Strength properties of self-compacting concrete incorporating iron ore tailings

AJAGBE Wasiu Olabamiji[1,a], OKPANACHI Robert Ojonugwa[1,b], GANIYU Abideen Adekunle[2,c*] and ABDULKAREEM Muyideen Oladimeji[3,d]

[1]Department of Civil Engineering, Faculty of Technology, University of Ibadan, Ibadan, Nigeria

[2]Department of Civil Engineering, British University of Bahrain, Saar, Kingdom of Bahrain

[3]Department of Civil & Environmental Engineering, UCSI University, Kuala Lumpur, Malaysia

[a]ajagbewas@gmail.com, [b]robert4stephen@gmail.com, *[c]a.ganiyu@bub.bh, [d]muyikareem@gmail.com

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Abstract. The quest for sustainable production of concrete is a major step towards achieving net-zero Carbon. The utilisation of industrial waste in the production of concrete entrenches both sustainability and economic viability. Iron Ore Tailings (IOT) are a byproduct of the beneficiation process of iron ore. The unbridled disposal of Iron Ore Tailings (IOT) has proven to be a great threat to the natural environment. Self-compacting concrete (SCC) has gained prominence in the construction industry based on its unique flowability quality. This study investigated the strength characteristics of SCC incorporating IOT as replacement for fine aggregate. Concrete containing 5%, 10%, 15%, 20%, 30%, 40%, and 100% IOT as fine aggregate replacement were prepared and subjected to compressive and flexural strengths tests. The results reveal a progressive increase in strength with age for compressive strength, and progressive increase in strength with increasing percentage contents of IOT for both compressive and flexural strength tests. The inclusion of IOT as partial replacement of fine aggregates in SCC has a potential to mitigate the environmental degradation caused by its disposal and excessive depletion of natural sand. Besides, it is a viable measure towards reduction of carbon footprint of concrete production with evident economical benefits.

Introduction

Aggregates are the key constituents of concrete accountable for the precipitous exhaustion of natural resources. Sand mining has a multitude of negative environmental effects, including depletion of virgin resources, reduction of water tables, riverbank collapse, and water contamination [1]. A novel approach to sustainable development of concrete is the partial replacement of aggregates with suitable industrial waste material thereby preserving the naturally available aggregates, reducing the cost, and preventing indiscreet dumping of industrial wastes into the environment and all its associated complications [2; 3]. In this vein, the adoption of alternative fine aggregates such as crushed rock sands, recycled fine aggregates, and industrial by-products has been put forward [4; 5].

Iron Ore Tailings (IOT) are a by-product of the beneficiation process of iron ore. The unbridled disposal of several tons of IOT in landfills and quarries has proven to be a great threat to the natural environment. In Nigeria, the National Iron Ore Mining Company (NIOMCO) Itakpe, produces 3,072 tonnes of IOT per day, a significant proportion of which are not productively utilised [6]. The high specific surface area, high density, and irregular shape of IOT have a detrimental effect on the workability and shrinkage of concrete [7; 8]. However, the chemical composition and micro-structural analysis of IOT reveal that it is suitable as a binding material in concrete either by micro filling of voids or in pozzolanic reaction [9].

Self-compacting concrete (SCC) is a concrete type that can flow, fill formwork, encapsulate the reinforcement, and maintain its homogeneity under its own weight. The adoption of SCC in construction reduces the labour cost, accelerates project schedule, and improves structural integrity and sustainability [10]. The rheology, strength, shrinkage, and durability of SCC are affected by the mix design process, raw material properties, chemical and mineral admixtures, aggregate packing density, and the water to cement ratio [11; 12]. SCC does not require compaction and has different strength properties as compared to normal concrete, although increase in strengths is observed with decrease in water cement ratio as observed for normal concrete [13].

Previous research on the utilisation of IOT in concrete has been limited to the normal concrete and/or high-density concrete as partial replacement for cement, fine and/or coarse aggregates, engineered cementitious composites (ECC), ultra-high performance concrete (UHPC) [14-16], but the adoption of IOT in SCC is less prominent. Ferreira *et al.* [17] utilised IOT as aggregate in the production of metakaolin based geopolymer and reported that IOT acts satisfactorily at improving the quality of the geopolymer. Siamardi [18] modelled the fresh and hardened properties of powder type light weight SCC produced with coarse grained light expanded clay aggregates (LECA) as partial replacement of normal weight aggregates. Tang *et al.* [19] utilised red mud to partially replace fly ash in SCC and observed that samples containing 50% red mud have the best performance in compressive strength and elastic modulus. This research investigated the strength characteristics of self-compacting concrete incorporating IOT as partial replacement for fine aggregates by conducting compressive and flexural strength tests on samples of different replacement percentages of IOT.

