TRENDS IN THE USE OF HIGH STRENGTH MATERIALS IN MACHINE CONSTRUCTION

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ABSTRACT: *The metal alloys frequently used so far in the construction of machines have begun to have limitations of use caused by the demands of increasingly restrictive working conditions. The use of general purpose alloys is particularly difficult in areas where the parts must be able to withstand very harsh conditions, such as high temperatures or high forces applied to them. The present paper intends to analyze some of the most used materials for high strength applications. A special emphasis in this regard is on the one hand on composite materials reinforced with polymer matrix fibers, and on the other hand on basalt. The most important properties, processing technologies and applications of these materials are analyzed and discussed and conclusions are drawn regarding their compatibility with the proposed purpose.*

KEY WORDS: fiber, ceramic, textile, basalt, sintered

1. INTRODUCTION

Within solid materials with special technical use, a special place is occupied by composite, ceramic and mineral materials along with other categories of materials (metals and alloys, non-metallic and metallic and textile bottles. Composite, ceramic and mineral materials are part of the unconventional category). , their elaboration knowing in the last years an impetuous development, both qualitatively and quantitatively, explicable by their exceptional properties: mechanical and high corrosion resistance, low weight, resistance to high temperatures, etc.

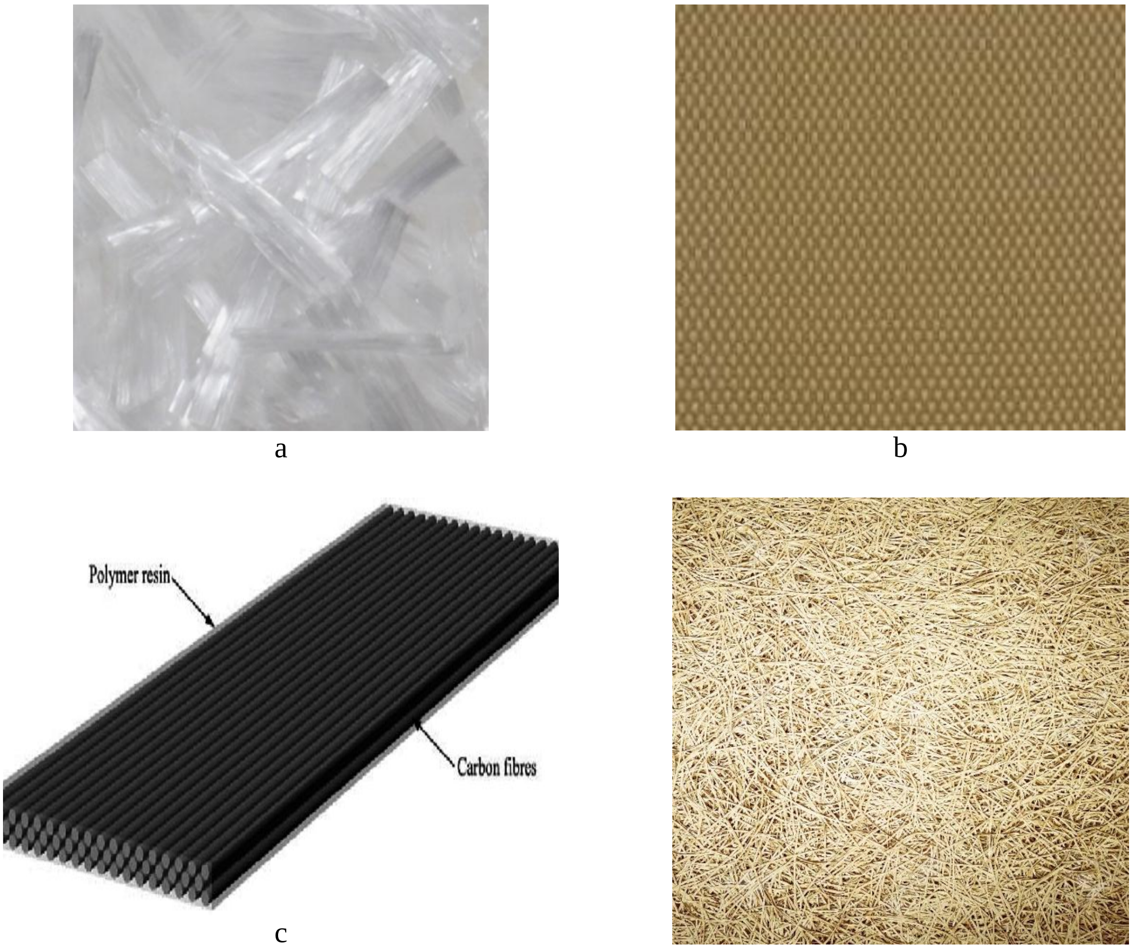
For example, in the construction of special motors that work at very high stresses and temperatures, the most commonly used are high-strength materials. The category of high-strength materials includes: alloys of various metals (aluminum, titanium) and high-strength steels (especially alloy steels) [1].

