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Compressive strength of mortar containing ferronickel slag as replacement of natural sand

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Abstract

Uses of various industrial by-products have been extensively studied in the past few decades in order to enhance the sustainability of construction industry. By-products can be used as alternatives to binders as well as aggregates in concrete. A large quantity of granulated ferronickel slag (FNS) is produced as a by-product in the smelting of nickel ore. This paper presents the effects of using ferronickel slag as a replacement of natural sand in cement mortar. The slag was produced by sea water-cooling of the by-product from the smelting of garnierite nickel ore. The grain size distribution of the slag was found suitable for using as fine aggregate in concrete. It was found that flow of fresh mortar increased with the increase of FNS up to 50% replacement of sand and then declined with further increase of FNS. The compressive strength of the hardened mortar specimens increased with the increase of FNS up to 50% and then declined with further increase of FNS. Use of fly ash as 30% cement replacement together with FNS as replacement of sand increased the flow of fresh mortar and decreased the strength of hardened specimens.

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Keywords: Ferronickel slag; fly ash; compressive strength; flow value; mortar

1. Introduction

Construction works require a significant amount of earth's natural resources. Sand has been used as a fine aggregate in concrete for decades. The demand for concrete is increasing with the growth in both developed and developing countries. However, our natural resources are limited, and sand is not extensively available in every

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country. Therefore, use of industrial by-products as aggregate can help solve this scarcity of natural sand and reduce the disposal cost of theses by-products. Moreover, the production cost of concrete may also reduce, which will have a positive impact on the economic growth of the society.

In search of suitable alternatives to natural sand, research is being conducted on different types of industrial by-products, for instance, steel slag, blast furnace slag, copper slag and FNS. Aggregates constitute almost 70% to 80% of the volume of concrete. As a result, aggregates affect the fresh and hardened properties of concrete to a great extent. For example, steel slag aggregate was shown suitable for producing high strength concrete [1-3]. Furthermore, steel slag aggregate also performed better than the natural aggregate to produce hot mix asphalt concrete [4]. However, blast furnace slag as a replacement of fine aggregate showed poor strength performance in concrete [5] though, ground granulated blast furnace slag and fly ash are usually found effective in improvement of the durability properties [6, 7]. The strength properties of mortar and concrete are influenced by the density, gradation and particle shape of aggregates used in the mix [5, 8, 9]. Granulated FNS showed higher density and lower water absorption compared to natural sand [10, 11]. The fresh concrete properties were also influenced by ferronickel slag. Concrete bleeding was shown to increase with an increment of ferronickel slag in concrete [12]. Compressive strength was found to increase by the replacement of sand by FNS [12]. However, there is a difference in opinion among the researchers. Sakoi et al. [11] pointed out that compressive strength remained same regardless the presence of FNS. Using industrial waste in construction works may impose a threat of leaching out of heavy metals and pollute the environment. However, FNS was found to be safe to use in land reclamation works as well as in construction works [13].

The properties of the ferronickel slag largely depend on the source of ore as well as the smelting process. No literature is available on the use of this particular slag as a fine aggregate. The slag used in this study was produced by sea water-cooling of the by-product from the smelting of garnierite nickel ore. The aim of the present study is to determine the workability and strength of cement mortar containing FNS in different percentages of the fine aggregate. Furthermore, the effects of fly ash on the workability and strength of mortar are evaluated. A concurrent study is being conducted on using the ground FNS as a supplementary binder in concrete [14].

2. Materials and Methods

Ordinary portland cement (OPC), class F fly ash, FNS and natural sand were used in this study. Density and fineness modulus were determined for both natural sand and FNS. The FNS (2.78 kg/m^3) had a higher density compared to sand (2.16 kg/m^3). Furthermore, the finesse modulus of FNS (4.07) was higher than that of sand (1.95). The FNS particles are angular in shape and coarser than sand in size. The gradations of natural sand, FNS and their combinations in different percentages are plotted in Fig 1. It can be seen that the grain size distribution becomes well-graded when the two aggregates are combined together. The best-graded combination is obtained for 50% replacement of sand by FNS.

Ten different mixtures were prepared in this study. In Series A, only OPC was used as the binder and sand was replaced in five different proportions (0%, 25%, 50%, 75% and 100%) with FNS. In series B, fly ash was used as 30% replacement of cement. Same combinations of the fine aggregates as in Series A were used in the mixtures of Series B. The water to cement ratio was kept constant at 0.47 for all the mixes. The reason for selecting 30% replacement of OPC with a class F fly ash was that it can reduce the CO_2 emission to a considerable extent [15]. The mixture proportions are given in Table 1.

