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AN INVESTIGATION OF FLY ASH AND LIGHTWEIGHT SAND ON HIGH-PERFORMANCE MORTAR

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Abstract. A high-performance mortar with high compressive strength and high flow is often used for repairing cracks, filling in the gap of a splice sleeve, and joints of precast concrete structures. In this study, a high-performance mortar with a compressive strength greater than 80 MPa was designed based on traditional sand, cement, water, and industrial wastes such as fly ash from thermal power plants. The mortar mixtures were studied based on practical investigation. The traditional sand was then replaced by lightweight sand from black lava stone to investigate the internal curing effect. The mortar which included 29.7%, 19.8%, and 5.5% of the unit volume for traditional sand, lightweight sand, and fly ash, respectively, satisfied the strength requirement. A 1% superplasticizer by weight of cement was adequate to create a flowable mortar. A suitable amount of lightweight sand in a mortar mixture could contribute to the compressive strength of the high performance mortar through internal curing.

Keywords: high-performance mortar, fly ash, lightweight sand, internal curing, compressive strength, slump flow.

1. INTRODUCTION

Cementitious construction materials, such as concrete or mortar, are still important materials to construct structures in civil engineering such as road and bridge structures, buildings, and ports. Concrete for reinforced concrete structures is a composite material primarily composed of fine and coarse aggregates and bonding material from cement and water. Meanwhile, cementitious mortar is mainly composed of sand, a cement binder, and water. Low-strength cementitious mortar is used to construct walls, fences, walkways and so on. Meanwhile, high-strength cementitious mortar is applied for special conditions such as concrete stitches and joints in precast concrete structures, filled mortar for splice sleeves and repairing cracks.

Nowadays, the properties of cementitious mortar have been constantly improved to enhance the capacity and durability of structures and reduce the cost of a project. High-performance cementitious mortar, including high strength, durability and workability, has normally been developed. Compressive strength is one of the important properties of high-performance mortar. The compressive strength of filled mortar for splice sleeves in some research projects was conducted from 45MPa to 84MPa [1]. The use of high-performance mortar to connect transverse joints for prefabricated concrete bridges with a desired compressive strength of 80 MPa was proposed by Choi *et al.* [2]. Therefore, the compressive strength of high-performance mortar that is applied for splice sleeves, repairs and strengthening of concrete structures, and joints of precast concrete structures can be greater than 80 MPa.

In order to improve the properties of high-performance cementitious mortar, some types of admixtures, such as fibers, powders with very fine particle sizes, or liquid admixtures, could be applied. The very fine powder as a nanomaterial contained in a cement mortar indicated higher strengths compared to a conventional mortar with the same water-cement ratio [3]. Nevertheless, the high cost, environmental and health risks are still challenges for nanomaterials in civil engineering. Until now, the fine powder admixtures from industrial wastes have been one of the ways to improve the properties of cementitious materials to become high-performance mortar. However, increasing the percentage of fly ash [4, 5] or cenosphere and waste powder glass [6] to replace the cement content in the mortar reduced the compressive strength of the mortar. Replacing the cement with silica fume and metakaolin increased the compressive strength of the mortar [7]. Meanwhile, replacing the percentage of concrete sand with blast furnace slag [8] or recycled fine aggregate [9] in the mortars also reduced the compressive strength of the mortar. From previous studies, the industrial wastes used to replace cement or sand could not confirm an increase in the compressive strength of mortar compared to that of the control mix. It may depend on the size distribution of industrial waste. Currently, a large amount of fly ash has been exposed to the environment in the local area. Therefore, fly ash was used to examine its contribution to high-performance mortar.

Curing methods are also being developed to enhance the properties of cementitious mortar and concrete. External curing methods are often considered [7, 8, 10]. When the mortar is applied for repairing or strengthening existing structures, it is difficult to have a good environment as the standard condition or electric oven to cure the mortar [10]. Therefore, the internal curing method [11] is more suitable for a high-performance mortar in the narrow space of cracks and the gap in a splice sleeve, especially in dry conditions. Nguyen *et al.* [11] showed that the partially lightweight sand (LWS) from grey volcanic basalt stone, an industrial waste, could be used as a material for internal curing to improve the compressive strength of concrete in dry conditions. However, LWS with lower strengths could reduce the strength of the mortar. Therefore, in this study, different percentages of the LWS are also applied for investigating its effect on the strength of high-performance cementitious mortar.

In this study, a high-performance mortar with a compressive strength greater than 80 MPa is produced. Industrial wastes, such as fly ash and lightweight sand, are used to replace traditional sand in different percentages. The effects of industrial wastes and superplasticizers on compressive strength and slump flow are investigated. The internal curing achieved by using lightweight sand is also considered.

