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STUDY ON THE USAGE OF SPECIAL MATERIALS FOR HIGH-STRENGTH PARTS USED IN THE MACHINES MANUFACTURING INDUSTRY

Marius BIBU[1], Cristian DEAC[2], Alina GLIGOR[3], Sorin CRISTEA[4]
[1]"Lucian Blaga" University of Sibiu, Romania, marius.bibu@ulbsibiu.ro
[2]"Lucian Blaga" University of Sibiu, Romania, cristian.deac@ulbsibiu.ro
[3]"Lucian Blaga" University of Sibiu, Romania, alina.gligor@ulbsibiu.ro
[4]"Lucian Blaga" University of Sibiu, Romania, sorin.v.cristea@gmail.com

Abstract—Whereas formerly metallic materials were used extensively and for various purposes in the machines manufacturing industry, nowadays new materials are sought that can replace the "conventional" machines manufacturing materials with new ones. This is especially challenging in areas where parts need to be able to withstand very tough conditions, such as high temperatures or large forces applied to them. The current paper intends to analyze some of the most widely used materials for high-strength applications. A special focus in this regard is on the one hand in fiber-reinforced composite materials with the polymer matrix 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 intended purpose.

Keywords— basalt, composite materials, fiber-reinforced, high-strength, sintering

I. INTRODUCTION

ONE of the major current problems at the world level is the need to replace in usage, as much as possible, primary resources from the category of ferrous and nonferrous materials. This is especially problematic when talking about the areas such as the machines manufacturing industry and specifically about parts that need to display high strength properties.

Within the category of high-strength materials with a high potential for usage in the machines manufacturing industry, a special place is occupied by nonconventional materials such as composite, ceramic and mineral materials. Over the last few years, these materials underwent a significant development, both in terms of their quality and in terms of quantity, a development that can be explained by their outstanding properties: high mechanical strength, high corrosion strength, low weight, good resistance at high temperatures etc.

An important group of materials, in this regard, is the group of high-strength fiber-reinforced composite materials. These managed to improve the parameters of high-strength parts considerably, leading to a decrease in their passive mass. [1] Among these materials, a special place is occupied by the composite materials with polymeric matrices reinforced with carbon fibers. These are realized using primarily epoxy binders, have a very high resistance to static fatigue, as well as dampening properties and resistance to vibrations that far exceed those of metallic materials. The higher thermal conductivity of carbon fibers confers the polymeric mass a very small thermal expansion coefficient - $1.5 - 5*10^{-6}$ (K^{-1}) for temperatures comprised between 20 and 300 (°C) [1], [2]

Other examples are carbon-carbon composite materials that use graphitized carbon matrices as binders. These materials are chemically inert and have superior thermoprotective properties that allow the maintaining of the very good mechanical strength characteristics even at high temperatures [2], [3], [4]

Graphite itself has a good resistance to high temperatures, a very good thermal conductivity and high corrosion and erosion resistance. An important type of industrial graphite, used extensively for manufacturing some parts is dense polycrystalline graphite. As its name implies, it has a high density ($1.8 - 2.0*10^3$ (kg/m^3)) and also a high erosion strength. Graphite cemented with silicon has a very high erosion strength, a good mechanical strength and also a small thermal expansion coefficient [3].

Pyrolytic graphite has a density that is almost as high as that of polycrystalline graphite and it can withstand high temperatures, of up to 3500 (K). The main characteristics of pyrolytic graphite and of graphite cemented with silicon are presented in table I [3].

The metallic matrices composite materials (based on Al, Mg, Ni) reinforced with carbon fibers are another category of composite materials that are often used in the high-strength structures in the machines manufacturing industry. They are cheap and can be obtained using simple and efficient manufacturing technologies [4], [5].

TABLE I
MAIN CHARACTERISTICS OF PYROLYTIC GRAPHITE AND OF GRAPHITE CEMENTED WITH SILICON [3]

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 the longitudinal direction	372	-
- on the 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	0.47-0.62	0.09-0.14
- at 2970 K	1.7	-

The composite materials with polymeric matrix reinforced with glass fibers are thermal insulators that can preserve their properties up to 1,000(°C) and are employed for realizing various components of mechanical subassemblies. Sometimes, the glass fibers are replaced with silica fibers or quartz fibers that allow the parts to maintain their outstanding properties up to temperatures of 1,200(°C) [6], [7], [8].

Table II [2] presents a comparison of the properties of the main categories of composite materials employed for manufacturing high-strength parts in the machines manufacturing industry.

