Microsc. Microanal. Res. 2020, 33(1) 13-17

Microscopy and Microanalysis Research
- The Journal of The Microscopy Society of Thailand

Journal Home Page: https://www.tci-thaijo.org/index.php/mmres/

Microsc. Microanal. Res.

Microstructure and strength behavior of steel slag mortar containing waste sand

J.Chanet, A. Jansamoot, A. Kerdkla, J. Ayawanna, S. Chaiyaput and N. Kingnoi*

School of Ceramic Engineering, Institute of Engineering, Suranaree University of Technology, Muang, Nakhon Ratchasima 30000, Thailand.

*Corresponding author's e-mail address: namthipkingnoi@hotmail.com

ARTICLE INFO

Article history
Submitted: 25 February 2020
Revised: 7 May 2020
Accepted: 8 May 2020
Available online: 25 June 2020

Keywords:
mortar; sand; steel slag; cement; compressive strength; microstructure

ABSTRACT

This study deals with the production of mortars containing steel slag (SS) as replacement of Ordinary Portland Cement (OPC) and mortars containing waste sand (WS) as an ordinary construction sand (CS). Four compositions of the mortar mixes of OPC:CS, OPC:WS, SS:CS and SS:WS were prepared in a weight ratio of 1:2.75 using a fixed water content of 0.485 by weight. The compressive strength and microstructure of samples from different aging time for 1, 7, 14 and 28 days in air and lime water were evaluated. The WS containing mortars showed higher flow percent values and longer setting time than the ordinary CS containing mortars. The compressive strength values of OPC mortars using CS mortars was better than those of slag mortars using CS and WS. The compressive strength increases with an increase in the curing time, the highest strength was 28 days-curing. Also, the mortars curing in air had higher compressive strength than the mortars curing in lime water. The observed microstructure revealed crystal-like calcium silicate hydrate (CSH) phase promoting strength in OPC mortars. Meanwhile, calcium hydroxide ($Ca(OH)_2$)-like crystals and needle-like ettringite crystals were observed in the slag mortars with low strength of the slag mortars both curing in air and lime water.

INTRODUCTION

Mortar is a bonding material used in masonry construction to provide strength of the structure and to resist all the loads coming over without disintegration. Mortars are typically made from a mixture of sand, cement or lime and water. In mortar, cement is used as a binding material, while sand is used as fine aggregates, inert material for increasing the volume of mortar for the economic reason and preventing the mortar from high shrinkage and cracking [1].

Waste sand (WS) is previously used as a molten-steel casting mold that cannot be recycled in the steel casting process. The WS contained sodium silicate binding agent and high silica, which is similar to an ordinary construction sand (CS). In case of steel slag (SS), it is one of the by-products containing high content of lime (CaO) from the steel refining process [2]. The SS is an enrich CaO slag since it is produced from the final stage in which lime (CaO) and dolomitic limestone ($CaMg(CO_3)_2$) are added in the electric furnace during steel making [3]. It also has silica (SiO_2) and iron oxide (Fe_2O_3) similar to the composition in Ordinary Portland Cement (OPC) [4]. This indicates that the steel slag can be used as a supplementary cementing material in civil engineering work [5].

Base on the composition of typical mortars, the SS from Siam Yamato Steel Company Limited (Rayong, Thailand), the WS from Metallurgical Laboratory (Suranaree University of Technology, Thailand) (Figure 1) and common OPC type I were proposed to use in the mortar mixes. The interesting compositions of those two waste materials from steel industry led the researcher to study the possibility of using the SS as an OPC replacement material, and using WS as a construction sand replacement material for the production of mortars. In this work, SS was entirely replaced OPC and waste sand was entirely replaced ordinary sand in order to observe extreme behaviour of mortar mixes prior to further development of mortar compositions. Therefore, four compositions of the mortar mixes; OPC:CS, OPC:WS, SS:CS and SS:WS were prepared. The relationship between compressive strength and microstructure of above four different mortars were discussed and reported.

