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INFLUENCE OF TEMPERATURE AND BINDER CONTENT ON THE PROPERTIES OF A SINTERED PRODUCT BASED ON RED MUD

VPLIV TEMPERATURE IN KOLIČINE VEZIVA NA LASTNOSTI PROIZVODA IZ SINTRANEGA RDEČEGA BLATA

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In this paper we present an investigation into the properties of a sintered product based on red mud with respect to the sintering temperature and the binder content (illite-kaolinite clay). In the Bayer process for obtaining alumina, red mud is a by-product (solid waste from the leaching of bauxite). Using red mud as a raw material mixture component to obtain sintered products, a cheap raw material for construction and ceramics would be obtained, and the environmental problems resulting from the frequent deposits of red mud in pools would be solved. Based on the overall results of our examinations in this study, it can be concluded that the change of basic parameters, sintering temperature and binder content (illite-kaolinite clay), can provide satisfactory characteristics for the sintered product in terms of mechanical properties, volume shrinkage during sintering and total porosity.

Keywords: red mud, clay, porosity, compressive strength

Članek obravnava preiskavo lastnosti sintranih proizvodov na osnovi rdečega blata v odvisnosti od temperature sintranja in vsebnosti veziva (glina ilit-kaolinit). Rdeče blato (trden odpadek pri izpiranju boksita) je stranski proizvod pri Bayerjevem procesu pridobivanja glinice. Rdeče blato kot surovina v mešanici za sintranje komponent je poceni material za gradnjo in keramiko, rešuje pa tudi okoljske probleme, ki izvirajo iz rednega odlaganja rdečega blata v bazene. Na podlagi rezultatov te študije se lahko sklene, da spreminjanje osnovnih parametrov, temperature sintranja in vsebnosti veziva (glina ilit-kaolinit), omogoča zadovoljive lastnosti sintranega proizvoda glede mehanskih lastnosti, krčenja prostornine med sintranjem in celotne poroznosti.

Ključne besede: rdeče blato, glina, poroznost, tlačna trdnost

1 INTRODUCTION

Red mud contains the following basic components: iron in the form of oxides, silicon in the form of sodium-aluminosilicate and titanium as sodium-titanate. Caustic soda, NaOH, is also present in red mud, while with the addition of lime to the process it also contains CaO in either the free or bound forms.

Illite-kaolinite clays, apart from basic clay minerals, illite and kaolinite, mostly contain α-quartz, Fe_2O_3, $CaCO_3$, and are considered as refractory clays (stable up to a temperature of 1350 °C).[1] During the sintering of this two-component mixture (red mud, illite-kaolinite clay), depending on the sintering temperature, different reactions in the solid state occur, as well as the polymorphic transformation of quartz and the formation of a liquid phase.[2] The relationship between the particular elements of the microstructure during sintering, in addition to the firing regime, is importantly influenced by the mineral content of the raw materials.[3,4] Liquid-phase formation accelerates the reactions in the solid state due to the diffusion-coefficient increase in such systems by up to one thousand times.[5] The formation of new crystalline phases in the solid-state reactions during the sintering process, apart from the above-mentioned factors, is also influenced by the temperature of the sintering.[6,7]

Investigations have shown that the relations between the elements of the microstructure and the total porosity of the sintered product are importantly influenced by the mass-ratio changes between the red mud and the clay in a two-component mixture.[8,9]

2 EXPERIMENTAL

The raw material mixture for the production of samples was formed on the basis of red mud (Aluminium Plant Podgorica) and illite-kaolinite clay ("Bijelo Polje") as binders. The content of the red mud in the raw material mixture in mass fractions was (10, 20, 30, 40 and 50) %. The samples were formed by plastic shaping in a mould corresponding to a parallelepiped with dimensions of 7.7 cm × 3.9 cm × 1.6 cm. The raw material mixture components were characterized by a determination of mineral content and the chemical content, while the particle size distribution was determined by granulometric analyses. The density and humidity of the raw material mixture components were also determined.

The sintering of the samples with different red mud contents was performed at temperatures of 1100 °C and 1200 °C.[5,8] The characterization of the sintered products included the following: a determination of the linear and volume shrinkage during sintering, and a determination of the total porosity and compressive strength. The determination of the mineral content of the sintered products was performed by X-ray analysis.

