Possibilities of Production of Wear Resistant Construction Elements by Processing of Serbian Basalt

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This paper covers the possibilities of domestic basalt processing by advanced ceramics and melting treatment. We used basalt from the locality of "Donje Jarinje" (Leposavic) and "Vrelo" (Kuršumlija) as a raw material.

Laboratory examinations of the possibilities of basalt processing have been made mostly in "Centre for Manufacturing of Advanced Ceramics and Nanomaterials", Queen's University (Canada). In processing, we applied two, in essence different processes. One included milling, pressing and sintering, and the other melting and casting.

Before sintering, basalt aggregate was milled in the powder then mixed with the additives and after that, isostaticaly pressed under pressure of 225 MPa.

Casting as a method of basalts processing consists of melting of the aggregate in an electric resistant furnace, pouring into the mold and cooling of the castings, with relaxation of internal stress.

Experimental results obtained in these examinations show that the casting method of treating the basalt gives more possibilities in a matter of shapes and dimensions of pieces, but the mechanical characteristics of final products were approximately the same. Wear resistance was high in both cases, considering that cast pieces have a slightly better wear resistance. Pieces received by advanced ceramics process show porosity, and in some cases, this characteristic can be the limitation in final products application.

Keywords: *basalt, basalt glass, sinter basalt, isostatic pressing, wear resistance.*

1. INTRODUCTION

Products made by the processing of basalt can be considered as entirely new products on our market. Basalt can eliminate some of the materials that are used today, and to be a substitute for different imported materials. Besides the properties of the materials, which define their application, it is necessary to point out that the basalt products are not cancerous and that the technologies of their preparation are clean from the ecological point of view.

Basalt is a very strong and hard aluminosilicate rock which belongs to a wide group of granites. Materials (rocks) from the locality of "Donje Jarinje" belong to andesite basalts. Andesite basalts are made of fenocrystals of andesine and basalt plagioclases, monoclinical augit, rhombic hyperstenes and olivine in a holodo microcrystalline porphyric base. In the structure of the basalt we noticed magnetite as a metallic material. Silica, calcite, chlorite and epydot are the secondary. Present feldspats are fresh, while alternative products appear on colored minerals. Andesite basalts have intensive black color, massive structure, and good toughness. Chemical compositions of representative samples from this locality are given in Table 1 [1,2].

Received: June 2010, Accepted: October 2010
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Table 1. Chemical composition of basalt from *Donje Jarinje* locality

Component	Percentage of respective components in five representative samples				
	1	2	3	4	5
SiO_2	57.39	55.96	56.82	56.21	55.11
TiO_2	0.71	0.74	0.80	0.68	0.74
Al_2O_3	18.90	19.40	17.27	18.64	18.78
Fe_2O_3	2.76	2.80	2.54	3.12	2.80
FeO	3.60	3.01	3.72	4.01	3.12
MnO	0.06	tr.	tr.	0.07	0.05
MgO	3.32	3.68	4.01	2.87	3.69
CaO	6.92	8.13	7.99	8.00	8.48
Na_2O	2.80	2.60	2.57	2.88	2.97
K_2O	1.36	1.40	1.58	1.27	1.60
CO_2	0.36	0.90	1.06	1.01	1.42
H_2O^+	0.86	0.72	0.60	0.51	0.74
H_2O^-	0.99	0.87	0.90	0.91	0.80
Totally	100.03	100.21	99.86	100.18	100.30

It can be seen from the analyses of basalt samples from "Vrelo" locality, that these rocks are very compact. Porphyric structure with distinctly marked fenocrystals, 1 – 3 mm size, was easily noted. Rock mass is very fine-grained, crypto crystalline and mat-black colored. Mineral composition appears in two ways: as olivine fenocrystals that are predominating and pyroxene that is inferior. Basic mass is made of plagioclases, glass and rare ferromagnesian ingredients. Chemical composition of basalt from this locality is shown in Table 2 [1,2].