METHODOLOGY

Chemical analysis of WS and SS passing through 40-mesh sieve (< 400 μm) and OPC were confirmed using X-ray fluorescence Spectrometer (XRF; Rigaku, ZSXPrimus IV) Crystalline phases of those raw materials were investigated using X-ray diffractometer (XRD; A Bruker D8 ADVANCE). SS were entirely used in the mortar mixes as replacement of OPC, whereas WS were entirely used in as CS replacement material in the mortar mixes leading to four compositions of the mortar mixes; OPC: CS, OPC:WS, SS:CS and SS:WS. All mortar mixes were prepared in a weight ratio of 1:2.75 using a fixed water content of 0.485 by weight. The flow table test was carried out on each

Figure 1. Steel slag and waste sand from steel casting process.

mortar batch. The compressive strength of cube specimens (50 mm x 50 mm) after different aging times for 1, 7, 14 and 28 days in air (The samples were covered with 3-layers of transparent plastic film leaving in room temperature) and soaking in lime water was determined using a compression machine (ELE, Germany). Microstructures of the mortars at different curing ages were examined by scanning electron microscopy (SEM JEOL JSM6010 LV) accompanied with an elemental analysis by Energy dispersive X-ray spectroscopy (EDS).

RESULTS AND DISCUSSION

Chemical and Phase compositions

The chemical compositions of OPC and SS determined from XRF technique are shown in Table 1. OPC and SS contained relatively similar quantity of CaO, Al_2O_3 SO_3 compositions, but difference in SiO_2, Fe_2O_3 and MgO contents. However, the presence of CaO in OPC and SS were found in different forms as shown in Figure 1. Dicalcium silicate (2CaO. SiO_2; C_2S) Tricalcium silicate (3CaO. SiO_2; C_3S) phases and Tricalcium aluminate (3CaO. Al_2O_3; C_3A) were major phases in OPC, meanwhile calcium oxide or lime (CaO) and C_3A were mostly detected in SS.

Flow ability

Flow ability of fresh mortar with different sand types were determined by flow table test and shown in Table 2. The flow percent values were higher in the WS containing mortars that made the WS mortars took longer setting time than the CS containing mortars. This result evidently indicates that the WS containing mortar had low-water retention compared with the CS containing mortar. Thus, the hydration reaction easily took place generating calcium silicate hydrate (CSH) strength phase in the CS containing mortars.

Compressive strength

The compressive strength and curing time of four different mortar mixes are shown in Figure 2. The compressive strength values of CS mortars were higher than those of WS mortars. This could be explained by the lower water retention leading to the slowdown of the hydration reaction in the WS containing mortars. In case of the SS mortars, the lower compressive strength was observed compared to the OPC mortars. It was due to the SS contained higher CaO compound or free-lime

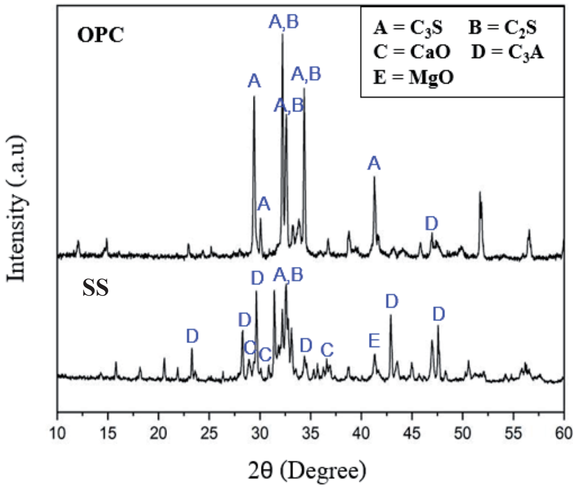

Figure 1. XRD pattern of ordinary Portland cement (OPC) and steel slag (SS).