3 RESULTS AND DISCUSSION

The mineral composition of red mud (**Figure 1**) determined by the X-ray analysis shows the presence of the following minerals: hematite, goethite, boehmite, diaspora, calcite, as well as the presence of soda. The results of the chemical analysis of red mud (**Table 1**) show a high mass content of Fe_2O_3 (40.78 %) and because of its negative influence on the quality of sintered product,[1] the content of red mud in the raw material mixture does not exceed 50 %. The clay used as a binder is an illite-kaolinite type (**Figure 2**, **Table 2**), with the presence of α-quartz.

Table 1: The chemical content of red mud in mass fractions (*w*/%)
Tabela 1: Kemijska sestava rdečega blata v masnih deležih (*w*/%)

Oxides	Fe_2O_3	Al_2O_3	SiO_2	TiO_2	Na_2O	CaO	lg. loss
	40.78	17.91	11.28	10.20	6.90	1.50	9.36

The results of the granulometric analysis show that the red mud has a larger fraction (average grain size 30 μm) compared to the used clay (average grain size 17 μm). The density of the clay determined by the pycnometer method is 2.34 g cm^{-3}, while the density of the red mud is 2.76 g cm^{-3}.

The results of the volume shrinkage during sintering (**Figure 3**) show higher values of shrinkage at the sintering temperature of 1200 °C compared to 1100 °C, and the shrinkage decreases with an increase in the content of red mud in the raw material mixture. This is explained by the granulometric analysis of the raw material mixture (red mud has a larger fraction), the relations between the elements of the microstructure, as well as by an increase of the total porosity of the sintered product with an increase of the red mud content.

The total porosity (**Figure 4**) has lower values at the sintering temperature of 1200 °C, compared to the sintering temperature of 1100 °C, and increases with an increase of the red mud content in the raw material mixture. During the sintering process of the ceramic particles all the well-known mass-transport mechanisms can occur, depending on the sintering conditions.[10] Based on the already-existing data and results it can be concluded that diffusion is the dominant mass-transport mechanism under these conditions. Along with the temperature rise, the reactions in the solid state are generated by increased diffusion.

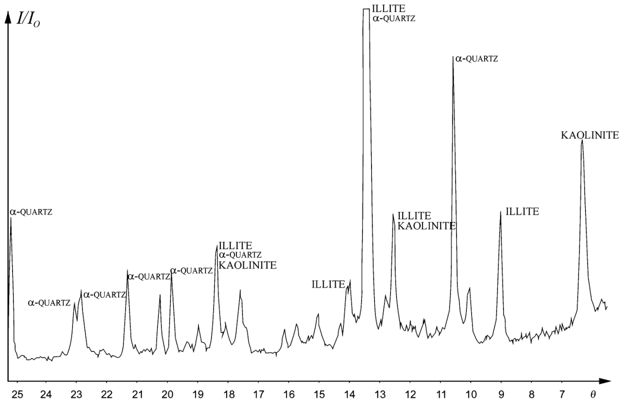

Figure 2: X-ray diffractogram of "Bijelo Polje" clay
Slika 2: Rentgenski difraktogram gline "Bijelo Polje"

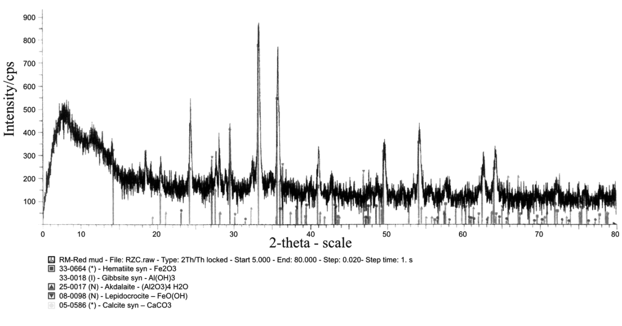

Figure 1: X-ray diffractogram of red mud
Slika 1: Rentgenski difraktogram rdečega blata

