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14. Međunarodna naučna konferencija

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iNDiS 2018

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ZBORNIK RADOVA

Novi Sad, Srbija
21–23. novembar 2018.

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21-23 November 2018

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V. Radonjanin
R. Folić

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u saradnji sa
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UNIVERSITY OF NOVI SAD
FACULTY OF TECHNICAL SCIENCES
DEPARTMENT OF CIVIL ENGINEERING AND GEODESY,
DEPARTMENT OF ARCHITECTURE AND URBAN PLANNING

in cooperation with
ASSOCIATION OF STRUCTURAL ENGINEERS OF SERBIA

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Profesor emeritus Radomir Folić, dipl.inž.građ.

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iNDiS 2018

Departman za građevinarstvo i geodeziju, Fakulteta tehničkih nauka u Novom Sadu organizuje četrnaestu međunarodnu naučnu konferenciju „iNDiS 2018“. Ove godine, u skladu sa savremenim trendovima u razvoju održivog graditeljstva, obuhvata i „Eco build“ subkonferenciju: Poljoprivredni otpad – izazovi i poslovne mogućnosti, koja se organizuje u okviru realizacije projekta Interreg – IPA CBC Hrvatska – Srbija.

Prvi skup održan 1976. godine bio je na temu „Industrijska izgradnja stanova“, zbog njene aktuelnosti u tom periodu. Kasnije su održavane konferencije sa nešto širom tematikom „Industrijalizacija građevinarstva“, da bi se ubrzo na skupu pojavili radovi iz svih oblasti graditeljstva od prostornog planiranja, projektovanja objekata različite namene do održavanja i većih intervencija na izgrađenom graditeljskom fondu. To je uslovilo i proširivanje oblasti koje obuhvata ovaj skup na kome se, pored građevinskih inženjera različitih usmerenja, pojavljuju urbanisti, arhitekti, inženjeri drugih struka koji rade u graditeljstvu, sociolozi, ekonomisti i drugi.

Ova konferencija, kao i nekoliko prethodnih, obuhvata probleme: planiranja, projektovanja, građenja i obnove graditeljstva, upravljanja rizicima od kastrofalnih događaja i zaštite od požara, što je naišlo na adekvatan odziv istraživača i inženjera različitih profila iz inostranstva i naše zemlje.

Članovi međunarodnog naučnog komiteta aktivno su učestvovali u pripremi konferencije, kako u recenziranju pristiglih radova, tako i radovima koji se objavljuju u ovom zborniku. Očekuje se da će prezentacije radova i diskusije na konferenciji omogućiti definisanje glavnih pravaca razvoja graditeljstva u skladu sa savremenim trendovima, s obzirom na to da je promovisano mnoštvo ideja i rezultata eksperimentalnih i teorijskih istraživanja u oblastima graditeljstva i zaštite životne sredine.

Za ovu konferenciju, „iNDiS 2018“, objavljen je zbornik radova, u kome su uključeni radovi na engleskom i srpskom jeziku, što omogućuje bolju i plodniju komunikaciju i razmenu iskustava sa kolegama iz inostranstva. Od značaja je i mogućnost sklapanja novih i jačanja postojećih profesionalnih i kolegijalnih veza.

Svim autorima radova urednici upućuju veliku zahvalnost.

Novi Sad, novembar 2018. godine. Urednici

iNDiS 2018

Department of Civil Engineering and Geodesy, Faculty of Technical Sciences in Novi Sad organizes the 14th International Scientific Conference "iNDiS 2018". This year, in accordance with the contemporary trends in the development of sustainable construction, includes also subconference "Eco Build": Agricultural Waste - Challenges and Business Opportunities, organized as part of the implementation of the Interreg project - IPA CBC Croatia - Serbia.

The first conference took place in 1976 with main topic "Industrial construction of apartments", due to its actuality in that period. In the following years, conferences were held with a somewhat broader topic "Industrialization of Civil Engineering", and soon, papers from all areas of construction, from urbanism planning and designing to maintenance and major interventions on the built construction fund appeared. This led to the expansion of the conference topics, where urban planners, architects, engineers of other professions working in construction, sociologists, economists and others appear alongside construction engineers of various orientations.