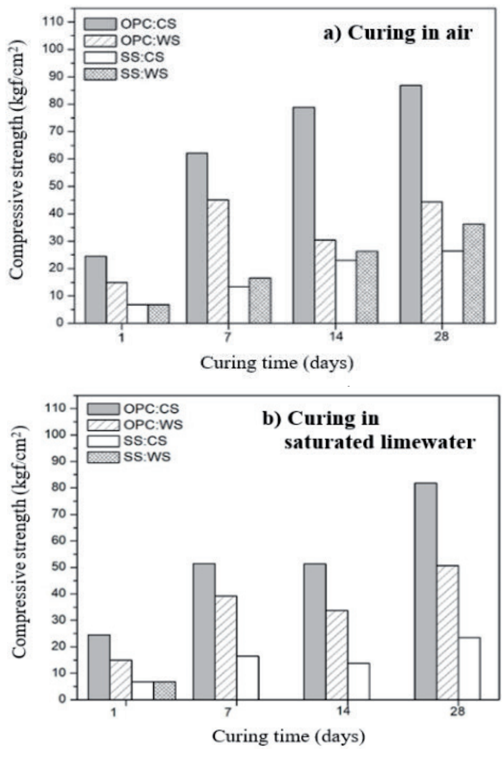

Figure 2. Compressive strength of four different mortar mixes with curing time for 1, 7, 14 and 28 days: (a) curing in air and (b) curing in lime water.

Table 1. Chemical compositions of Portland ordinary cement (OPC) and steel slag (SS).

Raw materials	Oxides, wt.%							
	CaO	SiO_2	Fe_2O_3	Al_2O_3	SO_3	MgO	CO_2	Other
OPC	57.41	15.59	2.91	3.75	3.63	1.21	10.61	4.90
SS	58.38	20.65	0.43	4.19	3.84	5.79	8.44	-

Table 2. Flow ability of Portland ordinary cement (OPC) and steel slag (SS).

Formula	OPC (g)	CS (g)	WS (g)	Water (ml)	Average flow table (%)
OPC:CS	250	690	-	210	115.18
OPC:WS	250	-	690	210	122.10

acting as a hydration retarder in the SS mortar [6]. The compressive strength values of all mortars were similar at the first day of curing both in air and lime water. The strength was continually much increased with an increase of curing time in air. In contrast, the highest strength was developed up to 7 days-curing in the lime water, beyond which, the strength started decreasing with further curing day. The slow hydration reaction of SS and low water retention of the WS were suspected to be a cause of deteriorated strength in the SS/WS mortar mixes after 7-days curing in lime water. Although curing in lime water is known to give higher strength than curing in air due to the water aiding the hydration, the lime water in this work was not confirmed to have enough lime saturation, then Ca^{2+} ions in the mortars could probably be leached out in a few days after soaking in lime water. Low concentrations of Ca^{2+} especially at early hydration stage produced low hydration reaction and decreased strength [7]. In contrast, the mortars covered with 3-layers of transparent plastic film during curing in air at room temperature probably affected water retention and aiding the hydration without Ca^{2+} ion leaching out, and therefore the compressive strength was higher under the air curing condition.

Microstructure

SEM images of four different mortar mixes curing for 7 and 14 days in air and in lime water are demonstrated in Figure 3 and 4, respectively. Overall microstructure showed that the crystal-like CSH phase (“A”) promoting strength was observed in the OPC mortars.

