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Effect of Iron Ore Tailings on The Water Absorption of Normal Weight Concrete

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ABSTRACT

Most of the important properties of hardened concrete are related to the quantity and the characteristics of the various types of materials in the concrete. In this study, iron ore tailings (IOTs), an inert, industrial waste material, was combined with sand in varying proportion as fine aggregate in concrete. Five concrete samples A, B, C, D and E were produced. Sample A served as control while samples B, C, D and E contains IOTs as partial replacement for sand. Physical properties, Energy dispersive x-ray (EDX) spectroscopy and X-ray fluorescence (ERF) of fine aggregates were determined. Slump and compacting factor of the fresh concrete were also determined. The density, compressive strength, flexural strength, ultrasonic pulse velocity and the microstructure of the hardened concrete were also assessed. The outcome of this study reveals that concrete sample with 40 % iron ore tailings (IOTs), is about 3.7 % denser than the control sample. Concrete sample with 30 % iron ore tailings (IOTs), recorded the highest compressive and flexural strengths. Ultrasonic pulse velocity values and the microstructure of the IOTs concrete samples shows that inclusion of Iron ore tailings in normal weight concrete reduces absorption of water in the concrete.

KEYWORDS: Fine aggregate; hardened concrete; iron ore tailings; water absorption; ultrasonic pulse velocity; compressive strength; flexural strength; microstructure.

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1 | INTRODUCTION

The main objective of this research is to evaluate the effect of iron ore tailings on the water absorption of hardened concrete, if this material is used as fine aggregate to partially replace natural sand in concrete. Generally, worldwide, normal weight concrete is widely used compared to other types of concrete (Zongjin *et al.,* 2022). The unit weight of normal weight concrete compared to other types of concrete is depicted in Table 1 and the compressive strength of different types of concrete is shown in Table 2. A normal weight concrete can be considered as a moderate-strength concrete (Zongjin *et al.,* 2022). Applicability of iron ore tailings in normal weight concrete for various usages will aid in solving numerous environmental problems.

According to United State Geological Survey, (2023), based on iron content, global production for the year 2022, amounted to 1.6 billion metric tonnes. Abundance of tailings waste are generated from processing of the ore, since on the average only 17 – 25 % of the iron ore are extracted from the main raw material magnetite and haemetite (Samayamutthirian, 2011). In addition, almost every mineral producing country is facing the problem of better utilization of mine waste because of its accumulation and lack of suitable storage space. Increasing public awareness about various health hazards and stringent contamination norms of pollution monitoring authorities have also created pressure on governments as well as the private sector to devise waste management and utilization solutions for various environmental hazards. Iron ore tailings (IOTs) is inert and is considered as potential waste material that can have positive effect on the properties of concrete, hence there is need for research into beneficial means of using this waste.

Researchers in the past have studied various means by which volume of pores in concrete can be reduced. Previous studies have reported ways to use aggregates and some forms of mineral binders to reduce pores and water absorption of concrete (Kumar & Battacharje, 2003; Alhozaimy, 2009) different forms of sand in concrete as siliceous material to produce concrete with high resistance to water (Winslow *et al.,* 1994; Jankovic *et al.,* 2014; Liu *et al.,* 2010) variation of the grade of concrete and increase in quantity of cement paste to improve the degree of filling of the cavities in the aggregate (Das & Kondraivedhan, 2012). Fly ash was also used in form of Pozzolanic material to make concrete less permeable (Pitroda & Umrigar, 2013). Rice husk ash (Kartini *et al.,* 2010) and pulverized brick (Sabir *et al.,* 1998) were also used to lower the water absorption of concrete.

This study considers the possibility of using Iron ore tailings (IOTs) to improve the water resistance of concrete by reducing the cavities and pores in normal weight concrete. Also, according to Oritola *et al.,* (2014), large volume consumption of Iron ore tailings is necessary to solve the problem of environmental pollution, hence the need to establish the utilization of the waste material in normal weight concrete is important. By physical examination, the IOTs is fine in nature and further experimental tests shows that the material has similar grading to that of sand. Micro-structure analysis further confirmed that the material is finer than sand and this suggest that the material can be used as pore blocker in concrete.

