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Lightweight Materials for Automobile Body and Chassis-A Review

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Abstract: *With stringent safety norms and the rising competition in the market, automobile manufacturers throughout the globe have been looking for new materials in addition to optimized designs. Lightweight materials with better mechanical properties play an important role in the advancement of this field. Automobile chassis and body in addition to being structurally critical parts, their weight has a considerable contribution in the total weight of the automobile. With the advances in the computer aided engineering durability as well as crash behavior of parts made of new materials can be studied. Researchers throughout the globe have been working on lightweight materials for automobiles. Our paper presents a review of the work done in this field.*

Keywords: *Automobile, Chassis, Body, Materials*

1. INTRODUCTION

Manufacturers and engineers are on a look out for new materials to maintain competitive edge and increase profit margin. Various parameters such as weight, fuel economy, fuel consumption, vehicle performance, weight to strength ratio, corrosion resistance, air resistance, recyclability, service life, government regulations on safety and emissions, tooling cost, level of comfort etc. are considered in this study for alternate materials like Aluminum, Magnesium, Carbon fiber reinforced plastics (CFRP), Bio composites involving Bio fibers, Light weight polymer composites. In an automobile, chassis accounts for about (30-40) percentage of the total weight, so with the use of the lightweight materials we can decrease the cost of our vehicle. For example using extruded members in Aluminum Intensive Vehicles (AIV) upper body of the car is made of Aluminum extruded members mated with steel chassis [5]. Magnesium used for casting and in sheets can also reduce weight and cause improvement in other properties. Our Study includes a comparison between different materials for different parameters so that an optimized material is selected for an Automobile body or Chassis.

2. ALTERNATIVE MATERIALS FOR AUTOMOBILES

2.1 Aluminum

Aluminum is one of the most important alternate materials used in automobile industry. From the chassis point of view use of Aluminum results in a weight reduction of up to 40percentage than conventional steel chassis. It results in inherent structural rigidity, lower tooling costs, increased fuel economy, high strength to weight ratio, high corrosion resistance and reduction in pollution[2].

Use of high tensile Aluminum alloys has completely superseded steel. Properties of Aluminum like high proof stress, percentage elongation, high shear stress, fatigue strength and high hardness properties makes it better than steel and the most preferred alternate material to be used in automobile. For example in European countries about (70-140) kg of weight is reduced per car which saves 982 million liters fuel per 10 million cars and about 2.3 million ton reduction in CO_2 Emissions. Undoubtedly cost is more but the cost objectives are met by using extruded members, optimizing design using CAE and minimizing expenses related to manufacturing. Aluminum has also a high degree of utilization of about (85-95) percentage as an example in AUDI company 34 kg of the 38 kg car chassis is used for second time which explains its high recyclability property [2].Also from the data collected between 1996 to 1999 it has been reported that about 65percentage increase in Aluminum usage over these past 3 years [3]. Moreover from envIronment point of view if 100 kg of weight is reduced then approximately 9 grams of CO_2 per kilometer is reduced maintaining same quality and safety. In Aluminum intensive vehicles the members are connected at joints using inert gas arc welding which also increases frontal impact safety [5]. From cost point of view 34percentage of weight reduction there is an increment of 7.8 pounds cost per kg of chassis[4]. In the recent times Aluminum is not used as a single component as a chassis material but as Aluminum-Alloy which increases seating capacity and decrease maintenance cost despite the elevated consumption of fuel in rapid speed ups and braking at stops and traffic lights[2]. Use of non-heat treatable Al-Mg (Mn) alloys and Al-Mg-Si alloys is also common nowadays. These alloys improve driving dynamics; provide better safety due to reduction in the un-sprung mass. Also they have good formability, weldability, and strength which results in better machinability and longer service period. The (Fig. 1) below depicts the amount of Aluminum used in different parts of the automobile (in million pounds) for all vehicles running in North America as per a survey conducted.