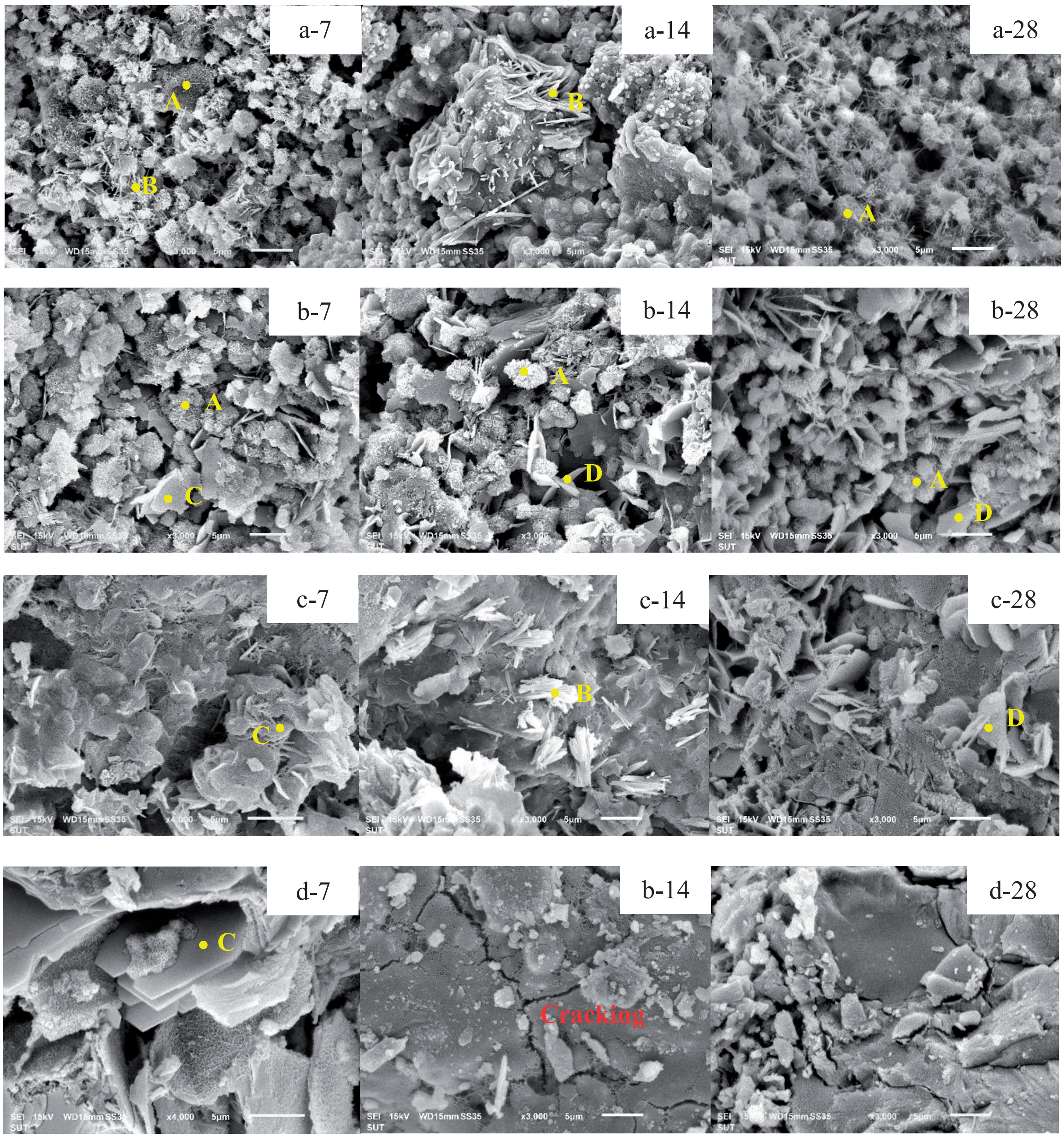

Figure 3. SEM images of different mortars mixes (a) OPC/CS, (b) OPC/WS, (c) SS/CS and (d) SS/WS curing in air for 7, 14 and 28 days.