2. MATERIALS

The quality of high-performance cementitious mortar depends on the quality of materials such as traditionally natural concrete sand, lightweight sand, fly ash, and superplasticizers. The natural concrete sand from a local area was washed with clean water and dried in a dry oven at a temperature of 110°C within 24 hours before being used. The dry sand was then sieved to evaluate the particle size. The maximum size of the sand must be considered because a high maximum size could affect the filling ability of the mortar into the gaps of the cracks, splice sleeves and joints of precast concrete structures. Concrete sand with a small maximum size increases the surface area of the sand which may affect its construction ability. Therefore, the maximum size of sand chosen for this study was 2.36 mm (No. 8). Experimental results from Guan *et al.* [12] showed that using the same size of sand, the uniaxial compressive strength of mortar was reduced when the size of the sand increased. Therefore, sand of different sizes was used. The finer percentages of the sand are presented in Fig. 1. The sand almost satisfied the grading requirements of ASTM C33 [13]. The finer percentage of the sand with the sieve opening size of 0.6 mm was 23.6% which was a little bit less than the minimum requirement of 25%. The fineness modulus of the sand, based on ASTM C125 [14], was 3.08. Water content also affects the quality of high-performance cementitious mortar. Water provided to mix proportions should be considered in relation to the absorption content of traditional and lightweight sands. The absorption content of the natural sand, determined following ASTM C128 [15], was 1.42%. The unit weight and density of the sand, determined based on ASTM C128 [15], were 1546 kg/m^3 and 2650 kg/m^3, respectively.

Fly ash used in this study was taken from a local thermal power plant. The scanning electron microscope (SEM) image of the fly ash for particle sizes is given in Fig. 2. The physical properties and chemical compositions of the used fly ash are given in Table 1. The retained fly ash on the sieve with an opening of 0.045 mm was about 10%. The moisture content of fly ash was 0.33%. The moisture content of fly ash was, therefore, ignored in mix proportions. Blended hydraulic cement types of PCB40 and PCB50 on the market were used. The mass density of cement is approximately 3.15 t/m^3. In order to improve the workability to

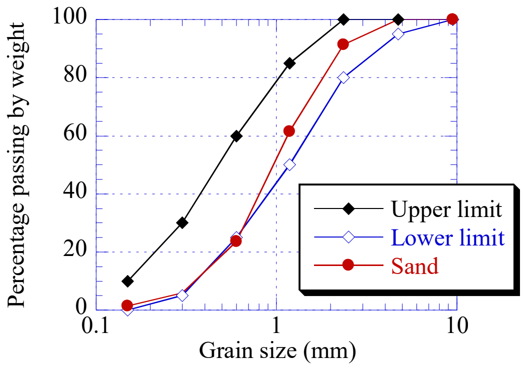

Figure 1. Particle size distribution of sand.

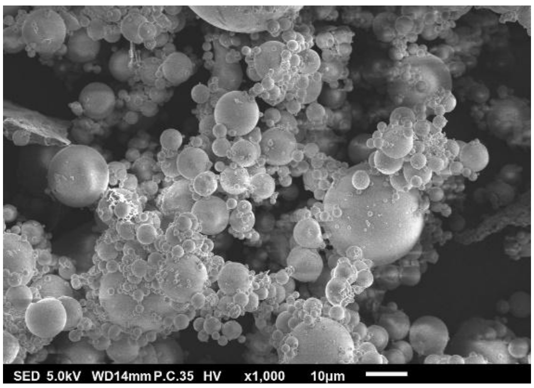

Figure 2. SEM image of fly ash.

Table 1. Chemical composition of fly ash.

No.	Composition (by weight %)	Value
1	Strength activity index at 28 days	96.6
2	Silica (SiO_2)	55.7
3	Sulfur trioxide (SO_3)	0.36
4	Alumina (Al_2O_3)	28.5
5	Iron Oxide (Fe_2O_3)	5.7
6	Total Alkali content (Na2O+0.658K2O)	2.41
7	Moisture content	0.33
8	Loss on ignition	2.6
9	Mass density (g/cm^3)	2.2

Figure 3. Waste of lava stone.

Figure 4. Crushed LWS from lava stone waste.

