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COMPOSITES IN THE AUTOMOTIVE PRODUCTION

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ABSTRACT: *The history of modern composites begins in the 20th century, when a number of new materials and technologies were invented. New materials are necessary for electrical engineering and computer industry, but their importance rapidly grows in mechanical engineering, especially in aerospace and automotive industry. Industrial demands force to rapidly innovate and bring new materials, with essentially improved properties. Submitted paper deals with the basic overview of manufacturing, processing and main features of the composite materials, based on carbon fibers and their application in the automotive industry.*
KEYWORDS: *Composite materials, carbon fiber, automotive industry, engineering, technology*

INTRODUCTION

Since the past, there has been a searching for new materials that would suit the specific demands. Among the first composite materials (CM) were combinations of natural materials such as wood, bones, bamboos, fabrics, clay bricks with straw, Mongolian laminated bows and so on.

History of modern composites begins in the 20th century, when new materials and technologies were invented; concrete reinforced with steel and phenol resin with cotton invented. In 1940s came plastics with fiberglass and the development continued in 1960s using boron-based, silicon carbide (SiC), and carbon fibers.

New materials are necessary for electrical engineering and computer industry, but their importance rapidly grows in mechanical engineering, especially in aerospace and automotive industry. Industrial demands force to rapidly innovate and improve new CMs, with essentially improved properties. Composites, based on plastics and elastic resins, upon the matrix from extremely strong, flexible, and heavy-duty fibers, made of glass, carbon, boron, steel, or ceramic materials, allow reducing weight and increasing the strength of manufactured components.

TECHNOLOGIES USED FOR COMPOSITE PRODUCTION

CM, or composite, is a heterogeneous material that contains at least 2 components (phases), each with different properties. Their combination results in unique properties in brand new quality levels. One phase, which forms the matrix of composite, is continuous phase. Secondary phase, which hardens the matrix, is usually discontinuous and contains particles of miscellaneous shapes and type. Through the proper choosing of matrix and binding phase material and mutual mixing volume ratio, various and unusual final component properties can be achieved. Numbers of material groups can be combined this way: metal with metal, metal with plastics, metal with ceramics, plastics with ceramics, plastics with plastics, etc. [1]

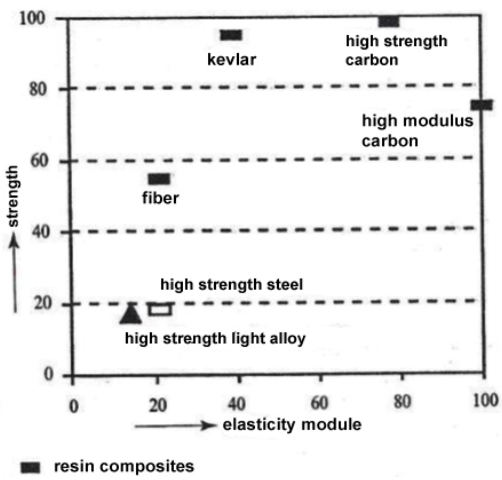

Fig.1: Comparing of CM physical properties

Fig.2: Production of carbon fiber body shell in Renault plant.

Thus, the composite is a material, which fulfils the following conditions [2]:

1. *it was made artificially*
2. *it is made of at least two, chemically significantly different components*

3. *from the macroscopic point of view, the components are uniformly distributed throughout the volume*
4. *resulting final properties of composites differ from the properties of individual components*

Most common CMs are:

- *reinforced concrete (composite of steel wires and concrete)*
- *fiberglass (composite of glass fiber fabric and polyester resin)*
- *asphalt mixture*

Among the other CMs belong composites of synthetic resins (epoxy or polyester) reinforced with carbon or aramid (aromatic polyamide) fibers, which are extremely strong and lightweight and are widely used as a construction material in aerospace and automotive industry.

The combination of properties of components in composites results in new material properties and has synergic effect in enhanced qualitative features of fiber composite – laminate. This implies that the technology processing is crucial factor that basically determines final properties, as well as economics of production. This emphasizes the need to choose the technology carefully [5].