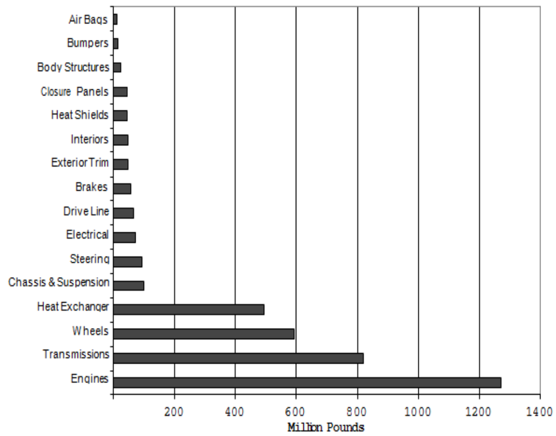


Fig. 1: Aluminum Content of The Automobile System [3]

The total use of Aluminum in different components like engine, transmissions, heat exchangers and wheels accounts for nearly 83percentage of the Aluminum used in North America as per a survey conducted in 1999 [3].

Engine can be further subdivided into components such as the engine block, pistons, and intake manifold. The penetration rates represent the percentage of the total market for a particular component that is produced in Aluminum. (Table 1) below represents Aluminum penetration rates in different engine components.

Table 1: Aluminum Penetration Components: Selected Engine Components

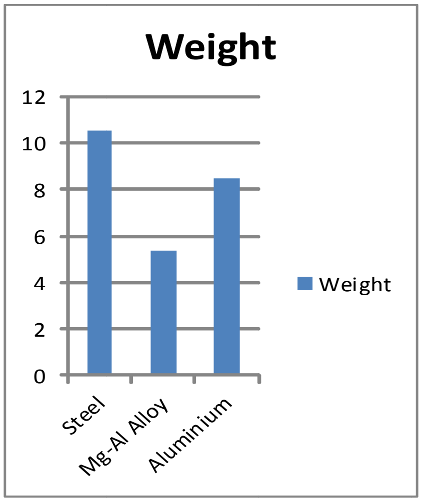
Engine Component	Percentage of penetration
Engine cylinder heads	75%
Engine blocks	22%
Engine pistons	100%
Intake manifolds	64%
Starter housings	100%
Engine oil pans	52%

The components with lower penetration rates provide greater opportunity for expansion of Aluminum use, unless there are technical limits on their expansion. Penetration in closure panels has been in hoods, which still has only a maximum penetration of 8 percentage at Ford. Lower amounts of penetration have occurred in deck lids and lift gates. Aluminum has lost some market share for certain components: front bumper beams, air bag components, and intake manifolds. Intake manifolds are changing from Aluminum to polymers, nylon, and Magnesium.

2.2 Magnesium

Magnesium age is often defined as the new age of the alternate materials. Magnesium is preferable in automobile because of its high specific strength, high damping capacity and high recyclability. Magnesium alloys have just the half the yield strength but they are a quarter as dense allowing them to hold more load per weight. They have a decent castability and low density. Therefore they are used in numerous non-structural automotive part including dashboards and steering wheels. Their inherent weakness has limited their use but increase in the alloy strength has broaden their application in the modern era [15]. Its growth is predicted at constant 12 percentage per year for the next 10 years [13]. It reduces the fuel consumption by 25percentage. Examples are of Volkswagen, Audi and 3-I lupo.

Also if there is about 10 percentage weight reduction due to which there is drop of about 5 percentage in consumption of fuel. There is a weight saving of about (20-25) percentage in comparison to Aluminum. About 60 kg of Magnesium is entirely realistic in the overall weight of the Automobile [7]. Areas where Magnesium is used are the drive train and vehicle interior. Major areas of concern for Magnesium are creep, contact corrosion and lower strength at elevated temperature. For that purpose we employ Hybrid Boot Lid which is basically (Mg-Al) alloy which results in high strength and ductility. Also from the weight comparison perspective we have steel (10.5 kg), Aluminum (8.5 kg), Mg-Al Alloy (5.4 kg).This can be shown in the bar graph below



In the Mg-Al alloy inner panel is Mg and the outer panel is Al which are joined together by welding and bonding which results in 50percentage weight saving approximately. Various other Technologies like Magnesium Sheet technology and Magnesium extrusion Technology are used to enhance the usage of Magnesium. With the help of Mg sheet Technology we cover safety requirements when the body is subjected to

Bending stresses in order to increase flexural rigidity and stiffness. This is used in making of panels like doors, boot, bonnet etc. which results in weight reduction of about 50 percentage as compared to steel and 20 percentage when compared to Aluminum. With the Mg extrusion technology we can increase the elongation to fracture ratio by 15 percentage due to which our yield strength increases and hence service life increases. With the help of Computer Aided Engineering (CAE) in design and processes, materials properties can be improved at competitive prices. Below are some figures presenting the comparison of the structural properties of Magnesium with Iron and Aluminum.

