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APPLICATION OF SELF-PRODUCED ARTIFICIAL SAND IN THE PRODUCTION OF GREEN MORTAR

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Abstract. Due to the large disposal of locally industrial wastes and the shortage of natural resources, turning industrial by-products into green artificial materials has been attracting many researchers in the world. Following this trend, this study evaluated the potential application of self-produced artificial sand (AS) in the production of green mortar. The AS was produced by the alkali-activated method using a mixture of 36.4% fly ash, 36.4% slag, 3.5% 10M NaOH solution, 11% Na_2SiO_3 solution, and 12.7% water. The mortar mixtures were designed based on the densified mixture design algorithm with the incorporation of the AS as the substitution of natural sand (NS) by 0 – 100 wt.% (interval of 20%). The engineering properties of the mortar samples in both fresh and hardened states were evaluated through the tests of workability, compressive strength (CS), water absorption (WA), and shrinkage/ expansion. The experimental results showed that the mortar sample incorporating 20% of AS to replace NS performed superior engineering properties in comparison to other samples. Further increasing the AS content generally caused a negative impact on the mortar's performance. Increasing AS content beyond 20% systematically decreased the CS while both WA and expansion were increased noticeably. However, the properties of the green mortar produced for this study satisfied all of the requirements of the official Vietnamese standards. Thus, the research results further confirmed a great potential in producing green mortar using AS to either partially or fully replacement of NS. In addition, the use of AS greatly contributes to not only saving natural resources but also limiting the negative effects on the environment due to the exploitation and use of naturally sourced materials.

Keywords: artificial sand, green mortar, natural sand, alkali-activated method.

1. INTRODUCTION

Mortar, a bonding agent between building materials, is normally a mixture of water, fine aggregate, and binding material like cement, lime, etc. So far, the applications of mortar in various construction phases have made it a very important civil engineering material. In the last decades, due to the increasing cost of raw materials and the continuous reduction of natural resources, the recycling of industrial solid wastes has become an interesting option for the building industry. Several industrial by-products, e.g. fly ash and granulated blast furnace slag after adequate treatment, have shown to be suitable as construction materials and readily follow the design requirements [1]. In particular, the large growth in the use of artificial materials has generated a growing interest worldwide in reusing the various types of recycled materials.

Several studies have already presented the impact of artificial aggregate (AA) on the mechanical features of mortar and concrete [2-5]. Ipek et al. [2] produced artificial lightweight aggregate through the cold bonding palletization method for lightweight aggregate concrete (LAC) production. They found that the strength values of LAC were comparable to that of the normal aggregate concrete. Iucolano et al. [3] used recycled plastic aggregate (RPA) to partially replace natural aggregate in hydraulic mortars. The study found that the incorporation of RPA improved insulation performance and enhanced water vapor permeability, leading to the reduction in both the flexural strength and CS of the mortars. Agricultural solid waste of oil palm shell (OPS) was used as an AA in LAC [4]. The study found that using OPS increased the density, strength, and drying shrinkage strain of the concrete while decreasing the modulus of elasticity of the LAC. In addition, fine bottom ash (FBA) was also used as a fine aggregate in a mortar [5]. The inclusion of FBA increased the flowability and CS of the mortar as compared to the normal fine aggregate mortar. Moreover, the FBA mortar absorbed water with a slower process than the mortar with normal aggregate.

AAs are being used widely because of their advantages in building constructions. To provide an additional way of producing and applying AA into the literature sources, the present study evaluated the potential application of self-produced artificial sand (AS) using the alkali-activated method in green mortar. Thus, the effect of partial and full substitution of NS by AS on the engineering properties of the mortar samples in both fresh and hardened states was investigated.

2. EXPERIMENTAL DETAILS

2.1. Properties of materials

In this study, the mortar samples were prepared using various proportions of cement, fly ash (FA), slag, natural sand (NS), AS, water, and a commercial superplasticizer (SP) of type Sikament R4. Characteristics of both binder materials (cement, FA, and slag) and fine aggregates (NS and AS) are shown in Tables 1 and 2, respectively.

It is noticed that cement and slag contain a high content of CaO, while the main component of FA is SiO_2 and Al_2O_3. Besides, the spherical and smooth shape of FA may support the flowability of the mortar mixture [6]. Locally available crushed sand was used as NS and the AS was produced by the alkali-activated method using a mixture of 36.4% FA, 36.4% slag, 3.5% 10M NaOH solution, 11% Na_2SiO_3 solution, and 12.7% water. Both NS and AS with a maximum size of 5 mm were utilized as the fine aggregates and they were in saturated surface dry condition. The particle size distribution of both NS and AS is presented in Fig. 1. Table 2 also shows that the AS had a lower density and a higher WA rate than the NS. These properties of the AS may negatively affect the engineering properties of the mortar.