Table 1: Classification of concrete in accordance with unit weight (Zongjin, 2022)

Classification	Unit weight (Kg/m^3)
Ultra-lightweight concrete	<1200
Lightweight concrete	1200 < UW < 1800
Normal-weight concrete	~2400
Heavyweight concrete	>3200

2 | EXPERIMENT PROGRAM

2.1 Materials

The ordinary Portland cement brand, with strength class of 42.5 in accordance with the British standard (BRE, 1998), obtained within Johor Malaysia was used as binder for the concrete work used in this study. The fine aggregate consists of iron ore tailings and natural sand. Particle size distribution of sand and iron ore tailings gave percentage passing 600µm sieve as 46% for sand and 92% for IOTs. The iron ore tailings (IOTs) was tested and found to have specific gravity value of 2.81 and fineness modulus of 1.5. The natural sand was obtained from a local river and the value of specific gravity and fineness modulus was determined as 2.65 and 3.2 respectively. The materials were used under saturated surface dry condition. The physical properties of fine aggregate determined experimentally are shown in Table 3. X-ray florescence (XRF) test was also conducted on the iron ore tailings for the purpose of knowing the chemical composition of the IOTs.

The oxide composition of the iron ore tailings is indicated in Table 4. Energy dispersive x-ray (EDX) spectroscopy further identifies the elemental composition of the focused material IOTs. The EDX identifies the elemental composition of materials imaged in a field emission scanning electron microscope (FESEM) for all elements with an atomic number greater than boron. The energy of each x-ray photon is characteristic of the element which produced it. The microanalysis system collects the x-rays, sorts and plots them by energy, identifies and labels the elements responsible for the peaks in this energy distribution. The energy dispersive x-ray spectroscopy for natural sand and the iron ore tailings are shown in Fig. 1 and Fig. 2 respectively. The FESEM morphology of natural sand at magnification of 2mm compared with that of IOTs at the same magnification is as shown in Fig. 3. 10mm crushed granite was used as coarse aggregate for the production of concrete samples.

Table 2: Concrete classified in accordance with compressive strength (Zongjin, 2022)

Classification	**Compessive strength (mPa)**
Low strength concrete	< 20
Moderate strength concrete	20 - 50
High strength concrete	50 – 150
Ultra-high strength concrete	>150

Table 3: Physical properties of fine aggregate

Physical properties	Fine aggregate	
	Sand	IOTs
Size Passing 600µm %	46	92
Coefficient of uniformity	3.7	4.7
Coefficient of curvature	0.02	0.01
Porosity %	14	12.1
Specific gravity	2.65	2.81
Fineness Modulus	3.2	1.5
Loose unit weight kg/m^3	1453	1599
Compacted unit weight kg/m^3	1687	1822

Table 4: Chemical compositions of IOTs

Oxides (wt %)	% Compositions
Fe_2O_3	11.30
SiO_2	48.02
Al_2O_3	9.50
CaO	9.71
MgO	0.95
Mn_2O_3	1.05
Na_2O	0.46
K_2O	1.50
SO_3	0.49
TiO_2	0.41
L O I	-

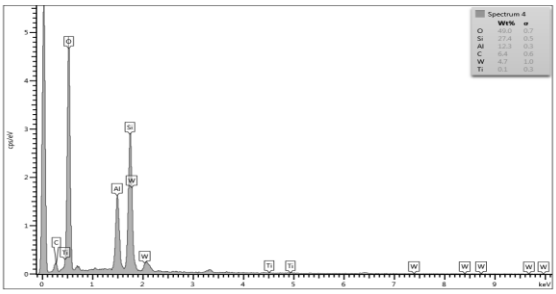


Figure 1: Energy dispersive x-ray spectroscopy for natural sand

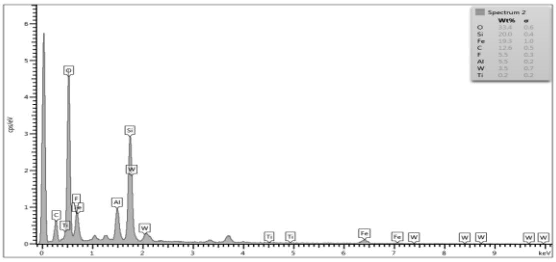
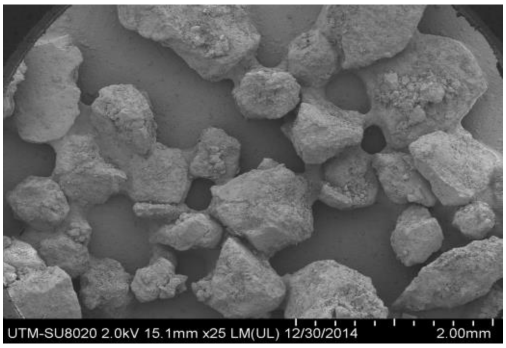
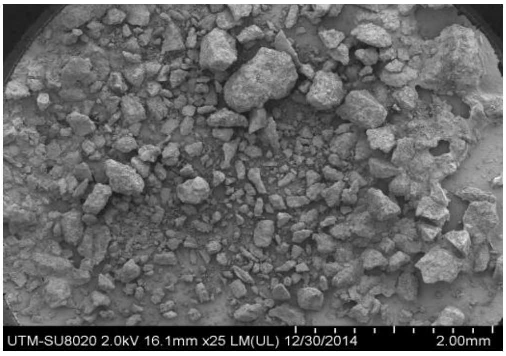