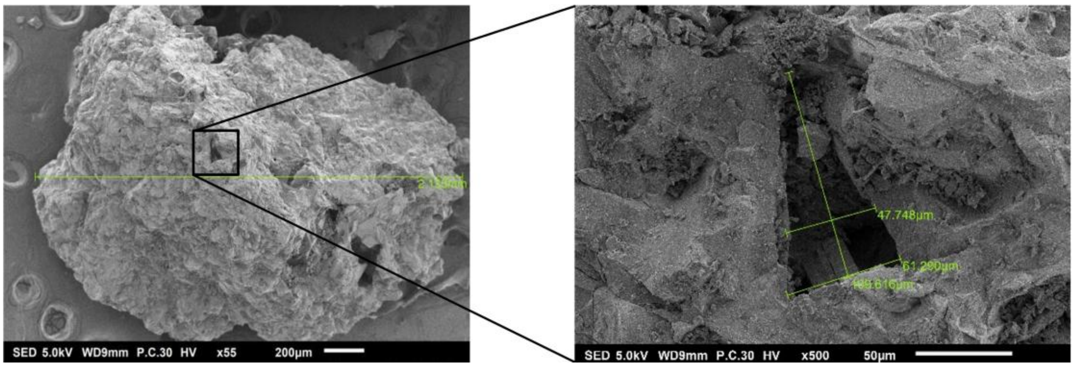

Figure 5. Surface of LWS scaled by SEM.

fill into the crack and splice sleeve, and reduce water requirements, the superplasticizer was selected for mixtures.

Lava sand had been used for mortars [16-18]. However, those are the normal mortar with the low slump flow and low compressive strength. The lava stone waste as shown in Fig. 3 was crushed into lightweight sand (LWS) for construction materials, as shown in Fig. 4. Vesicles are the small holes left behind after cool lava that could hold water for the internal curing process in mortar or concrete. The SEM image given in Fig. 5 shows the small holes in the LWS. Similar to the traditional sand, the maximum size of the LWS was also limited by 2.36 mm. However, the minimum size was sieved at 0.106 mm because the smaller size could not be effective in holding the water for internal curing. In addition, sand replaced by the small pumice size reduced the compressive strength of concrete [16, 19]. The LWS was also washed and dried before use. The water absorption and density of the LWS determined based on ASTM C128 [15] were 5% and 2670 kg/m^3, respectively. To eliminate the water adhering to the surface of the LWS particles, absorption papers were used rather than dry clothes for an aggregate or a heat gun for natural concrete sand.

3. MIX PROPORTION AND TESTING

Many researchers have proposed mix proportions for high-performance mortar and curing methods. The cement-to-sand ratio of 1:1.5 to 1:2.75 by weight [7, 20, 21] were normally used. Using the cement-to-sand ratio of 1:3 or more sand made the compressive strength smaller than 50 MPa [3, 8, 9]. Mix proportion of mortar in the unit volume of 1m^3 was determined based on the volumetric percentages of sand (V_s), cement (V_c) and water (V_w) as in Eqs. (1)-(2):

$$V_c + V_w + V_s = 1 \quad (1)$$

$$C\rho_c + W\rho_w + S\rho_s = 1 \quad (2)$$

In which C, W and S are the weights of cement, water and sand, respectively; ρ_c, ρ_w and ρ_s are the densities of cement, water and sand, respectively. In this study, the volume of sand, V_s was fixed at 55%. In almost all of the above-referenced studies, the water-to-cement ratio ranged from 0.3 to 0.5. The *W/C* ratios in the range of 0.3 to 0.4 were selected as a parameter for this study. From the percentage of sand and *w/c* ratio, the weight of sand and cement was determined by Eqs. (3)-(4). Based on the weight of cement and the *W/C* ratio, the weight of water was calculated.

$$S = V_s * \rho_s = 55\% * \rho_S \quad (3)$$

$$C = \frac{1-V_S}{1+\frac{W}{C}*\frac{\rho_C}{\rho_W}}\rho_C \quad (4)$$

The control mixture, C1 with a *w/c* ratio of 0.4, included cement, water and sand. The test results by Kurbetci *et al.* [22] showed a reduced compressive strength. The reason may be the replacement of cement with fly ash. Therefore, the fly ash was used to replace the concrete sand with different weight percentages of 5%, 10% and 15% in C2, C3 and C4, respectively. Nguyen *et al.* [11] showed a well internal curing method using LWS as a replacement for traditional concrete sand from 30% to 40% that could improve the strength of concrete. The particle size of LWS in this study was smaller than that of Nguyen *et al.* [11]. Therefore, the traditional concrete sand replaced by the LWS of 35%, 40%, 45% and 50% was examined. Before mixing, the dry LWS (KN) or soaked LWS (CN) was considered a parameter in the research. The slump flow of the mortars was measured by a slump cone based on ASTM C230 [23]. However, the tabletop did not need to be raised and dropped vertically to simulate the construction situation of the mortar in the narrow gap in cracks or splice sleeves without compaction. The slump flow of the mortar, determined by its diameter in Fig. 6, should not be smaller than 13 cm to be able to fill in the gaps. However, the diameter of the slump flow was also not larger than 32 cm to prevent the segregation of the mortar. The expected flow slump value of self-compacting mortar by EFNARC [24] is 24 cm to 26 cm. To check the compressive strength, the mortar samples were manufactured with a size of 5x5x5 cm based on ASTM C109 [25]. After 24 hours in the molds, the mortar samples were remolded. Some samples were cured underwater in the laboratory condition (CB), while others were exposed

Table 2. Mix proportion of mortar for 1m^3.