TABLE II
COMPARISON BETWEEN THE PROPERTIES OF COMPOSITE MATERIALS USED FOR THE MANUFACTURING OF HIGH-STRENGTH PARTS FROM THE MACHINES MANUFACTURING INDUSTRY [2]

Material	Density (kg/m^3)	Ultimate tensile strength (N/mm^2)	Modulus of elasticity (N/mm^2)	Specific thermal strength (J/kg)	Maximal relative elongation (%)	Temperature at which fiber strength starts to decrease (°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

II. CONSIDERATIONS ON THE USAGE OF BASALT AND BASALT-BASED COMPOSITES FOR REALIZING HIGH-STRENGTH PARTS FOR THE MACHINES MANUFACTURING INDUSTRY

One of the materials that has come to the attention of materials engineers, but also of manufacturing engineers worldwide is basalt.

Basalt is a black or grey rock, with fine crystallization and a porous structure. It can be found abundantly in nature and is relatively cheap to obtain.

From a chemical point of view, basalt may contain [9]:

1) 43-50% silica;
2) 1-3% titanium dioxide;
3) 12-16% alumina;
4) 1-4 % ferric oxide;
5) 7-9% ferrous oxide;
6) 7-9% magnesium;
7) 2-4% calcium oxide and
8) 0.4-2% potassium oxide.

The main advantages of basalt, recommending its usage in the machines manufacturing industry or other industrial areas are [9], [10]:

1) high resistance to abrasive wear;
2) stability in aggressive, corrosive environments (even at high temperatures) and stability towards atmospheric influences;
3) high pressure resistance;
4) high hardness and exceptional durablity of coatings;
5) good thermal insulator.

The main physical and mechanical properties of basalt are presented in table III [9].

Basalt may be used [9], [10], [11]:

1) in natural state, in normal construction works
2) processed by forming in order to obtain high-compactness structures for protecting nuclear reactors;
3) cast as various types of parts that need to withstand wear and the action of chemical substances.
4) sintered at temperatures of 2500-2800(°C) and pressures of 50-80 (N/mm^2) for parts with complex geometries, that demand a high dimensional precision.
5) as basalt fibers in the structure of some composite materials;
6) as basalt coating (obtained through the thermal spraying of basalt).

TABLE III
MAIN PHYSICAL AND MECHANICAL PROPERTIES OF BASALT [9]

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

Forming allows to use basalt both as replacement for some conventional, expensive materials, but also as a new synthetic material, with applications according to the range of its properties. For example, it was possible to manufacture a series of experimental parts with an unit mass comprised between 1 and 500 (g), by using the die casting forming method: cylindrical parts for nozzles, guidance parts, thin-walled cylindrical parts, annular profiled parts, thick-walled tubular parts, thinner or thicker plane disks and plates etc. [9], [11].

For casting, the basalt rocks are first melted and then the molten material is cast in metallic molds, either through classical casting procedures or by centrifugal casting, function of the size and the final configuration of the parts. Casting is usually followed by a heat treatment that aims to restore the initial crystalline structure of the basalt rock. Molten basalt can be used to obtain pipes for the cement-manufacturing industry or for transporting coal powder, plates for padding containers etc. [9], [10].

However, cast basalt parts have a relatively low tensile and bending limits, are more brittle than most metals and can successfully replace mechanical components that are subjected to mechanical and thermal shocks only if they undergo special treatments [10].

Basalt fibers may represent an efficient reinforcement material in polymer matrix composites. The modulus of elasticity for basalt fibers is significantly higher than that of glass fibers (up to 93.1 (N/mm^2) for the basalt fibers compared to up to 75.5 (N/mm^2) for E-glass fibers) [12].

Table IV [9] presents the main properties of basalt fibers. Fig. 1 [12] presents two bobbins of basalt roving that can be used for example as reinforcement in composite materials.

TABLE IV
MAIN PROPERTIES OF BASALT FIBERS [9]

Property	Unit	Value
Fiber diameter	(μm)	7-15
Density	(kg/m^3)	2850
Ultimate tensile stress	(N/mm^2)	2200-2500
Tensile modulus of elasticity	(N/mm^2)	79.3-93.1
Work temperatures range	(°C)	250-600

Similarly to glass fibers, for example, basalt fibers can be manufactured by means of a continuous process, such as melt blowing [12]. For this the basaltic rock is crushed, washed and then transferred into melting baths operated in gas-heated furnaces. Since the structure and composition of basalt fibers are less complex than those of glass fibers, for example, the manufacturing process of basalt fibers is much simpler than that used for glass fibers [12].

