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The effect of Basic Oxygen Furnace, Blast Furnace, and Kanbara Reactor Slag as Reinforcement to Cement Based Mortar

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Abstract
Slag is a waste from steelmaking industries that was released into the environment. Slag was used as reinforced material in mortar. Different types of slag, including Air Cooled Slag (ACS), Granulated Blast Furnace Slag (GBFS), Basic Oxygen Furnace Slag (BOFS), and Kanbara Reactor Slag (KRS), were used as a reinforcing material in this study. The composition of slag in the mixture on mortar was 10%, 20%, 30%, 40%, and 50%. The sample was made with a water-cement ratio (w/c) of 0.35, with the ratio of sand and cement being 1:1.5, respectively. Treatment of mortar sample at ambient temperature was applied. The mortar samples were left to cure until 3, 7, and 28 days, which performed a compression test. The results show that adding slag to the mortar enhanced the compressive strength of the pristine mortar. The highest strength was obtained by adding 10% slag at 28 days. The compressive strength of GBFS, BOFS, KRS, and ACS was 23.76 MPa, 23.28 MPa, 19.68 MPa and 17.48 MPa, respectively. Based on the XRD result, it was discovered that the mixture has more Calcium Silicate Hydrate Peak than Pristine mortar.

Keywords: Granulated Blast Furnace Slag (BRFS), Air Cooled Slag (ACS), Basic Oxygen Furnace Slag BOFS), Kanbara Reactor Slag (KRS).

1. Introduction

Mortar is a mixture consisting of cement, water, and fine aggregate both in the state of hardened or not hardened. The main constituent of slag oxides consisting of CaO, SiO_2, Al_2O_3, and MgO was also found in mineral cement, especially Portland cement [1]. It allows for using slag as a reinforcing material that can provide adhesive properties more effectively in a mortar [2]. The mortar compound will affect the strength of the mortar. The admixture is usually added to improve the mechanical strength of the mortar. Slag is one example of mineral admixture used to improve the mechanical properties of mortar. This study used Granulated Blast Furnace Slag, Air Cooled Slag, Basic Oxygen Furnace Slag, and Kanbara Reactor Slag.

Granulated Blast Furnace Slag (GBFS) is a by-product of the steelmaking process that cooled rapidly using water. Rapid cooling causes slag solidification as glass particles or glass phase. Glass' irregular structure gives nature moderate hydraulic cementitious material [3]. Air Cooled Slag (ACS) is an iron slag produced from the manufacture of the solidification process under atmospheric or ambient conditions [4]. The cooled material is hard and dense, although it can have a vesicular texture with closed pores. Basic Oxygen Furnace Slag (BOFS) is slag formed by refining hot metal into steel in a basic oxygen furnace [5]. Kanbara Reactor Slag (KRS) is a solid waste generated from the molten iron desulfurization process with the mechanical mixing process of steelmaking in the kanbara reactor. BOF and KR have a crystalline structure as well as GBFS since it was cooled under atmospheric conditions [6]. The content of silica and alumina in the slag react with $Ca(OH)_2$ to form a

Table 1. Proportions of materials in mortar mixture.

Mixture Labels	Slag (%)	Cement (%)
C	0	40
X-10	10	30
X-20	20	80
X-30	30	70
X-40	40	60
X-50	50	50

compound calcium silica hydrate (CSH) [7]–[9]. The reaction results in the form of CSH, which is equal to the hydration reaction of C_3S and C_2S in cement. CSH derived from the hydration reaction of slag will give additional strength to the mortar [10]. Therefore, this study aimed to determine the effect of slag on the compressive strength of mortar. The development of slag as a novel reinforcing mortar will be elaborated, and resultant mortar materials will be characterized systematically.

2. Method

This part consists of materials, preparation of mortar mixtures, compressive strength, and microscopical characterization.

2.1. Materials

Ordinary Portland Cement (OPC) was purchased from Gresik Cement company. Sand from Cimalaka Quarry prepared in Saturated Surface Dry (SSD) was used as an aggregate. GBFS, ACS, BOFS, and KRS were used as a reinforcement extensively produced as a by-product through iron and steel production and were kindly provided by PT Krakatau POSCO, Cilegon, Indonesia. The aggregates were sieved through a 4.75 mm sieve and kept on a 30 μm screen following ASTM C-33 standards.

