SYSTEMATIC APPROACH ON MATERIALS SELECTION IN THE AUTOMOTIVE INDUSTRY FOR MAKING VEHICLES LIGHTER, SAFER AND MORE FUEL–EFFICIENT

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Abstract:
The replacement of parts manufactured with conventional materials by pieces manufactured with compound or composite materials contributes to the reduction of the weight of the vehicle, to greater efficiency in the consumption of fuel and to an improvement in the relation between power and weight of the vehicle what translates in a greater performance of the same. Historically, the use of composite materials in the automotive sector has seen limited had to, fundamentally, to the capacities of production. However, the new requirements in the automotive sector are promoting the use of materials composed in this sector.

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1. INTRODUCTORY NOTES

Now more than ever, the automotive industry is under increasing pressure to meet higher fuel efficiency, environmental and performance demands at competitive costs. All material industries – plastics and polymer composites, as well as steel, aluminum, and magnesium, are operating to respond to the automotive industry changing needs [1]. For decades, advanced plastics and polymer composites have helped the improvement of appearance, functionality, and safety of automobiles while reducing vehicle weight and delivering superior value to customers at the same time. New regulations, shifts in consumer preferences, and recent technological innovations are encouraging automotive industry to continue increasing their use of advanced plastics and polymer composites to meet tomorrow's challenges and opportunities [1].

Composite materials offer an opportunity to significantly reduce the weight of a vehicle while still meeting strength requirements [2]. Today, engineered plastics are fast becoming the future for two industries – chemical and automotive – as environmental concerns are increasingly affecting both. To preserve optimum fuel efficiency, automakers are using materials that are more lightweight – plastics and polymer – based components [3].

The automotive composite materials, reinforced plastics and polymers are among widely preferred alternatives for light weighting of the automobile as they offer enhanced properties such as impact strength, easy mold–ability, improved aesthetics, and reduced weight as compared to conventional automotive components. The main advantages, which offer opportunities in the automotive industry, are their potential for maximum mass reduction of automobile and carbon emission reduction potential by light weighting of the vehicle. The factors restraining the market are high material costs and huge investments in material research activities by companies [4].

The automotive sector is under constant pressure to reduce carbon emissions and bring down fuel consumption by reducing the weight of vehicles, with an increase in safety requirements. The underlying reason for this is the need for lower weight, different types of materials, as well as stricter environmental legislation and related traffic regulations [5].

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2. MATERIALS IN THE AUTOMOTIVE INDUSTRY – AN OVERVIEW

Various materials are used to make cars. The main materials used for making cars, parts and components, along with future trends, are steel, aluminum, magnesium, copper, plastics and carbon fiber. The main factors for selecting the material, especially for the automobile body, are numerous and include thermal, chemical or mechanical resistance, easy manufacturing and durability.

Affordability is an important issue in vehicle manufacturing, which includes factoring in the costs associated with a car's complete life–cycle, including manufacturing, operating and disposal costs. Composite materials may have big advantages over steel in automobile manufacturing in the future. Composites are considered to make lighter, safer and more fuel–efficient vehicles. A composite is composed of high–performance fiber (such as carbon or glass) in a matrix material (epoxy polymer) that, when combined, provides enhanced properties compared with the individual. Carbon–fiber composites are equally good or better concerning stiffness and strength. They also do not rust or corrode like steel or aluminum, and they could significantly increase vehicle fuel economy by reducing vehicle weight [6]. The issue with today's composites is that they have been developed for aerospace applications where the cost is not so critical. Material costs of carbon fiber composites are at least 20 times higher than steel, and the automotive industry is unlikely to use them until the price of carbon fiber drops significantly [6].

Therefore, if we want to choose material with these characteristics, steel is the first choice. There were many developments concerning iron and steel over the past couple of decades that made steel more lightweight, stronger, stiffer and improved other performance characteristics. Applications include not only vehicle bodies, but also engine, chassis, wheels and many other parts (doors, hoods, hatchbacks etc.). Iron and steel form the critical elements of the structure for the vast majority of vehicles, and are low–cost materials. The prime reason for using steel in the body structure is its inherent capability to absorb impact energy in a crash situation.

Aluminum usage in automotive industry has grown within past years, due to its low density and high specific energy absorption performance and good specific strength . The use of aluminum can potentially reduce the weight of the vehicle body. Recent developments have shown that up to 50% weight saving for the body in white can be achieved by the substitution of steel by aluminum. Aluminum is used for body structures, chassis applications, closures and exterior attachments such as crossbeams, doors or bonnets.