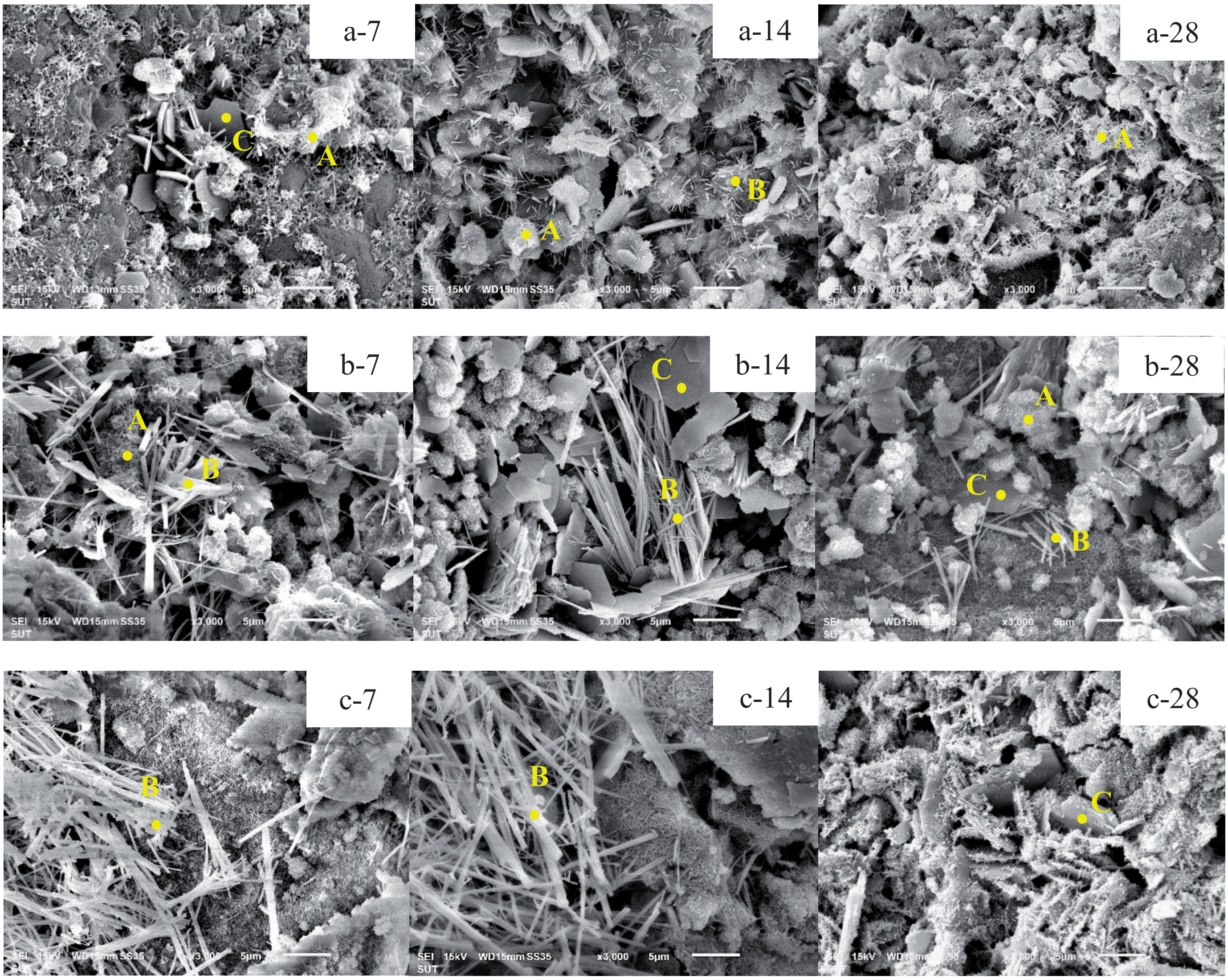

Figure 4. SEM images of different mortars mixes (a) OPC/CS, (b) OPC/WS, (c) SS/CS curing in lime water for 7, 14 and 28 days.

Meanwhile, crystal-like calcium hydroxide ($Ca(OH)_2$) phase ("C"), which is not served the strength, was observed in the SS mortars. Also, the formation of needle-like ettringite crystals ("B") and monosulfate ("D") from ettringite development were observed in both OPC mortars and SS mortars. This was due to a presence of C_3A phase in both OPC and SS raw materials as well [8].

As evidence from the microstructures, low strength values of the SS mortar both curing in air and lime water were caused by low hydration activity leading to the absence of CSH binding phase and remaining of needle-like ettringite crystals in the SS mortars as shown by the relationship in Figure 5. CSH as a result of the hydration reaction between silicate phase in OPC and water was observed as a main phase in OPC mortars. Meanwhile, the reaction in SS mortar mixes generated $Ca(OH)_2$ as a result of the reaction between free lime in SS and water. Once this reaction finished, the volume expansion and cracking were developed in the SS mortars leading to the extremely deteriorated strength [9]. This behavior was obviously observed in the SS/WS mortars with huge cracks after curing in air and the whole structure was totally damaged while curing in the lime water.