2.2. Preparation of Mortar Mixtures

Six mixes were prepared by adding slag with 0%, 10%, 20%, 30%, 40%, and 50% slag by mass. The mixed proportions of the studied mortars are listed in Table 1. C (control) is mortar without slag, and X is kind of slag (GBFS, ACS, BOFS, and KRS). The water to cement ratio (w/c) was 0.35 by mass. The ratio of cement and aggregate was 1:1.5, respectively. Briefly, dry mixtures were placed and mixed to ensure the component mixed homogeneously. Afterwards, the required amount of mixing water was poured into the dry mixture, followed by continuous mixing. Each specimen was cast into 50 × 50 × 50 mm cubic moulds. The specimens were left for 24 hours. Eventually, the specimens were released from the mould and cured at room temperature for 3, 7, and 28 days.

2.3. Compressive Test and Microscopical Characterization

The compressive strength (f_c) test of the specimens was examined according to the ASTM C 109 standard. Each mixture was evaluated at 3, 7, and 28 days. The maximum compressive load was obtained using the RAT 100 Type Universal Testing Machine (UTM) in the Center of Infrastructure Built Environmental (CIBE), Institut Teknologi Bandung. The compressive strength mortar was calculated by dividing the maximum compressive load received by the specimen during the test by surface area (Equation 1).

$$f_c(\text{MPa}) = \frac{\text{Max. Compressive Load } (N)}{\text{Surface Area } (\text{mm}^2)} \quad (1)$$

X-Ray Fluorescence (XRF) by using AMETEK EDAX Orbis PC Micro-XRF Analyzer and X-Ray Diffraction (XRD) by Bruker D8 Advance X-Ray Powder Diffractometer was conducted in the Center of Advanced Science Institut Teknologi Bandung. XRF was used to determine the oxide composition of GBFS, ACS, BOFS, and KRS. In contrast, XRD was used to analyze the resulting compound from mixing cement, slag, and water.

Table 2. Proportions of materials in mortar mixture.

Sample	Fe_2O_3 (%)	CaO (%)	SiO_2 (%)	Al_2O_3 (%)	MgO (%)	SO_3 (%)
GBFS	1.43	41.20	34.20	11.70	8.81	-
ACS	0.44	44.17	35.92	7.11	2.01	-
BOFS	50.00	32.60	7.00	2.20	1.27	0.65
KRS	38.00	20.70	12.80	14.90	8.87	0.69

3. Result and Discussion

3.1. X-Ray Fluorescence (XRF) Result

The primary chemical constituents using the XRF Spectrometer of the GBFS, ACS, BOFS, and KRS are presented in Table 2. XRF results show that all slags have a considerable amount of CaO, SiO_2, and Al_2O_3 which are the main factors that affect strength [11]. MgO can affect the strength, carbonation resistance, chloride penetration resistance, and formation of magnesium silicate hydrate (M-S-H) phases [12]. Fe_2O_3 in BOFS and KRS were high because it is obtained directly from basic oxygen furnace and kanbara reactor, respectively.

3.2. Compressive Strength

The variation in the compressive strength of mortar incorporating different proportions of GBFS, ACS, BOFS, and KRS as a reinforcement for improved compressive strength for 3 days was graphically represented in Figure 1 and for 7 days in Figure 2. At an early age (3 and 7 days), mortar without slag addition (C) compressive strength was higher than mortar with slag reinforcement. All mortar mixes exhibited a progressive decrease in compressive strength with increasing percentages of slag. Slag may have cementitious properties but slow reaction velocities [13]. That was caused by the hydration mechanism of slag being different from cement. When cement comes into contact with water, the dissolution of some phases takes place quite rapidly. However, when slag is mixed with water, hydration depends upon the breakdown and dissolution of glassy structure slag by hydroxyl ions [14]. Compressive strength at 28 days data was shown in Figure 3. All mortar with 10% slag addition has higher compressive strength than control. Compressive strength of mortar for proportions of slag more than 10% was decreased along with an increase in slag percentage. That happened because the hydration for making compound CSH needed more curing time, resulting in the mortar with proportions of 50% addition of all slags. The compression test showed not much difference.

