# Materials substitution in the industry

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**ABSTRACT**

In an increasingly competitive market, new materials that are a source of innovation and development are expanding. These are developed according to the characteristics and properties that meet the needs of the industry, and can be replaced by existing ones.

The replacement of new or existing materials occurs through their competition; analyzing relevant factors such as cost, availability, continuous process with a focus on market requirements. In the automotive sector, the replacement of metal by polymer has been approved by the guidelines, as it exhibits considerable benefits. In the aerospace sector, the composite appears as an option due to its multiple functions.

**Keywords**: Materials, Substitution, Polymers, Metal, Composites.

**RESUMO**

Em um mercado cada vez mais competitivo, novos materiais que são fonte de inovação e desenvolvimento está se expandindo. Esses são desenvolvidos de acordo com as características e propriedades que atendem a necessidade da indústria, podendo ser substituídos por outros já existentes.

A substituição de novos materiais ou já existentes, se dá pela competição desses; analisando fatores relevantes como custo, disponibilidade, processo contínuo com foco nas exigências do mercado. No setor automotivo, a substituição do metal pelo polímero vem apresentando aprovação das diretrizes, pois exibe benefícios consideráveis. Já no setor aeroespacial, o compósito surge como opção por conta de suas múltiplas funções.

**Palavras-Chave**: Materiais, Substituição, Polímeros, Metal, Compósitos.

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## OBJECTIVE

This article aims to present a literature review on material substitution in the industry related to the automotive and aerospace industrial segment comparing the materials used and their requirements.

## INTRODUCTION

In the last decade, scientific and technological research has been assuming new forms in the sense of a systemic and integrated conception. In general, what is most striking in this process, in the field of materials, is the great variety of discoveries of properties of new uses and the variety of applications developed. The result is a very large number of alternative materials to those that have traditionally been used. There is a move away from the multifunctionality of the same material for several products toward a greater specialization of several material options for the same product. [1]

Currently, we see that the demand for products that are sustainable and appealing has increased. This implies two issues, on one hand we already positively notice a timid transition from the society driven by consumerism to a society that respects and appreciates the aspects of eco-efficiency and appearance, on the other hand, the increased supply of products in the market without a minimum concern for their manufacturing processes, can lead us to the same cycles of production and consumption that generates waste of resources and environmental degradation. [2]

Then, an increasing scientific and technological attention is being given to the studies and the use of new materials, especially eco-friendly ones, in the most diverse industry segments. [3]

The trend is that materials are developed for specific purposes and by sectors involved with their end use, and not only with the production of the material. Thus, a product no longer relies on a given material; on the contrary, several materials start to compete with each other to assume a certain function, at a certain cost, promoting an inversion in the production logic. Previously, the initial stage (material) determined the final stage (product incorporating the material), today there are conditions for a selection that is better suited to the specifications of a given product. [1]

In this context, we consider that the topic of materials is complex due to the amount and diversity of materials available. This requires greater attention and knowledge of their properties and predictability of their behavior, considering that they can be influenced by different aspects determined even by the region where they are located or by their manufacturing processes. Such information conditions the use and application of materials and resources, as well as can respond appropriately to certain behavioral requirements. [3]

For materials producers, parts suppliers and assemblers, a key factor for success is for them to work together in defining the new characteristics and advances in the field of materials, a future pointing to simultaneous engineering. All this makes the current materials replacement process revolutionary in direct proportion to the depth and breadth of the transformations generated. [1]

The qualitative and quantitative changes are the result of a complex of scientific, technological, and organizational innovations that affect the entire industrial economic system. In addition, the development of new materials takes on a multidisciplinary character, since it requires knowledge produced in several areas. This is an important non-measurable result, since the partnership of specialties makes the research itself a form of learning that transfers knowledge during its execution by the entire team. The diffusion of knowledge necessary for the introduction of new technologies in production is fast and direct, dispensing with intermediary mechanisms. [4]

## METHODOLOGY

AUTOMOTIVE INDUSTRY – Over the years the automotive industry has been undergoing major transformations and it could not differ in the process of choosing the materials employed in automobiles. [5]

Over the years, consumer demand for vehicles has increased significantly, always seeking cars with high performance, however not discarding items such as reliability, safety, comfort, economy, style, competitive price and environmental factors. [6]

The ease of knitting, the economy, and the aspects of its materials and processes have made polymers gain new global horizons in the automotive industries, becoming a key piece in the composition of research and studies, aiming at the constant improvement of the material used in addition to its manufacturing process. [7]