<table>
<tr><th rowspan="2">Mix</th><th rowspan="2">W/C</th><th rowspan="2">S (kg)</th><th colspan="2">LWS</th><th>Water</th><th>Cement</th><th colspan="2">Fly ash (FA)</th><th>SP</th><th>Cement</th><th>Curing</th></tr>
<tr><th>(%)</th><th>(kg)</th><th>(W) (l)</th><th>(C) (kg)</th><th>%</th><th>kg</th><th>(%)</th><th>types</th><th>method</th></tr>
<tr><td>C1</td><td rowspan="6">0.4</td><td>1455</td><td rowspan="6">0</td><td rowspan="6">0</td><td rowspan="6">272</td><td rowspan="6">627</td><td>0</td><td>0</td><td rowspan="4">0</td><td rowspan="12">PCB50</td><td rowspan="11">CB</td></tr>
<tr><td>C2</td><td>1382</td><td>5</td><td>73</td></tr>
<tr><td>C3</td><td>1310</td><td>10</td><td>145</td></tr>
<tr><td>C4</td><td>1237</td><td>15</td><td>218</td></tr>
<tr><td>C5</td><td rowspan="2">1310</td><td rowspan="2">10</td><td rowspan="2">145</td><td>1.0</td></tr>
<tr><td>C6</td><td>1.5</td></tr>
<tr><td>C7</td><td rowspan="2">0.375</td><td rowspan="2">1310</td><td rowspan="2">0</td><td rowspan="2">0</td><td rowspan="2">264</td><td rowspan="2">650</td><td rowspan="2">10</td><td rowspan="2">145</td><td>1.0</td></tr>
<tr><td>C8</td><td>1.5</td></tr>
<tr><td>C9</td><td rowspan="3">0.35</td><td rowspan="3">1310</td><td rowspan="3">0</td><td rowspan="3">0</td><td rowspan="3">257</td><td rowspan="3">674</td><td rowspan="3">10</td><td rowspan="3">145</td><td>0.75</td></tr>
<tr><td>C10</td><td>1.0</td></tr>
<tr><td>C11</td><td>1.5</td></tr>
<tr><td>C12</td><td rowspan="3">0.325</td><td rowspan="3">1310</td><td rowspan="3">0</td><td rowspan="3">0</td><td rowspan="3">248</td><td rowspan="3">700</td><td rowspan="3">10</td><td rowspan="3">145</td><td rowspan="3">1.0</td><td rowspan="2">CB</td></tr>
<tr><td>C13</td><td rowspan="9">PCB40</td></tr>
<tr><td>C14</td><td>KB</td></tr>
<tr><td>C15</td><td rowspan="4">0.325</td><td>851</td><td>35</td><td>459</td><td>265</td><td rowspan="4">700</td><td rowspan="4">10</td><td rowspan="4">145</td><td rowspan="4">1.0</td><td rowspan="4">KN-KB</td></tr>
<tr><td>C16</td><td>786</td><td>40</td><td>524</td><td>267</td></tr>
<tr><td>C17</td><td>720</td><td>45</td><td>590</td><td>269</td></tr>
<tr><td>C18</td><td>655</td><td>50</td><td>655</td><td>272</td></tr>
<tr><td>C19</td><td rowspan="3">0.3</td><td>786</td><td>40</td><td>524</td><td>258</td><td rowspan="3">729</td><td rowspan="3">10</td><td rowspan="3">145</td><td rowspan="3">1.0</td><td>CN-KB</td></tr>
<tr><td>C20</td><td>720</td><td>45</td><td>590</td><td>260</td><td>CN-KB</td></tr>
<tr><td>C21</td><td>1310</td><td>0</td><td>0</td><td>239</td><td>KB</td></tr>
</table>

Note: S is a concrete sand, SP is a super-plasticizer, CB means the samples are cured under the water in the laboratory condition, KB means that the samples are exposed in the laboratory air, KN means LWS is dry before mixing, CN means LWS is soaked 1 hour before mixing [16].