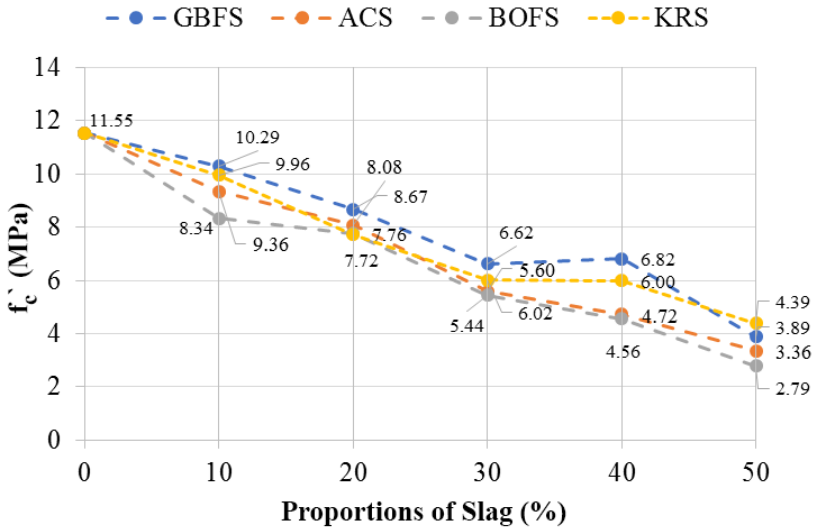

Figure 1. Compressive strength of mortar at 3 days.

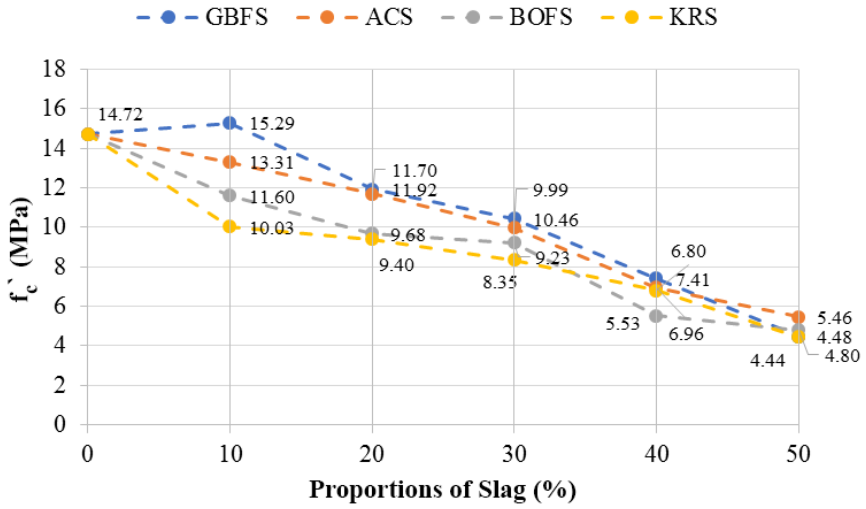

Figure 2. Compressive strength of mortar at 7 days.

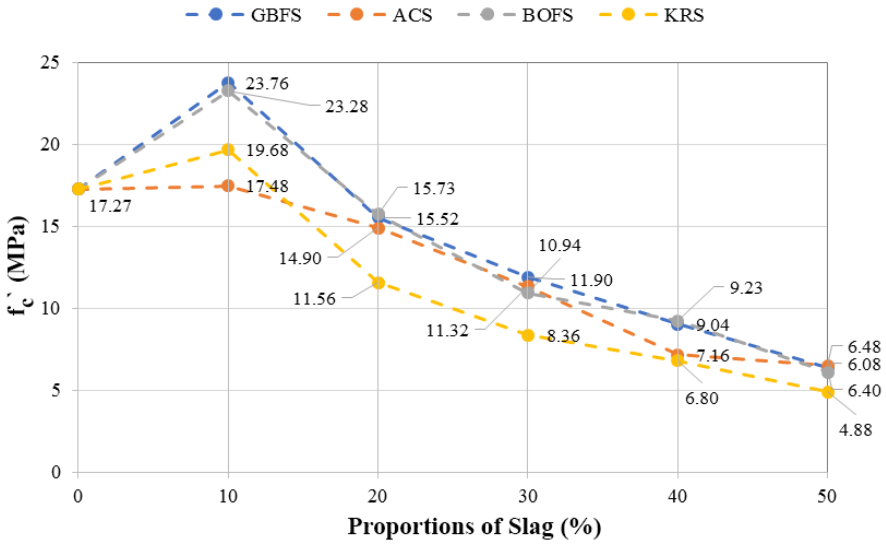

Figure 3. Compressive strength of mortar at 28 days.

The highest compressive strength achieved at 28 days was the mortar added with GBFS that has an amorphous structure so that the hydration in the GBFS was more manageable than any other slag (ACS, BOFS, and KRS), which has the crystalline structure [15]. The result mentioned above shows that the optimum percentage of added GBFS, ACS, BOFS, and KRS was 10%, which has a noticeable effect on the compressive strength of mortar. Slag is a by-product of iron and steelmaking which is expected to be used as much as possible, so different applications can be considered by the compressive strength value, with the highest slag percentage can be used for low load application materials such as building brick and refractories [16]–[18].

