Metal to Plastic conversions in Automobile

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Abstract—today we can see metal to plastic replacements in industries like automotive, aviation, medical, lighting/electrical, electronics, furniture and so on. The automobile industry has shown increased interest in the replacement of metal components with the material offering low cost and weight saving. Lightweight design with thermoplastics is a robust approach in order to reduce the CO2 emission and fuel consumption. This paper reviews the role of plastics in the automobile field.

I. INTRODUCTION

Many companies have already been replacing components of their products with materials offering low-cost, weight-reduction options and also to supplement their green footprint on environment. Plastic engineering is synonymous in almost all modern day industries due to versatility of plastic materials today. Right from transplants in the medical field to the soles in footwear industry, there is a plastic available to suit every possible requirement. All of these have been possible only due to the relentless research and development in the polymer science/plastic engineering field. Add to this, the blurring of lines between various engineering fields and we have a whole new dimension. Today we can say that plastic engineering is a mix of mechanical engineering and chemical/polymer engineering with various other facets of science and technology

In the persistent search for cost reduction, plastics continue to advance in replacing metal parts. Performance benefits like weight reduction and corrosion resistance can be achieved other than lowering cost. However, plastics materials which are fundamentally different from metal in molecular structure are vitally different from metals not only in intrinsic short term properties but also in the way they react under application to the influences of time, temperature, and load. Failure to use techniques that consider the influence of these variables in the application of the part frequently leads to products that are either over- or under- engineered.

Automotive industry has now shifted majorly from metals to plastics for many of their components, presently made in iron or aluminium alloys, which provide them with weight reduction opportunities, thereby leading to cost savings, energy savings and improving their carbon footprint. Metal to Plastic Conversion is now seen in automotive body parts, power-train, motor management, brake parts, fuel pump parts, etc. In the aviation industry, Plastic composites make up 25% of the total airframe on the Airbus A380, where composites replace aluminum. In food processing industry, stainless steel food hoppers, used for the accurate dispensing of ‘sticky’ foodstuffs, have been substituted with metal filled acetyl polymer thereby significantly improving the feeding of high-adhesion food stuffs. Examples of successful metal to plastic replacements are not limited to the ones above. BMW has developed a car made from carbon fiber which is the first effort to mass produce a car made largely from carbon fiber and represents the biggest shift in automobile production since at least the 1980s when the first all-aluminum car frames were made.

II. BENEFITS OF METAL TO PLASTIC REPLACEMENTS

Some of the primary benefits of plastics over metals are:

A. *Reducing weight*

Plastic provides weight reduction since all plastic materials including composites are lighter than metals. Studies show that every 5 percent of vehicle weight removed can improve fuel economy by 2 percent.[W8] Generally, replacing a metal component with a plastic one results in a 50 percent weight reduction, so the math is attractive to designers for striving to improve Corporate Average Fuel Economy (CAFE) targets.

B. *Reduction in Green House Gases*

Since plastic part production is less energy consuming compared to metal part production or metal forming like die casting, sand casting, etc. reduces emission of CO2 which reduces carbon footprint of the company. Also improved CAFÉ reduces the greenhouse gases producing from automobiles.

C. *Cost Reduction*

Plastic materials are comparatively less costly than metals. That’s why it reduces raw material cost. Also plastic parts can be directly produced in the final shape and no requirement of secondary operations which reduces manufacturing cost of the plastic part. Also elimination of fasteners and part consolidation reduces assembly cost.

D. *Design freedom*

Advances in polymer formulation technology are enabling more design freedom than ever before. Rather than welding, fastening, and bending -- all of which require secondary operations and therefore more cost -- most automotive plastic parts are produced to net shape in one operation.

E. *Part geometry*

It is yet another freedom. Plastic part design has become a sophisticated science, enabling parts to be designed to exact contours to save space under the cover. Additionally, outlook can be more aerodynamic and stylish.

F. *Part consolidation*

Finally, all of these factors combined allow multiple metal parts to be redesigned and replaced by plastics and consolidated into a single unit for reduced after-sale maintenance and production process improvement.

G. Improve Aesthetics of a Product

Designers now have a variety of plastics, all with different "feel" and textures that can be modified to further please the customer as they use the product. Not only are tactile improvements workable, but almost any color also is possible

Some of the secondary benefits of plastics over metals are:

1) Fewer assembly operations may be achieved.
2) Assembly time reduction.
3) Removal of fasteners.
4) Electrically nonconductive, predominantly.
5) Ability to withstand temperatures to more than500°F.
6) Ability to withstand most chemicals and corrosive environments.
7) Broad range of properties tailored to meet specific applications.
8) Functional integration.
9) Noise dampening.
10) Product differentiation.