Table 1. Characteristics of raw materials.

Items		Cement	Slag	FA
Specific gravity		3.07	2.86	2.13
Chemical compositions (wt.%)	**SiO_2**	23.5	35.9	59.2
	Al_2O_3	6.0	13.0	26.7
	Fe_2O_3	3.7	0.3	6.1
	CaO	59.9	38.1	1.1
	MgO	2.0	8.0	0.9
	SO_3	-	-	0.1
	Others	4.9	4.7	5.9

Table 2. Physical properties of fine aggregates.

Properties	Density (g/cm^3)	Water absorption (%)	Fineness modulus
NS	2.79	3.52	3.61
AS	2.45	16.88	3.95

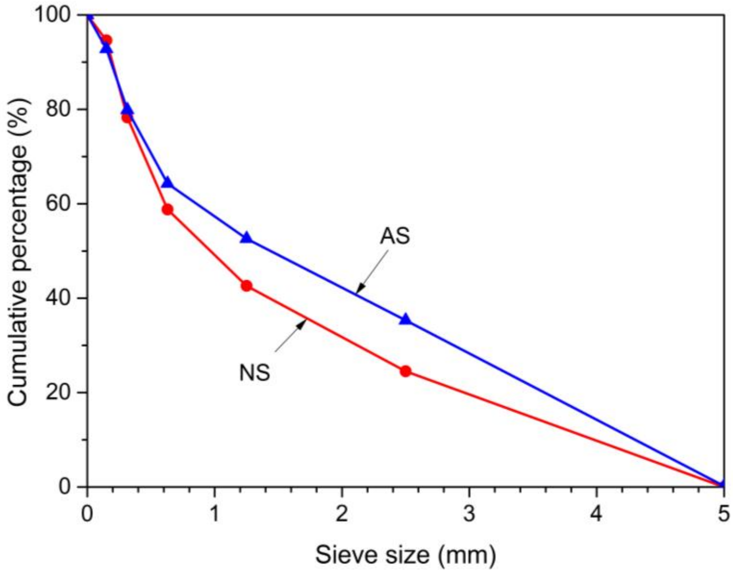

Figure 1. Particle size distribution of NS and AS.

2.2. Mix design and proportions

Six mortar mixtures (CNT00, CNT20, CNT40, CNT60, CNT80, and CNT100) were designed by replacing NS with AS at different percentages (0 – 100 wt.% with an interval of 20%). It is known that the properties of the mortar were enhanced if its density reaches the maximum value [7]. Therefore, a densified mixture design algorithm (DMDA) [7, 8] was applied for the proportioning of the mortar's ingredients (Table 3). In this study, DMDA used FA to fill the voids between fine aggregate particles and then using blended FA-fine aggregate to fill the voids between coarse aggregate particles to minimize the porosity and ensure the good engineering properties of the mortars [9]. Besides, slag was used to replace 20% of cement in the mortar mixtures based on the performance of the mortar samples during the pre-trial work in the laboratory. On the other hand, various dosages of SP were used to control the flow diameter of all mortar mixtures within the ranges of 19 ± 1 cm as the mortar can be used for different applications [10].

Table 3. Mixture proportions of green mortars.

Mix ID.	Water/ binder	Materials (kg/m^3)						
		Cement	Slag	FA	NS	AS	Water	SP
CNT00	0.35	371.3	92.9	143.8	1568.6	0.0	212.8	4.6
CNT20		365.6	91.5	141.7	1235.9	308.9	209.6	4.4
CNT40		360.5	90.2	139.7	913.8	609.2	206.6	3.1
CNT60		355.6	89.0	137.8	601.0	901.5	203.8	1.3
CNT80		350.6	87.7	135.8	296.2	1185.1	201.0	0.6
CNT100		345.7	86.5	133.9	0.0	1460.5	198.1	0.0

2.3. Samples preparation and test methods

The mortar samples were prepared by the following processes: Firstly, all binder materials were dry-mixed for a minute. Water and SP were mixed to create a liquid before being used. Then, two-third of the liquid was gradually added into the mixing bowl and mixed for another one minute. Afterward, fine aggregates were added to the mixture followed by the last part of the liquid, and continuously mixed for additional three minutes to obtain a homogenous mixture. After mixing, the fresh mortar mixtures were checked for workability based on TCVN 3121-3:2003 [11], and then the mortar samples were cast in different sizes as prism samples of 40×40×160 mm were prepared for testing of CS and WA and prism samples of 25×25×285 mm were prepared for monitoring the shrinkage/ expansion.

