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Evaluation of iron ore tailings as replacement for fine aggregate in concrete

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HIGHLIGHTS

- Concrete containing iron ore tailings (IOT) enhances compressive and splitting strengths.
- IOT concrete improves durability properties and resists carbonation.
- IOT as sand replacement in concrete reduces cost and environmental problems.

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ABSTRACT

Millions of tons of iron ore tailings (IOT); a by-product of iron ore processing, are disposed of every year in landfills, quarries, rivers, oceans among others thereby posing environmental problems. The major aim of this study is to evaluate IOT as replacement for river sand in concrete and compare with the result of conventional concrete. Concrete mixtures containing 25%, 50%, 75% and 100% IOT as river sand replacement were prepared with 0.5 water-to-cement ratio (W/C). Compressive and splitting tensile strengths, modulus of elasticity and durability tests (drying-shrinkage, water absorption, chloride penetration and carbonation effects) were conducted on concrete containing IOT. A statistical fitted linear regression analysis was performed on compressive strength to evaluate the significant level of concretes containing IOT. According to British standard, sieve analysis results indicated that IOT were of medium grade quality. Test results indicated that the concrete workability was reduced with IOT while all other strength and modulus of elasticity data were consistently higher than conventional concrete at all levels of replacement. It is recommended that IOT should be used in concrete as sand replacement to minimize environmental problems, cost and natural resources depletion.

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1. Introduction

In recent years, steel production has increased significantly to meet the construction industry demands. This has resulted in the generation of huge amount of iron ore tailings (IOT) which are disposed of as waste in landfills, quarries, rivers, oceans, etc. Malaysia produces millions of tons of IOT. A statistical survey on one of the iron ore mining industries in southern Malaysia showed that it produces about 625,000 tons of IOT every year. These tailings pose serious environmental problems besides occupying large area of landfill sites [1]. One way of disposing these IOT is to utilize them in construction industry where they would be recycled and reused to produce green and sustainable product. It would also save landfill space and decrease the extraction of natural raw materials [2].

It was reported that the use of waste materials in concrete products will lead to sustainable concrete and greener environment [3–6]. Senthamarai and Devadas [7] reported that the industrial and other wastes used in concrete-making will improve concrete properties and reduce cost. Growth in construction industries and the consequent increase in consumption of natural fine aggregate dwindle the natural resources. This increased in the consumption of river sand for construction activities means that the river beds are being over-exploited. This leads to a range of problems which include increased river bed depth, water table lowering, intrusion of salinity and destruction of river embankment [8]. Hence, there is a dire and urgent need to explore alternative materials to replace river sand as fine aggregate in concrete. The use of

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wastes and by-products as concrete aggregates is of great practical significance since they often constitute as much as three-quarters of the concrete by volume [9].

Recent studies have shown that the IOT have potentials that can be utilized effectively to produce concrete. Liu et al. [10] carried out a research on sprayed concrete with IOT. In their experiments, natural sand was replaced with IOT of up to 100% and obtained strength of 23.4 MPa at 28 days. Zhao et al. [11] studied the possibility of using IOT to replace natural aggregate to prepare ultra-high performance concrete. They reported that 100% replacement of natural aggregate with the tailings significantly decreased the workability and compressive strength of the concrete. This submission contradicted the study by Uchechukwu and Ezekiel [12] on the evaluation of IOT in concrete. Their investigation indicated that the use of IOT increased the compressive strength of concrete either as sand or cement replacement but better performance was recorded for cement replacement.

Iron ore tailings were also used in other concrete applications. For example, Das et al. [13] studied the use of IOT to develop ceramic tiles and their study showed, that tiles produced at a maximum of 40% of IOT were superior in terms of scratch hardness and strength, compared to European standard specifications. In a related research, Yao et al. [14] produced a novel glass–ceramic tile consisting of one glass–ceramic layer using IOTs and other raw materials. They reported that glass–ceramic tiles containing 25% IOTs solve indoor electromagnetic pollution at a frequency of 2–18 GHz; reaching peak of 98.27% microwave absorption of 10.31 GHz was cost-effective and eco-friendly.

Kuranchie et al. [15] studied the utilization of IOT for the production of geo-polymer bricks. Their results indicated that, the geo-polymer brick cured for seven days had superior characteristics than ASTM C62 (2013) standard requirements for building brick. Aruna and Kumar [16] utilized IOT to manufacture concrete paving blocks and reported that the compressive strength of concrete paving blocks with IOT was higher than concrete paving blocks containing sand only.

Durability of concrete is its ability to perform satisfactorily in the exposed conditions to which it is subjected to over an intended period of time with minimum maintenance. Circumstances such as chloride penetration, water absorption, and carbonation among others can lead to severe deterioration of concrete.