COMPOSITE MATERIALS PROPERTIES

The most significant advantage of composites is their weight (i.e. the ratio between weight and strength). Compared with conventional steel materials, CMs have significantly lower weight, even higher volume. It simplifies their transport and allows easier assembly and disassembly. Deformation of CMsis also not significant – the ultimate strength and breaking strength are the same. Their fatigue limit is high and they are stable [6].

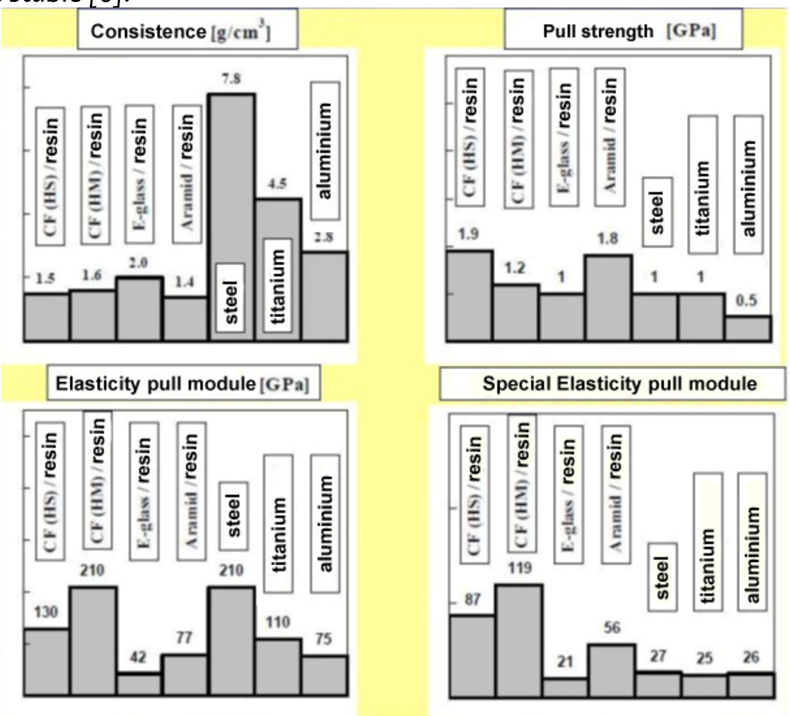

Fig.3: Properties comparing between composite and metal materials

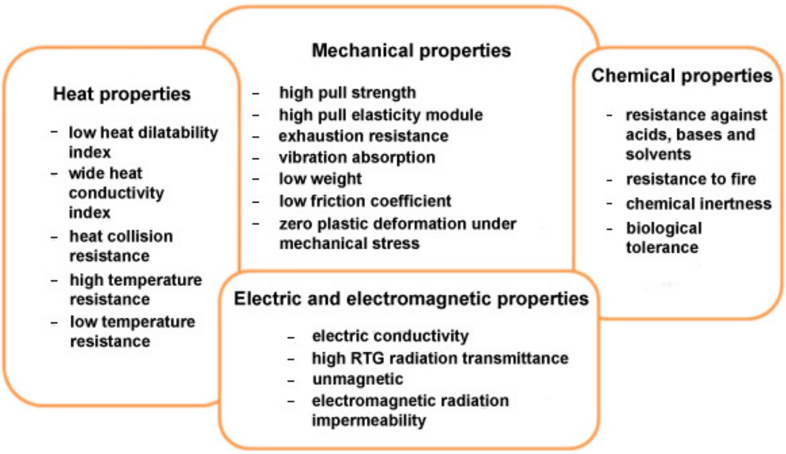

Fig.4: Summary of composites properties

Compared to light alloys, CMs are heat-resistant, but their vapors can be toxic. Disadvantage of CMs, especially CMs based on epoxy resins, is the low resistance to organic solvents. Other common chemicals used in machines, like Vaseline, lubricants, paints or petroleum, usually don't have damaging effect on CMs. The aging of CMs depends on humidity and temperature of the environment [6].