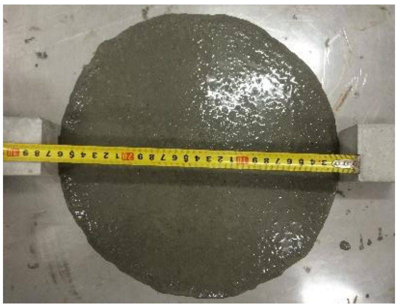

Figure 6. Flow of mortar.

Figure 7. compressed sample.

to the air in the laboratory (KB). The soaked samples were taken out of the water and cleaned on the surface by dry towers for 3 hours before testing. All the mix proportions of mortar are shown in Table 2. The mixtures had a cement-to-sand ratio in weight from 1:1.8 to 1: 2.32.

4. RESULTS AND DISCUSSIONS

4.1. Effect of fly ash and super-plasticizer (SP)

Table 3 lists the testing results in fresh and hardened stages, including slump flow and compressive strengths on different days. The compressive strength of the mortar with the effect of fly ash was taken on the average of three samples as shown in **Fig. 7.** The residual value of all specimens was ± 2kN, about ±0.8 MPa. The values In the mixtures C1 to C4, a superplasticizer was not used. Fig. 8 showed that the compressive strength of C3, where 10% traditional sand was replaced by fly ash, showed the highest values at both 7 and 28 days. Replacing 10% of the weight of traditional sand with fly ash, the volume of the traditional sand in the mixture decreased by 49.5%. The fly ash occupied 5.5% of the unit volume. When the content of replaced fly ash was increased, the slump flow decreased. It is because the size of the fly ash is smaller than that of the sand. It leads to an increase in the surface area of the aggregates. Therefore, the amount of water in the mixture to react with cement was reduced,

Table 3. Testing results.

Mixture	**W/C**	**Flow (cm)**	**Compressive strength, f'_c (MPa)**			
			1 day	**3 days**	**7 days**	**28 days**
C1	0.400	24	-	-	44.2	64.5
C2		22	-	-	42.7	67.9
C3		13	-	-	49.2	73.1
C4		12	-	-	36.8	55.8
C5		27.5	27.9	-	59.9	77.4
C6		29	22.9	-	58.5	74.2
C7	0.375	25	37.4	-	67.7	83.1
C8		27.5	36.3	-	65.3	79.8
C9	0.350	24	32.4	-	67.9	84.9
C10		24.5	38.5	-	71.4	90.2
C11		25	35.4	-	68.3	88.8
C12	0.325	24	37.9	-	74.4	96.2
C13		22	26.4	61.8	68.5	85.2
C14			-	59.5	-	68.0
C15		26	-	51.0	55.4	-
C16		28	-	59.4	69.2	-
C17		26	-	52.6	61.0	-
C18		28	-	56.3	61.6	-
C19	0.300	24	-	58.9	-	80.3
C20			-	53.8	-	81.1
C21			-	57.6	67.6	77.4

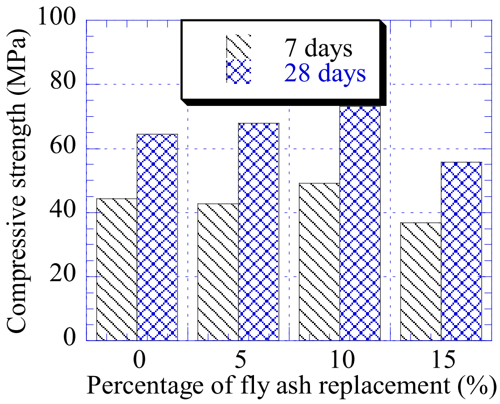

Figure 8. Effect of fly ash content.

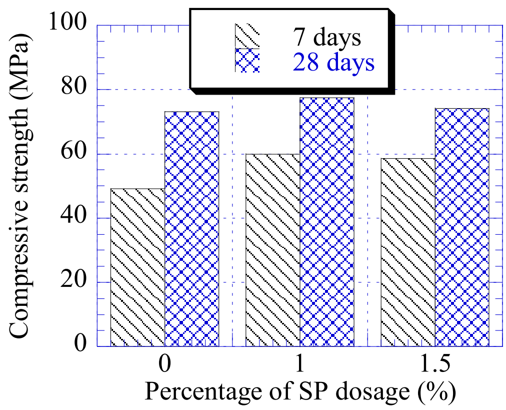

Figure 9. Effect of SP content.

decreasing the slump flow compared to the control mixture. A mortar with a 13 cm slump flow value can be applied for joining precast, but it is difficult to fill the narrow gap of splice sleeves.