3.3. X-Ray Diffraction

X-Ray Diffraction (XRD) was conducted to control mortar, and the highest compressive strength mortar was added with 10% GBFS, ACS, BOFS, and KRS. The XRD result showed that compounds of cementitious mortar such as SiO_2 (JCPDS #461045), CSH (JCDPS #060359), and CH (JCPDS #040733) were presented in Figure 4. The XRD result of mortar showed in proportions 10% slag, more CSH compounds were formed, and the CH compound in the mortar was reduced. Suspected, an increase in the CSH compound will increase the compressive strength of the resulting mortar product, while the increase in CH compound will decrease its compressive strength [19], [20]. SiO_2 presented in diffractogram suspected was crystalline silica in all kinds of slags.

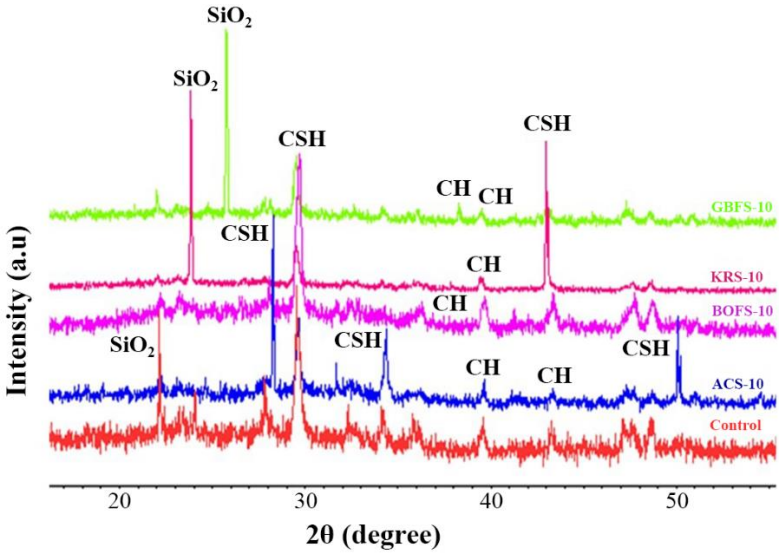

Figure 4. XRD results of control mortar and mortar with addition of 10% slags.

4. Conclusion

In this study we have developed slag as novel reinforcing material, mainly Basic Oxygen Furnace (BOF) and Kanbara Reactor Slag (KRS). The composition and grain size of the material making up the mortar will affect the results of compressive strength. The growth rate of mortar strength with 10% slag composition at the age of 3 days is relatively slow compared with the control mortar but began to increase at the age of 7 days and 28 days. Mortar with the addition slag of 10% produces the highest strength at 28 days. Based on semi-quantitative calculation of the relative intensity of the XRD results obtained CSH were higher in a mortar with 10% slag more than the control mortar. It would be anticipated that slag could be developed as a component for novel mortar materials.

References

[1] S. P. Dunuweera and R. M. G. Rajapakse, "Cement types, composition, uses and advantages of nanocement, environmental impact on cement production, and possible solutions," *Adv. Mater. Sci. Eng.*, vol. 2018, p. 4158682, 2018, doi: 10.1155/2018/4158682.

[2] A. S. Ouda and H. A. Abdel-Gawwad, "The effect of replacing sand by iron slag on physical, mechanical and radiological properties of cement mortar," *HBRC journal*, vol. 13, no. 3, pp. 255–261, 2017, doi: 10.1016/j.hbrcj.2015.06.005.

[3] H. El-Didamony, A. A. Amer, T. M. El-Sokkary, and H. Abd-El-Aziz, "Effect of substitution of granulated slag by air-cooled slag on the properties of alkali activated slag," *Ceramics Int.*, vol. 39, no. 1, pp. 171–181, 2013, doi: 10.1016/j.ceramint.2012.06.007.

[4] A. Harmaji *et al.*, "Effect of air-cooled slag and granulated blast furnace slag addition as substitutor on fly ash based geopolymer," In *AIP Conf. Proc.*, vol. 1887, no. 1, 2017, p. 020019, doi: 10.1063/1.5003502.

[5] W. -T. Lin, C. -J. Tsai, J. Chen, and W. Liu, "Feasibility and characterization mortar blended with high-amount basic oxygen furnace slag," *Mater.*, vol. 12, no. 1, p. 6, 2019, doi: 10.3390/ma12010006.