This conference, as well as several previous ones, covers the problems of planning, design, construction and restoration of construction, disaster risk management and fire safety, which resulted in the adequate response of researchers and engineers from various profiles from our country and also from abroad.

Members of the International Scientific Committee actively participated in the preparation of the conference, both in the review of the received papers and with the papers published in this Proceeding. It is expected that the presentations of papers and discussions at the conference will enable the definition of the main directions of construction development in line with contemporary trends, since many ideas and results of experimental and theoretical research in the field of construction and environmental protection have been promoted.

For this conference, "iNDiS 2018", a collection of papers, in English and Serbian was published, which enables better and more fruitful communication and exchange of experiences with colleagues from abroad. Also, it provides great possibility of concluding new and strengthening existing professional and collegial relationships.

The editors would like to express sincere gratitude to all authors for the effort invested in writing papers and for the contribution to this event.

Novi Sad, November 2018 Editors

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Jelena BIJELJIĆ[1], Nenad RISTIĆ[2]
Zoran GRDIĆ[3], Gordana TOPLIČIĆ-ĆURČIĆ[4]
Dušan GRDIĆ5, Dejan KRSTIĆ[6]

EFFECTS OF GROUND GRANULATED BLAST FURNACE SLAG ON PHYSICAL-MECHANICAL CHARACTERISTICS OF GEOPOLYMER MORTARS BASED ON FLY ASH

Abstract: Geopolymers are composite materials created during the chemical process called geopolymerization, which transforms the amorphous mass of the precursor material into a binding material, which after hardening forms a compact structure. In the paper are tested physical-mechanical characteristics of geopolymer mortar mixes made with fly ash (FA) and ground granulated blast furnace slag (GGBFS) whose masses have the following percentage: 100:0, 75:25, 50:50; 25:75 and 0:100. In the research, two curing procedures wer implemented, in ambient conditions and at the temperature of 95ºC, in order to establish how temperature of curing affects the geopolymer mortar based on fly ash and ground granulated blast furnace slag.

Key words: geopolymer mortars, fly ash, ground granulated blast furnace, curing, consistency, mechanical characteristics

UTICAJ MLEVENE GRANULISANE ZGURE VISOKE PEĆI NA FIZIČKO-MEHANIČKE KARAKTERISTIKE GEOPOLIMERNIH MALTERA NA BAZI ELEKTROFILTERSKOG PEPELA

Rezime: Geopolimeri su kompozitni materijali nastali tokom hemijskog procesa zvanog geopolimerizacija, kojim se amorfna faza polaznog materijala transformiše u vezivni materijal, koji nakon očvršćavanja formira kompaktnu strukturu. U radu su ispitivane fizičko-mehaničke karakteristike geopolimernih malterskih mešavina spravljenih sa elektrofilterskim pepelom (FA) i mlevenom granulisanom zgurom visoke peći (GGBFS) u procentualno masenom odnosu 100:0, 75:25, 50:50; 25:75 i 0:100. U istraživanju su primenjena dva postupka nege, u ambijentalnim uslovima i na temperaturi od 95ºC, kako bi se ustanovilo na koji način temperatura nege utiče na geopolimerni malter na bazi elektrofilterskog pepela i mlevene granulisane zgure visoke peći.

Ključne reči: geopolimerni malteri, elektrofilterski pepeo, granulisana zgura visoke peći, nega, konzistencija, mehaničke karakteristike

[1] PhD student, Collage of applied technical studies Niš, jelena.bijeljic@vtsnis.edu.rs
[2] PhD, Ass. Prof.., University of Nis, Faculty of Civil Engineering and Architecture, Serbia, nenad.ristic@gaf.ni.ac.rs
[3] PhD, Prof., University of Nis, Faculty of Civil Engineering and Architecture, Serbia, zoran.grdic@gaf.ni.ac.rs
[4] PhD, Assoc. Prof., University of Nis, Faculty of Civil Engineering and Architecture, Serbia, gordana.toplicic.curcic@gaf.ni.ac.rs
[5] MSc, Assist., University of Nis, Faculty of Civil Engineering and Architecture, Serbia, dusan.grdic@gaf.ni.ac.rs
[6] MSc., University of Nis, Faculty of Civil Engineering and Architecture, Serbia, dejan.krstic@gaf.ni.ac.rs

1. INTRODUCTION

In recent years, there is an increasing awareness on the quantity and diversity of hazardous solid waste generation. Its impact on human health and concern about the environmental consequences of waste disposal has led to investigation of new utilization avenues [1,2]. Geopolymers are a kind of inorganic polymers that have been gradually attracting global attention as potentially revolutionary materials [3].