Materials and Methods

Natural river sand obtained from Osogbo, Nigeria was used in this research. Locally available granite, also sourced from Osogbo with a maximum size of 20mm was used. The coarse aggregate used is the locally available granite, also sourced from Osogbo, the maximum size of which was 20mm. Figure 1 (a and b) show the aerial view of NIOMCO Itakpe, Nigeria, and the IOT sample obtained therefrom.

Figure1: (a) Aerial view of NIOMCO, Itakpe, Nigeria (b) IOT sample

Particle size distribution, specific gravity and bulk density tests were conducted on all aggregates. Portland Limestone cement, of Grade 32.5R (locally available Dangote brand) which complied with BS EN 197-1 was the binder used. MasterRheobuild 858 superplasticizer, a ready-to-use, high range water-reducing admixture designed to produce high slump concrete was used as chemical admixture to aid the workability of the concrete. It was added at an optimum dosage not exceeding 1.0 % by weight of cement. Table 1 gives the properties of the superplasticizer as obtained from the manufacturer.

Table 1: Properties of the Superplasticizer

Colour	Specific gravity @ 25°C	Chloride content	Freezing point	Flashpoint
Dark Brown	1.240	Chloride-free to EN 934	0°C	N/A

Potable water conforming to the requirements of water for concreting was utilised for mixing the concrete. A mix ratio of 1:2.2:2 for cement, fine and coarse aggregates, respectively with a water/cement ratio of 0.5 was used. The mould of 100 mm×100 mm × 100 mm size was used to produce the test samples for the concrete cubes and 100 mm× 100 mm × 500 mm was used to produce the test samples for the beams in accordance with BS EN 12390. Samples containing IOT as replacement of fine aggregates at 0, 5, 10, 15, 20, 30, 40 & 100 % were produced. The concrete was poured into the mould and compacted thoroughly, its surface was levelled, after which it was kept for 24 hours before being demoulded and immersed in a water curing tank containing clean water until the day of testing (7, 14 & 28 days for cubes, and 28 days for beams). Three samples were made and tested for each mix, and the results reported for each mix are the average of three samples, the cube samples were tested for compressive strength and the beams for flexural strength. Figure 2 (a and b) show the concrete samples in compressive and flexural strength tests, respectively.

Figure 2: Concrete sample in (a) Compressive (b) Flexural strength tests

Results and Discussions

Figure 1 presents the particle size distribution obtained from the sieve analysis for coarse aggregates (gravel) and fine aggregates (sand and IOT), the curve indicates that the size of fine aggregates used was between 0.063 mm and 4.75 mm, while the size of coarse aggregates was between 4.75 mm and 19.5 mm. The bulk density, specific gravity, compacted and uncompacted bulk density of the aggregates are presented in Table 2. The void in IOT has a greater tendency to absorb water, hence the high moisture content, also IOT is denser than both fine (sand) and coarse aggregates used, thus a rise in the density of concrete is expected with the addition of IOT. The ratio of uncompacted to compacted bulk densities are 0.81, 0.88 & 0.89 for the gravel, sand and IOT, respectively.