[6] N. T. Abdel-Ghani, H. A. El-Sayed, and A. A. El-Habak, "Utilization of by-pass cement kiln dust and air-cooled blast-furnace steel slag in the production of some "green" cement products," *HBRC J.*, vol. 14, no. 3, pp. 408–414, 2018, doi: 10.1016/j.hbrcj.2017.11.001.

[7] H. El-Diadamony, A. A. Amer, T. M. Sokkary, and S. El-Hoseny, "Hydration and characteristics of metakaolin pozzolanic cement pastes," *HBRC J.*, vol. 14, no. 2, pp. 150–158, 2018, doi: 10.1016/j.hbrcj.2015.05.005.

[8] J. Zapała-Sławeta, "Alkali silica reaction in the presence of metakaolin-the significant role of calcium hydroxide," In *IOP Conf. Ser.: Mater. Sci. Eng.*, vol. 245, no. 2, 2017, p. 022020, doi: 10.1088/1757-899X/245/2/022020.

[9] S. Singh, G. D. Ransinchung, and P. Kumar, "Effect of mineral admixtures on fresh, mechanical and durability properties of RAP inclusive concrete," *Constr. Build. Mater.*, vol. 156, pp. 19–27, 2017, doi: 10.1016/j.conbuildmat.2017.08.144.

[10] G. F. Huseien, J. Mirza, M. Ismail, S. K. Ghoshal, and M. A. M. Ariffin, "Effect of metakaolin replaced granulated blast furnace slag on fresh and early strength properties of geopolymer mortar," *Ain Shams Eng. J.*, vol. 9, no. 4, pp. 1557–1566, 2018, doi: 10.1016/j.asej.2016.11.011.

[11] A. Jan *et al.*, "A review on the effect of silica to alumina ratio, alkaline solution to binder ratio, calcium oxide+ ferric oxide, molar concentration of sodium hydroxide and sodium silicate to sodium hydroxide ratio on the compressive strength of geopolymer concrete," *Silicon*, vol. 14, pp. 3147–3162, 2022, doi: 10.1007/s12633-021-01130-3.

[12] J. K. Jang, H. G. Kim, J. H. Kim, and J. S. Ryou, "The evaluation of damage effects on MgO added concrete with slag cement exposed to calcium chloride deicing salt," *Mater.*, vol. 11, no. 5, p. 793, 2018, doi: 10.3390/ma11050793.

[13] Y. Dhoble and S. Ahmed, "Study on cementitious properties of steel slag by partial replacement of cement," *Glob. J. Eng. Sci. Res.*, vol. 5, no. 7, pp. 213–220, 2018.

[14] L. Wang, Y. Wei, G. Lv, L. Liao, and D. Zhang, "Experimental studies on chemical activation of cementitious materials from smelting slag of copper and nickel mine," *Mater.*, vol. 12, no. 2, p. 303, 2019, doi: 10.3390/ma12020303.

[15] A. Saludung, Y. Ogawa, and K. Kawai, "Microstructure and mechanical properties of FA/GGBS-based geopolymer," In *MATEC Web of Conf.*, vol. 195, p. 01013, 2018, doi: 10.1051/matecconf/201819501013.

[16] M. Karhu *et al.*, "Ferrochrome slag feasibility as a raw material in refractories: evaluation of thermo-physical and high temperature mechanical properties," *Waste and Biomass Valorization*, vol. 11, no. 12, pp. 7147–7157, 2020, doi: 10.1007/s12649-020-01092-4.

[17] Ş. Koçyiğit and V. V. ÇAY, "Investigation of mechanical and thermal behavior of basalt cutting waste (BCW) added clay brick," *Europ. J. Tech. (EJT)*, vol. 9, no. 2, pp. 209–218, 2019, doi: 10.36222/ejt.643209.

[18] N. Cobîrzan *et al.*, "Volcanic tuff as secondary raw material in the production of clay bricks," *Mater.*, vol. 14, no. 22, p. 6872, 2021, doi: 10.3390/ma14226872.

[19] W. Kunther, S. Ferreiro, and J. Skibsted, "Influence of the Ca/Si ratio on the compressive strength of cementitious calcium–silicate–hydrate binders," *J. Mater. Chem. A*, vol. 5, no. 33, pp. 17401–17412, 2017, doi: 10.1039/C7TA06104H.

[20] A. Ramelan *et al.*, "Pengaruh penambahan silica fume, rasio air-semen, dan rasio semen-agregat terhadap kekuatan tekan beton," *J. Metal. Mater. Indones.*, vol. 1, no. 1, pp. 10–16, 2018.