CS and shrinkage/ expansion of the mortar samples were measured at 1, 3, 7, 14, and 28 days following the guidelines of TCVN 3121-11:2003 [12] and TCVN 8824:2011 [13], respectively. The WA test was performed at 28 days following TCVN 3121-18:2003 [14]. It is noted that the average value of three repeated measurements for each test program was used as the final value herein.

3. RESULTS AND DISCUSSION

3.1. Workability

The workability of the mortar mixtures was checked right after mixing and presented in Fig. 2. As expected, the flow diameter values of all mortar mixtures were recorded at 19 ± 1 cm as the target of the mix design is to ensure the homogeneity of the mixtures and ease for job site application. Fig. 2 also reveals that the dosage of SP decreased with the increase in AS content. As above mentioned, the AS used in this study was in saturated surface dry condition and the WA of AS was much higher than that of NS. Also, the amount of fine powder in AS was less than in NS. Thus, under a similar range of flow diameter, the use of more AS to replace NS required less SP.

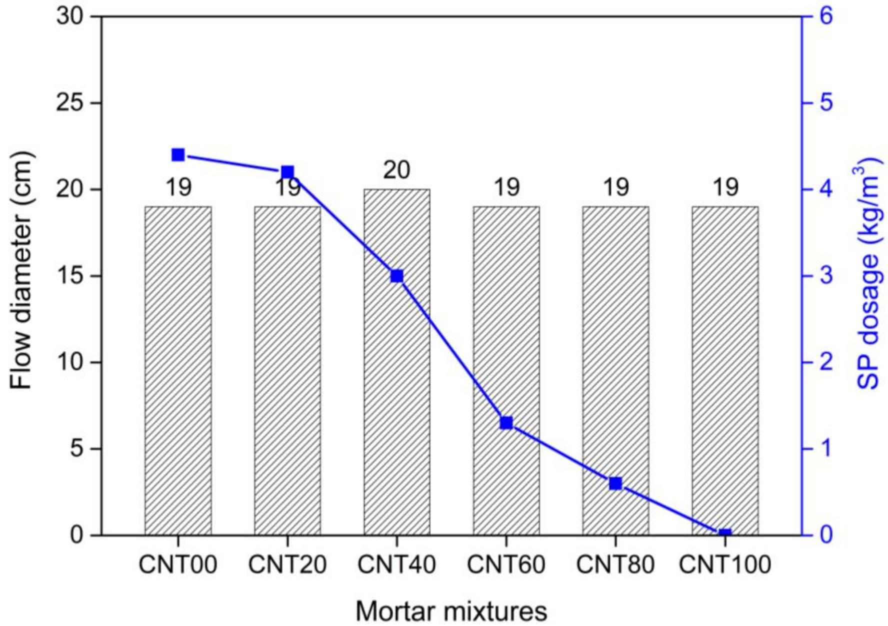

Figure 2. The slump flow of mortar mixtures.

3.2. Compressive strength

The CS development of the mortars with different AS contents is presented in Fig. 3. There was a general trend of increasing strength with curing age for all mortar samples. The increase in the CS of mortar samples was noted owing to the cement hydration, the pozzolanic reaction of FA and slag, and the strength of AS as well. It is believed that these hydration processes generated C-S-H gel, which filled internal pores and enhanced the connection between the aggregates. As a result, the mortar's strength was improved [15].

The 28-day CS of the 100% NS sample was 47.05 MPa while the CS values of the mortars incorporating 20, 40, 60, 80, and 100% AS were 47.61, 37.93, 26.12, 23.47, and 14.87 MPa, respectively. Replacing 20% of NS by AS was found to improve the CS of the mortars. This improvement may be explained as (i) the content of AS in this sample was the lowest among the mixtures. In this case, fine grains of NS could fill the pores created by the AS, reducing the number of pores and increasing the strength of the mortars; and (ii) the hydration of cementitious materials (cement, FA, and slag) together with the continuous development in the strength of the AS formed the C-S-H gel, which filled the internal voids/ pores of the samples and reinforced the mortar structure [15]. However, further increasing the replacement level caused a reduction in the mortar's strength. This phenomenon may be due to the lower CS and modulus of elasticity of AS in comparison to the NS [16, 17]. In addition, the AS was made from FA and slag, which was weaker than the matrix of NS [18]. Another possible reason is that the fineness modulus and particle size distribution of the aggregate matrix were changed by adding AS and thus making the samples weaker due to the appearance of pores [15].