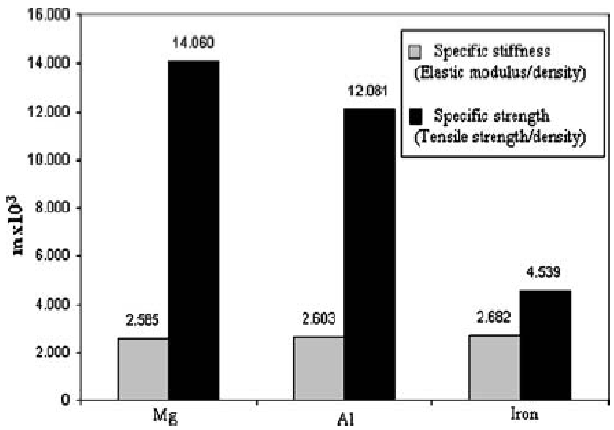


Fig. 2: Comparison of Basic Structural Properties of Magnesium with Aluminum and Iron [11]

From the above Fig. we can infer that the specific stiffness of all the three materials is nearly the same but there is a significant difference in the specific strength which tells that for a given specific stiffness tensile strength for the Magnesium is the maximum

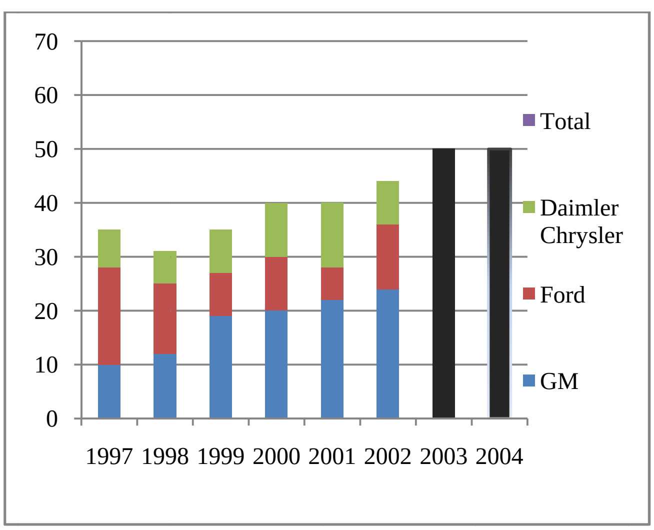


Fig. 3: North American Automotive Magnesium Usage [11]

This Fig. shows the total usage of Magnesium for different models for the given range of years in North America. From the Fig. we can see over the period of time the amount of Magnesium used increases except Ford motors for which it keeps on fluctuating over the years. From this we can predict increase in the usage of in different areas of different models.

3.3 Light Weight Polymer Composites

Composite enables the construction of safe automobiles, aircrafts with high range, and extremely light machine components. In a quest for sustainable designs, composite materials contribute considerably. Schlarb et.al has reported that the mechanical behavior of the composites is not governed by the fiber alone but by a synergy between the fiber and the matrix. The reason is that matrix materials are usually ductile (Elastic or Plastic). The various mechanical properties are given below:-