Magnesium is another light metal that is becoming increasingly common in automotive engineering. It is 33% lighter than aluminum and 75% lighter than steel/cast iron components. Magnesium alloys have distinct advantages over aluminum that include better manufacturability, longer die life and faster solidification. In addition, magnesium components have higher machinability.

Titanium has been mainly used in high temperatures zones, and high strength requirement areas, such as exhaust systems, suspension springs, valve springs, valves and connecting rods.

Fiber reinforced composites offer a wide range of advantages to the automotive industry. It is because the composite structures are the high strength/low weight ratio. Carbon fiber–reinforced or fiber glass–reinforced composites offer numerous new design possibilities for structural components in cars. These advanced materials are not only light in weight, but also stiff, strong and durable. The future lightweight materials will be used in the automobile industry [5]. Now, carbon fiber is very expensive, but the automobile industry has been developing affordable carbon fiber, so the future cars will be lighter. Fiber–reinforced composites are now being used to make structural and non–structural components such as seat structures, bumpers, hoods, and fuel tanks.

3. THE DEVELOPMENT OF NEW AUTOMOTIVE MATERIALS AND COMPONENTS

The producers in the automotive industry are expressing more and more interest in the industrial applications of light, strong and thus energy–efficient and cleaner solutions, such as composites. This requires innovations in materials, design, production, processing and process automation – and, above all, cost effectiveness [1]. Increased R&D efforts and government subsidies have since then contributed to numerous innovation programs and innovative concepts for sustainable

mobility. As a result, more flexible and more cost–efficient production methods will be required. The traditional production processes for cars are still focused mainly on the processing of metal chassis and other components. Although plastics are extensively used, the deployment of fiber–reinforced composites for high volumes of cars is still in the pioneering phase [2]. For larger volumes of cars, automated production processes are necessary. The time required to make a component, for example, should be one minute maximum. Such requirements are feasible when use is made of thermoplastic composites [2]. The creation of industrial processing capacity will further stimulate the use of these advanced materials in the automotive industry [1]. The thermoplastic composites enable automotive manufacturers to produce affordable structural components to substitute conventional metal solutions.

Three global trends play a crucial role in the current developments in the automotive industry: emission legislation, urbanizing mobility and customized vehicles [5]. Ever stricter legislation requires the carbon emissions of vehicles to be further reduced. Rapid urbanization goes hand in hand with changing mobility requirements. Individualization leads to a growing need for customized mobility, which in turn results in new requirements being made on the flexibility of design and on existing production methods [5].

To develop new automotive materials, components, and systems in the most effective way, the completely automotive supply chain needs to work together [7]. Although many advances in materials development, design and selection, and manufacturing and assembly will occur throughout the automotive plastics and polymer composites industry, there is a significant need for the increased industry–wide demonstrations and coordination both within the automotive supply chain and with other industries [7]. Collaborative research and development is more focused on material properties and technology issues (on innovative forming processes). Industries will also work together to investigate new production and assembly processes, such as a way to join metals, lightweight plastics and composite materials [4]. To become more lightweight composite material–oriented, the automotive industry and the chemical industry are likely to join forces in a value chain that includes peripheral companies such as plastic–injection companies and automotive suppliers [3]. This integrated value chain will have two goals:

- to improve lightweight composite material's performance standards to better meet consumer needs and comply with regulations; and,
- to develop innovative ways to reach sometimes contradictory objectives of sustainability in the automotive industry.

The increasing global competition, pressure to reduce cost, ever–higher quality requirements and new materials are all challenging tasks for the automotive industry. In the current requirements, it is challenging for automakers to rethink the function of every component and the system. This is a defining moment, not just for materials, but also for the automotive industry as a whole. The automakers have recognized this essential requirement and have therefore focused on the development of a new product line, which meets the latest challenges in the automotive industry. Therefore, composites appear to be more in the automotive materials mix than ever before. Moreover, the composite materials, reinforced plastics and polymers (into innovative forming processes), demonstrate that they could eventually replace the traditional metallic body–in–white primary vehicle structure [4].

The researches on composite materials, reinforced plastics and polymers have come up with improved material qualities that make them suitable for use in interior, exterior, and under bonnet components of automobiles. The automotive composite materials are used in various automotive components such as bumpers, seating, dashboards, internal and external trims. The careful selection of these automotive materials enables designers to improve durability, meet load–bearing requirements, and achieve reduction in vehicle weight [7].