As the world is becoming environmentally conscious, a variety of other waste materials have been used to replace sand in concrete to find solutions and measures to counteract the problem of poor durability performance of concrete. Evangelista and de Brito [17], observed that the penetration of chloride in concrete increases linearly with the replacement ratio of fine recycled aggregate. On the other hand, the carbonation resistance is reduced with the addition of fine recycled aggregate to the concrete. Similarly Levy and Helene [18] observed that the carbonation depth decreases with the increase of recycled fine aggregate as replacement to natural aggregate. However, by using 100% recycled aggregates, they found that the carbonation depth is still lower than reference mix.

Kayali [19] reported that the light weight concrete incorporating fly ash as aggregate has low carbonation depth and chloride ion penetration. Pazhani and Jeyaraj [20] studied the durability of high performance concrete with industrial wastes. They reported that the chloride ion penetration decreases in concrete when 30% of ground granulated blast furnace slag and 100% of copper slag were replaced for cement and fine aggregate, respectively.

Research studies on IOT for concrete infrastructures are increasing, but little or no documentation on their durability performance. This necessitates the objective of this investigation to study the strength and durability properties of concrete incorporating maximum IOT as replacement for river sand.

2. Materials

2.1. Cement and aggregate

Ordinary Portland cement (OPC), CEM I with strength of 42.5 MPa, conforming with ASTM C150 [21] was obtained from Tasek Cement Manufacturing Company of Malaysia. The fine aggregate (river sand) and coarse aggregates used for this study were natural and locally sourced. A Polycarboxylic ether based superplasticizer that complies with ASTM C494 [22] was used to increase the workability of the mix to avoid increase of water.

2.2. Iron ore tailings

Iron ore tailings (IOT) were obtained from one source in Johor; a southern State in Malaysian Peninsula. Physical test data showed that it had: specific gravity = 2.6, relative density = 1.27 g/cm^3, fineness modulus = 1.05 and water absorption rate = 7.0%. The particle size distribution indicated that IOT are fine particles and fall to medium grade quality of BS 882 standard [23] (Fig. 1).

Table 1 shows the chemical composition of IOT. X-ray diffraction (XRD) analysis indicated that the main crystalline phases were quartz (SiO_2), gibbsite, hematite (Fe_2O_3) and chamosite [$(Fe^{2+}, Mg)_5Al(AlSi_3O_{10})(OH)_8$] (Fig. 2). Traces of calcite ($CaCO_3$) were also detected in the spectrum and these can be attributed to the high loss on ignition observed in the chemical composition [14].

Fig. 3(a) and (b) shows the Field Emission Scanning Electron Microscopy (FESEM) results on IOT at different magnifications. SEM analysis showed that it consisted of porous and irregular shaped particles which were well dispersed. The irregular shaped particles coupled with the loose ones are responsible for the high surface area and water demand.

The concentration of heavy metals including As, Ba, Cd, Cr, Pb, Se, Ag, Zn and Cu in the IOT were examined to ensure that the materials were non-hazardous. Toxicity Characteristic Leaching Procedure (TCLP), developed by the United States Environmental Protection Agency (US EPA) was used in evaluating the concentration of heavy metals from IOT material. The test was performed according to the US EPA procedure, where the IOT materials were mixed with deionized water at a liquid - solid ratio of 20:1 and 30 rpm agitation for 24 h was used. After the extraction and filtration of the leachates, heavy metal ions concentrations therein were determined by Inductively Coupled Plasma–Mass Spectrometry (ICP–MS). The test results are listed in Table 2 along with the regulatory limits. The results in Table 2 indicate that all the heavy metals concentrations were below the regulatory limits; therefore, the IOT used in this study can be considered as a non-hazardous mine waste material.

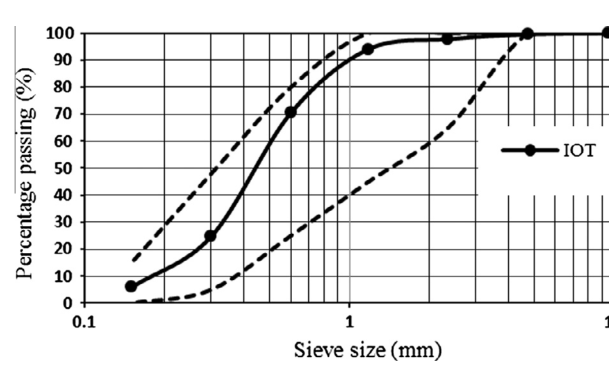

Fig. 1. Particle size distribution of IOT.

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