Unwanted effect might be the CM´s absorption during the manufacturing process. In addition to excellent mechanical and strength properties, the CMs are absolutely resistant to corrosion, UV radiation, and they have excellent heat-isolation properties. Color of CM is usually permanent and the laminated constructions are tested in long-term runs. Almost unlimited variability of shapes and colors enables ideal match with any construction [6].

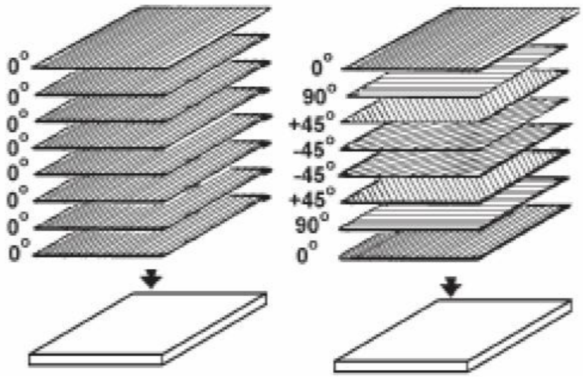

Fig.5: Fiber orientation

Factors, affecting the properties of composite materials [7]:

- *Matrix and fiber type,*
- *Fiber orientation,*
- *Fiber volume ratio,*
- *Choosing of suitable manufacturing technology.*

DETERMINING FACTORS FOR TECHNOLOGY SELECTION

Manufacturing technology is influenced by required properties of final product and its selection depends on following demands [5]:

a) Production batch,
b) Size and shape complexity of product,
c) Surface quality,
d) Required properties, especially strength and weight,
e) Production cost limits.

Usually there must be made trade-offs to fulfill all the requirements, or at least approximate the most important required properties.

Production batch is one of basic requirements that affect the production selection. It's obvious that small batch doesn't need costly machinery; on the contrary, large series would be impossible to process only as handmade [5].

Size and segmentation of component: Some technologies allow only specific shapes of final products (such as wind up). Other can be applied only for simple shapes (such as machine spraying) [5].

Surface quality: Some technologies allow gaining the quality surface only on one side.

Requirements on final properties: Most mechanical properties depend on volume ratio and orientation of reinforcement matrix (fiber fabric), and type of used resin. These factors depend significantly on technology used [5].

TRENDS IN THE FIELD OF CARBON COMPOSITES PRODUCTION

Carbon fiber is a fiber containing carbon in various modifications. It is a long, thin strand of material with a diameter of 5-8 μm composed mostly of carbon atoms. Carbon atoms are linked together in microscopic crystals that are more or less oriented parallel to the long axis of the fiber. Crystal arrangement causes the high fiber strength compared to its thickness. Several thousands of such carbon fibers are wrapped and form the yarn, which may be used individually, or woven into fabric [9].

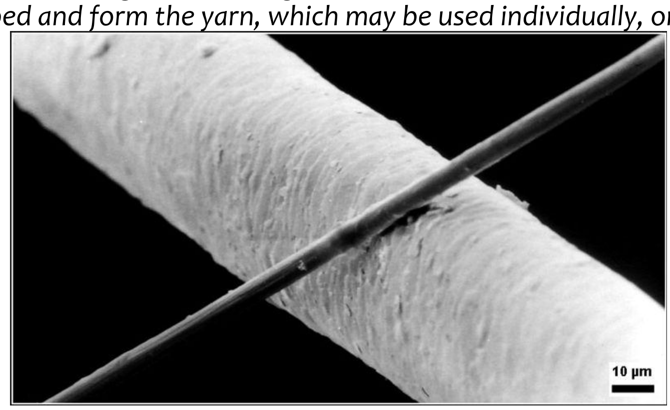

Fig. 6. Size comparison between carbon fiber and human hair

CARBON FIBER MANUFACTURING PROCEDURE

Edison used the bamboo wood to fabricate the first carbon fiber for the light bulb in 1880. For the current manufacturing are the textile fibers used as the raw material in the form of precursors.