III. GENERALIZED SYSTEMS APPROACH FOR METAL TO PLASTIC CONVERSION

Materials development efforts in the past several years that were aimed at raising stiffness, impact, and heat resistance in plastic materials have succeeded on all counts. Combine that with the increasing sophistication of automotive designers, who are pushing the envelope on material selection as they seek to reach fuel economy goals. Automotive designers were originally focused on replacing metal with plastics in a limited number of applications, but today's polymeric materials are meeting the challenges of emerging design and engineering criteria in more areas of the vehicle.

While the easy applications have long since been converted -- those that are left are the tougher ones. But, now the palette of polymer alternatives has become tougher, as well. Further, engineers now have a better grasp of best-practices for designing with polymers. Rather than looking for materials that can replace a metal part using the identical geometry, designers are now capitalizing on the additional freedom to form plastics into net shapes. Industries going for metal to plastic conversion today use many tools for this purpose. A fair amount of experience has been gained in this field with tried and tested methods developed by companies specialized in this area with the help of plastic raw material suppliers.

However, metal to plastic replacement projects still have hurdles because of the continuing entry of new products and applications yet untried. This sometimes leads to no proper direction to problem-solving, data insufficiency and lack of clarity on relationship between important parameters of new product which may ultimately lead to project failure. Hence a necessity is created to bring in a systems approach. By viewing metal to plastic replacement project as a system, we can actually compute the various inputs that are required for the process and successfully achieve the output of substituting a metal component with a plastic one.

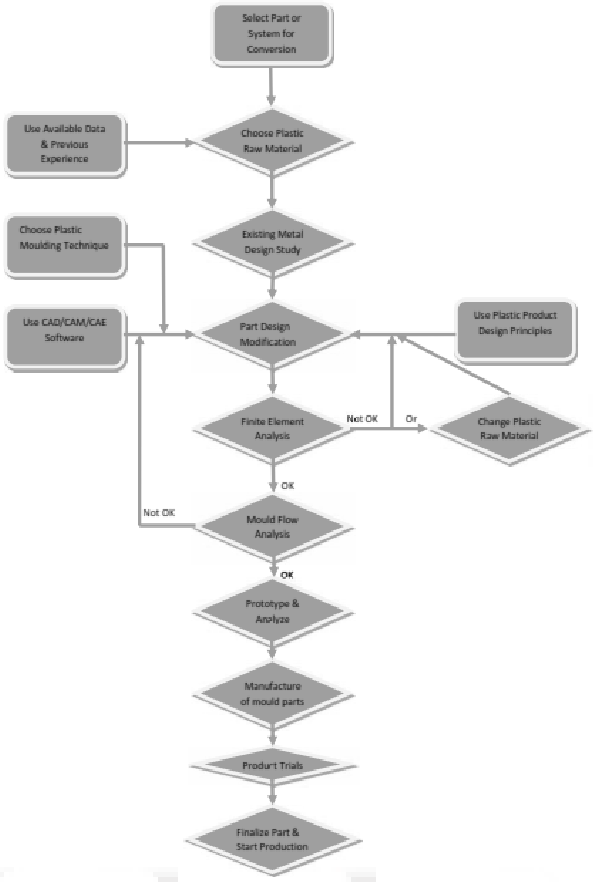

Fig. 1:A Generalized systems approach for metal to plastic conversion

There are significant design, material, process, and service use considerations with the conversion of a metal component to its plastic counterpart, requiring considerable research and design. A Generalized systems approach for metal to plastic conversion is given in Fig. 1.

IV. RESEARCH BASED ON MATERIAL CONVERSION IN AUTOMOBILE.

Jan D. van Dam presented paper on "An analysis of variables influencing the material composition of automobiles."[P1]

In this paper the use of materials is studied broadly, because of the environmental problems related to extraction, production, consumption and waste treatment. Studies have been done to describe the material flow or to measure the impact of materials or products on the environment. However, these studies do not often consider economic, substitution and dynamic aspects of material flows.

For environmental policy making economic, technological and environmental aspects of the use of materials need to be considered. In various countries material and product policies are imposed on a variety of materials and products. For evaluation of these policies their environmental and economic effects need to be examined in detail. This study aims to analyze the economic and technological factors influencing the use of materials and the substitution between different materials dynamically. The statistical analysis is performed on a specific product-group because decisions on the use of materials are taken on a product-level. The case study is performed on automobiles.

Conclusion: The material use is largely an autonomous development. The price of aluminium has a positive, significant effect on the use of that material. The price of plastics has a positive, but not significant effect on the use of plastics. Reasons may be that the costs of a raw material are small relative to the processing costs, and that the production process can only be changed slowly. This implies that levies or subsidies on certain materials are not a promising policy to change the use of materials. Besides time, there are two other factors that have a positive and significant relationship with the use of aluminium and plastics: the fuel efficiency, which is the distance driven divided by the energy used; and, the road tax, which depends on the weight of a car. However, these effects are caused by their positive relationship with time. The main conclusion of the case study is that imposing a levy on materials may not have the desired or expected effect of reduction in material use.