Alkali activated materials (AAM) – geopolymers (GP) are composite materials created during the chemical process called geopolymerization, which transforms the amorphous mass of the precursor material into a binding material, which after hardening forms a compact structure. Geopolymerization represents a reaction of solid aluminosilicate materials, in the form of natural materials or waste by-products and alkaline solutions. The result of geopolymerization reaction is creation of inorganic polymers, which are characterized by good mechanical characteristics, and they are environmentally acceptable [1]. Industrial by-product materials, abounding in aluminosilicates are used as precursor materials, while for their activation are used alkaline solutions such as sodium hydroxide and sodium silicate. Geopolymers are made of long molecular chains created by polymerization of silicon tetrahedron and aluminium octahedron, bound with oxygen, and whose structure resembles the natural materials, zeolites. The polymerization concept was first introduced by Joseph Davidovits in 1978, who proposed the term "geopolymers" [4]. According to Davidovits, geopolymer materials represent amorphous inorganic polymer materials created by alkaline activation of aluminosilicate materials such as fly ash, metakaolin, red mud, etc. The basic property of these materials is their binding and hardening at slightly elevated temperatures, whereby they develop high mechanical strengths, high chemical thermal resistance, stability and durability.

Glukhovsky and Krivenko, in 1950 developed the concept of alkaline activated system – calcium silicate hydrate (CSH) and aluminosilicate phase. Such a system occurs during hydration of Portland cement and in crystalline phases of zeolite [5]. Aluminosilicate resources can be found in nature, in the form of clays from the earth's crust, or in industrial by-products. Temperature curing of natural materials leads to change of the crystalline structure and creation of amorphous phase materials, whereby raw material activity is improved. The alkaline activators such as strong alkali NaOH or KOH, in combination with Na_2SiO_2 ori K_2SiO_3 are most frequently used in the production of geopolymers [6].

Ther is a large number of researches of geopolymer mortars and concretes based on fly ash, granulated slag, metakaolin, red mud and other by-products. Temuujin et al. [7] investigated influence of calcium compounds (CaO and $Ca(OH)_2$ on the mechanical properties of fly ash based geopolymers. Improvement of mechanical properties was observed for ambient temperature curing samples, while there was deterioration of the samples cured at 70°C. Cheng et al. [3] investigated the possibility of using GGBFS as an active filler in the making of geopolymers pasta. Properties such as setting time, concentration of potassium hydroxide (KOH), addition of metakaolinite and sodium silicate were investigated. The research results showed that physical and mechanical properties of the geopolymer were correlated with the concentration of alkaline solution and the amount of metakaolinite that is added. Xiaolu Guo et al. [8] investigated influence of different modul ratios of NaOH and Na_2SiO_3 to class C FA. The compressive strength of these samples was 63.4 MPa when they were cured at 75°C for 8h. The results are followed by curing samples that were cured at 23 °C for 28 days. Kumar [9] investigated isothermal properties, X-ray diffraction and scanning electron microscopy–X-ray microanalysis of FA based geopolymer where precursors were replaced by a varying amount of GGBFS (in 5–50% content), in order to monitor the change in the microstructure. Alumino–silicate–hydrate (A–S–H) and calcium–silicate–hydrate (C–S–H) gels with varying Si/Al and Ca/Si ratio are found to be the main reaction products.

Coexistence of A–S–H and C–S–H gel indicates the interaction of fly ash and GBFS during geopolymerisation. Rovnanik [10] investigated MK based geopolymers and the effect of curing temperatures from 10 to 80 °C and of the time on the mechanical and microstructural properties. Evaluated tests showed that both early-age and final mechanical properties are dependent on curing temperature. Higher temperatures of curing improve the early age mechanical properties, that might be reached in 24 hours. However, the mechanical properties of 28 days-aged materials show lower values when materials are temperature treated than when they are cured in ambient conditions. Authors explain, that quick formation of the hard structure probably does not result in a quality product.

