Applied Mechanics and Materials
ISSN: 1662-7482, Vol. 735, pp 122-127
doi:10.4028/www.scientific.net/AMM.735.122

Submitted: 2014-08-10
Revised: 2014-11-27
Accepted: 2014-12-01
Online: 2015-02-25

Performance of Iron Ore Tailings as Partial Replacement for Sand in Concrete

ORITOLA Sikiru[1,a *], SALEH Abd Latif[1,b] and MOHD SAM Abd Rahman[1,c]

[1]Faculty of Civil Engineering, Universiti Teknologi Malaysia, Skudai, Malaysia
[a]sforitola2@live.utm.my, [b]alatif@utm.my, [c]abdulrahman@utm.my
*sforitola2@live.utm.my

Keywords: Iron ore Tailings, Waste material, Concrete properties, Compressive strength, Flexural strength

Abstract. The findings on the properties of concrete produced using iron ore tailings obtained from ZCM Minerals SDN BHD located in Kotta Tingi, Johor, Malaysia as partial replacement for sand, is reported in this paper. The Iron Ore Tailings (IOT's) a waste product, with particle size range from (850μm - 75μm) obtained from Iron Ore Processing was utilized as fine aggregate to produce concrete. Based on British Standard (BS) guidelines, normal concrete mix was designed. Five types of concrete samples (C0, C1, C2, C3, and C4) were produced, with the percentage of tailings used to replace sand as fine aggregate ranging from 0 to 40[%]. The reference sample is referred to as C0, with no tailings while the other four , contained tailings at 10[%] replacement intervals. The effect of iron ore tailings on the consistency of the fresh concrete were studied, as well as the density, compressive strength, flexural strength and splitting tensile strength, of the hardened concrete. The results of the consistency tests on concrete shows that the slump values ranges from 81 to 53[mm] from concrete sample C0 to C4 respectively, while the compacting factor values ranges from 0.92 to 0.89 respectively. The density of the produced concrete cube samples falls within the range 2350 to 2430[kg/m^3]. The concrete sample C3 gave the highest compressive strength value of 43.70[N/mm^2]. The concrete sample C3 also gave the highest flexural strength value of 4.79[N/mm^2], while the The concrete sample C4 gave the highest splitting tensile strength value of 4.0[N/mm^2] after curing period of 28[days].

Introduction

The main focus of this study is to find ways of utilizing the waste tailings obtained from Iron Ore processing in Malaysia. According to [1] in 2012, iron ore production topped all other minerals in Malaysia, with 10.7million tons mined. The iron ore output in 2011 is just 3.5 million tons. The production of iron ore is increasing on a higher trend up to-date from our investigation, implying that the government is showing much interest nowadays in iron ore production in Malaysia.

While researchers are working in some other parts of the world with similar record of iron ore availability like Malaysia, on how best to make use of the tailings, the only known research conducted on this material in Malaysia up to this present moment is by [2]. He only conducted research on the particle size analysis of the iron ore tailings. The present increasing trend of iron ore production in Malaysia is the major reason for conducting this research, in order to recommend ways of utilizing the waste tailings generated from the production process.

In this work, Iron Ore Tailings, waste product (with particle size range from (850μm - 75μm) obtained from Iron Ore Processing has been utilized as fine aggregate to produce concrete. Similar work must have been done elsewhere outside Malaysia, but the significance of this study is based on the fact that, it's the first that looks into what iron ore tailings generated in Malaysia can be used for. To substantiate this, [3] mentioned that the composition of iron ore tailings depends directly on the composition of the ore and the process of mineral extraction used on the ore. [3] in their study of mineral composition of 19 Iron ore tailings pond, found out that, Iron ore tailings from different origins; do not have the same geotechnical behaviour. Iron ore tailings may even show similar

grading, but the parameters cannot be generalized for mines in terms of mineralogy or beneficiation process, hence the significance of this study.

Some researchers in the past have studied on how to utilise iron ore tailings in concrete or concrete related products. The experimental work done by [4] with regards to the feasibility of using iron ore tailings as fine aggregate in ultra high performance concrete, reveals that, from the perspective of mechanical behavior, it is feasible to use iron ore tailings to partially replace natural sand to make ultra high performance concrete. This present study; consider it, highly significant to establish the use of iron ore tailings in normal weight concrete, because of the large abundance of iron ore tailings (IOTs) and the wide applicability of normal weight concrete.

The research carried out by [5] reveals that when iron ore tailings is mixed with sand, there was increase in strength, *but did not simply indicate the limit of mix proportion.* This present study shows the effect of IOTs on the consistency of concrete and the *extent at which the strength of concrete is improved based on the percentage of IOTs in the mix proportion.*

This paper presents findings on preliminary work of an ongoing research, the substantive recommendations on what the waste tailings can be used for can only be given when other major durability tests are concluded.

