Abstract—With the developments in automobile technologies: more focus is given to the vehicle weight reduction. About 30\% weight is contributed by the automobile body. Now-a-days, plastic composites are used to manufacture automobile bodies as they are strong, light, corrosion resistant and easy to use. This paper represents the selection of plastic composites to build vehicle roof as a replacement of conventional metal roof. Different types of plastics and plastic composites were studied and their mechanical properties and cost were compared with steel and aluminium.

Keywords—Alternative materials, crashworthiness, FMVSS standard, rollover, roof crush.

I. INTRODUCTION

The automobile industry is one of the fastest growing fields as thousands of researches and inventions arise. A full attention is given to the vehicle performances, fuel economy and safety. These three requirements may shapes the modern vehicle design and opens the big research area for the automobile engineers. An overall weight reduction is the key point in vehicle performances and fuel economy but the major problem occurred with occupant as well as vehicle safety. Many automotive manufacturers focus on occupant safety than performances and fuel economy. Various safety criteria like FMVSS and IIHS are developed which gives vehicle safety ratings in all kinds of accident conditions. So here the task arrived to engineers to reduce vehicle weight in such a way that above safety criteria must fulfilled.

In the topic of overall weight reduction of a vehicle, most of weight gained by the body and the framework. In the BIW (Body in White) section of a vehicle, maximum concentration of weight could be found in roof section. In traditional vehicles, the roof is made of metals, can be replaced by alternate material having less weight and equal or more strength. Plastic composites offer greater strength and contribute lesser weight compared to metals. As the roof and pillars protects the occupant from the head and neck injuries, these sections must be strong enough to withstand in rollover accidents. The strength of a roof can be specified according to FMVSS 216 regulations. Hence the task is to select suitable materials which are lighter than metals and fulfil the FMVSS 216 regulations.

In this paper, various alternate materials and their mechanical properties were studied and compared against existing materials on the basis of requirements that are essential in rollover accidents and weight reduction. The loading condition in rollover accidents was also explained in this paper.

II. MATERIALS FOR AUTOMOTIVE

In the engineering materials, steel is the best material for building structures as it offers greater strength. The main problems with the steel are the corrosion and weight per volume. Aluminium alloys is the best alternate material in weight reduction and offers considerable strength. Hence BIW section of modern vehicles is made of aluminium steel with spot welds. Variaty of alloy configurations in aluminium may possible with certain amount of Mg and Li content.

Composite materials become newest trends in the field of engineering materials. Two or more materials are combined together with the help of engineering techniques to obtained the combined properties of its constituents are called as composite materials. Now days composites finds their usages mostly in aerospace and marine applications as they offered light weight, mechanical strength, corrosion resistivity, ease of manufacturing and ease in maintenance. Because of these advantages of composites, it becomes popular in automotive frameworks. The configurations of composites are so flexible that it can accommodate any material which is suitable for engineering applications. Hence it may categorise like plastic composites, plastic-metal hybrid composites, ceramic composites, fibre composites etc. In case of reduction in weight, plastics and plastic composites or polymer composites are preferred. The use of plastic for manufacturing components in the automotive industry has been increasing over the last decades. The average vehicle uses about 150 kg of plastics and plastic composites versus 1163 kg of iron and steel and currently it is moving around 10-15\% of total weight of the car [2]. Plastics and plastic composites were used to build not only the internal parts but also the exterior components in automotive like bumpers to body panels, laminated safety glasses, trims and other small components.

Sainath A. Waghmare1, Prashant D. Deshmukh2
1Research Scholar-ME, Datta Meghe College of Engineering, Airoli, Navi Mumbai
2Asst. Prof. Mechanical Department, Datta Meghe College of Engineering, Airoli, Navi Mumbai
III. MATERIAL & CRITERIA FOR ROOF APPLICATION

Vehicle roof is subjected to the rollover accidents which are most dangerous among all kinds of accidents since it is directly attack occupant’s head and neck. The chances of vehicle rollover are very less i.e. 3% in overall accidents but the risk of life is high. Hence the material used for manufacturing the roof must have high flexural strength to deform less for the given load and high energy and impact absorption capacity. Steel has very less shock absorption capacity and it may transmit shock to the occupant during collision of roof with the ground. Here plastic with the best supporting material can become the solution as plastic were famous for shock absorption capacity. Different plastics like acrylonitrile butadiene styrene (ABS), Polybutylene Terephthalate (PBT) and plastic composites like Glass Fiber Reinforced plastics (GFRP), Carbon Fiber Reinforced Plastic (CFRP) which were suitable for roof application were elaborated in subsequent sections on the basis of following requirements.