Table 2. Chemical composition of basalt from *Vrelo* locality

Component	Percentage of respective components in four representative samples			
	1	2	3	4
SiO_2	43.94	45.92	45.63	47.82
TiO_2	1.12	1.04	1.20	1.20
Al_2O_3	28.97	26.85	25.43	25.03
Fe_2O_3	3.68	4.20	4.98	2.89
FeO	5.78	5.19	4.84	4.48
MnO	0.12	0.10	0.10	0.11
MgO	3.92	4.93	5.33	3.81
CaO	7.19	6.99	7.89	7.71
Na_2O	2.25	2.45	2.45	2.90
K_2O	0.85	0.83	0.83	1.62
P_2O_5	0.03	0.02	0.09	0.11
S	0.05	0.03	0.03	0.03
H_2O^{110}	0.68	0.54	0.59	0.28
H_2O^{1000}	1.61	1.03	1.06	2.09
Totally	100.19	100.12	100.45	100.08

Physical and mechanical properties of andesite basalt (*Donje Jarinje*) and olivine basalt (*Vrelo*) are very similar, and are shown in Table 3.

Table 3. Physical and mechanical properties of andesite basalt

Characteristic	Measure unit	*Donje Jarinje*	*Vrelo*
Density	kg/m^3	2600	2630
Melting point	°C	1170	1150
Compression strength (dry state)	MPa	260	240
Compression strength (hydro saturated state)	MPa	225	210
Compression strength (after freezing)	MPa	195	190
Wear resistance (Böhme method)	$cm^3/50\ cm^3$	4.50	4.10
Wear resistance (Los Angeles method)	%	11.5	12.0

2. AIM OF RESEARCH

Because of its exceptional mechanical properties, basalt is a valued raw material, which is used in civil engineering, mechanical engineering and processing industry. Basalt aggregate is irreplaceable in "fast railways" construction; basalt fibers are excellent isolation materials that also are used for glass-plastic composites. Basalt glass is used for wear resistant plate production, high-quality kitchenware, and many machine parts and elements of constructions. The aim of this paper is just to examine the possibilities of machine parts and similar elements production, using domestic basalts as basic raw material. To find the optimal way of basalt aggregate processing, we performed a wide range of research, mostly in the *Centre for Manufacturing of Advanced Ceramics and Nanomaterials*, Queen's University, Kingston, Canada. We considered two possible technologies:

- sintering of fine milled and isostatic pressed basalt powder, and
- melting of basalt aggregate and casting of melt in moulds.

Both processes are manifested as suitable for production of above mentioned parts, although, we should say that the sintering process is limited to small parts and parts where porosity has no influence on exploitation.

3. RESEARCH PROCEDURES AND THE RESULTS OF INVESTIGATIONS

Pressing and sintering as a process of making test samples and later machine parts consisted of: a phase of milling, namely micronising of basalt aggregate, mixing with additives, pressing and sintering. Basalt powder was milled and micronised in a tungsten-carbide vibrating mill. Milling lasted 60 minutes, and after that granulometric composition (grain size) was as follows:

- < 100 microns 100 %;
- < 10 microns 60 %.

Then, basalt was mixed with pressing additives (5 % PEG or 0.6 % cellulose) and dried in an electric dryer at 100 °C. Pressing was done in two steps. Standard moulds and a hydraulic press, with force of 30000 N, were used for shaping of the samples. After that samples were isostaticaly pressed at the pressure of 225 MPa. Sintering of the samples was done in an electro-resistant furnace at a temperature range from 1000 to 1100 °C. For getting high-density, 5 % of a very fine powder of MnO was added to a certain number of samples.

A number of experiments that we have done showed that the optimal sintering temperature for the clean basalt powder is 1060 °C, and for the powder with 5 % MnO is 1020 °C. Dependence between density of sintered basalt and sintering temperature is shown in the Figure 1.

