POTENTIAL OF IRON ORE TAILINGS AS SUPPLEMENTARY MATERIAL FOR SAND

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Abstract
Due to the high demand for concrete in the construction industry and the problem of depletion of sand, resulting from climate change ravaging all parts of the world, particularly in areas prone to erosion, there is a need for alternative material for sand. In this study, the classification of iron ore tailings (IOTs) as a complementary material for sand in concrete is reported. The IOTs were characterized using x-ray fluorescence (XRF), field emission scanning electron microscopy (FESEM), electron dispersive spectroscopy (EDS) and the determination of the physical properties. The results revealed that IOTs has similar and distinct properties, compared with sand. The outcome of the x-ray fluorescence shows the dominance of silicon dioxide, in the chemical composition. Electron dispersive spectroscopy identified silicon and calcium as the key elements present in the IOTs. Field emission scanning electron microscopy image clearly revealed that, the iron ore tailings has larger particles per surface area compared with the natural sand. The sieve analysis and specific gravity results indicate availability of finer particles in IOTs compared to sand. Based on the outcome of the characterization of the iron ore tailings, it suggests that it can be used as fine aggregate in concrete, to partially or fully replace sand.

Keywords: Characterization, Iron ore tailings, fine aggregate, physical properties, material microstructure

Introduction
The main purpose of this study is to further emphasize the need for research into the suitability of using iron ore tailings as a construction material. It is significant to know that Iron ore tailings from different origins do not have the same geotechnical and mechanical characteristics. Iron ore tailings may even show similar grading, but the parameters cannot be generalized for all mines in terms of mineralogy or beneficiation process (Vale et al., 2013). Iron in the natural state, is usually found in the form of magnetite (Fe_3O_4), hematite (Fe_2O_3), goethite ($FeO(OH)$), limonite ($FeO(OH).n(H_2O)$) or siderite ($FeCO_3$). During the production process, to obtain iron ore, iron ore tailings (IOTs) are generated as waste product. The total accumulation of this waste from 2000 to 2009 was reported, to have exceeded 28 billion ton. Also huge amount of IOTs are stockpiled at various mines all over the world and the current utilization rate is below 10% of the quantity of IOTs generated as waste (Haung et al, 2013).

The stockpiled waste can cause serious waste management problems and the effect on the environment can be catastrophic such as contamination of farmlands, pollution of surface and underground water. Although IOTs has been used to produce infrastructure materials such as earth backfilling (Zhang et al, 2013), in the production of ceramic tiles (Liu et al, 2009), in the production of autoclaved aerated concrete (Li et al, 2011) and in the production of ultrahigh strength concrete (Zhang, 2014), there is still a need for more comprehensive utilization. Based on the above mentioned records, no significant impact could be felt in the consumption of IOTs, it therefore implies that, there is a need for large volume utilization of IOTs. Also due to the depletion of the environment as a result of huge consumption of natural sand for construction purpose, there is a need for alternative material as substitute for sand in concrete production. Some of the latest approach aimed at utilizing IOTs as construction material includes, usage in production of mortar (Carrasco et al., 2017), production of interlocking concrete pavers (Filho et al., 2017) and the powdered form of IOTs in form of pozzolan for partial replacement of cement (Young & Yang, 2019).

The emergence concept of using waste material in concrete has brought significant advancement in the development of renewable concrete technology. Outcomes from previous researches have made it possible to produce concrete using agricultural, urban and industrial wastes. These wastes are used as binder to partially replace cement, as fine or coarse aggregate in concrete, in their natural or processed states. Previous researches have also suggested ways on how to enhance the sustainable management of construction waste. These waste materials to mention but a few are iron ore tailings, copper tailings, coconut pith, wheat husk, rice husk, groundnut husk, palm kernel shell, broken concrete, broken bricks, scrap tires and plastics, crushed glass, blast furnace slag, fly ash or pulverized fuel ash, red mud, silica fume and pulverized oil fuel ash.

Some waste materials that has been used to partially or fully replace sand as fine aggregate in concrete includes iron ore tailings, copper tailings and slag granules. These waste materials can be used in varying combinations with sand, to produce concrete mixtures with reduced permeability, increased strength and more economical concrete products. Recent approach in the production and casting of concrete, using waste materials are making appreciable progress in terms of enriched concrete durability as well as cost efficiency. This has been testified to by Leadership in Energy and Environmental Design, which is a point rating system devised by the United States Green Building Council (USGBC) to evaluate the environmental performance of buildings (Kosmatka & Wilson, 2016).