In order to increase the slump flow, the dosage of SP of 1% and 1.5% in the weight of cement in C5 and C6, respectively. The mixtures C5 and C6 were based on C3. The result showed that the slump flow of the C5 and C6 increased up to 27.5 cm and 29 cm, respectively, and was much larger than that of the C3, which was 13 cm. The effect of SP on the compressive strength is shown in Fig. 9. The C5 with a *w/c* of 0.4 and 1.0% of SP showed an optimal mixture compared with the C3 and C6.

4.2. Effect of water by cement ratio

The slump flow values of the C5 and C6 were relatively high. Therefore, the *w/c* ratio could be reduced to gain the compressive strength of mortar. Fig. 10 shows the effect of the water-by-cement ratio and the SP content on the compressive strength of the mortars. When the *w/c* ratio was decreased, the compressive strength of the mortar mixtures increased, and the slump flow was reduced. The compressive strength of the mixture with an SP of 1.0% was greater than that of other mixtures. In the mixture from C7 to C12, the slump flow was from 24 cm to 27.5 cm. These slump flow values could make the mortar well-suited for narrow spaces. Except for mixture C8 with a compressive strength of 79.8 MPa, the compressive strengths of other mixtures ranged from 83.1 MPa to 96.2 MPa which was greater than the 80 MPa goals of this study. It notes that the cement type of the mixtures from C1 to C12 was PCB50. The mixture C13 was similar to C12, but the cement type PCB40 was used. The compressive strength of the C13 was 85.2 MPa, while the slump flow was 22 cm. The mixture C13 also met the requirement of the objective.

4.3. Influence of LWS on internal curing

The compressing samples in all the mixtures from C1 to C13 were cured in the standard condition (CB) in which the samples had been soaked in water in the laboratory environment for 27 days after remolding. The standard condition is a rare case in construction conditions. Therefore, the compressing samples of mixture C14, which was the same mixture as C13, were exposed to the air in the laboratory condition (KB). The effect of the curing methods is shown in Fig. 11. The effect of the curing methods on the compressive strength of the mortar after 3 days was not clear. However, the compressive strength of C14 at 28 days was equal to 79.8% of that of C13.

The LWS could accumulate water to provide water for the internal hydration process when the mortar gets hard. Especially in a high-strength mortar with a small permeability coefficient, the amount of water that penetrated into the mortar after hardening could be limited. Therefore, the effect of LWS as the internal curing agent on the compressive strength was investigated in the mixtures C15 to C18. In these mixtures, the dry LWS was mixed with the dry traditional sand, cement and fly ash within 2 minutes as part of preparing a dry mortar. Next, the mixture of SP and water was put into the dry mortar to mix within 3 minutes. It notes that the absorption contents of LWS and traditional sand were considered to add to the mixtures. The results showed that the slump flow of the mixtures C15 to C18 was from 26 cm to 28 cm which was higher than that of C14. This was because there was not enough time to absorb the added water into the LWS. Therefore, the light segregation of the mortars was observed. The compressing samples of C15 to C18 were also totally exposed to the air in the laboratory. The compressive strengths at 3 days and 7 days of the mixtures of C16 with 40%

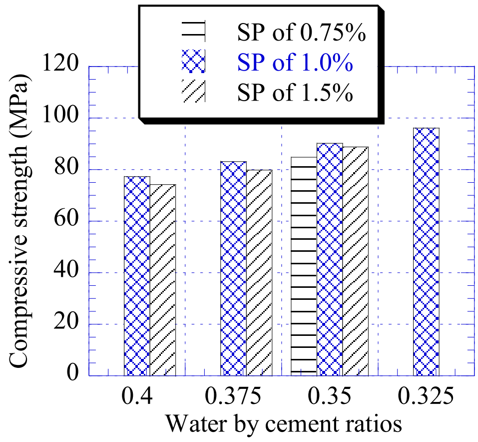

Figure 10. Effect of w/c ratio and SP content.

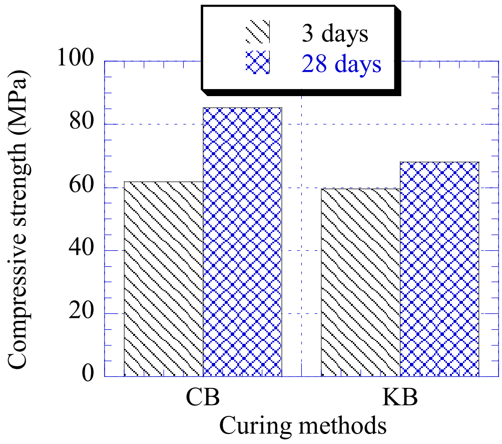

Figure 11. Effect of curing methods.

