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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.