CONCLUSIONS

In this study, the steel slag and waste sand were used in the mortar mixes in order to study the possibility of using the steel slag and waste sand for the production of mortars. Four compositions of the mortar mixes of OPC:CS, OPC:WS, SS:CS and SS:WS were prepared and tested in different aging time for 1, 7, 14 and 28 days in air and lime water. The findings are as follows:

1. The mortar containing waste sand has low water retention and low hydration activity leading to poor compressive strength compared to the construction sand mortars.

2. The compressive strength of OPC mortars was higher than that of the steel slag mortars. The compressive strength increased continuously during 28-days curing in air and in limewater.

3. The difference in microstructures of OPC mortar and the steel slag mortars contributed to the different compressive strength was obviously observed.

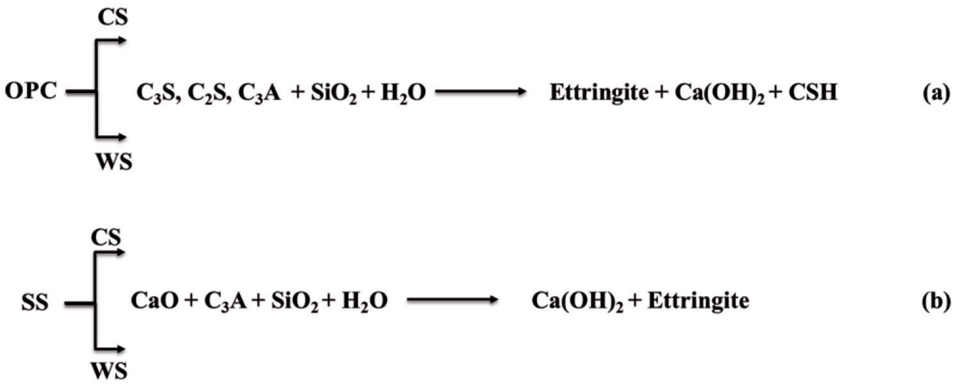

Figure 5. Hydration activity in (a) OPC mortar mixes and (b) SS mortar mixes.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Suranaree University of Technology for their funding support.

REFERENCES

[1] Imrose B. Muhit, Muhammad T. Raihan and MD. Nuruzzama, Determination of mortar strength using stone dust as a partially replaced material for cement and sand, *Advances in Concrete Construction,* **2014**, 2, 249-259.

[2] Á. Rodriguez, J.M. Manso, Á. Aragón, J.J. Gonzalez, Strength and workability of masonry mortars manufactured with ladle furnace slag. *Resources, Conservation and Reclying*, **2009**, 53, 645-651.

[3] Radenovic, A., Malina, J., Sofilic, T., and Sorrell, C., *Characterization of ladle furnace slag from carbon steel production as a potential adsorbent,* Advance in Materials Science and Engineering. 2013, 1-6.

[4] M.E. Parron-Rubio, F. Perez-Garcia, A. Gonzalez-Herrera, M.D. Rubio-Cintas, Concrete properties comparison when substituting a 25% cement with slag from different provenances, *Materials*, **2018**, 11, 1-11.

[5] Serjun, V.Z., Mirti, B., and Mladenovi, A., *Evaluation of ladle slag as a potential material for building and civil engineering*, Material and Technology, 2013, 47(5): 543-550.

[6] S. Maschio, E. Aneggi, L. Fedrizzi, F. Andreatta, M. Lekka, A. Lanzutti, E. Furlani, Production and compressive strength of mortars containing unprocessed waste powdered steel slag, *Sustainability*, **2017**, 7, 1-11.

[7] Mark B., Kevern J. T., Eric O.A., Effect of Curing Environment on the Strength Properties of Cement and Cement Extenders Mater. Sci. Applications, **2015**, 6, 33-39.

[8] Md.A. Hasan, Md.M. Islam, Md.H. Kabir, Md.S. Islam, Strength behavior of mortar using slag as partial replacement of sand, 1st Int. Conf. Adv. Civil Eng., **2012**.

[9] Joseph F. Lamond, J.H. Pielert, *Significance of Tests and Properties of Concrete and Concrete-making Materials,* ASTM international, 2006.