2. COMPOSITE MATERIAL

Along with high-strength metals, composite materials, especially high-strength fibrous composites, have gained frequent use in the construction of strength structures. These materials have considerably improved the working parameters, leading primarily to a reduction in the passive mass of the parts. Fibrous composite materials have superior strength characteristics sometimes to metal alloys and they make it possible to achieve strength structures that best meet the specifics and operating conditions in the field of reactive technology. Composite materials with polymer matrices (plastics) reinforced with boron fibers received the largest spread. Another category of composite materials used in the construction of resistance structures are composite materials with polymer matrices reinforced with carbon fibers. They are made, in particular, with the use of epoxy binders, have a very high resistance to static fatigue and much higher damping and vibration resistance properties than metals. The superior thermal conductivity of carbon fibers provides the plastic with a very small coefficient of thermal expansion of (1.5 ... 5) x 10^{-6} at 1 ^{o}C at temperatures between 20 - 300 ^{o}C [1], [2].

Carbon-carbon composite materials have been developed for the construction of resistance structures in which graphite carbon matrices are used as a binder for carbon fibers. Such materials have superior thermal protective properties, with inert chemical action and which retain the characteristics of resistance to very high temperatures. Metal matrix composite materials (Al, Mg, Ni) reinforced with carbon fibers represent another category of composite materials used in the construction of strength structures. They are cheap and have simple and efficient manufacturing technologies [2], [3], [4].

Composite materials with glass fiber reinforced polymer matrix are part of the category of thermal insulating composite materials that retain their properties up to a temperature of 1000 oC and are successfully used in the construction of various components of strength structures. For these materials, glass fibers can be replaced with silica and quartz fibers, which retain their properties up to temperatures of about 1200 ^{o}C [6], [7], [8]. Figure 1 shows some such types of fiber materials.



a b c d

Fig.1. Fiber-reinforced composite materials: a - glass fibers; b - boron fibers; c - carbon fibers; d - textile fibers.

In Table 1 shows the comparative characteristics of the composite materials used in the construction of resistant structures [2].

Table 1 - Comparison between the properties of composite materials used for the manufacturing of high-strength parts from the machines manufacturing industry

Material	Density [kg/m^3]	Ultimate tensile strength [GPa]	Modulus of elasticity [GPa]	Specific thermal strength [J/kg]	Maximal relative elongation [%]	Temperature at which fiber strength starts to decrease [^{0}C]
Composite with polymeric matrix reinforced with glass fibers	2070	1.1	39.2	$47.3*10^{-4}$	2.5	350
Composite with polymeric matrix reinforced with boron fibers	2060	0.88	117	$42.7*10^{-4}$	0.75	500
Composite with polymeric matrix reinforced with carbon fibers	1540	0.55	110	$35.7*10^{-4}$	0.5	2000
Composite with polymeric matrix reinforced with organic fibers	1350	0.78	42.17	$57.8*10^{-4}$	2.1	80

For example, the choice of materials for the construction of nozzles (nozzle block) of an engine is determined by two basic criteria, namely: the distribution of temperature along the nozzle during engine operation and the chemical and erosive action of combustion products on the nozzle. Materials for engine nozzles must meet the following properties: high temperature resistance up to 3500 K^o, high breaking strength (high toughness), resistance to gas erosion flowing with supersonic speed at very high temperatures, low density and compatibility with adhesion to interior and exterior coatings [3]. The sufficiently easy nozzle can be obtained only by using in its construction the principle of stratification (when each separate start fulfills strictly a determined function, and the whole, as a whole, ensures the capacity to work with satisfactory performances.

Graphite and carbon-carbon composites are also widely used for making engine nozzles. Graphite is characterized by: high resistance to thermal stress, very high thermal conductivity and a superior resistance to corrosion and erosion. There are several types of industrial graphite, of which the most common for the execution of nozzle elements is polycrystalline (dense) graphite. Polycrystalline graphite has a high density (1.8 - 2.0) x 10^3 kg / m^3 and is characterized by a sufficiently high resistance to erosion. Silicon cemented graphite has a very high erosion resistance, very good mechanical strength and a low coefficient of thermal expansion.

Currently, pyrolytic graphite is being used more and more, which has a density almost identical to that of polycrystalline graphite and is very resistant to high temperatures (3500 K^o). The main characteristics of pyrolytic graphite and of cemented with silicon are presented in table 2 [4], [5].