Figure 2: Energy dispersive x-ray spectroscopy for iron ore tailings



Sand



Iron ore tailings

Figure 3: FESEM morphology of sand and iron ore tailings

2.2 Methods

2.2.1 Design of Concrete Mix

The guideline in the current British method for the design of normal strength concrete made with Portland cement (BRE, 1988) was used for the design. The mix design ensures proper selection and proportioning of ingredients to produce concrete of the required properties. Normal strength concrete was designed to have 28-day characteristics concrete cube compressive strength of 30 N/mm^2.

2.2.2 Proportioning of Materials

Total of five different types of concrete samples were produced. A reference mix, which contain sand as the only fine aggregate and four other different types of concrete samples based on varying percentage of iron ore tailings as 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 description of the concrete samples is shown in Table 5 while the proportioning of concrete materials are depicted in Table 6.

Table 5: Percentage of fine aggregate in concrete samples

Samples	% of fine aggregate	
	Sand	IOTs
A	100	0
B	90	10
C	80	20
D	70	30
E	60	40

Table 6: Proportioning of concrete materials

Concrete samples	Materials				
	Water	Cement	Sand	IOTs	Granite
A	245	457	670	0	968
B	245	457	603	67	968
C	245	457	537	134	968
D	245	457	469	201	968
E	245	457	402	268	968

2.2.3 Production of Concrete

The mixing of concrete was done based on BS 1881-125. All concrete materials were weighed to an accuracy of ±0.5% and mixed at laboratory temperature of (20 ±5) °C. The tilting drum mixer with capacity of 0.035m^3 was used. The process of buttering the mixer was carried out before mixing the first batch of concrete. The whole batch of concrete was mixed for about (3 ±0.5) minutes, until the concrete appears homogeneous.

2.2.4 Testing of concrete

The fresh and hardened properties of concrete were determined based on guidelines in British Standard and America society for testing materials.

2.2.4.1 Workability of concrete

Fresh properties of concrete were assessed in order to determine the performance of the mixture. The workability measurement of the concrete was achieved using slump test done in accordance to BS 1881-102 and compacting factor test conducted according to BS 1881-103.

2.2.4.2 Ultrasonic pulse velocity and density

The purpose of the ultrasonic pulse velocity test is to determine the transition time of an ultrasonic longitudinal wave in concrete. When the transition time is known, the pulse velocity can be calculated, and inferences can be drawn concerning the strength and overall quality of the concrete. Three samples 100 x 100 x 100 mm concrete cube for each type of concrete were tested for the pulse velocity after 28 days of curing. The test was conducted based on guidelines in BS EN 12504-4. The density of concrete test was done for the purpose of evaluating the solidity of the concrete. The guidelines given in BS EN 12390-7 was followed to obtain values of densities for all the concrete cubes.

2.2.4.3 Compressive strength

The compressive strength of reference concrete sample and those containing iron ore tailings was determined using standard uniaxial compression testing machine in the laboratory. It is the most important property which gives an idea about the major characteristics of the concrete. For each type of concrete, three samples 100 x 100 x 100 mm concrete cubes were cured in water at 21ºC for 3, 7, 14, 21 and 28 days. The average of three cube results was taken as the compressive strength. The test was accomplished based on procedure in BS EN 12390-3.

2.2.4.4 Flexural strength

The flexural strength of concrete samples was determined based on guidelines outlined in BS EN 12390-5. For each type of concrete, three samples 100 x 100 x 500 mm concrete prisms were cured in water at 21ºC for 3, 7, and 28 days. The average flexural strength of three concrete prism samples was calculated from results obtained, using flexural strength testing machine in the laboratory.