Experimental Work

Materials. The iron ore tailings used for the experiment was obtained from ZCM Minerals SDN BHD, located in Kota Tinggi, Johor, Malaysia. *X-Ray Florescence (XRF) test* was conducted on the iron ore tailings to reveal the oxide composition of the tailings. The chemical compositions of the ZCM iron ore tailings compared with others are shown in Table 1. Portable water, obtained within the concrete laboratory of Universiti Teknologi Malaysia was used for the concrete production. The ordinary Portland cement brand, obtained within Johor Malaysia was used as binder for the concrete work. The sand and granite used were also obtained from quarry located in Johor.

Table 1. Chemical Compositions of ZCM Iron Ore Tailings Compared with others Selected from Previous Researches

Properties of IOTs	**Compositions from various Locations**							
Chemical Xtics content (wt %)	K/Tinggi Malaysia	Miyun China	Itakpe Nigeria	Goa India	*Rui China	*Rui China	*Rui China	Sujing China
Fe_2O_3	22.10	8.13	15	44.36	11.99	7.04	10.41	9.13
SiO_2	37.20	69.52	66	51.12	68.63	70.27	58.76	52.06
Al_2O_3	10.70	7.44	3.8	1.22	6.72	8.43	11.84	17.14
CaO	8.52	4.14	1.8	0.22	2.76	3.92	5.14	12.74
MgO	0.96	3.72	1.2	-	3.82	3.03	6.11	3.68
Mn_2O_3	1.04	-	1.0	-	-	-	-	0.25
Na_2O	0.46	1.38	-	-	1.6	1.66	2.71	0.97
K_2O	1.71	1.97	-	-	1.98	2.62	1.62	0.30
SO_3	0.26	0.03	-	-	1.91	2.02	0.10	-
TiO_2	0.43	0.016	-	-	-	-	-	0.45
L O I		2.5	-	2.95	-	-	-	3.23

Methods. Based on the British Standard specifications, materials used for concrete production (sand, crushed granite, and iron ore tailings) were tested before using them. Sieve analysis test [6], determination of moixture content and specific gravity test were conducted in order to arrive at a viable concrete mix design.

Concrete Mix Design. The current British method for the design of normal weight concrete made with Portland cement, produced by the Department of Environment (DOE), Building Research Establishment (BRE) Laboratory [7] was used for the Concrete mix design. This allows for proper

selection of the proportions of ingredients for concrete, to make the most economical use of available materials and to produce concrete of the required properties. Based on the procedure of the concrete mix design and using the appropriate design tables and figures, a normal weight concrete with water content 250[Kg/m^3], cement content 463[Kg/m^3], fine aggregate content 769.4[Kg/m^3] and coarse aggregate content of 867.6[Kg/m^3] was designed using water-cement ratio of 0.54.

Proportioning of Concrete Materials. Five different types of concrete samples (C0, C1, C2, C3, and C4) were considered, with the percentage of tailings used to replace sand as fine aggregate ranging from 0 to 40[%]. The reference sample is taken as C0 with no tailings and the four others, containing tailings at 10[%] intervals.The reference mix adopted is that, which contain sand as the only fine aggregate. The quantities of cement, water and the coarse aggregate were kept constant for all the mix samples, the only variant are the materials used as fine aggregate (sand and iron ore tailings). The five different types of concrete samples produced and the details of the concrete mix proportioning of materials, based on water-cement ratio of 0.54, is shown in Table 2.

Table 2. Concrete Samples and the Proportions of their Constituent Materials

Concrete Samples	Constituent Materials [Kg/m^3]				
	Water	Cement	Sand	Tailings	Granite
C0	250	463	769.4	0	867.6
C1	250	463	692.46	76.94	867.6
C2	250	463	615.52	153.88	867.6
C3	250	463	538.58	230.82	867.6
C4	250	463	461.64	307.76	867.6

Testing of Concrete. The fresh concrete produced were tested for Slump and compacting factor, while Samples of hardened concrete cubes, prism and cylinder were also tested for density, compressive strength, flexural strength and splitting tensile strength using the average of three samples each, based on British Standard (BS) guidelines [8, 9, 10, 11, 12, 13] respectively.

Results and Discussions

Materials used for Producing the Concrete. The Particle size distribution curve for sand, iron ore tailings and crushed granite is shown in figure 1. The result indicates that the iron ore tailings are finer than the sand and the crushed granite are uniformly graded. Uniformly graded aggregate, indicates aggregate containing particles of almost the same size [14]. With this type of grading, aggregates are not well packed, and resulting concrete will require lot of paste.Based on this, the quantity of fine aggregate in the concrete sample is almost the same with that of coarse aggregate and for the main reason that, it is required to utilise large quantity of the tailings.