The IOTs studied in this research were characterized using microstructure tools, x-ray fluorescence, field emission scanning electron microscopy and electron dispersive spectroscopy. The physical properties of the IOTs are also reported. The confirmation of using iron ore tailings (IOTs) as a complementary material for sand in concrete is hereby highlighted in this study.

Materials and methods

The two materials used in this study are iron ore tailings and natural sand. In order to characterize the iron ore tailings, the chemical composition, microstructure, elemental composition and the physical properties of the materials were determined. The tests were similarly done for the natural sand and the results compared.

Chemical analysis of IOTs

The X-ray fluorescence (XRF) analyzer was used to determine the chemical composition of the iron ore tailings. The analyzer was equipped with a 50 kV x-ray tube with an 8-mm aperture. The measurement time was selected ranging from 30 seconds up to 300 seconds for the purpose of meeting up with higher precision and accuracy requirements stipulated by the Environmental Protection Agency (EPA). The electromagnetic radiation of wavelengths of x-rays that ranges between 0.1 Å and 20 Å was used. The materials were excited by bombarding with high-energy X-rays (gamma rays) and this enabled the determination of the oxides composition of the iron ore tailings. A detector was used which collected and reports the intensities of the emitted x-rays, which in turn was used in a calibrated system to determine the relative proportions of elements in the sample. The tests were conducted on three samples of the IOTs material and the average result was used.

FESEM/EDS morphology of materials

The morphology of river sand and the iron ore tailings were characterized using the field emission scanning electron microscope. The sand and the IOTs samples were each coated with platinum and later placed horizontally at 180° on the substrate holder for surface analysis. The cross-sectional view to observe the thickness was placed at vertical angle of 90°. The microstructure of the samples were then analyzed at varying magnifications. The energy dispersive X-ray spectroscopy was performed at an accelerating voltage of 2 kV to identify the elemental composition of the sand and the IOTs materials. The FESEM/EDS study provided the topography of the materials at different magnifications as well as qualitative/quantitative information about the materials.

Determination of physical properties of materials

The physical properties of the fine aggregate materials that were determined are the particle size distribution including the coefficient of curvature, coefficient of concavity and fineness modulus, others include porosity, specific gravity, loose and compacted unit weight. The sieve designation used is based on BS guidelines and the sieve analysis test was carried out following the BS 812:103 (1985) specifications. The bulk specific gravity was determined using the displacement method, which is based on Archimedes' principle.

Results and Discussion

Chemical composition of IOTs

Based on the x-ray fluorescence test, the oxide composition of the iron ore tailings are indicated in Figure 1. The figure revealed that the dominant oxide in iron ore tailings is silicon dioxide (SiO_2). These oxides structure of iron ore tailings can be compared with those available in natural sand. From Figure 1, it can also be deduced that the common oxides in iron ore tailings with high percentages are silicon dioxide, iron oxide and aluminium oxide. These types of oxides can contribute to gain in strength in mortar or concrete.