The first big step was when in 1911 SAE (Standard American Engineering) standardized the first steel, SAE 1050. In the same year, more emphasis was placed on the metallurgy of materials, thanks to advances in the development of microscopes and the awareness of treating heat treatment as a science. [8]

Aluminum began to be used in the automotive industry in 1915 and by the 1930s was replacing cast iron in the engine piston. In 1936 in Germany Volkswagen began using cast magnesium in the crankshaft, the engine drive system, and other small parts, which made the car 50 kg lighter, about 7% of the total weight. In the 1940s Du Pont introduced nylon as an automotive material, and this was the first synthetic polymeric material used in automobiles. [8]

Starting in the 1950s automobiles with body parts made of "plastic" materials began to be launched. Plastic offered a new material to choose from. It was light, strong, and could easily be molded into complex shapes. This new material offered problems, as its manufacturing process was slow and it was too labor-intensive to paint. Even so, plastics in one decade, 1960 to 1970, increased their share of automobiles by 34 kg, this increase occurring mainly in decorative components in the interior of automobiles. The major advantages of plastics over steel, which are pointed out to justify the growth in the share of plastics in cars, are the reduction in weight and their great resistance to corrosion. [8]

The automakers' decision to adopt this or any new component, or material on a larger scale increasingly depends on the assessment of the contribution they bring to raising the efficiency of the industry, an increasingly relevant consideration in light of the intense competition to which they are subjected. [8]

Given the high molding capacity of plastic, the integration between the parts is facilitated, enhancing the assembly of subassemblies by suppliers, a worldwide trend adopted by the automotive industry. The fitting system of the parts made of plastics can provide the elimination of metal fixtures, reducing tooling and assembly costs. [5]

The use of composite materials in the automotive industry gradually developed during the 1970s and 1980s. [5]

Composite materials have stood out, since they offer physical-mechanical attributes not achieved by other materials and are economically more viable. These materials are composed of two or more combined phases, one being the matrix and the other, the dispersed phase or reinforcement. The dispersed phase makes it possible to reduce the use of virgin materials, since short, medium or long fibers of various origins can be used. [2]

Among the research in this area, the ones that seek the application for natural modifiers stand out, especially regarding the use of natural fibers. [9]

However, the use of these materials in mass produced automobiles had been limited to decorative and semi-structural applications (dashboard interior, hood, floor and bumpers in a second case). The next step was the extension of the use of composites to structural applications, such as: in the body and in the chassis-suspension system. [4]

POLYMER AND THE AUTOMOTIVE INDUSTRY – A polymer is a macromolecule composed of several (tens of thousands) repeating units called meres, linked by covalent bonding.

These materials have as their raw material of production the monomer, that is, a molecule with one (mono) repeating unit. [10]

Many of the polymers are organic compounds with their chemistry based on carbon, hydrogen and other non-metallic elements. [7]

The replacement of traditional materials by polymeric ones in the automotive industry has been gradually executed over the past decades, with the pace of replacement intensifying over the last 20 years. The oil crises of 1973 and 1979 brought awareness to the problem of scarcity and vulnerability of the use of materials from non-renewable sources. Once the technological limits were overcome, with the emergence of high performance polymers, plastics became an essential part of automobiles. [7]

Polymeric materials are differentiated from each other according to their degree of differentiation, scale of production, level of consumption and added value. [7]

Depending on the chemical structure, depending on the average number of meros per chain and the type of covalent bond, polymers can be divided into three classes: Plastics, Rubbers (or Elastomers) and Fibers. [11]

The main advantages that polymeric materials have are:

- Possibility of injecting complex parts with a high level of production and quality;
- Reduced vehicle weight with consequent fuel savings;
- Corrosion resistance. [7]

Polymer properties – Among the properties of polymeric materials, it is worth mentioning, despite their mechanical sensitivity, their resistance to weather changes, oxidation, heat, and ultraviolet rays, among others. [6]

Mechanical properties – The properties of polymers, like many metallic materials, are specified through parameters such as the modulus of elasticity, tensile strength limit, and the impact and fatigue strengths. [6]

Figure 1 outlines the typical behavior of polymeric materials in the stress-strain type graph. The curve A shows the brittle polymers, it is observed that they have their breaking point at the elastic point. Curve B presents the behavior similar to metallic materials and characterizes the initial elastic stretch, followed by yielding (Ϭ1) and a region of plastic deformation until rupture. The C curve is totally elastic, typical of rubber, this is presented as a characteristic of the Elastomers class. [11]