Sintering is carried out in tunnel-type furnaces, in work cycles that can take 30-36 hours. The optimal sintering range for basalt is 1180-1320(°C). Through sintering, the ceramic mass of the basalt rocks undergoes a series of chemical-structural changes that lead to transforming the dry ceramic mass into an artificial rock [9], [11].


Fig. 1. Bobbins of basalt roving [12]

Thus can be obtained products that have mechanical, electrical and anticorrosive properties that are comparable to those of industrial metallic materials and are better than those of molten and cast basalt. There can be obtained for example bushels, sealing rings and other parts for the machines manufacturing industry, but also for the automotive industry, aviation etc.

The products obtained through the melting and casting or sintering of basalt are five times more durable, three times lighter and two times cheaper than similar products made of steel or cast iron [9], [13].

Fig. 2 [11] presents the diffractogram for a part made of sintered basalt. By comparing this to the diffractogram of natural basalt, it can be seen that the procedures of calcinating and sintering led to no noteworthy chemical reactions in the material.

Thermal spraying allows to protect metallic surfaces by coating them with a basalt layer. This implies first the milling of basalt rocks and obtaining of basalt powder, which then passes through an oxyacetylenic flame. Cylindrical parts can be coated by fastening them on a lathe that provides the rotation motion, while the spraying gun is fastened on the lathe's carriage, executing a longitudinal feed motion. The thickness of the coating layer can be between 40-1000 (μm), although most often it is between 100-300 (μm).[14].

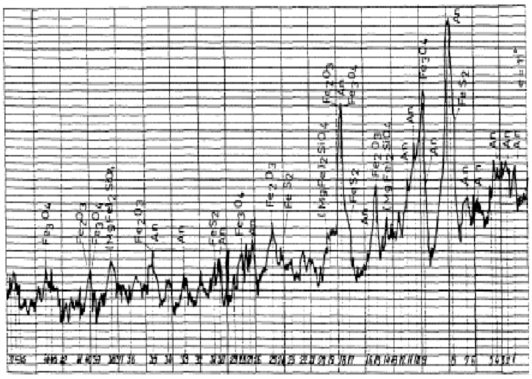

Fig. 2. Diffractogram of a sintered basalt part [11]

It can be used for the plating and padding/insulating of various installations such as cooling chambers of generators in the naval industry or blades of sandblasting installations [9], [14].

III. CONCLUSIONS

The analysis carried out by the authors in this paper has shown that nonconventional materials, such as the composite materials, but also mineral/ceramic materials such as basalt, can be used as successful replacements of the "conventional" technical materials, in various industrial areas. They can be processed through different technologies in order to obtain finite parts that allow to save both money and important resources.

In this paper, the authors have realized an original synthesis and comparison of the main usage domains and possibilities for valorizing composite materials with polymer matrix and basalt, respectively, in the machines manufacturing industry. Also, the authors realized a study with regard to the mineralogical composition of basalt and its physical and mechanical properties. Furthermore, there were analyzed the main elements of the technology to obtain cast basalt, as well as notions on the processing variants of sintering, thermal spraying and machining of basalt.

The products obtained from the presented nonconventional materials have remarkable physical, chemical and mechanical properties, such as a high oxidation and corrosion resistance, high resistance to the action of some chemical substances (even to strong acids like H_2SO_4 or HCl); high resistance to mechanical stresses and to high temperatures;

Basalt, which belongs to the category of mineral materials, can be processed through technologies as diverse as melting and recrystallisation (casting), sintering or basaltisation. After being subjected to these processing methods, basalt shows improved mechanical, physical and chemical characteristics (up to 400-600(°C)), resistance to mechanical shocks and corrosion resistance.

This allows basalt to be used successfully for manufacturing high-strength and even refractory parts for the machines-manufacturing industry, but also for other more specialised industrial applications, for example in aviation or in naval construction.

Basalt can also be used for the obtaining of fibers that, when incorporated into polymer matrices allow the creation of composite materials that, due to their outstanding properties, can be used in a wide range of applications. It has been provem that the modulus of elasticity of these materials is 20-25% larger than the one of composites reinforced with glass fibers, while also being 1.5 times lighter than aluminum.

In future, the authors intend to continue their researches with regard to fiber-reinforced composite materials, but also with regard to basalt, in order to obtain high-quality parts for the machines manufacturing industry.

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