The effect of Iron ore Tailings on the Consistency of Concrete. Tests results for consistency of the fresh concrete are presented in Table 3. The slump values obtained, lies within the range 53-81mm which is categorized as medium Slump according to [14]. The slump reduces with the increase in content of tailings. The Iron-ore Tailings has high affinity for water because of it's rough surface and high specific surface area. This result is line with that obtained by [4].

The compacting factor test results ranges between 0.89-0.92. For normal weight concrete, compacting factor value ranges between 0.8 to 0.92 [14]. The compacting factor decreases with the increase in tailings content. This can be attributed to the fineness of Iron-ore Tailings and thereby being able to fill up more void in the fresh concrete, resulting in higher compacted weight.

The effect of Iron ore Tailings on the mechanical properties of Concrete. Variation of density and compressive strength with age are presented in Figure 2 and Figure 3 respectively. The density of the produced concrete cubes samples falls within the range 2350 to 2430kg/m^3. The compressive

strength values ranges from 31.27 to 43.70[N/mm^2] at 28[days]. The compressive strength increases with the increase in tailings content up to 30% addition level. This is due to the angular and rough texture of Iron ore Tailings which improves the bond between cement and aggregate interface, resulting in higher strength. The work done by [5] also shows similar behaviour.

The 28[days] splitting tensile strength and flexural strength results are shown in Table 4. Similar to the compressive strength results and for the same reason, the splitting tensile strength and flexural strength increases with the increase in tailings content.

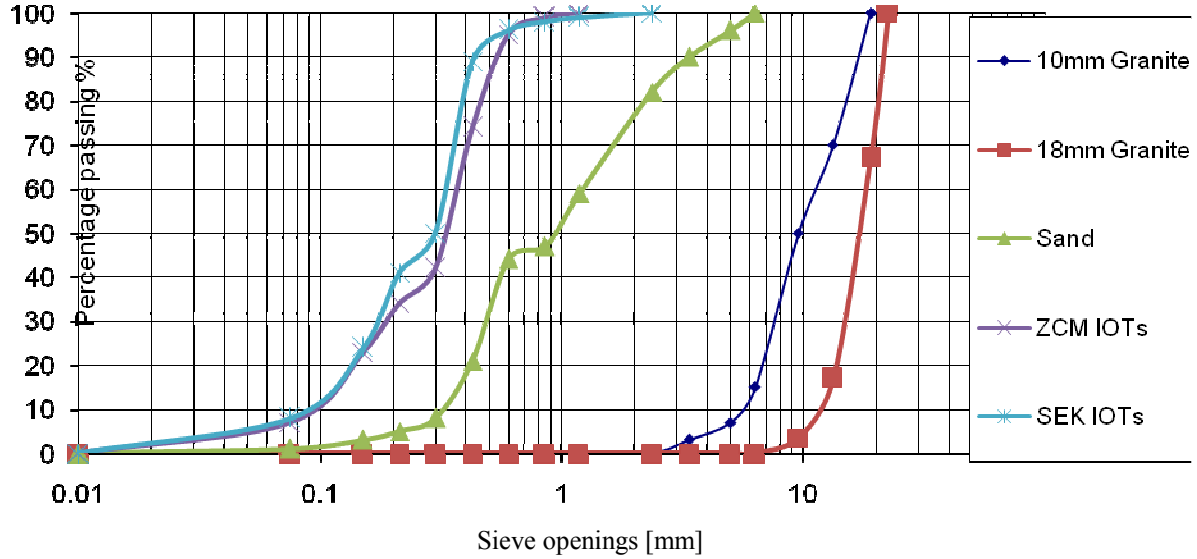

Fig. 1 Particle Size Distribution Curve for Sand, Tailings and Granite

Table 3. Consistency of Fresh Concrete

Concrete Sample	Slump [mm]	Remarks	Compacting Factor
C0	81	Medium Slump	0.92
C1	79	Medium Slump	0.91
C2	67	Medium Slump	0.90
C3	59	Medium Slump	0.90
C4	53	Medium Slump	0.89