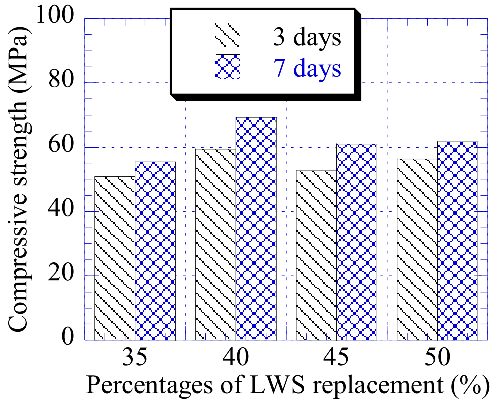

Figure 12. Effect of LWS content in w/c of 0.325.

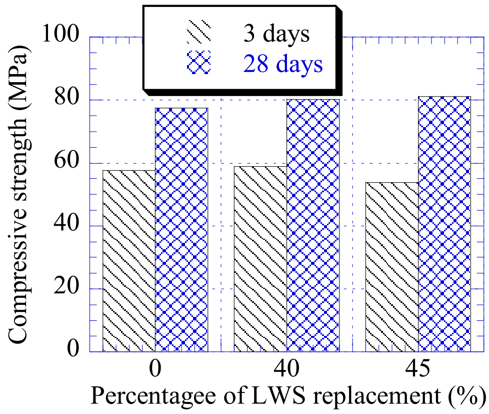

Figure 13. Effect of LWS content in w/c of 0.3.

LWS replacement were approximately those of C13 as shown in Fig. 12. Meanwhile, the compressive strengths of C15, C17 and C18 were lower than those of C13. It seems that 40% of traditional sand replaced by LWS could be optimum content compared to other percentages.

In mixtures of C19, C20 and C21, the LWS was soaked in amout of water, that was three times the absorption content of the LWS, 1 hour before mixing to increase absorption content for internal curing. After mixing dry traditional sand, cement and dry fly ash within 2 minutes, the SP and water were put into a mixer and mixed for 2 minutes. Finally, the soaked LWS was added and mixed within 1 minute. The mixtures of C19, C20 and C21 had the slump flow of 24 cm which was smaller than that C16. It means that 1 hour soaked LWS kept larger water than dry LWS. The compressive strength of C21 was 77.4 MPa which was higher than 68 MPa of C14. Meanwhile, the compressive strengths of C19 and C20 (see Fig. 13**)** were 80.3 and 81.1 MPa. It means that 40% traditional sand replaced by LWS could increase the compressive strength of the mortar without curing in the standard condition. The application of 40% LWS replacement for the traditional sand means that amount of traditional sand for the mixture was 29.7%. The total weight of industrial wastes such as LWS and fly ash substituted for the traditional sand was 25.3% which could contribute to the environmental protection and the shortage of traditional sand in the local area.

4. CONCLUSIONS

High-performance mortar is widly used in civil engineering. Based on the experimental results conducted with various mix proportions in the laboratory, the following conclusions were made:

- High-performance mortar could be designed based on volume of materials such as traditional sand, lightweight sand from black lava stone waste, fly ash from thermal power plants, cement and superplasticizer to improve the compressive strength and flow.
- The mortar mix, comprising 29.7% traditional sand, 19.8% lightweight sand, and 5.5% fly ash, achieved a compressive strength exceeding 80 MPa.
- LWS from black lava stone with size from 0.106 mm to 2.36mm could improve the compressive strength of the mortar by internal curing contribution.
- The superplasticizer of 1% weight of cement was suitable for the mortar to control the slump flow.

REFERENCES

[1]. H. K. Kim, Bond strength of mortar-filled steel splice reflecting confining effect, J. of Asian Arc. and Build. Eng., 11 (2012) 125-132.

[2]. J. Choi, S. K. Park, H. Y. Kim, S. Hong, Behavior of high-performance mortar and concrete connections in precast concrete elements: Experimental investigation under static and cyclic loadings, Eng. Struct., 100 (2015) 633-644. https://doi.org/10.1016/j.engstruct.2015.06.009

[3]. M. Ashok, A. K. Parande, P. Jayabalan, Strength and durability study on cement mortar containing nano materials, Adv. in Nano Res., 5 (2017) 99-111. https://doi.org/10.12989/amr.2019.8.2.137

[4]. C. S. Poon, L. Lam, Y. L. Wong, A study on high strength concrete prepared with large volumes of low calcium fly ash, Cement and Conc. Res., 30 (2000) 447-455. https://doi.org/10.1016/S0008-8846(99)00271-9