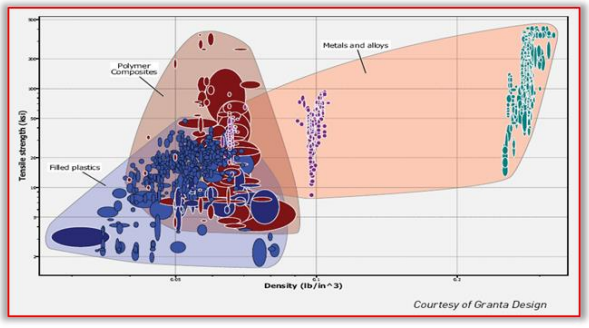

Fig. 1. Tensile strength vs. density for automotive materials [7]

The chart above provides the data on the tensile strength and density of filled plastics, polymer composites, metals, and alloys. As shown in the chart (figure 1), many plastics and polymer composites are significantly less dense than most metals and alloys while offering similar tensile strengths. These data illustrate the fundamental physical advantage that many plastics and polymer composites offer over metallic automotive materials: higher strength–to–weight ratios that can enable automakers to lightweight vehicles while maintaining safety and performance [7].

The use of lightweight plastics and composite materials in the automotive industry has been increasing in recent years due to legislative and consumer demands for lighter weight, fuel–efficient vehicles. In some cases, plastics are replacing heavier ferrous materials whereas; in other cases, plastics and composites are being added for consumer comfort purposes. In addition to being lightweight, these materials are also durable and easily molded. Substituting heavier materials with plastics leads to an overall weight reduction [8]. The percent of plastics by mass in an average vehicle has gone from 6% in 1970 up to 16% in 2010 and is expected to reach 18% in 2020 (see figure 2) [8]. Lightweight plastics and composite materials are increasingly becoming a preferred material choice in designing and developing complex consumer products, such as auto vehicles [8].

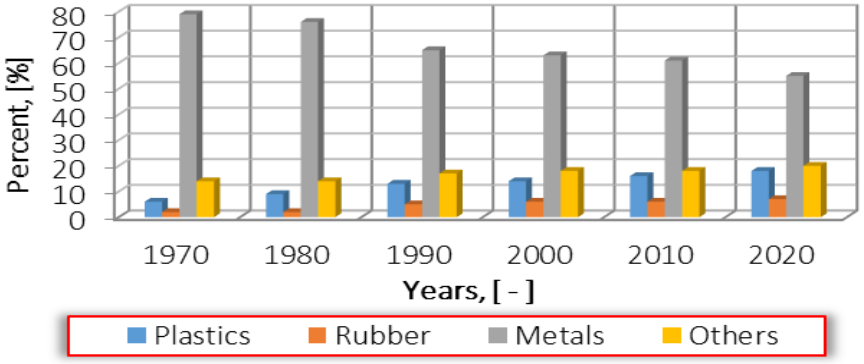

Fig. 2. Change in vehicle composition from 1970 to 2010 [8]

Composite materials currently have high purchase price, but when viewed from a lifecycle perspective they make good economic sense. On top of low weight, composite materials provide strength and rigidity, while fatigue and ageing are not generally seen as problems. Composites also do not rust, and they do not degrade in the same way as metal structures [5]. Another advantage with composite use in chassis structures is that it is possible to create larger integrated structures than with steel. This means fewer joints, which in turn further reduces weight. The researchers say that tomorrow's vehicles will be made from a bigger mix of materials, with focus on both function and weight [5].

While the plastics and polymer composites industry has been working collaboratively with the automotive industry for many years, barriers remain that limit the use of plastics and polymer composites in vehicles. Coordination within the automotive supply chain and with other industries and cost modeling of certain plastic and polymer composite components can be strengthened to stimulate growth in the use of these materials [7].

Plastics and polymer composites continue to deliver significant weight savings to automakers [7]. In addition to their current role, as an excellent choice for light weighting, aesthetics, aerodynamic design and value in many interior and exterior applications, plastics and polymer composites – particularly the fiber reinforced composites – are also fast becoming a contender in structural applications like body–in–white and chassis components, due to their ability to drastically reduce overall vehicle weight while maintaining or improving safety and performance.