2.2.4.5 Water absorption

The water absorption test was done for the purpose of estimating the maximum amount of water that can be absorbed by the various concrete specimens. It provides a measure of the total, water permeable pore space in a concrete sample. The concrete cubes were cured in water at 21ºC for 28 days; for each type of concrete, three concrete core samples 100 x 75 mm ϕ was used for the water absorption test. The three specimens were placed in the drying oven 30mm from each other, to allow all their surfaces to be accessed by air. The specimens were dried in the oven for 72 hrs. on removal from the oven; they were cooled in the dry airtight vessel for 24 hrs. The mass of each specimen was weighed and recorded after cooling. The specimens were then immersed completely in water at 21°C, using cumulative immersion periods of 10, 30, 60 and 120 minutes, with the same specimens being used and returned to the water tank after each measurement. These immersion periods were used to ascertain the efficiency of iron ore tailings as pore blocker in concrete. The average increase in mass as a percentage of dry mass was evaluated. The water absorption test was conducted according to BS 1881-122.

2.2.4.6 Microstructure of Concrete

The Field emission scanning electron microscopy (FESEM) provides topographical and elemental information at useful magnifications for the concrete specimens. Energy dispersive x-ray (EDX) spectroscopy further identifies the elemental composition of materials in the concrete samples. FESEM morphology of the concrete samples was studied at diverse magnifications.

3 | RESULTS AND INTERPRETATION

3.1 Workability of concrete

The concrete slump test is an empirical test that measures the workability of fresh concrete. The test determines the consistency of the fresh concrete samples. The slump variations with the amount of IOTs in the concrete samples are presented in Fig. 4. The control sample had the highest value of 81mm slump while the concrete sample with 40% iron ore tailings as fine aggregate had the least value of 53mm. Due to the high affinity of iron ore tailings for water at the fresh state of concrete, there was reduction in slump values for fresh concrete samples containing IOTs. The mixing water was consumed by the iron ore tailings and this reduced the slump of the concrete.

The compacting factor test is another useful tool used to measure the workability of fresh concrete. There was no significance difference in the values obtained for the control sample and those containing iron ore tailings. The compacting factor for the reference sample gave 0.93 and for those samples containing iron ore tailings ranges between 0.88 - 0.91. Higher content of IOTs results in greater values of compacted weight. The BS 1881-103 prescribes for normal strength concrete, compacting factor value range of 0.8 to 0.92. Table 7 shows the results of the compacting factor test.

Table 7: Compacting factor of concrete samples

Concrete sample	A	B	C	D	E
Compacting factor	0.93	0.91	0.90	0.90	0.88

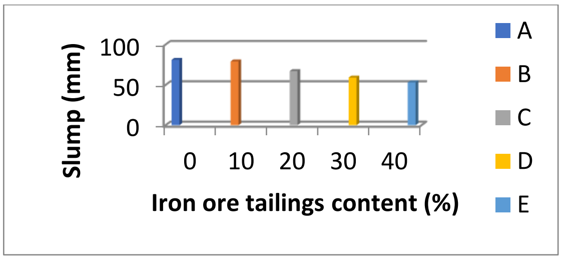


Figure 4: Relationship between slump and iron ore tailings content

3.2 Density and Ultrasonic Pulse Velocity (UPV)

In order to determine the uniformity of concrete with respect to the presence of cracks or voids and changes in properties of concrete with time, the pulse velocity of the concrete samples was measured. The ultrasonic pulse velocity determination is a convention because the path length over which the pulse travels may not strictly be known. Density of materials is also an important physical property that influence pulse velocity. Correspondingly the density of materials has effect on the density of concrete. The density of concrete samples and the ultrasonic pulse velocity as related to iron ore tailings content are shown in Fig. 5 and Fig. 6 respectively.