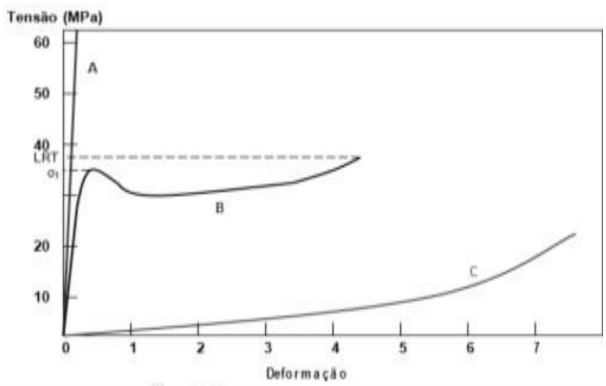


Figure 1. Stress-Strain Behavior for Polymers
Source: CALLISTER, 2002.

Thermal properties – Polymers have low thermal conductivity and when applied to overheating thermal degradation occurs and the chains break down, reducing the molar mass and increasing the release of gases or chemical vapors. [6]

<u>Optical properties</u> – Among the main optical properties of polymers is the transparency shown by amorphous polymers or those with a low degree of crystallinity. This characteristic is presented by the ratio between the light extensions that pass through the material and those that collide perpendicularly to the surfaces, reaching up to 92% in common plastic. The crystalline polymeric material becomes semitransparent or, in some cases, even opaque. [11]

The ease in manipulating this type of material led industries to use it in their processes. Thus leading to a result of technological, economic and environmental elevation, with respect to the ease of disposal. [6]

Polymers demonstrate a high degree of reliability and many advantages over traditional materials. In addition to greater design flexibility and production savings, their low density is essential for reducing fuel consumption. For every 100 kg of polymer used in a vehicle, 200 to 300 kg of other materials are not used. Thus, estimating the useful life of a vehicle at 150,000 kilometers, one can save 750 liters of fuel due to the use of plastics. [12]

Comparing the decision variables and the expectation regarding vehicular components, in figure 2 [13], we notice that polymers have been gaining space in the industrial area due to their outstanding characteristics and properties necessary for metal succession.


Figure 2: Expectation of Automotive Components
Source: GORNI, 2012.

In general, the main advantage of using polymers in the automotive industry is the economy, both in fuel and in production investments. There is also the possibility of design sophistication, the use of less traditional shapes and solutions combined with increased safety. [14]

There is a trend in the Brazilian automotive industry to replace parts made with high performance polymers with similar ones made with locally available materials that are cheaper and have similar characteristics. [15]

POLYMERS VS. METALS – The cases that metallic materials should be chosen are when there are:

- Great mechanical strength is required;
- High hardness values are required;
- Part dimensions cannot vary or have very close tolerances;
- Applied stresses are too high;
- Working temperature is constantly high. [16]

In the following situations are the ones that plastic materials should be chosen when:

- The conditions of use are abrasive;
- Environment is corrosive, because the chemical resistance of most plastics is much higher than that of metals;
- Materials cannot be glued together (aggregation), as in gutters and coatings;
- A low coefficient of friction is required;
- It is not possible to use lubricants or when a self-lubricating material is required;
- Noise and vibration reduction control is necessary, because plastics produce less noise than metallic materials;
- A dielectric material is required;
- Transparency or translucency is required;
- Weight reduction is necessary. [16]

The criteria required for the substitution of a material, in this case from metal to polymer, must be rigorously analyzed taking into account all its process, properties, production and results, as can be seen in figure 3.

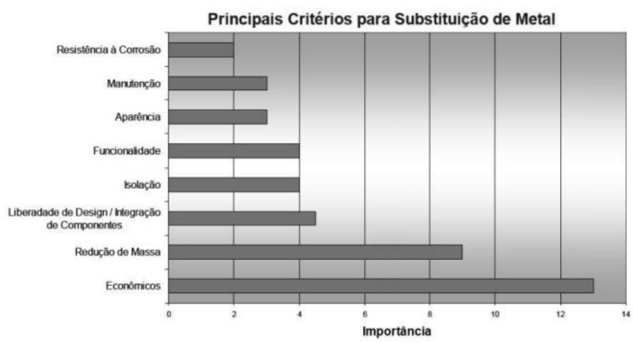


Figure 3. Main Criteria for Metal Substitution
Source: GORNI, 2012.