Several studies were based on using a different molarity of NaOH. Chindaprasirt et al. [11] investigated basic properties, workability and strength of geopolymer mortar made from class C FA, activated with sodium hydroxide (NaOH) of concentration variation 10M to 20M and sodium silicate (Na_2SiO_3). The results show that workable flow of mortars depends on mass ratio Na_2SiO_3 to NaOH while varying the concentration of NaOH between 10M to 20M was found to have a small effect on mechanical properties. Budh et al. [12] investigated the effect of molarity on compressive strength of geopolymer mortar. Precursor material such as low calcium FA was used. The investigated methods were Ultrasonic pulse velocity and compressive strength.

Partha Sarathi Deb et al. [13] investigated the effect of GGBFS of class F (in the content of 0 – 20% of total binder mass) on the properties of FA based geopolymer concrete and of properties such as setting time and strength development on geopolymer concrete when cured at ambient temperature, when $NaOH/Na_2SiO_3$ ratio 1,5-2,5. The research shows increasing in strength and decreasing in workability with higher content of GGBFS and lower $NaOH/Na_2SiO_3$ ratio. Tensile strength is correlated with compressive strength of ambient cured geopolymer concrete. Kong et al. [14] research the effect of elevated temperature on geopolymer paste, mortar and concrete while using FA as a precursor, KOH and Na_2SiO_3 for synthesizing. Parameters such as specimen and aggregate sizing, aggregate and superplasticizer type were examined. Pradip Nath et. al. [15] showed the possibility of using FA based geopolymers without heat elevated curing. In final, the results show that FA based geopolymer concrete, cured at ambient temperature shows better setting time and compressive strength when GGBFS is added in 10%, 20% and 30% of total binder.

The purpose of this study was to compare the physical and mechanical properties of geopolymer mortar bars made of industrial by-products such FA and GGBFS as precursors (binders) that are cured in an oven, at temperature of heating of 95°C with mortar bars cured at ambient temperature.

2. DETAILS OF THE EXPERIMENT

2.1. Materials used in the experiment

In this study FA and GGBFS were used as binder materials. Fly ash originates from thermal electric power plant Kostolac “B”, while GGBFS is a by-product of iron ore processing in the Smederevo still mill. The chemical compositions of FA and GGBFS were given it Table 1. Previously, granulated slag was pulverized in steel-ball mill and passed through the sieve with 0.063 mm openings. Also, fly ash was sifted through the same sieve. The used binders are presented in figure 1. The aggregate used was the sand from the South Morava river, with maximum grain size of 2 mm.

Table 1- Chemical composition of used binders

Parameter		Fly ash [16]	Blast furnace slag [17]
SiO_2	%	51,68	37,5
Fe_2O_3	%	11,58	0,73
Al_2O_3	%	20,16	7,27
CaO	%	7,43	38,48
MgO	%	2,41	10,86
SO_3	%	1,02	0,39
P_2O_5	%	0,12	-
TiO_2	%	1,04	-
Na_2O	%	0,88	0,54
K_2O	%	1,04	0,26
LOI	%	2,57	2,13

Figure 1 – Used binders: ground granulated blast furnace slag (left) and fly ash (right)

Sodium silicate (Na_2SiO_3) and sodium hidroxide NaOH solutions were used for synthesis. Sodium silicate as an alkaline activator produced by ‘‘Galenika-Magmasil” d.o.o., Serbia of the following characteristics: module (Ms) 2.2; content SiO_2 – 26.70%, Na_2O – 13.30% and H_2O – 60%). No other chemical admixtures were used in the experiment. Standard tap water was used during the mortar production in all mixtures. Sodium hydroxide was prepared by dissolving of sodium hydroxide pellets with water. The solution was left for 24 hours to cool down to room temperature before mixing with sodium silicate solution.

2.2. Mortar mixture composition

For the research, five different mortar mixtures were made. One mixture was made with only fly ash as a binder, while in the others, fly ash mass was replaced by granulated slag, in the following percentage: 25, 50, 75 and 100%. The mortar mixture with fly ash only was designated as 0S, the mixture where fly ash was replaced with granulated slag in the amount of 25% was designated as 25S, and analogously the mixtures where 50, 75 and 100% of fly ash was replaced with granulated slag were designated as 50S, 75S and 100S.