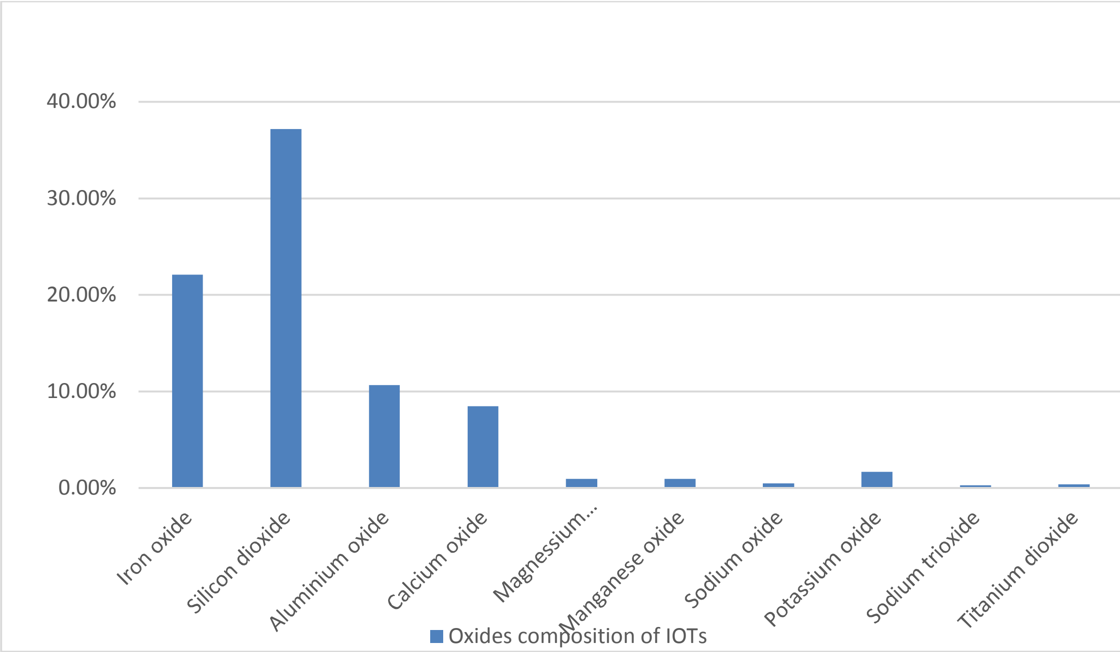

Figure 1: Oxide composition of the iron ore tailings Field emission scanning electron microscopy – morphology of materials

The Field emission scanning electron microscopy shows the morphology of iron ore tailings compared with the river sand. The morphology of the natural sand at varying magnifications scale in contrast to those of iron ore tailings are shown in Figure 2 to Figure 4. The FESEM morphology reveals that, using the same magnifications, more grain particles of IOTs are observed compared with the river sand within the same area of coverage. This implies that, the iron ore tailings are more densely packed in contrast to the sand. This also implies that, if these two materials were to be used as fine aggregate in mortar or concrete, more particles of iron ore tailings would be available for combination with cement to produce more dense structure.