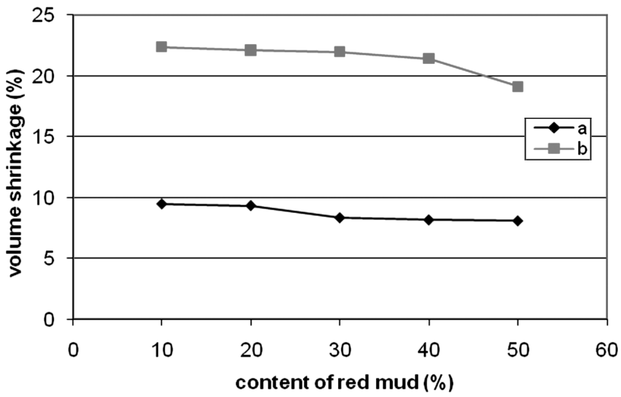

Figure 3: Volume shrinkage of products during sintering: a) T = 1100 °C, b) T = 1200 °C
Slika 3: Krčenje prostornine proizvoda med sintranjem: a) T = 1100 °C, b) T = 1200 °C

Table 2: The chemical content of "Bijelo Polje" clay in mass fractions (*w*/%)
Tabela 2: Kemijska sestava gline "Bijelo Polje" v masnih deležih (*w*/%)

Oxides	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	lg. loss
	72.68	5.7	10.98	0.48	0.7	0.31	1.12	–	8.03

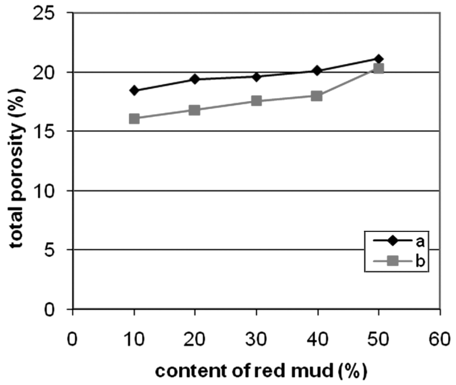

Figure 4: Total porosity of sintered products: a) T = 1100 °C, b) T = 1200 °C

Slika 4: Skupna poroznost sintranih proizvodov: a) T = 1100 °C, b) T = 1200 °C

The highest values of the compressive strength (**Figure 5**) are present for the samples with the lowest content of red mud. The samples sintered at the temperature of 1200 °C have significantly higher values of compressive strength than those sintered at the temperature of 1100 °C.

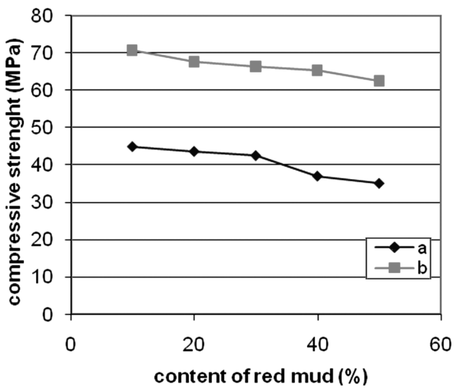

Figure 5: Compession strenght of sintered products: a) T = 1100 °C, b) T = 1200 °C

Slika 5: Tlačna trdnost sintranih proizvodov: a) T = 1100 °C, b) T = 1200 °C

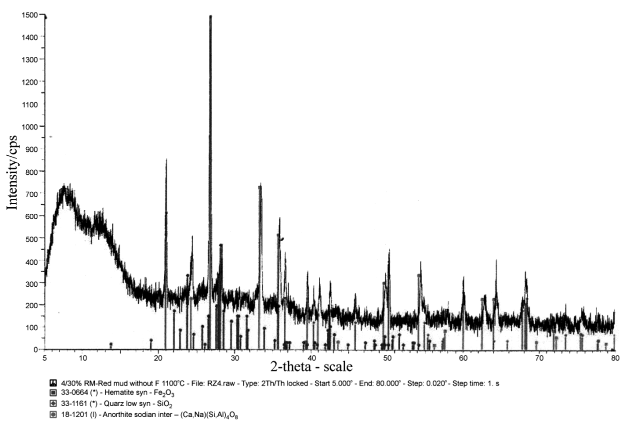

Figure 6: X-ray diffractogram of sintered product (w = 30 % red mud; T = 1100 °C)

Slika 6: Rentgenski difraktogram sintranega proizvoda (w = 30 % rdečega blata; T = 1100 °C)

The X-ray analysis results (**Figures 6**, **7**, **8** and **9**) show different relations for the crystalline phases at the different sintering temperatures. The Fe_2O_3 remains