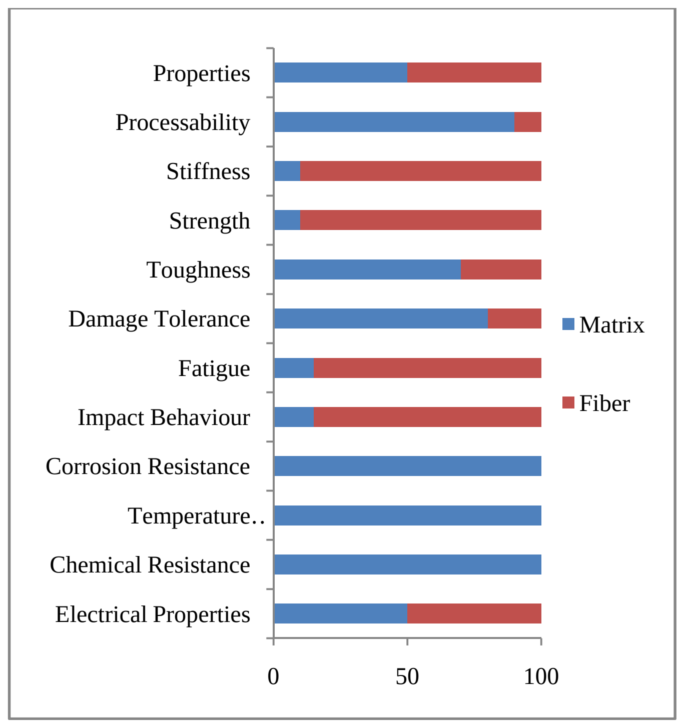


Fig. 4: Relative Importance of Fiber and Matrix in Polymer Composites [9]

In light weight polymers composites load is transferred from matrix to reinforcing fibers by means of shear forces acting on the surface. Thus for effective reinforcement the surface area is much larger than the cross sectional area, hence for reinforcement of the material critical aspect ratio of the length to diameter at which the fiber becomes capable of sustaining enough stress to break it, is about 100:1. The exact Fig. depends on the strength of the fiber and the character of the matrix and the degree of bonding between them. It is estimated that 75 percentage of the fuel consumption is directly related to the wheel weight [9]. (6-8) percentage increase in fuel economy can be achieved for every 10 percentage reduction in weight.

The overall advantages of composites compared to steels for automotive and transportation are:

1. Weight reduction of (20–40) percentage
2. Styling flexibility in terms of deep drawn panels, which is a limitation in metal stampings
3. (40–60) percentage reduced tooling cost;
4. Reduced assembly cost and time in part consolidation;
5. Resistance to corrosion, scratches, dents, reduced noise vibration harshness (NVH) and higher damping;
6. Materials and process innovations capable of adding value while providing cost savings
7. Safer structures due to higher specific energy absorption leading to better crash behavior.

Most recently startup automakers are using significant amount of composites for hydride and battery electrical vehicles to reduce mass and extend driving range.

2.4 Bio-Composites

Material formed by matrix and reinforcement of natural fibers like (Flax and Hemp) are called as Bio-composites. Bio Fibers are viable alternative to synthetic fiber as it is reinforced in plastics because of their low cost. According to P.Barghoorn it has also properties like lightweight, good mechanical performance and biodegradable properties .They have found a vast number of applications in automotive industry. Door panels, seat backs, dashboards and package trays, head restraints and seatback linings being some of the important applications. In 2003, The Araco Corporation of Japan presented a fully electric vehicle whose body was totally made out of plant-based composites mainly kenaf [1]. In this field Ford Motors successfully built an endurance racing car made with natural fiber-reinforced plastics. The primary targets are front end section and body-in- white (BIW) framework of the high volume vehicle. An innovative aspect of the ECOSHELL (Development of new light high performance environment benign composites made of bio materials and bio resins for electric car application) [14]. The concept of ECOSHELL proposes full bio-composite for the realization of large-size structural part destined to bear high mechanical loads for transport applications. It aims to reduce weight by 20 percentage over a tradition vehicle, to reduce gasoline consumption and CO_2 emissions by 22 percentage, and to reduce price by 15 percentage.

The recyclable natural fiber reinforced composites used for automotive load bearing applications in compact class car .The sandwich composite is used for construction as well as hollow beams are currently used for reduction in weight. As bio composite have low density, high tensile strength, it is a good alternative material for automobiles.