H. A. AL-Qureshi presented a paper on "Automobile leaf spring from composite materials."[P2]

The automobile industry has shown increased interest in the replacement of steel springs with fiberglass reinforced composite leaf springs. Therefore the aim of this paper is to present the general study on the analysis, design and fabrication of composite springs. From this viewpoint, the suspension spring of a compact car, "a jeep" was selected as a prototype.

A single leaf, variable thickness spring of glass fiber reinforced plastic (GFRP) with similar mechanical and geometrical properties to the multi leaf steel spring, was designed, fabricated and tested. The testing was performed experimentally in the laboratory and was followed by the road test. Comparison between the performance of GFRP and the multi leaf springs is presented.

Conclusion was maid that the development of a GFRP single leaf spring having constant width, where the stress level at any section in the leaf spring is considered constant due to the parabolic tape of the thickness of the spring, has proved to be very effective. Such a spring normally has lower flexure stress but higher nominal shear stress. In general, this study demonstrated that composites can be used for leaf springs for light trucks (jeep) and meet the requirements, together with substantial weight saving. However, in the case of automobiles, the significant weight reduction may not cause the technological impact that it would for air craft.

Other work has shown that composite leaf sprigs have better fatigue behavior than steel springs. Needless to say, the hybridization technique can be used effectively to improve weight saving and performance in the automotive industry.

It is worth mentioning that additional field testing is needed to define correctly the secondary design loads such as torsion, thrust, creep, fatigue and operational restrictions. This test should provide correlation with the existing laboratory data.

Dai Gil Lee et al presented a paper on "Novel applications of composite structures to robots, machine tools and automobiles."[P3]

In this paper, the novel application examples or continuous fiber reinforced composite materials for the stiffness design are presented.

The composite double arm type robot hands and wrists for large liquid crystal display (LCD) panel handling have been successfully designed and manufactured. They are now being used in major electronic companies (Samsung and LG) in Korea. The previous aluminum hands are no longer used because the composite hands have more than five times higher specific stiffness with much high damping capacity and natural frequencies than the aluminum hands. For the material of the hand, very high modulus pitch based carbon fiber epoxy composite (URN300, SK Chemicals, Korea) was selected. For the wrists, high strength carbon fiber epoxy prepare (USN150, SK Chemicals, Korea) was used.

The carbon fiber composite rotating boring bar has made the deeper hole boring of engine cylinder blocks possible with four times higher machining speed due to its high specific flexural stiffness than the conventional tungsten boring bar. The tungsten carbide boring bar is not only difficult to machine but also has very low whirling vibration frequency, which limits the maximum rotating speed of the 25 mm diameter boring bar to 2500 rpm when the length of the boring bar is 800mm although the boring has a supporting bush at the end of the boring bar. The composite boring bar, maid from very high stiffness pitch based carbon fiber epoxy composite material, can be operated up to12.000 rpm, which increases the machining efficiency as well as improves the quality of machined surface. The composite boring bars are being used successfully in major automotive companies (Hyundai and Kia) in Korea.

The composite one-piece propeller (or drive) shaft has been developed to substitute conventional two-piece metal propeller shafts for rear wheel drive cars. In order to reduce the material cost of carbon fiber, the propeller shaft was manufactured as a hybrid shaft in which the inside aluminum shaft transmits the required torque, while the outside carbon fiber layer increases the fundamental whiling vibration natural frequency over 6500 rpm. During the co-curing operation an axial compressive preload was given to the inside aluminum shaft to eliminate the tensile thermal residual stresses generated in the aluminum shaft. The composite hybrid propeller shaft manufactured with the compressive preload has 30% improved fatigue life compared with the shaft manufactured without any preload.

Erica R. H. Fuchs et al presented a paper on "Strategic materials selection in the automobile body: Economic opportunities for polymer composite design."[P4]

Previous studies on materials choice in automotive bodies have looked at both composite and aluminum alternatives, but have always found steel to be the most cost-effective option at the production volumes found in the over whelming majority of vehicle models. This paper finds composites to have significant economic potential when considering emerging advances in the polymer composite body-in-white (BIW) design against the mild-grade steel body currently on the road. With the significant implications of a polymer composite body for vehicle light-weighting and thereby improved fuel efficiency, these results come at a time when they are particularly pertinent.