- *First industrial carbon fibers were produced in 1957 from rayon (cellulose fiber, viscose). However, this raw material has its efficiency at 25%, maximum. In the last years are carbon fiber produced this way only in Russia and Belarus.*
- *Approximately 90% of the worldwide production (45 000 tons in 2009) of carbon fiber is made of polyacrylonitrile (PAN). The industrial manufacturing started in 1971 in Japan.*
- *In 1976 started the carbon fiber production that used the petroleum pitch (isotropic or mesophase). The mesophaseproducts are characterized by significantly higher elasticity modulus and higher thermal conductivity.*
- *In 1990s were tested the phenolaldehyde precursors as a raw material. Outcoming fibers were characterized by better adhesiveness with resin matrix in composites.*

Types of commonly manufactured carbon fibers

Main types of commonly manufactured carbon fibers [11]:

- *AS (average strength)*
- *HS (high strength)*
- *HT (high tenacity)*
- *HM (high modulus) graphitized fibers*
- *IM (intermediate modulus) –high strength, intermediate tenacity modulus*
- *VHM (Very High Modulus) - high strength, high tenacity modulus*
- *UHM (Ultra High Modulus) - high strength, ultra high tenacity modulus*
- *SBCF (Stretch-Broken Carbon Fiber) –discontinuous fibers, broken through stretching*

Other types of manufactured carbon fibers:

- *Nanofibers with diameter 0,2 micrometerswith strength up to 7 GPa (Vapor-Grown Carbon Fibers).*
- *Experimental nanotubes with length up to 5 mm, available to be woven into fabric with tensile strength up to 150 GPa.*
- *Ground carbon fibers.*
- *Hollow carbon fibers.*
- *Recycled carbon fibers.*

Tab.1 Properties of selected carbon fibers

Fiber/precursor	Tensile strength GPa	E-modulus GPa	Ductility %	Producer (example)
Carbonized PAN (95 % carbon)	5,5	250	1,9	Toray, Japan (1997)
Graphite PAN (99 % carbon)	4,4	377	1,2	Toray, Japan
Mesophase pitch (99% carbon)	3,8	900	0,4	Mitsubishi, Japan
Viscose (99% carbon)	1,2	100	0,5	Sohim, Belarus
Nanofiber 0,2 µm	7,0	600	0,5	AppliedScience, USA
S-glass	4,5	85	5,7	agy, USA

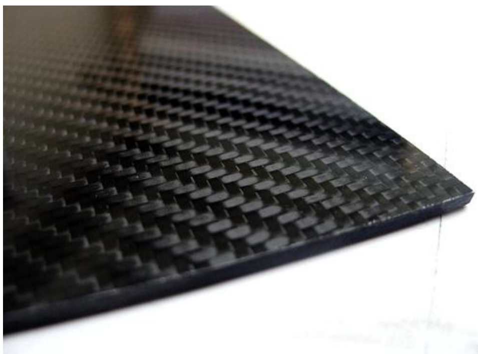

Fig. 7: Laminated carbon fiber fabric

PROPERTIES OF CARBON FIBERS

Carbon fibers are the lightest composite material. They are characterized by high strength, low weight. Their disadvantage is fragility. A typical feature of the carbon fibers is their anisotropy. Properties of composites thus depend on the direction of the laying, i.e. on the orientation of *reinforcing fibers; the fibers have the same strength throughout its length. Newest experimental solutions using carbon nanofibersreached the tensile strength up from 40000 to 65000 MPa. The fibers have an average density of 1750 g/cm^3 and diameter 5-10 μm [9].*

Compared with other textile fibers, carbon fibers differ in [12]:

- *Significantly lower elasticity modulus in the direction perpendicular to the fiber axis,*
- *Brittleness – their ductility is lower than glass fibers,*
- *When heated, fiber shortens itself, but in the perpendicular direction it has higher coefficient of thermal expansion than the glass,*
- *In the longitudinal direction, the carbon fibers have a low electrical resistance.*

Tab. 1 Comparison of carbon fiber and steel properties

	Tensile strength [MPa]	Density [kg/m^3]
Carbon fibre	3500	1750
Steel	300 - 1500	7900

CARBON COMPOSITES USING IN PROTOTYPING OF AUTOMOTIVE COMPONENTS

State-of-the-art product design in the automotive production requires enhanced utilization of prototypes, which means that the samples fabrication is one of the crucial parts of the innovation process. Within the frame of the project first phase is the main focus on the using of composite materials.