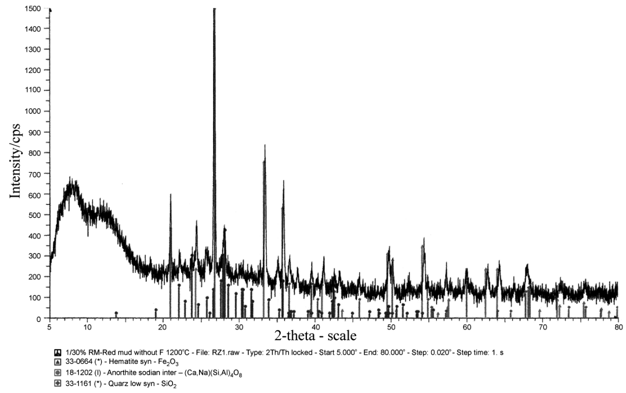

Figure 7: X-ray diffractogram of sintered product (w = 30 % red mud; T = 1200 °C)

Slika 7: Rentgenski difraktogram sintranega proizvoda (w = 30 % rdečega blata; T = 1200 °C)

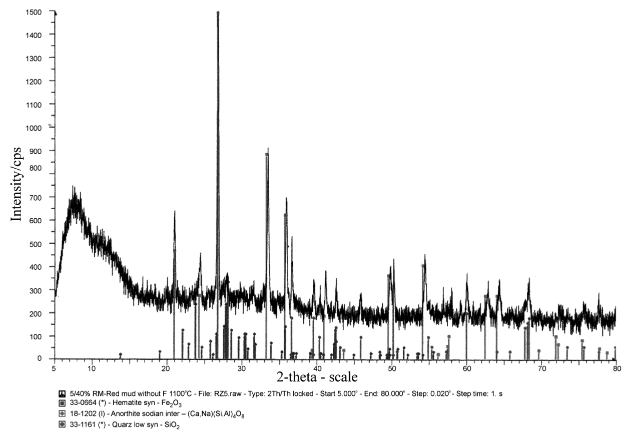

Figure 8: X-ray diffractogram of sintered product (w = 40 % red mud; T = 1100 °C)

Slika 8: Rentgenski difraktogram sintranega proizvoda (w = 40 % rdečega blata; T = 1100 °C)

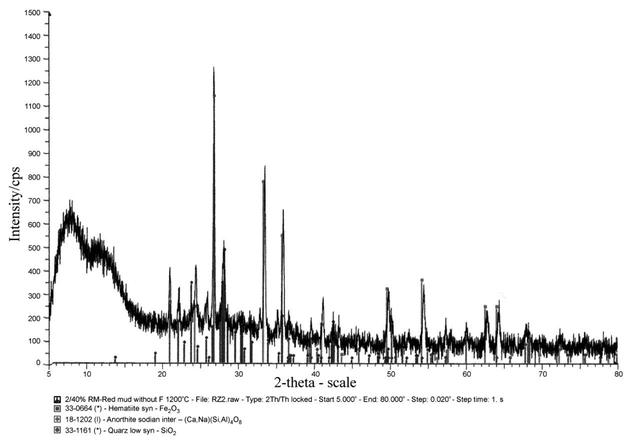

Figure 9: X-ray diffractogram of sintered product (w = 40 % red mud; T = 1200 °C)

Slika 9: Rentgenski difraktogram sintranega proizvoda (w = 40 % rdečega blata; T = 1200 °C) mostly unbound (which is more evident at the lower sintering temperature). This also influences the different values of the total porosity and the microstructure changes of the sintered product, which has an effect on the values of the compressive strength.

4 CONCLUSION

On the basis of the performed examinations the influence of the sintering temperature and the binder content on the properties of a sintered product containing red mud we can conclude:

- red mud as a component of a raw material mixture can be used in ceramic technology (for bricks, blocks, etc.),
- the most important factors that determine the properties of the sintered products based on red mud are: the amount of red mud in the raw material mixture, the granulometric content of the components of the raw material mixture and the sintering temperature,
- at the higher sintering temperature (1200 °C) more favourable results regarding the total porosity and the compressive strength are obtained,
- the differences in the values of the total porosity, the volume shrinkage during sintering and the compressive strength, with an increase of the red mud in a raw material mixture (up to w = 50 %) are not significantly higher.

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