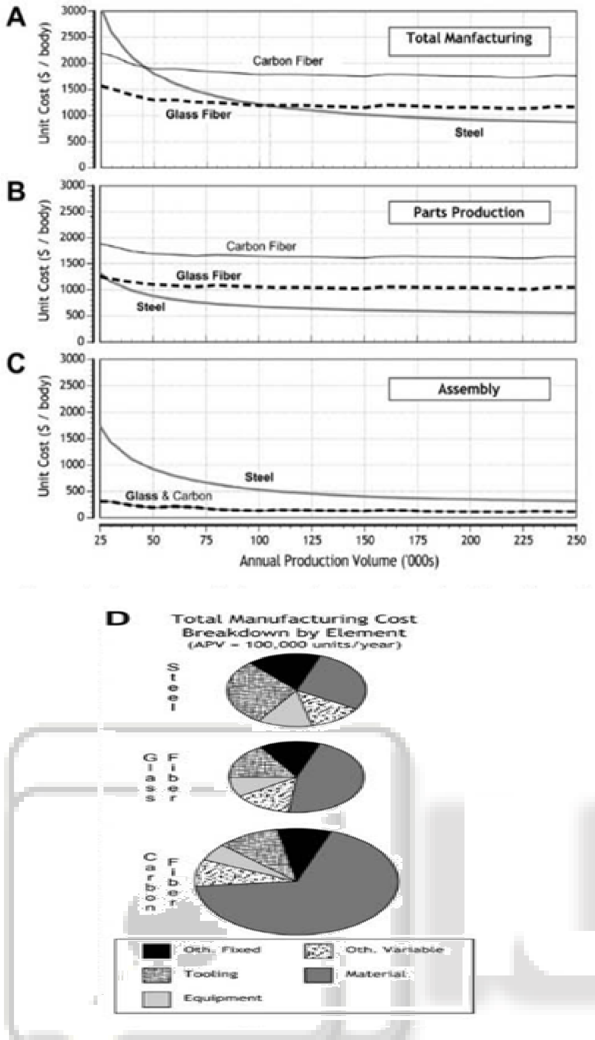

Fig. 2 US body-in-white production cost sensitivity to production volume for (A) Total manufacturing cost (B) Part production and (C) Assembly. (D) Total manufacturing unit cost breakdown at 100,000 units per year

Fig 2A shows the estimated unit cost of producing and assembling each of the three alternative BIW cases in the US. At annual production volumes under 105,000, the model results suggest that the glass-reinforced BIW is less costly than the steel, and at annual production volumes under 45,000, the carbon-reinforced BIW is also less costly than the steel.

Fig. 2B shows that, although the composite BIW has far fewer total components than steel, the sum of the modeled composite component and insert costs is significantly larger than the sum of the steel component and insert costs (so long as annual production volumes are above 30,000 for glass.)

Fig. 2C shows that, the estimated cost of assembling the composite BIW, however, is significantly cheaper than that of the steel BIW assembly.

Fig. 2D shows that, at annual production volumes (APV) of 100,000 units per year, machine, equipment, building, maintenance, and overhead-all fixed expenses - make up 59% or steel BIW costs. These fixed expenses account for only 24% or carbon, and 40% of glass BIW cost estimates.

V. Ganeshram et al presented a paper on "Design and Moldflow Analysis of Piston Cooling Nozzle in Automobiles."[P7]

Automobile industries have shown great interest in replacing metal to plastic parts in order to reduce the cost and weight of the component. This can be achieved mostly by replacing metal component with injection molded components. This study deals with the use of mold flow simulation in as a case study of metal to plastic conversion of automobile component piston cooling nozzle. In this context the aluminium piston cooling nozzle is replaced byNylon66+30GF piston cooling nozzle. Then based on the final product design, hand injection mold of the component was designed and manufactured. Finally the plastic part has to be tested for the working condition, its performance in usage and compared with the aluminium part.

V. CONCLUSION

Automobiles today are over 63% iron and steel by weight. With rising energy and environmental concerns, as well as increases in electronics and other on-board vehicle systems, vehicle light-weighting continues to be a prominent concern for vehicle manufacturers. Fiber-reinforced polymer composite technologies offer a way of light-weighting the vehicle, both to increase fuel economy and to allow for the addition of other vehicle systems (features). Previous studies have suggested that polymer composite unibodies could potentially have economic viability at low production volumes; however, these studies are no longer up-to-date on the latest design and process technology, and fail to include plat forming considerations. Since these studies, several advances have occurred in fiber-reinforced polymer composite, component processing, and assembly technology.That's why after the many attempts for replacing the metal parts with plastic or FRP parts for environment and energy concerns and also to reduce the cost of production in some extents, still there are many opportunity to convert the existing metal parts into the plastic one with newly developed material or reinforced polymer composite, component processing and assembly technology.

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