Flow test was conducted to determine the workability of the freshly mixed mortar. The flow table with the mortar was dropped 25 times in 15 seconds after removing the mould. The percentage of the final diameter of the spread after the drops to the original diameter is used as the flow value of the mortar. Fig 2 shows the flow value measurements of the mixes. Mortar cubes (50 mm) were cast for compressive strength tests. The samples were left in the mould for one day and then stripped from the moulds. The samples were then cured in a water tank in fully submerged condition. The compressive strength of mortar was determined at 3, 7, 28 and 56 days after casting.

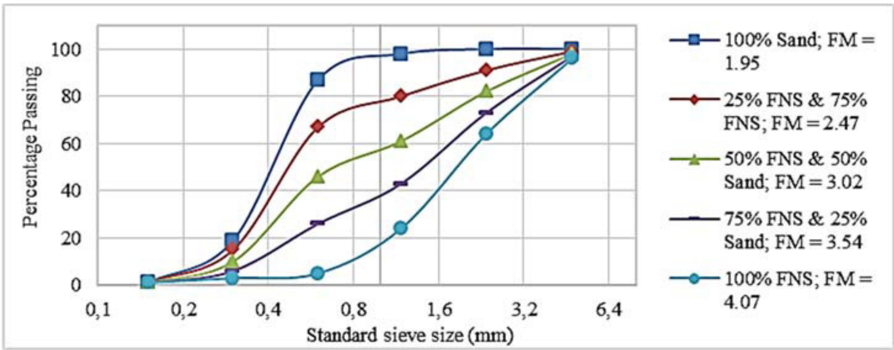

Fig. 1. Gradation of fine aggregates

Table 1. Mix proportions of concrete

Series	Sample ID	Binder (Kg/m^3)		Fine aggregate (Kg/m^3)		W/C
		OPC	FA	Sand	FNS	
A	A1	602	0	1355	0	0.47
	A2	602	0	1015	338	
	A3	602	0	678	678	
	A4	602	0	338	1015	
	A5	602	0	0	1355	
B	B1	421	181	1355	0	
	B2	421	181	1015	338	
	B3	421	181	678	678	
	B4	421	181	338	1015	
	B5	421	181	0	1355	

a.

Fig. 2. Flow test (a) 100% sand; (b) 50% FNS and 50% sand (c) 100% FNS

3. Results and discussion

3.1. *Workability of mortar*

The flow value was used to determine the workability of the mortar mixes. Fig 3 shows the plot of flow value with the FNS content. From the plot, it can be seen that the flow of mortar increased with the increase of FNS. However, the flow declined for replacement of sand by FNS beyond 50%. The particle shape of sand is a round; on the other hand, particle shape of FNS used in this experiment is angular. Since FNS particles are coarser than sand particles, less water is required to wet the FNS particles [16]. Moreover, Workability of mortar largely depends on the gradation of fine aggregates in the mix [17]. Since the 50% sand replacement resulted in the well-graded aggregate combination, this also showed the highest flow value of the mortar. The flow declined by FNS content of more than 50% because of the increase of angular particles in the mixture. Furthermore, fly ash has a positive effect on the workability of the mix. Fly ash blended mixes exhibited higher flow value than the OPC-only mixes. This is because of the well-known ball bearing effect of the fly ash particles.

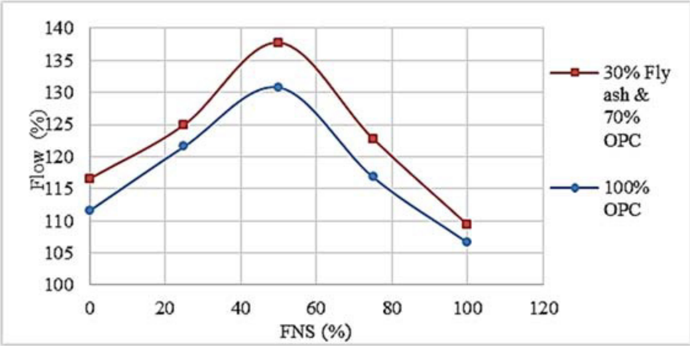

Fig. 3. Flow value of mortar mixes

3.2. Compressive Strength

The samples were dried in air before testing for the compressive strength. The compressive strength results for series A are given in Fig 4. It can be observed from the figure that compressive strength increased with the increase of FNS content up to 50% replacement level and then it declined with further increase of FNS. The similar phenomenon was observed at the ages of 3, 7, 28 and 56 days. The maximum 28-day compressive strength of 57 MPa was achieved for 50% FNS (Mix A3). The 28-day compressive strength of the samples with no FNS was 38 MPa. Therefore, 50% FNS resulted in about 50% increase of the 28-day compressive strength. Moreover, the compressive strength of samples containing 100% FNS (Mix A5) aggregate is 44 MPa, which is higher than that of the control sample.

