at the front and at the rear which also acts as a strengthener to the whole composite structure. These frame elements are also made from composite materials and are rigid as well as light in weight. On finishing these details the later stage was to start with designing of the interiors.

Details of front fixed door

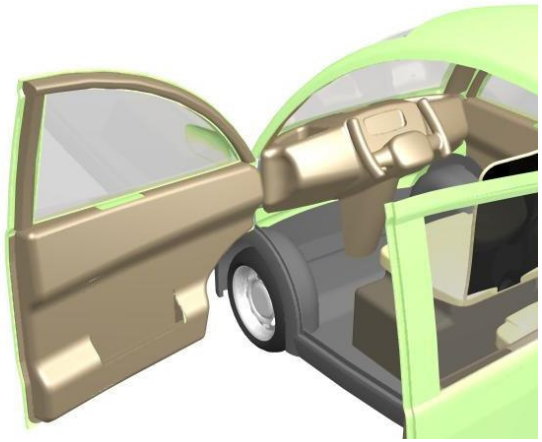


Cross section detail of the door

Inner details of the door

Design and development of the interiors:

In this stage the interior panels had to be designed including the dashboard, the door trims and other trims required to cover the exterior body panels from inside. The panels had to be manufactured by vacuum forming and hence had to keep the individual panels as simple as possible yet also had to look good. The interiors had to look modern and since the vehicle is a two seater it should not look clumsy. The basic dashboard layout was kept as simple as possible with just a central bulge housing all the basic instruments and also housing the steering wheel and its column and linkages. There are big depressions provided on dashboard acting as storage to accommodate any form of stuffs. The same theme is



Interior of the vehicle

carried over the side door panels with broad shoulder line which diverges from front and later again converges from half. There are small pockets in the door interior trims to accommodate small things and the handle for the door is in form of a depression positioned on the shoulder line of the trim. These trims are again bonded onto the external panels through the provision provided along the edges. The seating layout selected for the vehicle is tandem seating so as to keep the width of the vehicle as minimum as possible for ease in maneuverability in urban conditions. To hide the suspension depression intruding the load floor and to house the electric control system a luggage compartment is kept just behind the passenger seat which can also take small necessary goods. The cover of the compartment also acts as a parcel tray to keep normal shopping stuffs. The other basic covering as the roof lining, a-pillar cover, rear trims are kept as basic as possible to keep the manufacturing process simple and in turn reducing the overall cost of the interior trim.

Experience:

While starting of the project the expectations that I had towards the project was basically to understand the working culture of the firm, a good practice of form studies, understanding prototyping stages, etc. The most important thing that I wanted from the project was a brief exposure to the industrial culture due to my inexperience in the industry and also to make myself capable of delivering a product to the industries standards. When the project work started and the whole objective and the required output was explained I was a bit disappointed about not being able to work on prototyping stage as the basic prototype of the concept already existed, but was happy that the most important process of the conversion of a concept to actual product could be learnt and I always was keen for doing such a task for an actual concept. The knowledge gained during the project is enormous from various fields as manufacturing, designing and also through the personal experience due to the one to one interaction with all the people involved directly or

indirectly with this project. Also gained was the way of handling the projects from industries point of view, the problems faced due to the in-house projects, how experience does matter while handling a project, etc. And above all the most important one being understanding the purpose of a particular component and thus selecting a suitable material and also further selecting a proper manufacturing process for the particular requirement, in this case (project) being shape, size and volume.

The atmosphere of work in Mahindra Composites is very pleasant due to the free nature of all the working personals of the firm. The pleasant nature is also maintained due to the constant interaction about the work and other matters going among the working personals. There is always keenness for involvement in any sort of work going around in the work place. The constant interactions and discussions and also the availability of Sir helped me get the problems solved at that moment itself.

The great thing that I noticed about Nachiket Sir was the keenness of sharing the knowledge with me as well as eagerly getting knowledge from the more experienced and knowledgeable persons and further conveying it to me. I was also been provided with the full freedom for the way of work and no serious

pressure for doing any particular activity but necessary feeding of his idea and thinking was always made available.

Apart from all these things as my feeling and understanding towards composite material and manufacturing technique, it's a unique and emerging technology for the future of the automobile and other industries. This technique is advantageous in several aspects as durability, strength, light weight, ease of attaining complex organic shapes, and ease of achieving good quality surface finish as well as class- A surface quality. Less tooling cost and non limited source of raw material make this technique ready for the all the fields of application of various sectors.

Apart from the above mentioned good bits about composites that I felt during the project period, there were a few other drawbacks. Though the material is tough and durable but the texture and form of the final components donot make them feel that tough and may fail to make the user feel secured, until and unless given some surface treatment as some colouring, as much as that in case of a sheet metal products. Also, except for the costly carbon fibre, full utilization of composite materials in the auto sector is still not made. There are models where composite materials are successfully used for making the body panels, but the way

they are used and the complexity of combining it with other materials as the metallic frames make them too costly for general use vehicles.

Overall the whole experience of the month long project was very enjoyable as well as knowledgeable with learning from my personal gains as the way of handling the project, managing the time and several loads of things as the importance of consistent interaction with the experienced, etc. This experience will surely help me out in handling my further P2 and P3 projects as well as in the other projects which I will have to be handled in the further stream of my career.

List of people involved in this project,

Mr. Nachiket Thakur, DGM, PDDC, Mahindra Composites Ltd., Pune

Mr. Tapan Basu, Sr.GM, Alternative Energy Vehicles, Mahindra.

Mr. Pravin Phatak

Mr. Vivek Kulkarni

Mr. Manoj Gaikwad

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