Table 2 - The main characteristics of pyrolytic graphite and silicon cemented graphite

Characteristics	Pyrolytic graphite	Graphite cemented with silicon
Density (kg/m^3)	2200-2230	1600 … 2000
Specific heat (J/kg*K)	$0.971*10^{-3}$	$0.712*10^{-3}$
Thermal conductivity (W/m*K)		
- on longitudinal direction	372	-
- on transversal direction	3.59	-
Ultimate strength at room temperature (10^9 Pa)	0.103-0.137	0.014 - 0.028
Specific strength (10^6 Pa m^3/kg)		
- at 290 K		
- at 2970 K	0.47-0.62	0.09-0.14
	1.7	-

3. USE OF BASAL IN THE CONSTRUCTION OF RESISTANCE STRUCTURES

One of the major, topical problems of the contemporary world, in the context of the global crisis of raw materials and materials, is that of saving ferrous and non-ferrous metal as well as other deficient and expensive materials (composite materials). This action also includes concerns for the introduction and expansion of the use of basalt, a material that is found in large quantities in nature, accessible and inexpensive.

The basalt is in the form of a black and gray rock, finely crystallized, with a porous structure, poorly visible microscopically (figure 2). From a chemical point of view, the composition of basalt varies between the limits: silica 43 - 50%; titanium dioxide 1 -3%; alumina 12 -16%; ferric oxide 1 - 4%; ferrous oxide 7 - 9%; magnesium 7 - 9%; calcium oxide 2 - 4% and potassium oxide 0.4-2%.

Fig.2. Basaltic rock

In terms of physical properties, basalt is characterized by: compressive strength between 250 and 300 MPa; shock resistance of 1.5 to 5 MJ / m^2; wear resistance between 0.05 and 1.5 g / cm^2; density 2.5 to 3.2 g / cm^3; melting temperature 1170 ... 1350 ^oC; water absorption, porosity, permeability and sensitivity to temperature variations are almost zero. Basalt can be used: in its natural state, in the field of ordinary constructions or processed by formation in order to obtain aggregates with high compactness for the protection of nuclear reactors; cast in metal forms in the form of tubes, pipes or other categories of parts resistant to wear and the action of chemical agents; in a sintered state at temperatures of 2500 ... 2800 ^oC and pressures of 50 - 80 GPa, in the form of bushings, sealing rings and other types of parts used in the construction of cars, automobiles, fine mechanics, aviation. Products obtained by melting basalt and casting it into metal or ground and sintered molds are five times more durable, three times lighter and twice as cheap as the same products made of steel or cast iron. The main physical and mechanical characteristics of the basalt that are of interest are: density, maximum use temperature, as well as a series of mechanical and electrical properties, properties that are presented in table 3 [9].

Table 3 – Physico-mechanical properties of basalt

Property	Unit	Natural basalt	Molten basalt	Sintered basalt
Color	-	grey-black	grey-black	reddish-brown
Density	kg/m^3	2900	2800-3000	2700 - 2900
Total porosity	%	5.39	0.5 - 5	2 - 6
Stability in H_2SO_4 at room temperature	-	-	98 - 99	98 - 99
Resistance to thermal shocks at the temperature of 150°C	no. of cycles	-	4	6
Maximal usage temperature	°C	400	400	600
Thermal conductivity	W	-	1.391	1.391
MOHS hardness	-	-	7.4 - 8	7.4 - 8

Known technologies allow the processing of basalt by:

- casting (melting and recrystallization);
- sintering;
- basaltization (basalt coating - thermal spraying of basalt).

The main advantages of molten basalt, which conditions its use in a number of industrial fields, are:

a) resistance to abrasive wear of hard materials;

b) stability in aggressive, corrosive environments of acidic or basic nature (at high temperatures) and stability against atmospheric influences;

c) pressure resistance;

d) exceptional hardness and strength of the coating;

e) thermal and sound insulating character (in the form of cotton wool).

Molten basalt is not a simple substitute for defective metals, but is a new material that, due to its high resistance to wear and corrosion, will penetrate where, due to these phenomena, thousands of tons of defective metals are lost annually. Its importance lies in the long service life of molten basalt castings, as well as its abundance in the natural state. Castings have a lower tensile and bending strength and a greater brittleness than metals and cannot replace mechanical components of machines, installations or some metal constructions without special treatment, in cases where they are subjected to mechanical and thermal shocks.