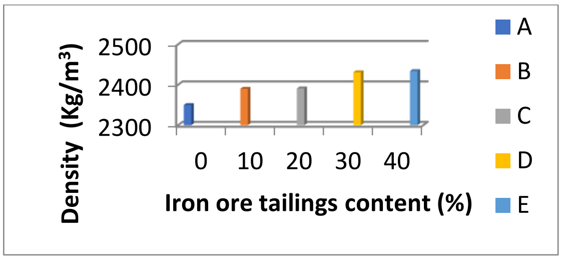


Figure 5: Relationship between density and iron ore tailings content

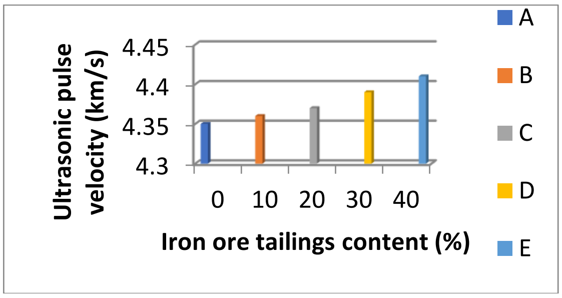


Figure 6: Relationship between Ultrasonic pulse velocity and iron ore tailings content

3.3 Compressive strength

The compressive strength is the most important properties of hardened concrete. It's the property generally specified in construction design and quality control. All concrete samples with partial replacement of sand with iron ore tailings as fine aggregate gave higher values of compressive strength than the reference sample. The relationship of age of concrete with the compressive strength for all the concrete samples is revealed in Fig. 7.

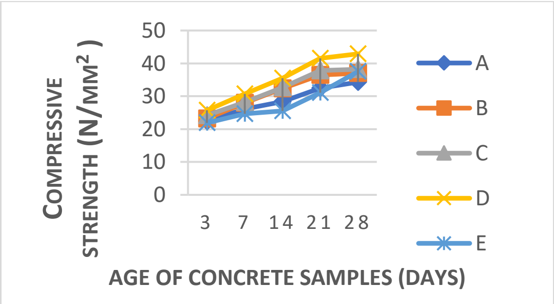


Figure 7: Age and compressive strength of concrete for varying IOTs content

3.4 Flexural strength

According to Neville, (2011) the flexural strength of concrete is usually lower than that of corresponding mortar. The IOTs used as fine aggregate can be considered to be responsible for higher flexural strength recorded by concrete samples containing iron ore tailings. Also flexural strength is more sensitive to features and defects in the microstructure such as micro-cracks in the material, than the compressive strength (Toutanji & Bayasi, 1999). The flexural strength of concrete prism samples as related to iron ore tailings content is shown in Fig. 8

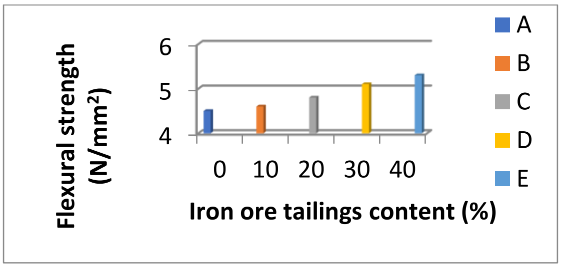


Figure 8: Relationship of flexural strength of concrete and IOTs content

3.5 Water absorption

The water absorption test gave indication about the effectiveness of the iron ore tailings as pore blockers. Usually, absorption values for cast specimens are normally slightly lower than those for a core from the same concrete, but the difference can be more significant if the aggregate is absorbent (ASTM C1585, 2013). The concrete samples containing iron ore tailings performed slightly better than the reference sample in terms of water resistance. The water absorption after curing concrete samples for 28days as related to the content of iron ore tailings is shown in Fig. 9.

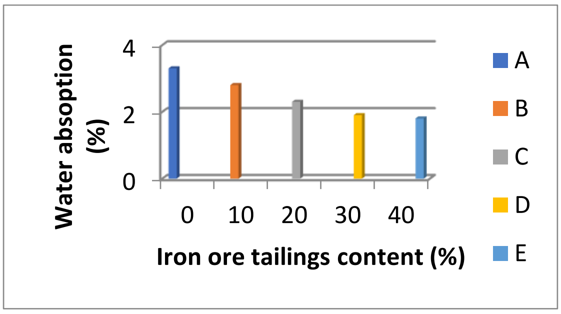
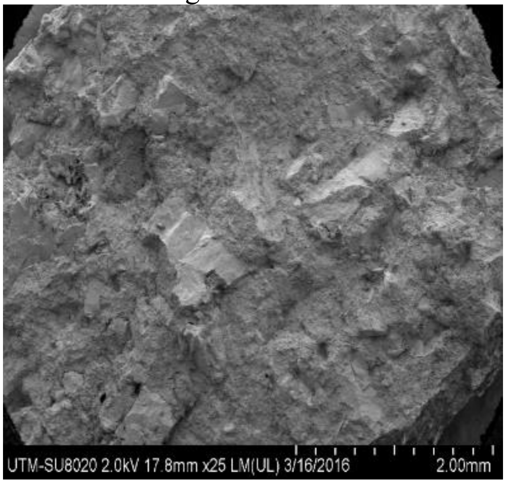