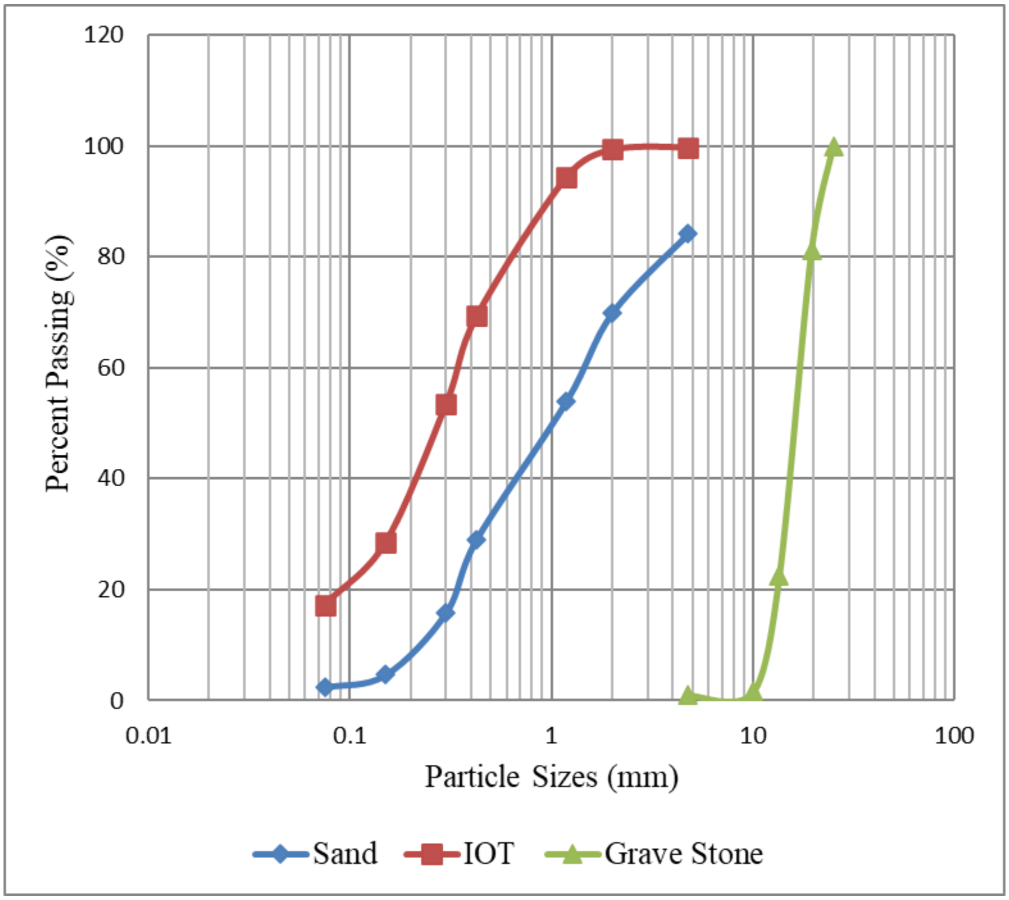

Figure 3: Particle size distribution curve for gravel, sand and IOT

Table 2: Physical and Mechanical Properties of the Aggregates

	Moisture Content (%)	Specific gravity	Bulk Density Uncompacted (kg/m3)	Bulk Density Compacted (kg/m3)
Gravel	0.92	2.63	834.8	1028.4
Sand	4.51	2.53	1052.9	1185.4
IOT	6.2	3.26	1747.5	1953.6

Figure 4 presents the compressive strengths at 7, 14 & 28 days of curing for the different percentages of IOT replacement of fine aggregates. The compressive strength of all the concrete samples increased with the increasing curing age, the compressive strength also increased with increase in IOT percentage, with 100 % replacement having the highest value and the control sample (0% IOT) the least strength for all curing days. The finer sizes of IOT particles may have contributed to the observed increase in strength by filling the pore and optimizing the pore structure of the mixes. Also, IOT particles have a rough and angular texture that strengthens the bond between the binding medium (cement) and the aggregate interface, resulting in increased strength. Likewise, the presence of iron at slightly higher quantities due to the inclusion of IOT in the mixes has a good effect on strength development similar to the incorporation of iron fibers [20-22].