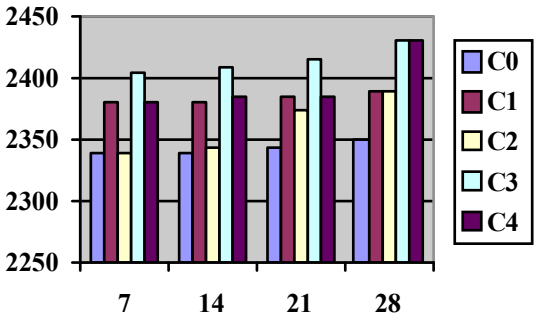

Fig. 2 Variation of Density [Kg/m^3] with Age [Days] of Concrete

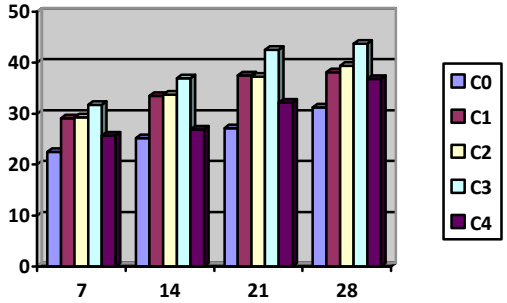

Fig. 3 Variation of Compressive Strength [N/mm^2] with Age [Days] of Concrete

Table 4. 28 days Splitting Tensile and Flexural Strength of Concrete

Concrete Sample	Splitting Tensile Strength [N/mm^2] 28 days	Flexural Strength [N/mm^2] 28 days
C0	3.54	4.45
C1	3.72	4.52
C2	3.75	4.47
C3	3.91	4.79
C4	4.0	4.41

Conclusion

Properties of concrete containing iron ore tailings obtained from mineral mine, owned by ZCM Minerals SDN BHD, Kota Tinggi, Johor, Malaysia, have been determined. The fresh and hardened properties of concrete evaluated are slump, compacting factor, density, compressive strength, splitting tensile strength and flexural strength.

The properties of concrete evaluated using the iron ore tailings in concrete meets and satisfy the guidelines requirements and specifications for normal weight concrete. The iron ore tailings show slight adverse effect on the consistency of the concrete but the addition of iron ore tailings as fine aggregate in concrete increases the compressive strength up to 30[%] addition level. There is also slight improvement on the value of the splitting tensile strength and flexural strength with the addition of the tailings.

Based on the findings from this research the iron ore tailings, rather than been discarded, can be used as fine aggregate in concrete, more importantly to reduce cost, in line with the global trend of sustainability and cost control in construction materials. The use of locally available alternative material, to the conventional ones normally used in concrete work tends to meet the present needs for infrastructural development.

Acknowledgements

This research is sponsored by RUG of Universiti Teknologi Malaysia with research grant Number Q.J130000.2505.09H37, the authors are grateful for the contributions of Rozana Zakaria and Mushairry Mustaffar. We also appreciate the support of Mr Nawawi and Mr Haqim for their assistance in the laboratory. The effort of Mr Nurul Huda (Mine Inspector at ministry of Minerals and Geosciences, Malaysia) for materials collection and other contributions towards the success of this research is forever appreciated.

References

[1] http://www. malaysiafactbook.com/iron ore mining in Malaysia, accessed on 5 April, 2014.

[2] P.Samayamutthirian, Beneficiation of Iron Ore Slime. Nova Publishers (2011) pp, 205-216.

[3] S.A. Vale , M.B. Mendes , J.G. Milonas, W. Pirete and W.J. Souza, Geotechnical Parameters of Iron Ore Tailings from the Quadrilátero Ferrífero after Different Treatments and Ore Processing, J.P.S. Silva University of São Paulo, Brazil, (2013).

[4] S. Zhao, J. Fan and W. Sun: Utilization of Iron ore Tailings as Fine Aggregate in Ultra-High Performance Concrete, Construction and Building Materials 50 (2014) pp 540–548.

[5] H. Yunfen, Comparison of Effect of Iron Tailing Sand and Natural Sand on Concrete Properties, Trans Tech Publications, Switzerland. Key Engineering Materials Vol. 599 (2014) pp 11-14.

[6] British Standard Institutions, Methods for Determination of Particle Size Distribution, BS 812: part 103, London, 1985.

[7] Building Research Establishment laboratory, Note on Mix Design method, Department of Environment (DOE), London, UK, 1988.

[8] British Standard Institutions, Methods for Determination of Slump, BS 1881: part 102, London, 1983.

[9] British Standard Institutions, Methods for determination of Compacting Factor, BS 1881: Part 103, London, 1983.

[10] ASTM C642, Standard Test Method for Density, Absorption and voids in Hardened Concrete, ASTM International, PA, 2006.

[11] British Standard Institutions, Method for Determination of Compressive Strength of Concrete Cubes, BS 1881: Part 116, London, 1983.

[12] British Standard Institutions, Method for Determination of flexural strength. BS 1881: part 118, London, 1983.

[13] British Standard Institutions, Method for Determination of Tensile Splitting Strength, BS 1881: part 117, London, 1983.

[14] A.M. Nerville, Properties of concrete. John Wiley and sons Inc., London, UK, (1996).