All mixtures were made of the same quantities of sand, total precursors, sodium silicate, sodium hydroxide and extra water. Mortars are based on FA as a precursor. Alkali activated mixtures were made of sand to binder ratio 3. The liquid solutions used in experiment were

NaOH of 10M concentration and Na_2SiO_3 with 2,2 module ratio. Water to binder ratio was 0,45 for all mixtures. For the purpose of better workability, all mixtures had 40g of extra water added. Mix design of mortar mixtures is provided in Table 2.

Table 2- Mix design of geopolymer mortar mixtures

Mix design	FA [g]	GGBFS [g]	NaOH [g]	Na_2SiO_3 [g]	Sand [g]	Extra water [g]
0S	450	0	56,16	303,13	1350	40
25S	337.5	112.5	56,16	303,13	1350	40
50S	225	225	56,16	303,13	1350	40
75S	112.5	337.5	56,16	303,13	1350	40
100S	0	450	56,16	303,13	1350	40

All geopolymer mortars were mixed using Hobart mixer. The liquid phase including sodium silicate and sodium hydroxide was mixed with extra water and precursor (FA and GGBFS) for 5 minutes at low speed. After 5 minutes, sand was added and the mixer ran for additional 5 minutes. Total mixing time was 10 minutes. The mortars were shaped in 40 mm x 40 mm x 160 mm molds using a vibration method.

For each mortar mixture, two batches of samples were made and cured in two different ways. One batch of the samples was submitted to temperature activation, i.e. exposed to a temperature of 95^0C in the first 24h, and they cured in ambient conditions at a temperature of 22^0C until testing. The second batch was all the time cured in ambient conditions at a temperature of 22^0C. The samples were after demolding protected by a plastic foil to prevent loss of moisture.

3. EXPERIMENTAL RESEARCH

Workability – test for flow of thixotropic mortars according to standard SRPS EN 13395-1:2010 and bulk density according to standard SRPS EN 1015-6:2008 were tested on fresh mortar. The compressive strength, flexural strength and bulk density of hardened mortar were tested on the prisms with dimensions 40 x 40 x 160 mm according to SRPS EN 196-1:2018 and SRPS EN 12190:2010. Also, ultrasonic pulse velocity was tested for mortar prisms of different ages, in order to monitor the hardening process, i.e. the degree of polymerization of binder.

3.1. Properties of mortar mixture on fresh state

Testing of mortar workability of was conducted by using test for flow of thixotropic mortars. A conical mould of a base diameter 100 mm was used for testing the workability. According to the standard, a mould was placed in the middle of the flow table and filled with mortar. Mould was removed, flow table was raised and dropped 15 times in 15 seconds. After raise-drop process, fresh mortar changed it shape from a conical to a “circular plate”. Eventually, „circular plate“ diameter has been measured in two perpendicular directions.

Bulk density was determined by using a measuring vessel of 1l capacity, comprising a cylindrical bowl with an internal diameter of about 125 mm. Determination bulk density of mortar samples depends on their consistence. The vibration method was used for filling and compaction in this examination.

The results of workability test and bulk density of fresh mortar are given in Table 3.

Table 3 – The results of workability test and bulk density

Mixture	Flow Value [mm]	Bulk density [kg/m^3]
0S	125	2120
25S	143	2175
50S	148	2195
75S	152	2205
100S	160	2260

3.2. Properties of mortar mixture on hardened state

Compressive and flexural strength of mortar bars are the most important mechanical property of mortar mixtures, and they might be useful to determine concrete properties. The compressive and flexural strength of 3, 7 and 28 days old specimens of geopolymer mortar are summarized in Figure 2 and 3. Three samples from each mixture were taken to specify physical and flexural strength characteristics, while for compressive strength test six samples were used.

The ultrasonic pulse velocity test through hardened concrete or mortar is one of the most frequently used non-destructive methods for determination of its characteristics. It is also used for detection of defect inside the material mass or for evaluation of the depth of cracks occurring during service. In the cement composites, it cans serve for determination of the degree of hydration of cement, i.e. degrees of polymerization of geopolymer materials during monitoring of the hardening process. In this research, measuring of ultrasonic pulse velocity through mortar prisms at the age of 3, 7 and 28 days was performed immediately prior to mechanical strength testing. The results of bulk density and ultrasonic pulse velocity tests of hardened mortar prisms are provided in table 4.