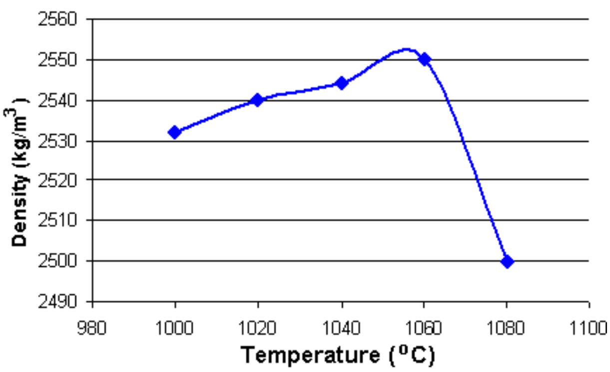

Figure 1. Dependence between density of sintered basalt and sintering temperature

Dependence between density of sintered basalt with addition of 5 % MnO and sintering temperature is shown in the Figure 2.

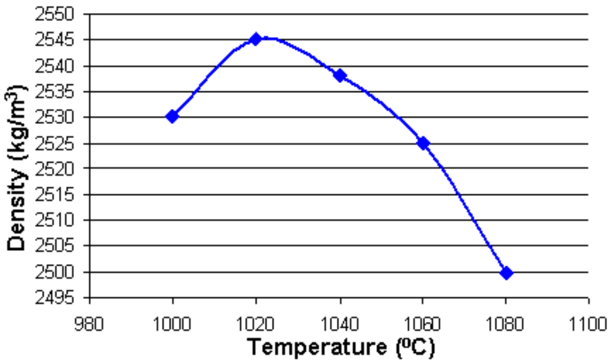

Figure 2. Dependence between density of sintered basalt with 5 % MnO and sintering temperature

Sixty minutes was the sintering time, which is necessary for our samples at these temperatures. While working on this project we noticed several interesting phenomena that could have influence, not only on technological parameters, but also on the selection of the possible basalt processing technology. It was found that small changes of temperature have an important influence on the quality and color of samples. At 1070 °C on the surface of the samples the vitreous phase already exists and at 1100 °C the liquid phase appears in considerable quantity with strong bubbling of samples. Opposite to that, with cooling down to 1030 °C, speed of sintering decreases and the same is with density and the bending strength. That means that the furnace, which we used, must have the possibility of precision regulation of temperature in the whole range, without appearance of temperature gradient. Respectively, the furnace, which is chosen, must have a very homogeneous temperature field. If it was not the case, sintered basalt would not have the reproductive quality regarding the mechanical properties and color of the samples. Optimal results that we got are given in Table 4.

Table 4. Physical and mechanical properties of sintered basalt

Characteristic	Measure unit	*Donje Jarinje*	*Vrelo*
Density of sintered samples	kg/m^3	2550	2550
Density related to theoretical	kg/m^3	97.77	96.95
Compression strength	MPa	250	250
Bending strength	MPa	80 – 100	80 – 90
Fracture	–	brittle, without pores, flaws and gas bubbles	
Color	–	brick red or dark brown	

It has to be mentioned that the sintering temperature has influence on the color of the samples. At the sintering temperatures that we used in our experiments, present FeO is oxidized into Fe_2O_3. The color of samples, which is pale gray, after pressing, becomes brick red. Of course, the color has no influence on the quality of machine parts.

Sintering, as a technology process, gives products of good quality, but it requires exceptional techno-logical discipline and strict respect of all process parameters. To that effect, process of production of basalt parts, by melting and casting is considered just as the sintering process alternative. Reasons for that are better economy and better lucrativeness of this process regarding pressing and sintering. According to this technology, coarse crushed basalt is directly melted and after that poured into metal or sand molds.

Milling, micronizing, and pressing are not necessary, and mixing, namely homogenization of molten basalt was done by natural diffusion or with a mixer. Possibility of waste castings occurrence is much smaller and the demands for respecting the technology parameters are considerably less strict. Mechanical properties of melted basalt are similar to products, which were produced by sintering, its density is equal to theoretical and porosity almost does not exist. Afterwards, the cast basalt plate has a very beautiful dark color, resembling natural stone, it is easy to polish and machine it, and because of that, it can also be used for production of decorative components.