A. Mechanical Strength

The mechanical strength of roof material of a vehicle is the most important criteria since it directly related to occupant safety. The mechanical strength of the material used for roof must be as high as possible. Since FMVSS 216 is based on Strength to Weight ratio, more the strength more will be the ratio. According to FMVSS 216 norms, the rollover conditions is reverted i.e. vehicle kept stationary and force is applied on roof in certain angle (Fig. 1). This force is generated due to vehicle hits the ground. Hence the roof part and supporting pillars deformed and crushed inside the occupant’s cabin (Fig. 2).

Here, the strength of roof material plays an important role by deforming less when force applied. Steel showed best strength in this case but now-days new composites with proper configurations could achieve same or even more strength than steel. In BIW section of vehicle, roof is attached and supported by the pillars which act as a simply supported beam. These pillars are the integrated part of a body and reactions acting on wheels (Fig. 1). The simplified solution is represented in fig. 3 as a 3 point bending test. Here flexural strength of material is more important along with tensile strength because when the material or body undergo bending, its outer portion sustain tension (Fig. 3-B).

Different materials which replaced the traditional steel in BIW used this type of flexural test for comparison. But along with flexural strength, other mechanical properties must be considered while selecting an alternate material for steel in automotive. Fig. 4 and 5 shows the tensile strength and modulus of elasticity of materials.
From these figures it can be seen that steel having maximum modulus of elasticity among above stated materials. Composite materials like CFRP-Epoxy, aramid Kevlar 49 and Boron fiber having tensile strength more than steel and aluminium and had best flexural properties (fig. 6 and 7). In plastic composites SMC and BMC fair tensile properties but showed better results in flexural cases.

When talking about material strength in automobile application, the most useful term is Specific Strength. It is defined as a ratio of force per unit area at failure to the density of that material. It is also knows as Strength to Weight ratio. In this, the material having less weight can have more specific strength. The advantage of weight reduction was explained in subsequent sections. Fig. 8 shows comparison between specific strength of alternating material.
B. Light weight (Density)

The Weight reduction of automobile parts may lead to higher fuel economy. Among all the techniques related to increased fuel economy, weight reduction plays a major role since 30% weight reduction gives 15-20% greater fuel economy. It is based on simple logic that an engine has to work less to accelerate and move the light parts. Another advantage of weight reduction through lighter materials is minimization of overall CO2 reduction. The weight of the materials depends on their density. Steel having density 7850 kg/m³ contributes more weight than a composite having density 1470 kg/m³. Fig. 9 shows density of various materials.

Lighter materials can lead better performance of vehicle like acceleration and handling. Let’s have a simple formula,

\[
\text{Force} = \text{mass} \times \text{acceleration}
\]

Here, reduction in mass results in less force to accelerate the things. Another advantage of lowering weight at the top of vehicle i.e. roof, results in lowering the centre of gravity of vehicle. This reduces the risk of vehicle rollover and improved vehicle performance other than fuel economy. Light weighted parts gives less load to suspension system of vehicle with reduction in noise and vibration. Light weighted materials gives automobile engineer to design a vehicle with more luggage space and capacity that can be moved by the same engine.

C. Cost and Ease in Manufacturing

The cost is an important parameter in selection of alternative material from composites. Composite materials are very emerging field so far and day by day new inventions and techniques arrived for their mass production that minimizes the production cost per unit. Making a perfect composite is not an easy task for manufacturers since various complicated process were involved.