The compressive strength results of the mixtures containing 30% fly ash as cement replacement are presented in Fig 5. It can be seen that compressive strength increased with the increase of FNS content up to 50% and then declined with further increase of FNS. The similar trend is observed at 3, 7, 28 and 56 days of age. Maximum 28-day compressive strength was 35 MPa for 50% FNS content. As expected, the compressive strength of the specimens of this series was less than the corresponding mixtures of series A because of the use of 30% fly ash as cement replacement.

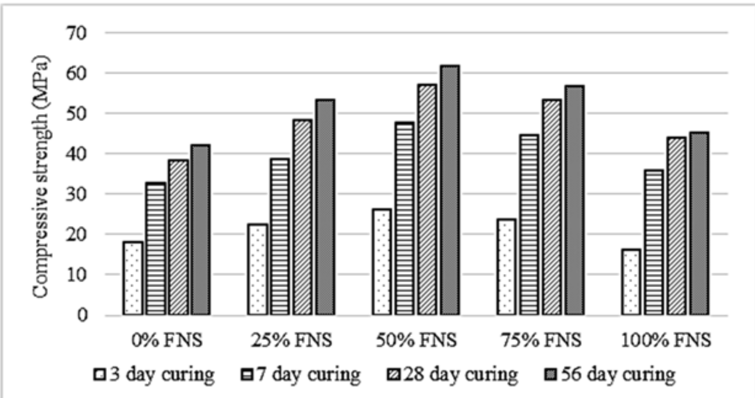

Fig. 4. Compressive strength of the mixtures with 100% OPC (Series A)

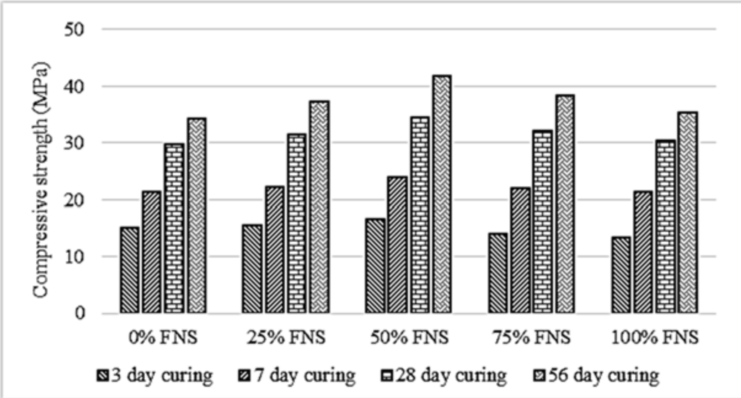

Fig. 5 Compressive strength of the mixtures with 30% fly ash and 70% OPC (series B)

Fig 6 exhibits the effect of 30% fly ash on the strength development of the mixtures containing 50% FNS. It can be seen that the strength development is slowed down by the fly ash from the early ages. However, the difference between the strengths at early ages is reduced by the pozzolanic reaction of fly ash with the increase of age.

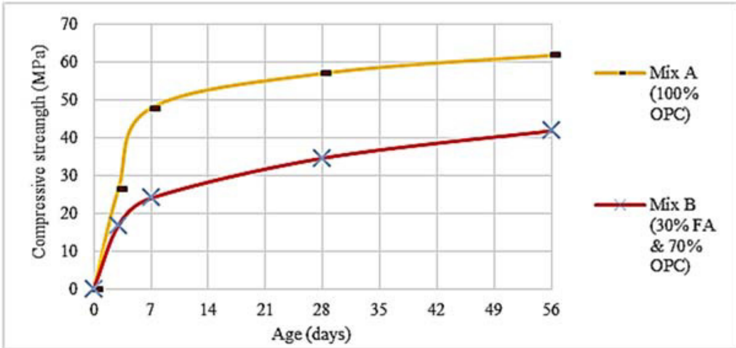

Fig. 6 Effect of fly ash on compressive strength development (50% FNS as aggregate)

From the above discussion, it is observed that FNS can improve the compressive strength considerably upto 50% replacement of sand. This is attributed to the particle packing effect of the well-graded aggregates for 50% replacement of sand by the FNS.

4. Conclusion

The workability and compressive strength of cement mortars containing different percentages of FNS as replacement of natural sand were evaluated. The results show that the optimum level of sand replacement by FNS is 50% for maximizing the compressive strength of mortar. This is because of the best particle packing achieved by the well-graded aggregates at this combination. Furthermore, 50% FNS also resulted in improved the workability of the mortar mix as determined by the flow test. The increase of flow by FNS is attributed to its relatively larger size compared to natural sand. Use of a class F fly ash as 30% replacement of cement improved the workability of the mixture because of the ball bearing effect. Fly ash decreased compressive strength of the mortars with and without FNS at both early and late ages up to 56 days.

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