The process that we used in our experiments consists of: melting in an electric resistant furnace, pouring into the moulds and cooling to ≈ 650 – 700 °C. Cooled samples were annealed at 650 °C, and the aim of annealing was relaxation of internal stresses, which appear during the cooling process. Melted basalt that we made, had a compact structure, without visible pores and inclusions and it was suitable for cutting and grinding. The melting point of pure basalt aggregate was ≈ 1420 °C, for andesite basalt, and 1360 °C for olivine basalt, but, in both cases, with addition of 20 % dolomite it was reduced to ≈ 1300 °C. Physical and mechanical properties of tested basalt glass samples are given in Table 5.

Table 5. Physical and mechanical properties of basalt glass

Characteristic	Measure unit	*Donje Jarinje*	*Vrelo*
Density	kg/m^3	2550	2550
Compression strength	MPa	270	250
Bending strength	MPa	50 – 70	50 – 70
Wear resistance (Böhme method)	cm^3/50 cm^3	4.05	4.00

It was necessary to solve several technological problems during the melting and casting process of basalt aggregate. Most important were bubbling of melt and gas segregation in cast basalt. Mostly present gas was oxygen that occurs by transforming of Fe_2O_3 to Fe_3O_4. The process of gas segregation is very slow, taking into consideration the fact that melted basalt has very high viscosity. It can be faster by adding additives – fluxes and with temperature increase. Only when gas segregation is completely over, we can begin pouring. In accordance to that, if gas bubbles stay in the basalt glass mass, they will create defects in pieces we made. Therefore, it is necessary to keep melted basalt at the pouring temperature for about 20 minutes for total degassing [3]. It is only an approximately determined time, because the degassing process is a function of several technological parameters: pouring temperature, sort and quantity of additives, mixing, chemical composition of initial aggregate, etc.

We tested basalt samples by melting in an electro resistant furnace without the protective atmosphere. The basalt aggregate was fragmentized in the tungsten carbide vibro mill. Milling of the charge lasted 10 minutes, and the granulometric composition after milling was:

- < 1 mm 100 %;
- < 0.1 mm 30 %.

Prepared granulation was heated in a corundum crucible to the pouring temperature, ≈ 1400 – 1470 °C, and then poured without additional pressing. For casting of experimental samples we used the parallelepiped shaped metal mould, with dimensions 13 × 25 × 116 mm, (according to standard ASTM C1674-08)[1].

The pouring temperature for basalt samples from *Vrelo* locality was 1400 °C, and for samples from the locality of *Donje Jarinje* was 1470 °C. Difference in pouring temperature is the result of SiO_2 content. The higher content of this component in the samples from the locality of *Donje Jarinje* (Tables 1 and 2) raises the viscosity of the melt, so to get good fluidity, the pouring temperature must be increased by 70 °C. In order to decrease melt viscosity and reduce the pouring temperature, in a number of samples 20 % the dolomite was added [4,5]. Dolomite increases fluidity of melted basalt and makes possible the reduction of pouring temperature by 70 to 90 °C.

Basalt castings were cooled down in the mould to approximately 700 °C, and then were taken out of the mould, then put in the furnace tempered at 650 °C, and cooled down slowly, together with oven. Cooling of solidified castings must be slow, because high cooling speed induces the appearance of internal stresses, which can exceed the strength of the material and provoke breakdown of the pieces. Namely, basalt is a poor heat conductor so, in conditions of fast cooling, the temperature gradient appears along the cross section of the castings, and consequently, the appearance of internal stresses. During pouring of basalt into metal moulds, the heat flux is very intensive; cooling is fast and can lead to the breakdown of castings. Due to that, it is necessary to cool castings in the control regime, thereby achieving relaxation of internal stresses and protection of all mechanical characteristics of the material.

Pouring of melted basalt can be performed in metal and in sand moulds. Sand mould castings have mostly a crystalline structure, while the structure of castings which have been poured into metal moulds is predominantly no-crystalline (glass phase). The type of structure is a function of cooling speed, and the slower the cooling, the higher the crystallization. Since the aim of this work was not structure testing, but the testing of processing possibilities in regard to achieving good physical and mechanical characteristics of castings, determination of amorphous structure content was done on only two samples, and the degree of crystallizations was 10 %. Extracted crystals were practically drowned into the homogeneous glass mass.