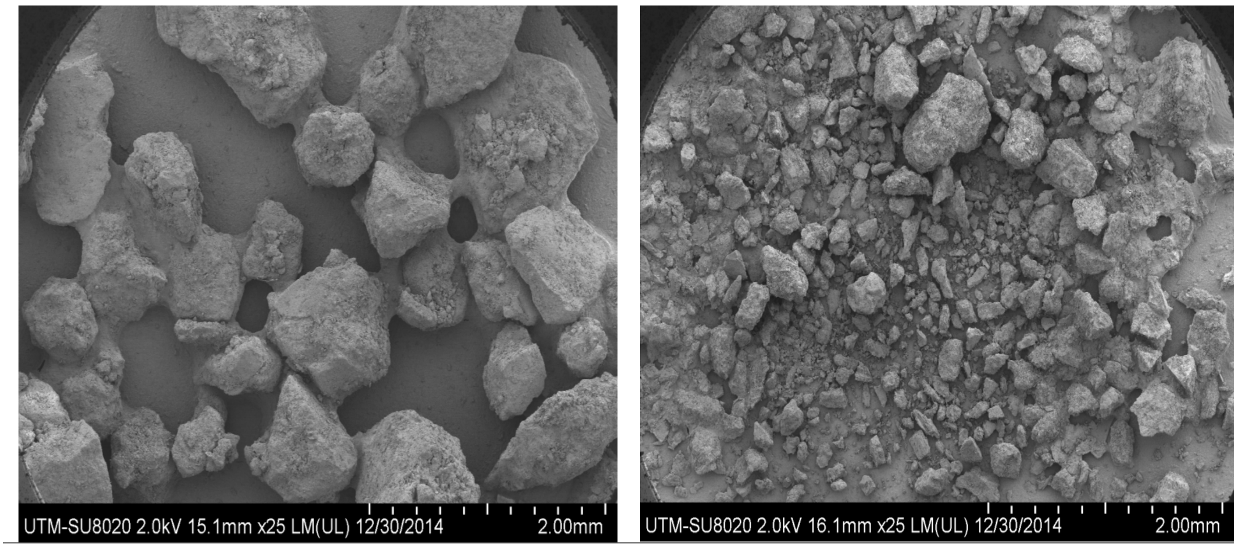

Figure 2: FESEM morphology of sand vs IOTs at 2 mm magnification

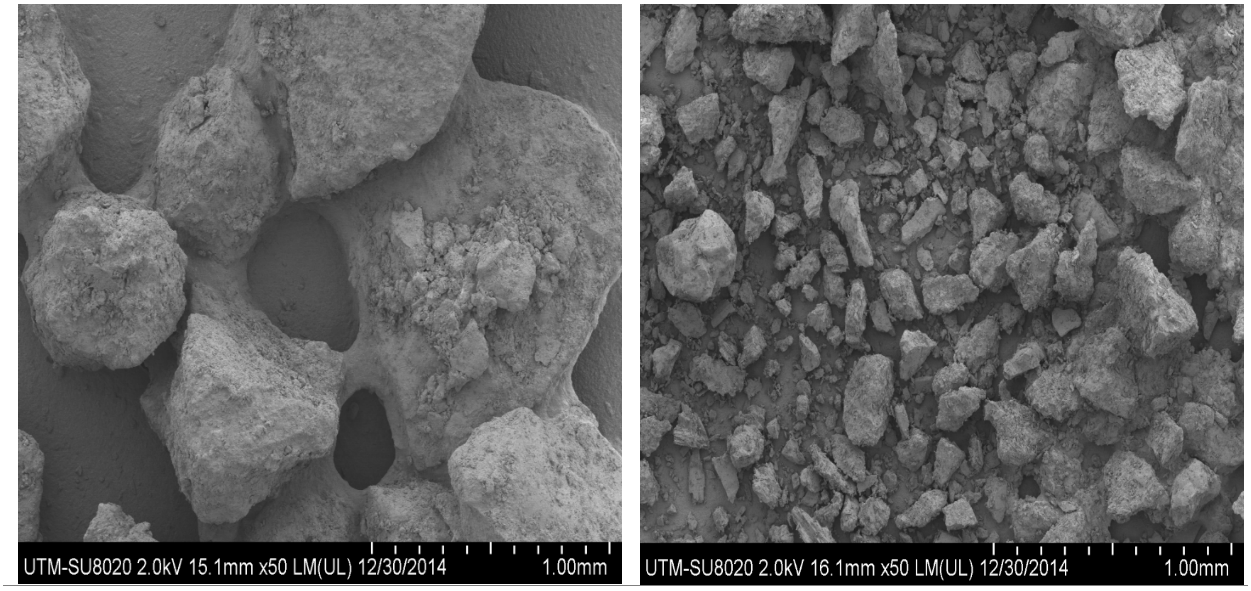

Figure 3: FESEM morphology of sand vs IOTs at 1 mm magnification

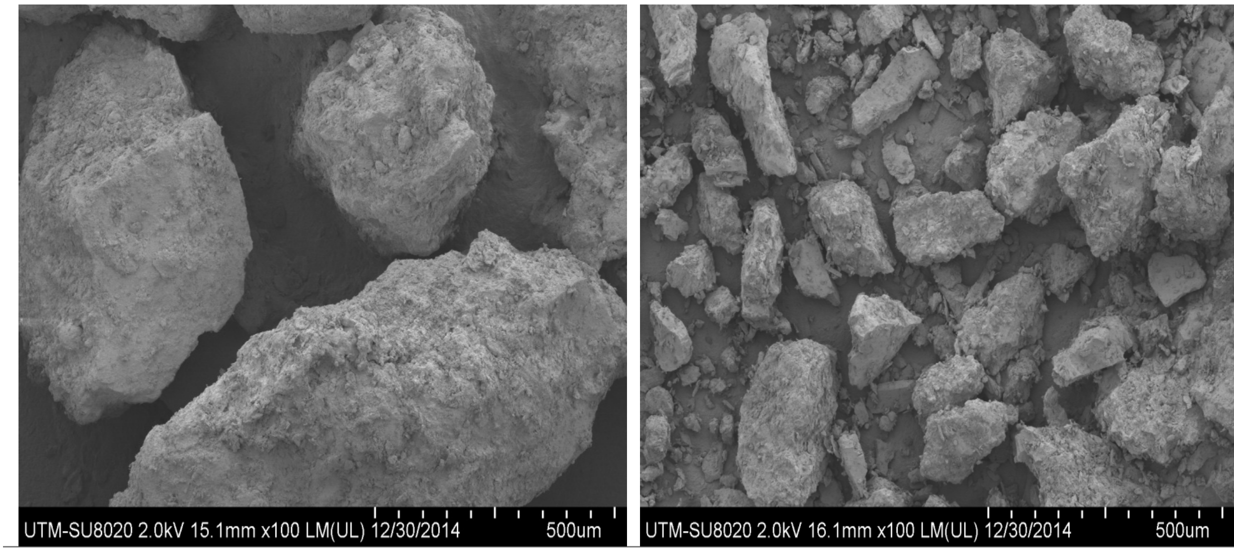

Figure 4: FESEM morphology of sand vs IOTs at 500 µm magnification

Energy dispersive x-ray spectroscopy of materials

The elemental composition of natural sand and that of iron ore tailings as identified by energy dispersive x-ray spectroscopy are shown in Figure 5 and Figure 6 respectively. The energy of each x-ray photon is characteristic of the element which produced it. The dominant elements in the iron ore tailings as revealed by the energy dispersive x-ray spectroscopy result are silica, iron and aluminium. This result is in conformity with the outcome of the X-ray fluorescence, oxide composition test, which indicate the dominance of silica dioxide, iron oxide and aluminium oxide in the iron ore tailings.