The term perfect composite conveys not only perfect quantity of resin and fibre but the way they were engineered i.e. the methods like RTM (Resin transfer Moulding), infusion moulding, sheet moulding etc. on the basis of major constituents of composites i.e. strengthening element and matrix, various combinations may possible and wide range of strength can be achieved but the cost and complexity in manufacturing constraints their applications.

Fig. 10 shows the cost comparison of materials. Note that this showed the material cost only. Total cost may be different including joining cost (Adhesives), processing cost and labour costs. At primary level, just material cost per kg became the base for their comparison.

D. Shock/Energy absorption capability

While replacing existing materials of automobile roof, the main aspect is its crashworthiness. The crashworthiness is defined as an ability of vehicle of a component to protect an occupant from serious injuries at a time of accidents. Selection of material with high energy absorption capability is the base of crashworthiness design. The amount of energy or impact absorbed by a material is given by \(EA\) (Energy Absorption) is the area under the load vs. displacement.

While comparing the performance of energy absorbers the useful property considered is the Specific Energy Absorption (SEA) which is defined as the energy absorbed per unit mass of crushed structure expressed in J/g. Though the geometry of a component helps in increasing SEA i.e. folding method and cross section, the material selection has more impact on it. Fig 11 and 12 shows typical load vs. displacement curve of steel component with folding and that of glass/polyester composite. Composite materials consist of two or more materials e.g. glass polyester composites. Glass contributes the strength and polyester became a matrix which is a softer material that absorbs shock.
Hence it acts like an ideal energy absorber, compared to the metallic structure, as the load level and energy absorption capacity is more stable.

In such accident cases an object is applied on vehicle became impact type of loading. The ability of a material to absorb rapidly applied energy is called as Impact resistance. It is based on the shape, size, thickness and type of material. Impact resistance can be measured by impact tests like Izod, Charpy impact tests etc. The results from these tests do not useful in designing a part but it helps design engineer to compare the relative impact resistance of various materials. Fig 13 shows the results of Charpy impact tests carried on various materials. GFRP shows the best results in Charpy impact test than Kevlar 49 and Boron fiber.

IV. SUMMARY AND CONCLUDING REMARKS

This paper described the proposed study of possible alternative materials which were suitable for roof crush analysis with weight reduction. These materials were compared by their mechanical properties and cost. A single property couldn’t help for proper selection for this purpose; hence grouped property comparison was carried out. Fig 14 shows the comparison of materials along with density, cost and specific strength. CFRP, GFRP, Kevlar-49 were always best in strength, weight and performance but it contributes high cost. The concentration of weight and cost curve was formed near SMC, FRP and BMC column; it means these materials having lowest cost for respective specific strength and density. ABS and nylon had lowest density and cost but lesser specific strength than BMC and PBT. Kevlar and CFRP were best in specific strength with less weight; hence they were widely used in aerospace and marine applications. These materials were used in high end cars like supercars, SUVs, sport cars. In sport cars weight reduction is the main requirement for speed and acceleration as well as safety features as the running velocity is very high.
In case of accidents, the energy absorption along with strength became the platform for comparison fig. 15. GFRP and Kevlar are the best energy absorbers than boron fiber and CFRP. In plastic composites SMC absorbs maximum energy than BMC and FRP. CFRP with vinylester and polyester resin showed poor result in Charpy impact testing but with Epoxy its impact strength increased considerably. PBT had good tensile strength but very much poor in energy absorption.

While designing any part the main consideration is always the strength of material before its cost. Cost can be minimised by the optimisation techniques or cost reduction techniques but compromise in strength is not affordable at all since it directly affects the human health. Excess strength can be a best part in any design but it has no use if it couldn’t affordable to customer. For roof application plastic composite has enough strength to pass strength criteria and weight reduction. SMC and BMC had cost advantage as well as good specific strength as compared with steel and aluminium. Basically SMC, BMC and FRP are pretty much similar in configuration, properties but differ in manufacturing techniques and characteristics. SMC and FRP have a wide range of configuration with glass filled content and it has live examples for automotive body too. Hence alternative material with above stated requirements in roof design, plastic composites stands better than in all respect.

REFERENCES