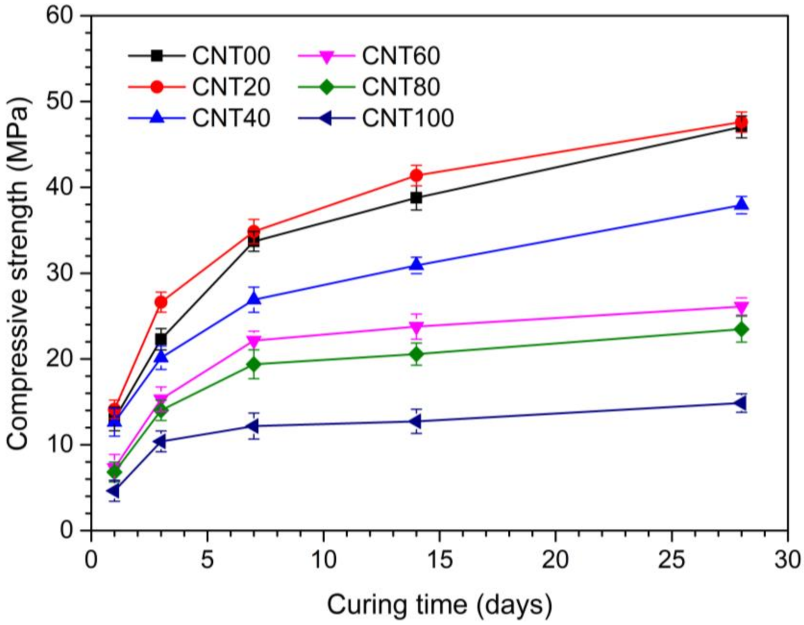

Figure 3. CS of the mortars.

3.3. Water absorption

The effect of AS content on the WA of the 28-day mortar samples was presented in Fig. 4. The WA rate of the AS-free mortars was 4.37%. The mortar samples with 20% AS and 80% NS achieved the lowest WA value of 4.06%. Since the transport properties of mortar were strongly dependent on its pore structure, the least permeability of the previously mentioned 20% AS mortar could be attributed to the decreased pore structures owing to the C-S-H created from the hydration of cementitious materials as well as the enhanced gradation. However, at the NS replacement level by AS of beyond 20%, the WA of the mortars increased significantly and it was found that the more the AS content, the higher the WA rate of the mortars. The mortars with 40, 60, 80, and 100% AS had WA rates of approximately 38, 122, 167, and 192% higher than the no AS samples, respectively. This was mainly due to the much higher WA capacity of the AS as compared to that of the NS. Previous studies also pointed out that the internal structure of AS was more porous than that of NS [19, 20]. The less compactness of the system caused by the incorporation of more AS could be another reason for the higher WA rates of the mortars.

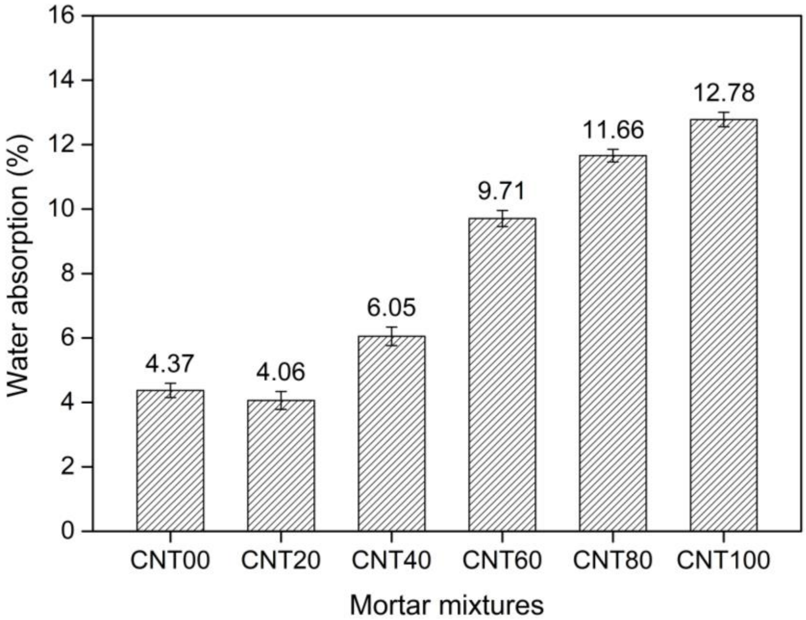

Figure 4. WA of the mortars.