[1] Testing was done in *Centre for Manufacturing of Advanced Ceramics and Nanomaterials*, Queen's University, Kingston, Canada

Besides pouring of experimental samples, we made trials of pouring some engine parts made of cast basalt, such as a wheel for laboratory mill and element for a sunflower huller. In the Figure 3 presented is the part of the huller made of cast basalt, poured into a metal mould.

Figure 3. Element of the sunflower huller made of cast basalt

Industrial procedure for production of machine parts from melted basalt, in principle, is not different from that we used in our experiments. Melted basalt is poured into warm molds, after that the casting is pressed, for final forming and solidification of the parts. Solid parts are carried to tempering tunnel to relax internal stresses by controlled cooling. The cooled parts are then sent to the finish machining. This is the way to get high quality parts, with good mechanical characteristics, precise dimensions, excellent wear resistance, excellent corrosion resistance and great resistance to atmospheric effects.

4. CONCLUSION

On the basis of the numerous experiments which were done, it can be decided the next:

- Basalts from *Donje Jarinje* and *Vrelo* localities can be used for the production of machine or other constructing parts by both sintering and melting process. Sintering method can be used only for small parts production, while melting technology has not any limitation regarding shapes and dimensions. Bending strength and toughness of basalt glass is less than sinter basalt but, on the other side, glass has no porosity, its strength is higher and the hardness and corrosion resistance are similar;
- In production of basalt glass parts, it is indispensable to use dolomite additives, since they lower pouring temperature, reduce energy consumption and simplify relaxation process of cast parts;
- Degassing of basalt melt is the function of temperature, and for dead degassing is necessary to heat the melt fairly over melting point, sometimes up to 1470 °C. To eliminate dissolved gasses is also necessary to add additives, which

improve fluidity of melted glass. We got the best results with addition of 20 % of dolomite aggregates;

- There are no any possibilities to avoid porosity in sinter basalt, and, if this property is important for exploitation, it is necessary to impregnate the final product, or to apply some other production process. Porosity is characteristic of the parts that are produced by pressing and sintering and we can not avoid that;
- Andesite basalt (*Donje Jarinje*) and olivine basalt (*Vrelo*) have very similar technological properties, except the melting temperature. Due to that, olivine basalt is more suitable for casting process than andesite basalt.

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МОГУЋНОСТИ ИЗРАДЕ КОНСТРУКЦИОНИХ ДЕЛОВА ОТПОРНИХ НА ХАБАЊЕ ПРЕРАДОМ БАЗАЛТА ИЗ СРБИЈЕ

Дејан Чикара, Александар Тодић, Деана Чикара-Анић

У овом раду изнети су резултати истраживања могућности прераде домаћих базалта поступцима синтеровања (техничка керамика) и поступцима топљења и ливења. Користили смо базалт са локалитета „Доње Јариње“ (Лепосавић) и „Врело“ (Куршумлија) као полазни материал. Истражене резерве базалта на локалитету „Доње Јариње“ износе 700.000, а на локалитету “Врело” 1.030.000 тона.

Испитивања могућности прераде базалта обављена су углавном у Центру за техничку керамику и наноматеријале, Универзитета Квинс (Queen's), Канада. У преради базалта применили смо два, у основи различита процеса. Један је обухватио млевење, пресовање и синтеровање, а други топљење и ливење.

Пре синтеровања, базалтни агрегат је био самлевен у прах, 60 % мање од 10 μm, затим се прах мешао са адитивима (5 % ПЕГ и 0,6 % целулозе) и потом, изостатички пресовао у алату, под притиском од 225 MPa.

Ливење као метода прераде базалта састојала се од топљења агрегата у електроотпорној пећи, изливања растопа у калуп и хлађења уз отпуштање унутрашњих напрезања.

Експериментални резултати су показали да прерада базалта ливењем пружа више могућности када су у питању облик, димензије готових производа, али и да су механичка својства била приближно иста, без обзира на примењену технологију. Отпорност на хабање била је висока у оба случаја, уз напомену да је код ливених узорака била нешто виша. Делови добијени поступком синтеровања били су порозни, а у неким случајевима ова карактеристика може представљати ограничење у примени финалних производа.