Table 4 – Bulk density and ultrasonic pulse velocity of 3, 7 and 28 days old samples

Mixture	Temperature curing				Ambient curing			
	V (m/s)			Bulk density [kg/m^3]	V (m/s)			Bulk density [kg/m^3]
	3 days	7 days	28 days		3 days	7 days	28 days	
0S	3013	3072	3072	2095	2105	2931	3246	2110
25S	2947	2947	2986	2120	2319	3059	3279	2110
50S	2802	2868	2878	2165	2920	3285	3353	2155
75S	3013	3013	3042	2170	2462	2883	3383	2155
100S	3213	3213	3213	2230	2721	3299	3572	2230

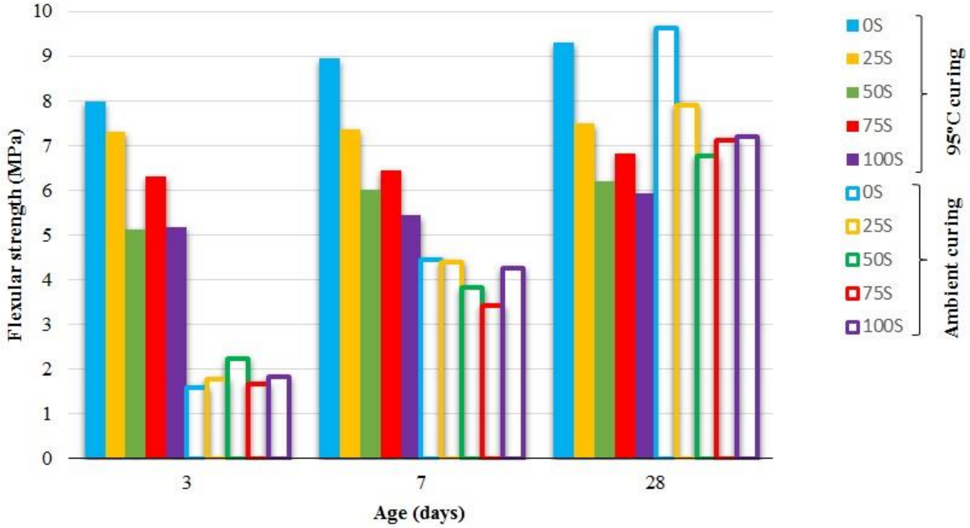

Figure 2 – Flexural strength diagram

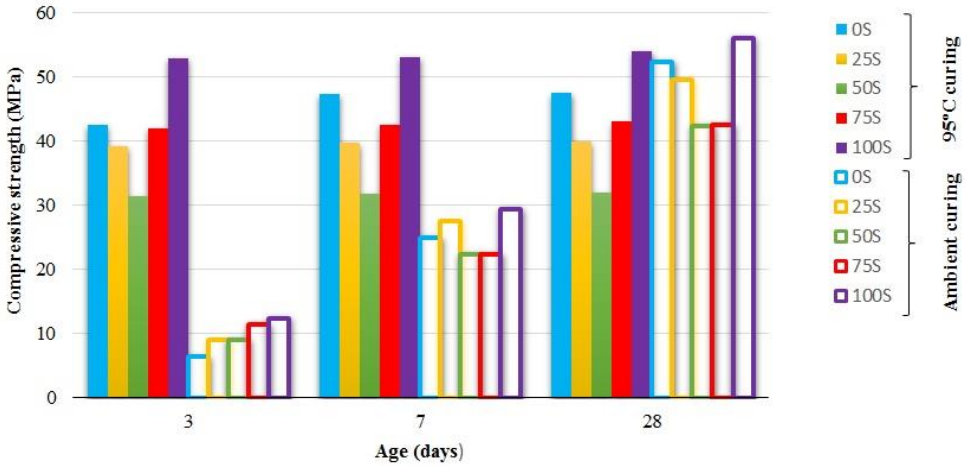

Figure 3 – Compressive strength diagram

4. DISCUSION OF RESULTS AND CONCLUSION

The workability testing results indicate that with the increase of granulated slag contents, increases the Flow Value, i.e. fluidity of mortar mixture. All the tested mortar mixtures have plastic consistence (Flow Value 140 – 200 mm) except the mixture designated as „0S“ which has stiff consistence. The lowest Flow Value has the mortar value made with only fly ash as a binder (125 mm), while the lowest value has the mixture with 100% of granulated slag (160 mm), Table 3. The reason lies in fly ash being a finer material than granulated slag, i.e. has more particles finer than 0.1 mm, so it requires higher amount of water for grain moistening which directly affects the workability of mortar mixture.