[5]. Y. Hu, S. Hu, B. Yang, S. Wang, Effects of subsequent curing on chloride resistance and microstructure of steam-cured mortar, Adv. in Conc. Constr., 9 (2020) 449-457. https://doi.org/10.12989/acc.2020.9.5.449

[6]. M. U. Salim, M. A. Mosaberpanah, Mechanical and durability properties of high-performance mortar containing binary mixes of cenosphere and waste glass powder under different curing regimes, J. of Mater. Res. and Tech., 13 (2021) 602-617. https://doi.org/10.1016/j.jmrt.2021.04.077

[7]. A. S. Shawkat, T. E. Dawood, Production of high-performance mortar containing metakaoline and silica fume, Int. J. of Progressive Sci. and Tech., 21 (2020) 32-39.

[8]. K. R. Patra, B. B. Mukharjee, Influence of granulated blast furnace slag as fine aggregate on properties of cement mortar, Adv. in Conc. Constr., 6 (2018) 611-629. https://doi.org/10.12989/acc.2018.6.6.611

[9]. S. C. Yaragal, M. A. K. Roshan, Usage potential of recycled aggregates in mortar and concrete, Adv. in Conc. Constr., 5 (2017) 201-219. https://doi.org/10.12989/acc.2017.5.3.201

[10].G. J. P. Venkatesh, S. S. Vivek, G. Dhinakaran, Study on compressive strength of self compacting mortar cubes under normal & electric oven curing methods, IOP Conf. Ser.: Earth Environ. Sci., 80 (2017) 012002. https://doi.org/10.1088/1755-1315/80/1/012002

[11].D. H Nguyen, L. Mai, T. H. Nguyen, Combining internal and external curing to improve quality of self-compacting concrete with consideration of climate effects, Adv. in Conc. Constr., 12 (2021) 85-91. https://doi.org/10.12989/acc.2021.12.2.085

[12].W. Guan, Q. Qi, Z. Zhang, S. Nan, Effect of sand particle size on microstructure and mechanical

properties of gypsum-cemented similar materials, Materials, 13 (2020). https://doi.org/10.3390/ma13030765
[13].ASTM International, Standard Specification for Concrete Aggregates, ASTM C33/C33M-18, 2018.
[14].ASTM International, Standard Terminology Relating to Concrete and Concrete Aggregates, ASTM C125-21a, 2021.
[15].ASTM International, Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate, ASTM C128-22, 2022.
[16].W. H. J. Tchamdjou, S. Grigoletto, F. Michel, L. Courard, M. L. Abidi, T. Cherradi, An investigation on the use of coarse volcanic scoria as sand in Portland cement mortar, Case Studies in Constr. Mater., 7 (2017) 191-206. https://doi.org/10.1016/j.cscm.2017.07.005
[17].M. Vyšvařil, P. Bayer, P. Rovnaníková, Use of Lava Sand as an Alternative to Standard Quartz Aggregate in Lime Mortars, Solid State Phenomena, 296 (2019) 73-78. https://doi.org/10.4028/www.scientific.net/SSP.296.73
[18].L. Contrafatto, C. L. Danzuso, S. Gazzo, L. Greco, Physical, mechanical and thermal properties of lightweight insulating mortar with recycled Etna volcanic aggregates, Constr. and Build. Mater., 240 (2020) 117917. https://doi.org/10.1016/j.conbuildmat.2019.117917
[19].H. Binici, O. Aksogan, E. B. Gorur, H. Kaplan, M. N. Bodur, Performance of ground blast furnace slag and ground basaltic pumice concrete against seawater attack, Constr. and Build. Mater., 22 (2008) 1515-1526. https://doi.org/10.1016/j.conbuildmat.2007.03.024
[20].C. C. Banand, M. Ramli, Optimization of mix proportion of high-performance mortar for structural applications, American J. of Eng. and Appl. Sci., 3 (2010) 643-649.
[21].M. M. Islam, M. S. Islam, Strength behaviour of mortar using fly ash as partial replacement of cement, Conc. Res. Letters, 1 (2010) 98-106.
[22].S. Kurbetci, M. Nas, M. Şahin, Durability properties of mortars with fly ash containing recycled aggregates, Adv. in Conc. Constr., 13 (2022) 101-111. https://doi.org/10.12989/acc.2022.13.1.101
[23].ASTM International, Standard Specification for Flow Table for Use in Tests of Hydraulic Cement. ASTM C230/C230M-21, 2021.
[24].EFNARC, specification and guidelines for self-compacting concrete. European Federation for Specialist Construction Chemicals and Concrete Systems, Norfolk, UK, English Eds., Feb. 2002.
[25].ASTM International, Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens), ASTM C109/C109M-21, 2021.