4. REQUIREMENTS OF THE MATERIALS IN AUTOMOTIVE DESIGN

The automotive industry is increasingly relying on a systematic approach to materials selection. The choice of materials for a vehicle is the first and most important factor for automotive design. There is a variety of materials that can be used in

the automotive body and chassis, but the purpose of design is the main challenge here. For the automobile manufacturers, the most important criteria that a material should meet are:

- lightweight, this criterion is the most important one for an automotive company, in the context of the high emphasis on greenhouse gas reductions, reduction of emissions and improving fuel efficiency;
- economic effectiveness, having in view that one of the most important consumer driven factors in automotive industry is the cost, that determines whether any new material has an opportunity to be selected for a vehicle component;
- safety, which criterion have in view the ability to absorb impact energy through controlled failure modes and mechanisms and be survivable for the passengers; and,
- recyclability of their products and life cycle considerations, having in view that the most important concerns in automotive industries are the protection of resources and the recycling possibilities, including strategies on research and development targeted on recycling techniques and the development of more easily recyclable materials and their incorporation into the vehicle and its constituent components.

The weight reduction in the automotive industry can be obtained inthree ways:

- replacing materials of high specific weight with lower density materials without reducing rigidity and durability (for example replacement of steel with aluminum, magnesium, composites and foams);
- optimizing the design of load–carrying elements and exterior attachments to reduce their weight without any loss in rigidity or functionality; and,
- optimizing the production process.

By continuing the development of composite materials technologies, the automobile industry is able to create cars increasing their performance and their appearance. The ability to leverage this kind of lightweight material gives a competitive advantage that will benefit the cars, as well as the production process, in the future.

However, the single main obstacle in application of lightweight materials is their high cost. Yet the weight reduction is still the most cost–effective means to reduce fuel consumption. The cost includes three components: the actual cost of raw materials, manufacturing value added cost, and the cost to design and test the product. Aluminum and magnesium alloys are certainly more costly than the currently used steel and cast irons. Since the cost may be higher, decisions to select light metals must be justified based on the improved functionality. Meanwhile the high cost is one of the major obstacles in the use of composite materials.

By 2030, the automotive industry and society will recognize plastics and polymer composites as preferred material solutions that meet, and in many cases set, automotive performance and sustainability requirements [7]. Plastics and polymer composites provide the weight savings, strength, and versatility the automotive industry needs to meet new standards without sacrificing quality [7].

The automotive industry is constantly seeking to improve aesthetics and reduce the weight of vehicles while simultaneously increasing their strength and improving crash performance. However, balancing the feel and appearance of a material with its strength, stiffness, ability to withstand dimensional tolerances, and cost is a critical challenge[7].

For vehicle manufacturers and their suppliers, materials have never been more strategic. Materials choice influences cost, safety, risk, weight, market image, and vehicle emissions. Materials knowledge gives competitive advantage: it enables you to meet quality and emissions goals, it is a critical input for virtual product development processes, and it gives you the means to respond quickly to supply chain disruptions and new legislations [7].

Plastics and polymer composites, which already dominate vehicle interiors, exteriors, trim, and lighting, are gaining use in other vehicle systems as lightweight, value–producing materials that can meet increasingly challenging automotive requirements [7]. These materials' many advantages have enabled them to grow to become a significant part of the materials mix in the automotive industry over the past 40 years (figure 3). As the push to lightweight vehicles intensifies, projections indicate that plastics and polymer composites can and should play an even more substantial role in the automotive industry through 2025 and beyond (figure 4) [7].

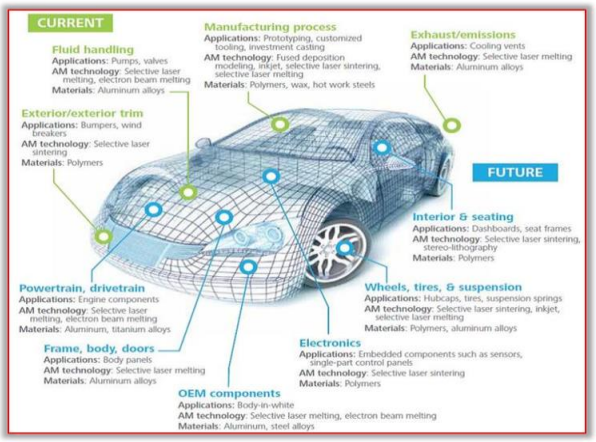

Fig. 3. Current and future tendencies in the automotive industry [4]