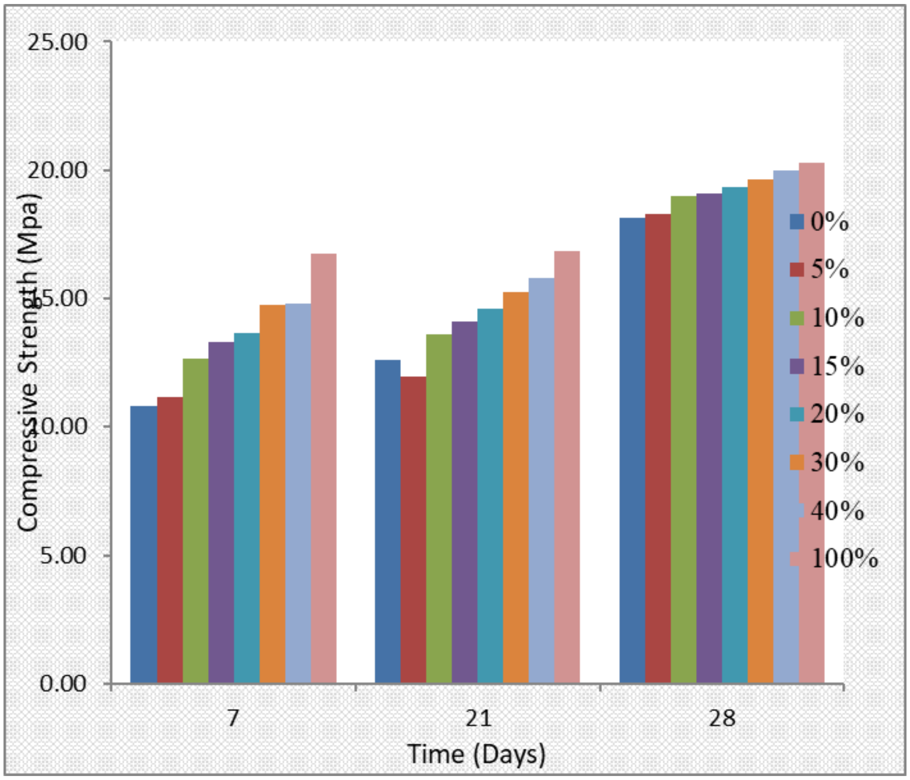

Figure 4: Compressive strength of SCC of different mixes of IOT at 7-, 21- & 28-days curing

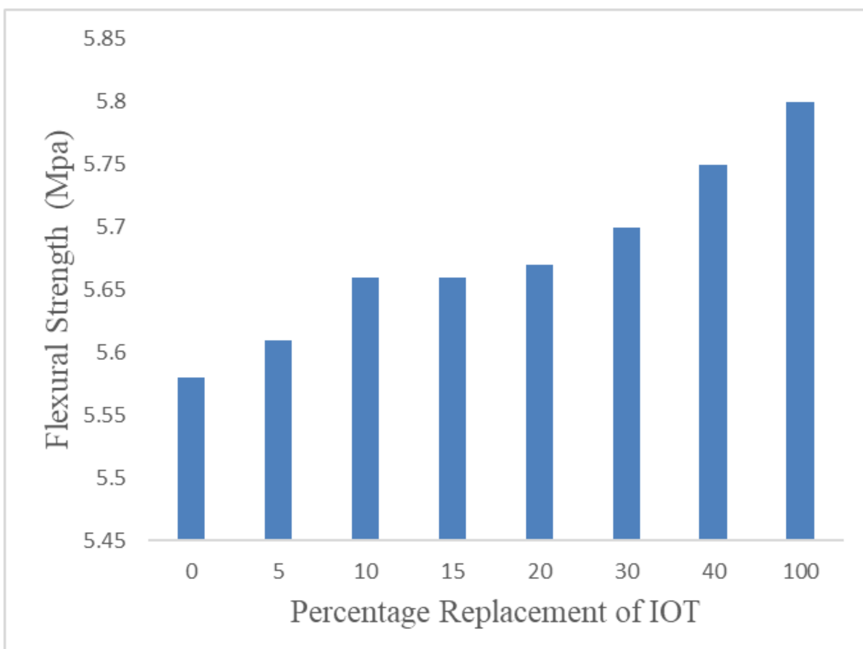

Figure 5: Flexural of SCC of different mixes of IOT at 28-days curing

The results of the 28-day flexural strength of the concretes are presented in Figure 5. From the Figure, the flexural strength of the different mixes behaved in a similar way to the compressive strength, as it increased with increase of IOT percentages, while the lowest and highest value of flexural strength are at 0% and 100% IOT replacements, respectively. Similar observation was reported by Zhao et al. [23] where IOT was used as partial replacement of aggregates in ultra-high-performance concrete (UHPC). The observed increase could be attributed to similar phenomena of finer particles, rough and angular texture of particles and increment of iron contents as earlier alluded to in the compressive strength. Thus, the partial replacement of fine aggregates with IOT increases the modulus of rupture of the concrete.

Conclusion

This study investigated the strength characteristics of SCC incorporating IOT as partial replacement of fine aggregate. The intent is to create large scale alternative uses for IOT, a by-product of a major industrial process which is being dumped recklessly and has already constituted a great nuisance to the environment. The results obtained revealed that the incorporation of IOT in SCC is viable and yielded improved compressive and flexural strength values. The adoption of IOT as replacement of fine aggregates in IOT will also reduce the wanton extraction of natural sand for concrete production, another positive step towards the reduction of carbon footprint of concrete. Already being a waste, any economical use of IOT is beneficial to the cost implications of its handling and disposal, and equally implies a reduction in the financial implications of concrete production.

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