3.4. Shrinkage/ expansion

The change in length of mortar samples was demonstrated in Fig. 5. The length change values of 28-day samples with 0, 40, 60, 80, and 100% AS were 0.022, 0.029, 0.043, 0.051, and 0.057%, respectively. Generally, it could be said that the mortar samples containing more AS tended to expand at higher rates. The expansion may be caused by (i) the hydration heat generated during the reaction process of the cementitious materials [21] and (ii) the increased void volume with the incorporation of high AS content. In addition, the presence of high content of Na_2O in AS may form a water-absorbing gel in the hardened mortars, causing expansion [22]. On the other hand, this study found that the mortar with 20% AS had the smallest change in length (only 0.014%) among the samples due to the presence of optimal C-S-H gel and a more compact structure.

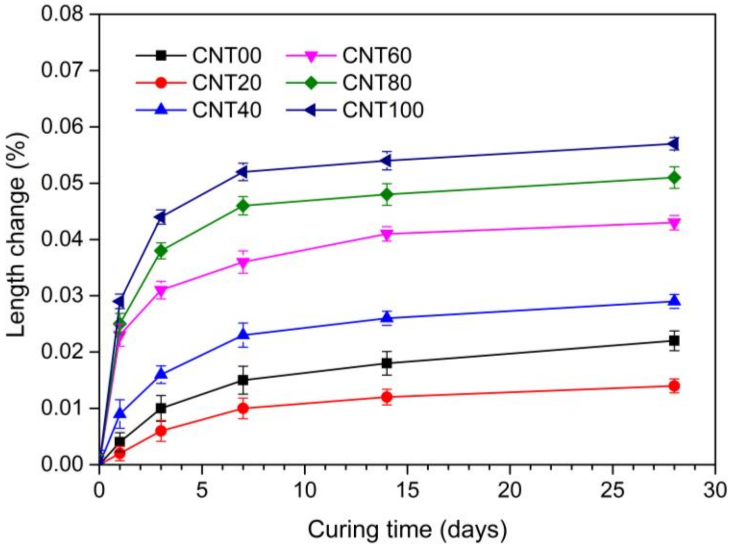

Figure 5. Change in length of the mortars.

4. CONCLUSION

The potential application of self-produced AS using the alkali-activated method in the green mortar was investigated in this study. The experimental results showed that (i) the workability of the mortar mixtures increased with the higher replacement level of NS by AS. Therefore, at a similar flow diameter, a lower quantity of SP was required when using more AS in the mortar mixture; (ii) The 28-day CS, WA, and length change values of the mortars were in the ranges of 14.87 – 47.61 MPa, 4.06 – 12.78%, and 0.014 – 0.057%, respectively. In which, the mortar samples with 20% AS exhibited the best engineering performance among the mortar samples; (iii) The properties of the mortar produced for this study satisfied the requirements of the TCVN 4314:2003 in terms of workability and compressive strength and further demonstrated great potential in producing green mortar using AS to fully replace NS.

REFERENCES

[1]. V. W. Y. Tam et al., Effect of fly ash and slag on concrete: Properties and emission analyses, Frontiers of Engineering Management, 6 (2019) 395-405. https://doi.org/10.1007/s42524-019-0019-2

[2]. S. Ipek, O. A. Ayodele, K. Mermerdaş, Influence of artificial aggregate on mechanical, properties, fracture parameters and bond strength of concretes, Construction and Building Materials, 238 (2020) 117756. https://doi.org/10.1016/j.conbuildmat.2019.117756

[3]. F. Iucolano et al., Recycled plastic aggregate in mortars composition: Effect on physical and mechanical properties, Materials and Design, 52 (2013) 916-922. https://doi.org/10.1016/j.matdes.2013.06.025

[4]. P. Shafigh et al., Oil palm shell as an agricultural solid waste in artificial lightweight aggregate concrete, European Journal of Environmental and Civil Engineering, 22 (2016) 165-180. https://doi.org/10.1080/19648189.2016.1182084