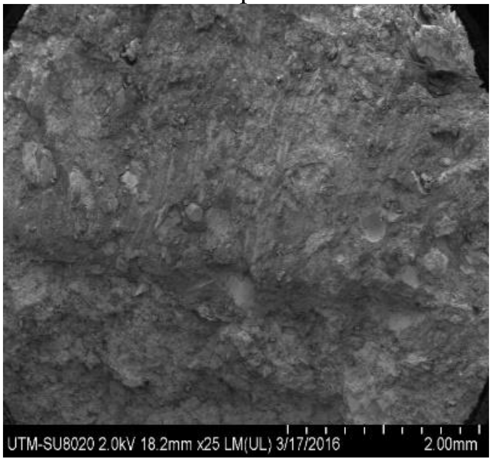
Figure 9: Water absorption of concrete vr IOTs content

3.6 Field emission scanning electron microscopy (FESEM)

The Field emission scanning electron microscopy (FESEM) provides the morphology of concrete samples containing iron ore tailings compared with the reference sample. The FESEM morphology of the reference sample A at magnification scale of 2 mm in contrast to sample D that contains 30 percent iron ore tailings, is shown in Fig. 10. The FESEM morphology reveals that more pore space can be seen in the concrete sample A compared to sample D implying that the iron ore tailings improve the packing density of the concrete. Also the interfacial zone between the aggregate and the cement paste looks porous and less resistant than the cement matrix in the control sample. The C-S-H hydrates which are bound weakly to the aggregate can easily be torn. The fracture surface of sample A can be considered as intergranular. In the case of sample D, there is intimate bond between the aggregate interface and the cement paste. There is no transition zone and no feasible cracks around the aggregate. The fracture surface can be considered as transgranular.



Sample A



Sample D

Figure 10: FESEM morphology of sample A and sample Sample D

3.7 Correlation between water absorption and ultrasonic pulse velocity

The correlation between the water absorption and ultrasonic pulse velocity is plotted in Fig. 11. It can be observed that there is strong inversely proportional relationship between water absorption and ultrasonic pulse velocity of iron ore tailings concrete. These results suggest that the small particle size of iron ore tailings was able to fill the pore space in concrete thereby producing more dense concrete, which gave higher values of ultrasonic pulse velocity and reduced water absorption.

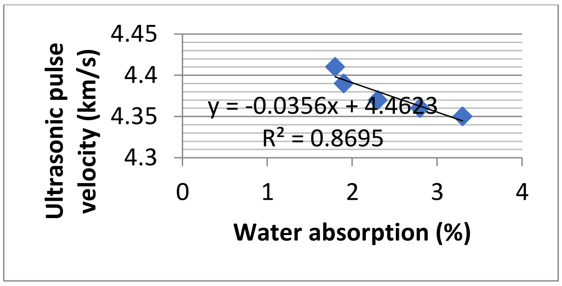


Figure 11: Water absorption and ultrasonic pulse velocity of concrete

4 | CONCLUSION AND RECCOMENDATIONS

The contribution of iron ore tailings as fine aggregate in concrete to improve the water resistance of normal weight concrete has been highlighted in this research. The following conclusions can be drawn based on findings from the experimental work:

i. The greater the replacement level of iron ore tailings in concrete the lower the amount of water absorbed by the concrete. This implies that iron ore tailings can be used as fine aggregate to improve the water resistance of concrete.
ii. The density and ultrasonic pulse velocity of concrete increased with more content of iron ore tailings thereby confirming the suitability of the tailings in reducing the volume of pore space in concrete.
iii. Flexural strength test of concrete is very sensitive to defects such as micro-cracks and pores in the microstructure of concrete. The concrete sample D, which recorded the highest flexural strength also gave the least water absorption value.
iv. The microstructure of concrete samples containing iron ore tailings shows closely packed and dense microstructure compared to that of the reference concrete sample.
v. Based on the findings from this study, iron ore tailings can be recommended as a suitable fine aggregate in concrete, for the purpose of protecting the reinforcement in concrete from corrosion, since it contributes to the reduction of water absorption in concrete.

vi. The use of iron ore tailings as fine aggregate in concrete can also find applications in concrete structures where it is desired to control or reduce dampness of concrete.

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