These products are obtained by casting basalt melts into metal molds, in forming mixtures or by centrifugal casting, the melting casting process being chosen according to the desired size and configuration of the parts. The casting operation is followed by a suitable heat treatment which aims to regain the initial crystalline structure of the rock from which the melt and the formation of mineralogical constituents were obtained, values that give the basalt parts some remarkable properties. From molten basalt are obtained: tubes of molten basalt; basalt tiles covering the walls of various tanks; use of basalt in the production of mortar materials; lining tanks for limestone, clinker and others; basalt lining of mills; basalt pipes for the pneumatic transport of coal dust from mills or tanks to burners; use of basalt in the manufacture of cement. Basalt cotton wool production. This fiber, in association with asbestos fiber, has been used as a filler and as a thermal and acoustic insulation product with better physical properties compared to glass and slag fibers [11], [12].

Basalt fibers are an effective reinforcing material for the use of reinforced plastics for various constructions. The value of the modulus of elasticity is very high compared to glass fibers (678.000 Kg / cm^2 for basalt fibers and 500.000 Kg / cm^2 for glass fibers) so the strength indicators are much higher (Table 4) [9], [10] .

Table 4 - Characteristics of basalt fibers

Nr. crt.	Denumirea caracteristicii	U.M.	Valoare
1.	Diametrul fibrei	μm	7-15
2	Densitate	kg/dm^3	2,85
3	Tensiune de distrugere la întindere	daN/mm^2	220-250
4	Modul de elasticitate la întindere	daN/mm^2	9000-10000
5	Intervalul de temperaturi de lucru	^{o} C	250-600

Basalt sintering is a modern process developed out of the need to obtain parts with complex shapes, with a high dimensional accuracy. Products are obtained that have mechanical, electrical and anticorrosive properties comparable to those of the replaced metals, superior to those of molten and cast basalt. Sintering (burning) of ceramic products is the operation by which they are subjected to heating at high temperature. As a result of sintering, the ceramic mass undergoes a series of chemical-structural changes that result in the transformation of the dry ceramic mass into an artificial stone. The sintering interval of the basalt ceramic mass is 1180 ... 1320 ^{o}C. The sintering is performed in tunnel type furnaces, in which the combustion cycle is 30 ... 36 hours [11], [14].

The mechanical, electrical, magnetic, wear and corrosion resistance properties, combined with sintered basalt, make it possible to use it both as a replacement for poor conventional materials and as a new synthetic material, with applications within its properties. Thus, a series of parts - experimental model, representative, within the technical capacities of some existing machines, with a unit mass between 1 g and 500 g, were executed, by applying the method of forming by pressing in the mold: cylindrical parts drilled from the category nozzles, profiled nozzles, cylindrical guides, cylindrical parts with thin walls such as sliding bearings, profiled annular parts such as front and rotary seals, tubular parts with thick walls, plates and flat discs with small or large thickness.

By thermal spraying, a basalt start is deposited on objects, for the protection of metal surfaces. The process consists in applying the basalt powder, after it has been passed through the oxyacetylene flame and is used for plating and lining of installations with metal replacement as follows:

- alloy steel, for plating generator cooling chambers in the shipbuilding industry;
- manganese steel and alloy cast iron, on the blades of sandblasting installations.

The coating of the cylindrical surfaces is performed by mounting the part on a universal lathe, which performs the rotational movement, and the spray gun is mounted on the lathe carriage and performs the longitudinal feed movement. The thickness of the deposited layer is 40 ... 1000 μm, usually 100 ... 300 μm.

4. CONCLUSION

The main conclusions that can be drawn from this study are the following:

a) Unconventional materials such as composite, ceramic and mineral materials can be used, along with other technical materials, in the most diverse fields of technology. The most diverse processes and technologies can be applied to them in order to obtain finished parts, thus reducing the consumption of expensive and deficient materials;

b) The products obtained from unconventional materials have remarkable mechanical, physical and chemical properties, among which are mentioned: high resistance to oxidation and corrosion; high resistance to the action of chemicals (H_2SO_4, HCl); resistance to mechanical stress and high temperatures (400^o ... 600^oC);

c) Basalt, which belongs to the category of mineral materials, can be processed by melting and recrystallization, sintering or basaltization. As a result of these processes and processing technologies, basalt improves its main mechanical, physical and chemical characteristics, becoming resistant to temperatures between 400^o ... 600^oC, mechanical shocks and corrosion. Under these conditions, basalt can also be used advantageously in the construction of the resistance structures of certain engines, especially for combustion chambers and nozzles, along with other materials already used;

d) From basalt can be obtained fibers that incorporated in organic (polymeric) matrices allow to obtain new materials such as composites, which due to their properties can be used successfully in the field of reactive technique. Thus, it turned out that the modulus of elasticity of these materials is 20-25% higher than those reinforced with fiberglass, they are 1.5 times lighter than aluminum.

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