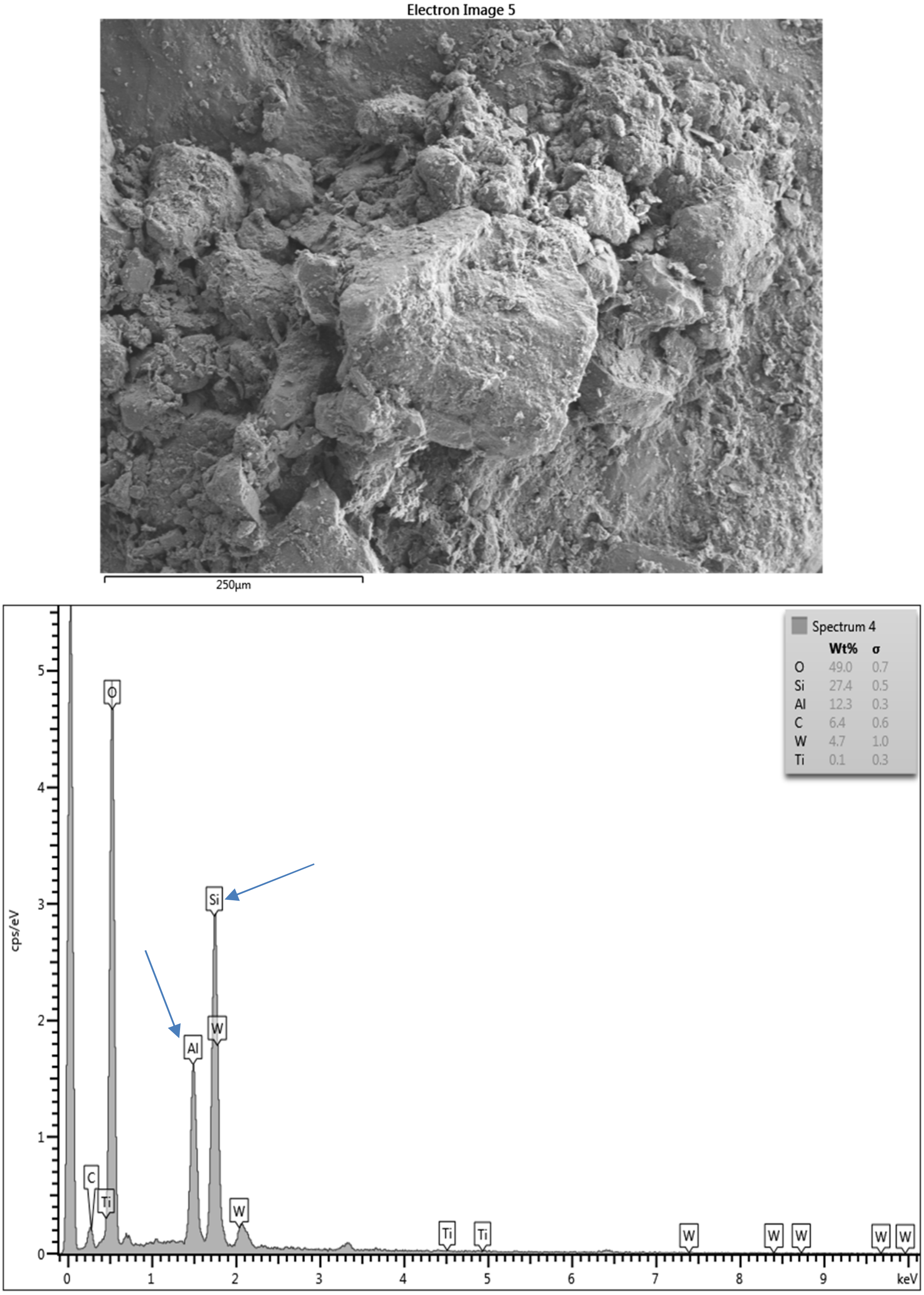

Figure 5: Energy dispersive x-ray spectroscopy of sand

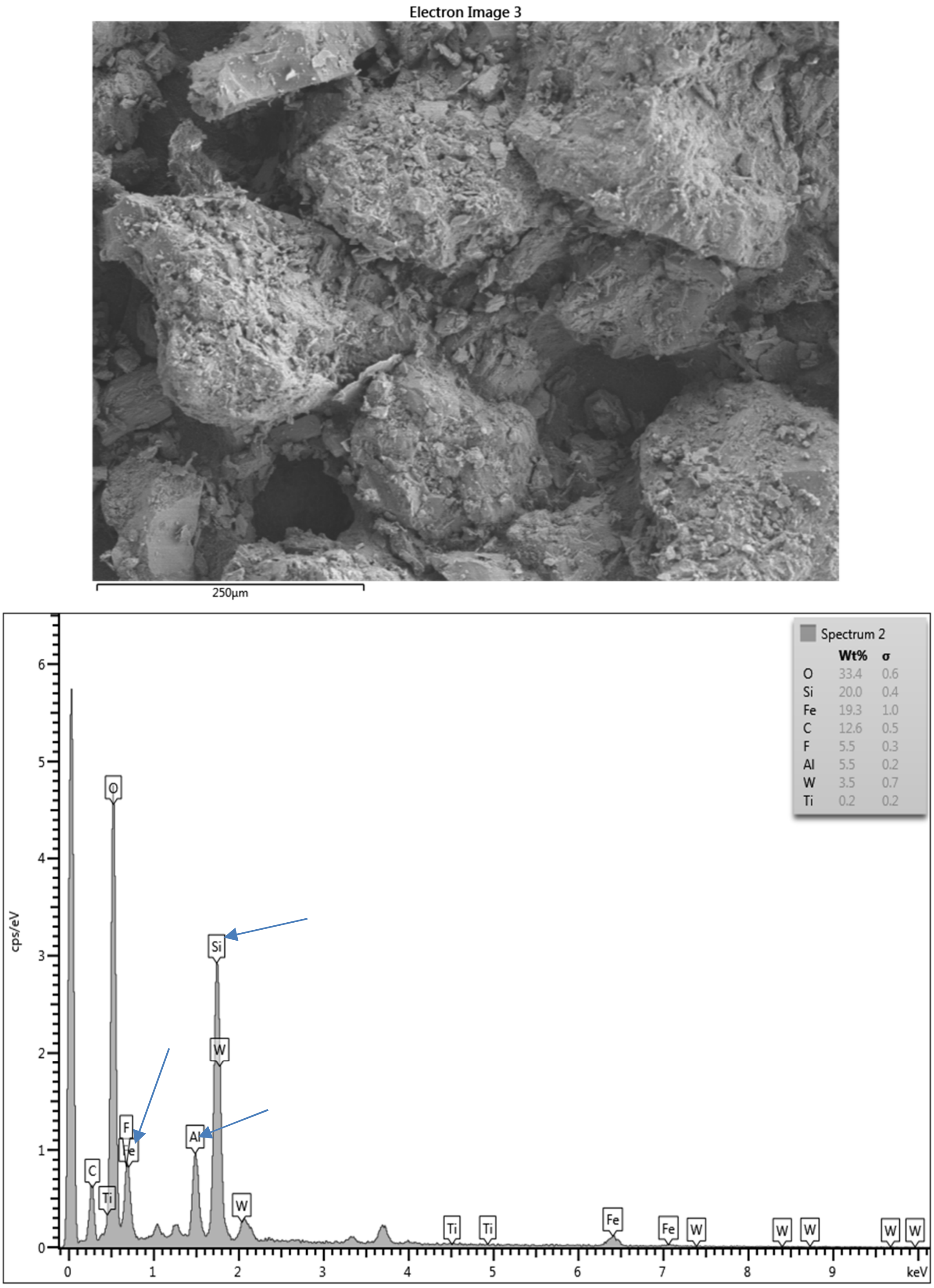

Figure 6: Energy dispersive x-ray spectroscopy of IOTs

Physical properties of materials

The percentage of particles of sand and those of iron ore tailings, passing the 600 µm sieve was 44% and 93% respectively. This indicate availability of finer particles in the IOTs compared to the natural sand. The iron ore tailings also recorded higher value of specific gravity, compared to that of the natural sand. The higher the specific gravity of any material, the finer is the material (Neville, 2011). Lower value of fineness modulus was recorded by the iron ore tailings in comparison with that of the natural sand. For fine aggregate materials, the lower the value of fineness modulus, the finer is the material (Neville, 2011). From the outcome of the sieve analysis and specific gravity test results, it can be concluded that the particle size distribution and the specific gravity test results are