There are a number of available technologies units which include among others:

- *Hand-layering technology*
- *Vacuum molding*

These two methods form the basis of samples fabrication for experiments. Hand-laying technology is technically less demanding, but the resulting samples have a relatively large mass. In contrast, vacuum molding technology is technically more difficult, but the samples produced by using this technology have excellent weight and strength properties. The basic material used in the production of samples is carbon fiber processed into the carbon composite. This material has the greatest potential for the automotive industry, so focusing on this type of composite material is the priority. Reducing the weight of components manufactured using the composite materials based on carbon fibers is closely associated with the need to monitor their mechanical properties. Weight loss in the real component may cause the unfavorable influence the mechanical properties of the resulting components.

Fig. 8: Part of the bonnet hinge made of carbon composite

Fig. 9: Hood of the Peugeot 207 made of the carbon composite

The biggest impact on the resulting change in mechanical properties of products produced by such methods has been proven the corresponding processing technology of carbon in final form, as well as the way of layering of the composite fabric. There has been ran a number of tests, where 10 test samples were made in each, using different technologies and different way to fold the fabric. Samples were made from carbon fiber according to the prescribed shape of the samples for a particular type of test.

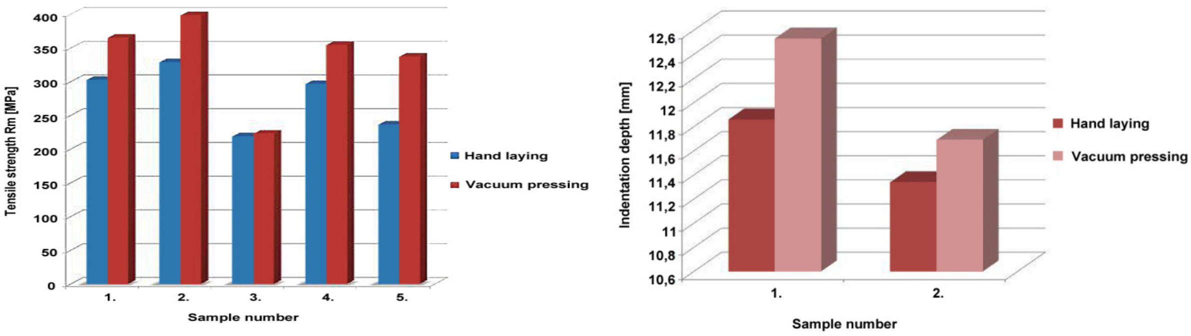

Fig. 10: Sample testing results of tensile and deep drawing Erichsen test

There were performed among the other tests (fig. 10):

- *Static tensile test - on a tensile machine TIRA - test 2300*
- *Deep drawing Erichsen test - test was performed on Hydraulic Machines RM – 501*

CONCLUSIONS

The use of various technologies for carbon fiber gives us the opportunity to change the properties of the final products. The technologies vary in intensity, procedures, sharing of equipment, and costs.

Reducing the weight of components manufactured using the composite materials based on carbon fibers is closely linked with the need for monitoring the mechanical properties of the manufactured composite structures. Weight reduction of components may bring the disadvantageous effect on the loss of mechanical properties of the final product. The biggest influence on the resulting change in mechanical properties of products produced by such methods, is through the using the suitable corresponding carbon processing technology in final form.

The main reason for the use of advanced materials like carbon fiber is to reduce the weight of the final product, while increasing its strength properties. The great advantage of carbon fibers is their ability to be formed into various shapes, so they have a wide range of uses not only in the automotive industry, but also in construction, chemical industry, aviation, and sports. The use of carbon composites, despite their excellent properties is still limited due to the high price of carbon fiber that exceeds the cost of producing the components by 50% compared to conventional steel material.

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