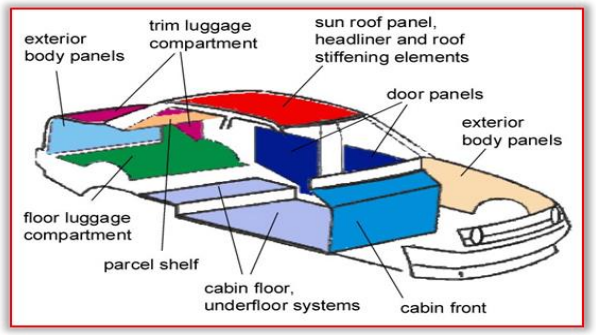

Fig. 4. Potential applications in automotive parts [4]

Actual selection of a particular material for a specific application is primarily driven by the trade-off between the material's cost (purchase price and processing costs) and its performance attributes (such as strength and durability, surface finish properties, and flexibility). The interrelationships among objectives, such as fuel economy, recyclability, and economics, are sufficiently tight that the materials engineer must always simultaneously balance different needs, and try to optimize decisions at the level of the entire system. These selection decisions are made within a material selection process that will continue to evolve. This evolution will largely reflect changes in the vehicle and component development processes to make them more responsive in terms of accuracy, time, and cost-to market and regulatory demands [9,10].

The complexity of an automobile and its manufacturing process presents many difficult challenges and decisions to an automotive manufacturer. Traditionally, environmental factors have not weighed as heavily as other criteria in material selection decisions [9,10]. However, the balance of environmental and other factors has begun to change, as the industry now faces increasing pressure from government regulations, environmental action groups, and its own internal cost constraints. These changes require a fundamental rethinking of industry's traditional methods of analyzing, allocating, and considering costs [9,10].

5. CONCLUDING REMARKS

Steel is strong and inexpensive, which is why it is the material of choice today. Most auto industry forecasts also predict significant growth in the use of aluminum as a lightweight material. Clearly, the metals industries are pursuing innovation targeting the automotive market. However, composites can be designed to be strong and light to provide better safety and fuel efficiency. With composite materials, the automakers get high strength–to–weight and stiffness–to–weight ratios, as well as excellent energy–absorbing capability per mass.

Globally, the automobile sector is currently facing a period of unprecedented change. New fuel economy and emissions standards are driving significant changes across the industry. While producing lighter weight vehicles is one of the top strategies to meet these regulations, it is also one of the most challenging tasks. New material strategies, including the use of automotive composites, play a critical role for taking the weight out of vehicles.

The potential of thermoplastic composites is great. There are excellent possibilities for combining advanced materials with technologies that are already familiar from the processing of plastics. In order to produce weight–saving automotive components and structures, the automotive industry, together with partners, will gradually develop an increasing number of customized applications using thermoplastic composites.

One type of polymer composite in particular – carbon–fiber–reinforced composites – presents major light weighting opportunities for structural vehicle components. At a weight 50% lighter than conventional steel and 30% lighter than aluminum, more automakers use these materials as the body structure or other car components. With advantages that align directly with the automotive industry’s needs, plastics and polymer composites can be a major part of the solution for automakers.

The processing of carbon fibers is too expensive and slow. The raw material, the energy needed to heat it to make fibers, and the required equipment all contribute to the high cost. As a result, carbon-fiber composites cannot yet compete economically

with steel in the auto industry. In fact, the development of low-cost carbon fiber is an active research area with great promise. In addition, the development of low-cost manufacturing methods for automotive composites is receiving a lot of attention. There are less expensive ways of manufacturing composite automobile parts that also reduce the number of joints and fasteners.

While the weight and strength benefits favorably place composites as a material of interest to the automotive industry, expanding its use has not been without challenges. Cost is certainly an issue. Speed of production is another significant hurdle. As a result, composite suppliers continue to explore processes and manufacturing solutions that can better meet automakers' needs. One such shift is a growing use of thermoplastic over thermoset composites in a variety of new applications.

In order to use continuous fiber materials for more automotive applications, automakers are working with industry partners to improve the processing technologies needed to accurately create multilayer continuous fiber inserts at automotive cycle time speeds. The answer is really going to be a mix solution. That can even include a combination of composites to metals, for example. It is not going to be exclusively all composite materials, but it is going to be the best combination depending on what the design for the part is and how it should function.

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