2.5 Carbon Fiber reinforced Plastics (CFRP)

Carbon fiber is defined as fiber containing at least 92 percentage weight carbons. It is a material consisting of several fibers and composed mostly of carbon atoms. Each fiber about (5-10) µm in diameter. Crystal alignment gives the fiber high strength to volume ratio. When carbon fiber is combined with the plastic resin and wound or molded it forms “Carbon Fiber Reinforced Plastic”. It is extremely rigid and brittle. Carbon Fiber Reinforced Plastics have their application in the aerospace and the aviation industries because of their light weight, high strength and high rigidity, but due to their high cost and difficult recycling process their use is restricted in the automobile sector till date. Modern techniques have led to the development of the low cost CFRP with the help of the life cycle assessment. Replacing steel with CFRP in bodies, chassis and equipment, we considered three cases: (1) Use of only CF/EP (Its matrix is epoxy, which is thermosetting.), (2) Use of CF/EP and CF/PP (Its matrix is polypropylene, which is thermoplastic.), (3) Use of CF/EP and CF/PP (matrix is polypropylene, which is thermoplastic) and Recycled CF/PP. From the above 3 cases it has been found that the energy consumption has been reduced by 17percentage, 21percentage, 25percentage respectively. Use of carbon fiber in automobiles allows about 30percentage weight reduction along with a 60percentage reduction in the tooling cost. For example the use of CFRP bearing for an AIRBUS A-340 tail reduction in the weight was found out to be 50percentage and the cost reduction is about 30percentage. Carbon fiber have the highest weight reduction potential (50percentage lighter than steel) but one of their major drawback is their cost which is almost 570percentage more than steel [15]. This shortcoming is tried to be overcome by improvement in methods of their production by industrialization techniques which can result in decrease of the cost by up to 70percentage [15]. CFRP vehicles are more eco-friendly than conventional steel vehicles. Carbon fiber is five times stronger than steel and two times more stiff [16]. In CFRP the fibers are first stabilized and are then heated to very high temperature to form tightly bonded carbon crystals which makes it strong and stiff. Following properties of CFRP have made it an important alternate material:-

1. High tensile strength
2. Low thermal Expansion
3. High abrasion and wear
4. Electrically and thermally conductive

In the above Fig. the comparison of the various metals is done on the basis of the percentage part of weight. High speed steel has the maximum weight while the carbon fiber has the minimum for the given value of strength to weight ratio of an automobile component.

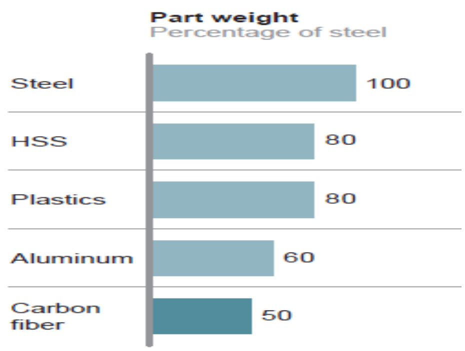


Fig. 5: Lightweight Materials Corresponding Weight Comparison [18]

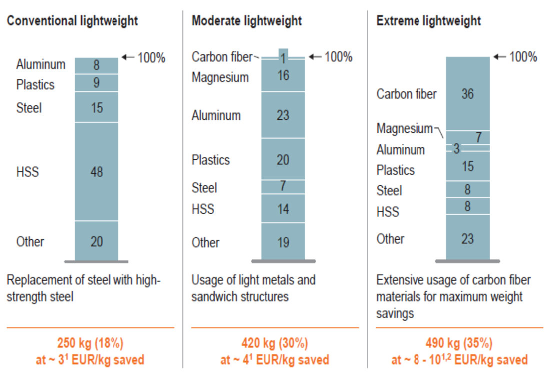


Fig. 6: Lightweight packages apply different lightweight material mixes with different weight and cost impact [18]

The above Fig. shows the percentage of the various metal used for different light weight packages. As in the conventional lightweight package the percentage of HSS is more and carbon fiber is rarely used. For moderate package carbon fiber is used but its percentage is very low. While carbon fiber find its extensive use in luxury cars with high percentage.

3. CONCLUSION

This paper presents a review of light weight materials for automobiles and their comparison with respect to various mechanical parameters and corresponding weight saving. The author believes that there is further scope for use of light weight materials in automobile parts, so as to achieve sustainable design with lesser weight.

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