Bulk density of fresh mortar increases with the increase of share of granulated slag. The highest value of bulk density has the mixture with 100% of granulated slag, while the mixture made with fly ash only as a binder has the lowest value, Table 3. The difference in bulk density of mortar mixtures occurs because of the difference in specific gravity of granulated slag and fly ash which are respectively 2850 kg/m^3 and 2200 kg/m^3.

The differences in densities occurring in hardened mortar prisms having different replacement shares of fly ash with granulated slag are equivalent to the differences of densities of fresh mortar mixes.

Development of mechanical strengths largely depends on conditions of mortar sample curing. The samples submitted to temperature activation reached around 90% of strength already at the age of 3 days. There is an increase of strength from day 3 to day 28 of prism age, but it is small in comparison to first three days. The increase of strength of the samples which were all the time cured in ambient conditions is continuous. The strengths of these samples at the age of 3 and 7 days are considerably lower than those of the temperature activated samples. However, at the age of 28 days, the samples which were cured the entire time in ambient conditions, achieved around 5% higher strengths in comparison to the samples submitted to temperature activation. This is explained by the fact that temperature activation accelerates polymerization on one hand, but on the other it prevents its total completion.

Based on the test result presented in figure 2 it can be concluded that the highest flexural strength have the mixtures designated „0S“ at all the ages of samples and with both curing methods, except in case of the samples cured in ambient conditions at the age of 3 days where the highest value is exhibited by mixture designated as „50S“. In case of the samples submitted to temperature activation, the lowest value of flexural strength is exhibited the mixture designated „100S“ at all ages. In case of the samples cured in ambient conditions, the lowest value of flexural strength has the mortar mix designated „50S“ at the age of 28 days, i.e. mixture designated „75S“ at the age of 7 days.

The highest value of compressive strength have the mortar mixture designated as „100S“ at all ages of samples and with both curing methods, while the lowest value has the mixture designated as „50S“, except in the case of ambient cured samples at the age of 3 days where the lowest value has the mixture designated „0S“, figure 3. Granulated slag affects only the initial increase of compressive strength of mortar samples cured in ambient conditions, proportionally to the share percentage. The diagram form of compressive strength of the samples cured in ambient conditions at the age of 28 day corresponds to the diagram of compressive strength of temperature activated samples. The values of compressive strength of the samples cured in ambient conditions at the age of 28 days of the mortar mixtures designated as „0S“, „25S“ and „100S“ are higher than 50 MPa, while for „50S“ and „75S“ they are around 43MPa.

Ultrasonic pulse velocity testing was performed for reasons of monitoring the degree of binder polymerization during the hardening process. Ultrasonic pulse velocity through the sample primarily depends on bulk density, which can be seen from the test results presented in Table 4. In the mortar samples which were submitted to temperature activation, there are no large differences of the ultrasonic pulse velocity at different ages of samples of 3, 7 and 28 days. However, in the case of samples cured in ambient conditions, the increase of ultrasonic pulse velocity with the passage of time is clearly evident. At the age of 28 days, the ultrasonic pulse velocity of ambient cured samples is around 5% higher than the samples which were temperature activated. Variation of ultrasonic pulse velocity through mortar prisms follows the variation of mechanical strengths in time. It can be concluded that based on the ultrasonic pulse velocity, one can assess the degree of binder polymerization, and thus, the mechanical strength of mortar samples cured in ambient samples, at any age. The precondition is that the ultrasonic pulse velocity through the mortar prisms submitted to temperature action at the age of 3 days is known.

According to the obtained characteristics, one can conclude that geopolymer mortars based on FA and GGBFS can be a good substation for traditional cement mortars. Their usage is justified by good mechanical strengths and by their environmental properties, because they contribute to the concepts of development of green building and sustainable development.

It is necessary to continue monitoring of the samples cured in both ways at the age of 56, 90 and 150 days. It is also necessary to confirm the obtained results on the concrete mixes, by testing of all the physical and mechanical characteristics.

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