synonymous. These results confirms the availability of more fines particles in iron ore tailings compared with the natural sand. The summary of the physical properties of the natural sand and those of the IOTs are presented in Table 1. The particle size distribution curve of the natural sand and that of the iron ore tailings as determined by sieve analysis is shown in Figure 7, which also indicate the BS grading limits for fine aggregate.

Table 1: Physical properties of IOTs and natural sand

Physical properties	IOTs	Natural sand
Size Passing 600µm (%)	93	44
Coefficient of uniformity	4.7	3.7
Coefficient of curvature	0.01	0.02
Porosity (%)	12.1	14
Specific gravity	2.91	2.65
Fineness Modulus	1.4	3.2
Loose unit wt (kg/m^3)	1598	1459
Compacted unit wt (kg/m^3)	1817	1696

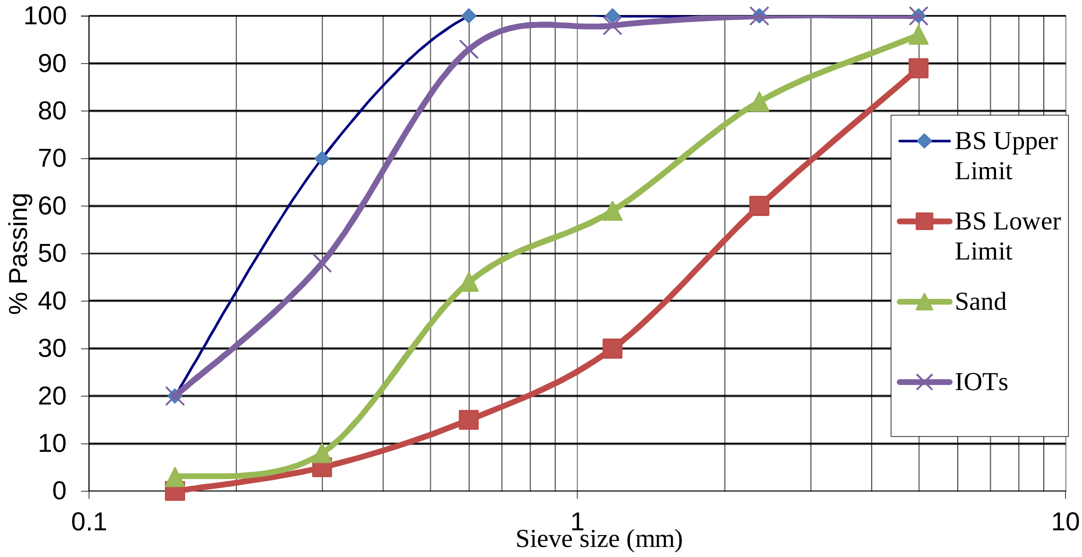

Figure 7: Particle size distribution curve for IOTs and natural sand

Conclusion

This study has further identified the potential of iron ore tailings as a suitable material to be used as fine aggregate in concrete or mortar production. In this case, the sustainability of the construction industry can be improved. The characterization of the iron ore tailings indicate close similarity with the properties of natural sand. The morphology of the iron ore tailings revealed that the material has larger particles per surface area compared to sand, this is an indication that the IOTs can combine more effectively with cement to reduce the pores, if used in mortar or concrete production. The morphology of the iron ore tailings also shows that the material can be used to reduce the formation of capillary cavities. The crystalline nature of the tailings in terms of void-less crystals or fragments of crystals is also an advantage, for the improvement of dense structure, if the material were to be used in mortar or concrete production. The iron ore tailings is a promising material that can be used to improve the interface between the fine aggregate and the binder within the transition zone in mortar or concrete.

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