Only plastic materials can meet the challenges posed by these conflicting demands. Furthermore, the increasing customization that consumers expect from vehicles, leading to an increase in so-called tailormade products, means that diversity will soon become the rule rather than the exception - and only the versatility and flexibility of plastics will allow different cars to be made. [12]

In the technological aspect, the search for innovation and improvement of polymers for use in the automotive sector is done constantly and in a way to adapt the aspects of plastic to the refined global demands, without neglecting the political and regulatory contribution of each country itself. Another conflicting factor in the area of technological pursuits is the process of non-globalization of information, that is, countries and industries realize technological monopoly, centralizing in a few world suppliers of high technology quality polymers. [6]

COMPOSITES – The term "composite material" emerged in the mid-20th century as a promising class of engineering materials. [17]

The word composite means: "formed by two or more distinct parts". By this definition, any material consisting of two or more components with distinct, non-miscible physicochemical properties can be treated as a composite material. [18]

Composite materials have stood out, since they offer physical-mechanical attributes not achieved by other materials and are economically more viable. These materials are composed of two or more combined phases, one being the matrix and the other, the dispersed phase or reinforcement. The dispersed phase makes it possible to reduce the use of virgin materials, since short, medium or long fibers of various origins can be used. [2]

Most composite materials are manufactured from two elements: a base material, called matrix, and a reinforcement or filler, dispersed in the first. The matrix is also known as the continuous phase, while the reinforcement, the dispersed phase. Such materials are separated by an interface, but still have a high adhesion capacity. [19]

Among the most commonly used composite materials today are fibrous reinforcements such as carbon fiber, fiberglass and aramid fiber, laminated and sandwich structural reinforcements that, together with PMC (polymer matrix composites) and MMC (metal matrix composites) matrices, combine different types of materials for the aircraft industry. [20]

The properties of composites depend on both the characteristics of the reinforcement (amount, size, shape, and distribution) and the matrix. Therefore, several types of classification are available for such materials. The taxonomy defines them in terms of the type of matrix and the morphology of their reinforcing agents. As for the type of matrix they can be polymeric, metallic or ceramic. As for the reinforcement, particulate (large or dispersed particles), fibrous (long or short fibers) or structural (laminates). Recently, with the insertion of nanoparticles as reinforcementagents, a new class of materials was created, being called nanocomposites. [18]

Figure 4 [21] makes a comparison, merely illustrative, between conventional monolithic materials, such as aluminum and iron, and composites. This figure indicates the possibilities of improvement that can be obtained by using composite materials. [18]

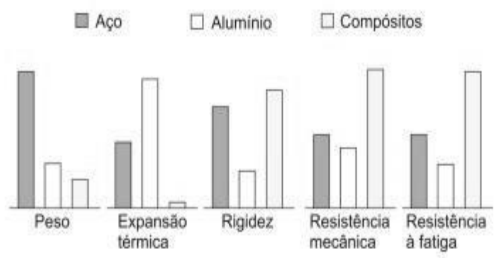


Figure 4. Comparison between conventional monolithic materials and Composite materials
Source: CHAWLA, 1998.

Advances in composites have created opportunities for high-performance, lightweight structures, favoring the development of strategic systems, such as in the area of missiles, rockets, and aircraft with complex geometries. [22]

Starting in the 1960s, high-performance composite materials were introduced definitively into the aerospace industry. [22]

In the aerospace industry, composite materials are often incorporated in the manufacture of aircraft structures, due to their high strength and stiffness, low coefficient of thermal expansion, good fatigue behavior, resistance to extreme temperatures, corrosion and wear, in addition to having reduced specific mass, and allowing smoother contours and more efficient aerodynamic curvature than conventional materials available on the market. [23]

## CONCLUSION

In view of the aspects observed, the substitutions of materials in industry in various segments are capable of being done efficiently and safely.

Plastics have demonstrated a high level of reliability and many advantages over the traditional materials they have replaced such as steel, aluminum and glass. Plastic parts are increasingly recognized as an integral part of automobiles, bringing, above all, economy, safety, and flexibility to the final product.

In the aerospace industry, the use of structural composites has been growing and has stimulated the training of more skilled people, in order to successfully meet the challenges of obtaining components with multiple functions, meeting the requirements of use such as lower weight, higher mechanical performance, transparency to radiation, resistance to erosion, among others.

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