[5]. H. K. Kim, J. H. Jeon, H. K. Lee, Flow, water absorption, and mechanical characteristics of normal- and high-strength mortar incorporating fine bottom ash aggregates, Construction and Building Materials, 26 (2012) 249-256. https://doi.org/10.1016/j.conbuildmat.2011.06.019

[6]. V. A. Tran et al., Effect of fly ash on physical and mechanical properties of mortar, The University of Danang, Journal of Science and Technology, 17 (2019) 35-38. http://doi.org/10.31130/JST-UDE2018-292

[7]. C. L. Hwang, M. F. Hung, Durability design and performance of self-consolidating lightweight concrete, Construction and Building Material, 19 (2005) 619-626. https://doi.org/10.1016/j.conbuildmat.2005.01.003

[8]. C. L. Hwang, M. F. Hung, Y. Y. Chen, The Comparison of ACI mixture design algorithm to HPC densified mixture design algorithm in the anti-corrosion and durability design, Journal of Chinese Corrosion Engineering, 16 (2002) 281-296. https://www.researchgate.net/publication/293649133_The_Comparison_of_ACI_Mixture_Design_Algorithm_to_HPC_Densified_Mixture_Design_Algorithm_in_the_Anti-corrosion_and_Durability_Design

[9]. C. L. Hwang, T. P. Huynh, Investigation into the use of unground rice husk ash to produce eco-friendly construction bricks, Construction and Building Material, 93 (2005) 335-341. https://doi.org/10.1016/j.conbuildmat.2015.04.061

[10]. TCVN 4314:2003, Mortar for masonry - Specifications, Ministry of Science and Technology, Vietnam, 2003. (In Vietnamese).

[11]. TCVN 3121-3:2003, Mortar for masonry - Test methods. Part 3: Determination of consistence of fresh mortar (by flow table), Ministry of Science and Technology, Vietnam, 2003. (In Vietnamese).

[12]. TCVN 3121-11:2003, Mortar for masonry - Test methods. Part 11: Determination of flexural and compressive strength of hardened mortars, Ministry of Science and Technology, Vietnam, 2003. (In Vietnamese).

[13]. TCVN 8824:2011, Cements - Test method for drying shrinkage of mortar, Ministry of Science and Technology, Vietnam, 2011. (In Vietnamese).

[14]. TCVN 3121-18:2003, Mortar for masonry - Test methods. Part 18: Determination of water absorption of hardened mortars, Ministry of Science and Technology, Vietnam, 2003. (In Vietnamese).

[15]. L. Zeghichi, The effect of replacement of naturals aggregates by slag products on the strength of concrete, Asian Journal of Civil Engineering, 7 (2006) 27-35. https://www.sid.ir/en/Journal/ViewPaper.aspx?ID=48903

[16]. N. U. Kockal, T. Ozturan, Durability of lightweight concretes with lightweight fly ash aggregates, Construction and Building Materials, 25 (2011) 1430-1438. https://doi.org/10.1016/j.conbuildmat.2010.09.022

[17]. E. Guneyisi et al., Influence of the artificial lightweight aggregate on fresh properties and compressive strength of the self-compacting mortars, Construction and Building Materials, 116 (2016) 151-158. https://doi.org/10.1016/j.conbuildmat.2016.04.140

[18]. M. Gesoglu, T. Özturan, E. Guneyisi, Shrinkage cracking of lightweight concrete made with cold-bonded fly ash aggregate, Cement and Concrete Research, 34 (2004) 1121-1130. https://doi.org/10.1016/j.cemconres.2003.11.024

[19]. U. S. Agrawal, S. P. Wanjari, D. N. Naresh, Characteristic study of geopolymer fly ash sand as a replacement to natural river sand, Construction and Building Materials, 150 (2017) 681-688. https://doi.org/10.1016/j.conbuildmat.2017.06.029

[20]. O. H. Oren et al., Physical and mechanical properties of foam concretes containing granulated blast furnace slag as fine aggregate, Construction and Building Materials, 238 (2020) 117774. https://doi.org/10.1016/j.conbuildmat.2019.117774

[21]. I. Yuksel, T. Bilir, O. Ozkan, Durability of concrete incorporating non-ground blast furnace slag and bottom ash as fine aggregate, Building and Environment, 42 (2007) 2651-2659. https://doi.org/10.1016/j.buildenv.2006.07.003

[22]. S. Sakir et al., Utilization of by-products and wastes as supplementary cementitious materials in structural mortar for sustainable construction, Sustainability, 12 (2020) 3888. https://doi.org/10.3390/su12093888