Assessment of Mechanical and Durability Properties of High Strength Concrete Using Iron Ore Tailings and Waste Rock as Aggregates

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***Abstract*--** **This paper investigates the suitability of using iron ore tailings (IOTs) and crushed waste rock (CWR) as fine and coarse aggregates to prepare high strength concrete (HSC) with 28-day target compressive strength of 80 MPa. This experimental investigation was carried out on four series of concrete mixtures with different combinations of fine and coarse aggregates, such as IOTs and crushed limestone (CLS), river sand (RS) and CLS, RS and CWR, LOTs and CWR. The specimens with RS and CLS was taken as control mixture. Tests were done to determine the compressive, flexural strength and splitting tensile strengths, elastic modulus, rapid chloride permeability, resistance to sulphate attack and freeze-thaw resistance in HSC specimens. The results indicated that superplasticizer demand increased in the three mixtures containing the mine waste aggregate of IOTs or CWR in order to achieve the same workability as that of the control mixture. The compressive strength of all HSC mixtures could meet the design requirement of C80 grade strength, but the mechanical and durability characteristics of HSC were adversely affected by the substitution of mine waste aggregates for natural aggregates.**

***Index Term*--** **Iron ore tailings; waste rock; high strength concrete; mechanical properties; durability**

1. INTRODUCTION

Each year mining and milling operations generate substantial amounts of waste rocks and tailings. In China, the total 10 billion tons of tailings have been discarded as a waste, and the annual generation of tailings reached to 1.2 billion tons and is estimated to be half of the world's total tailings [1]. Especially, the generation of iron ore tailings (IOTs) has been increasing rapidly with the growing demand of iron and steel of China in recent years. For instance, the annual generation of IOTs increased from 137 million tons in 2000 to536 million tons in 2009, and the total accumulation of IOTs from 2000 to 2009 exceeded 2800 million tons, and the generation of IOTs is 38.5% of the total tailings[1]. However, the current comprehensive utilization ratio of tailings in China is only 13.3% [1]. Such underutilization of a secondary resource not only covers huge land and produces serious environmental problems, but also gives rise to security risks (tailings dam failure) in the mining regions.

The generated wastes from the industry are increasing substantially worldwide while at the same time natural resources are depleting. Aggregates are the important constituents in the concrete and occupy nearly 60%–80% of the volume of concrete, their impact on various characteristics and properties of concrete are undoubtedly considerable. Usually, fine and coarse aggregates are obtained either from natural sources or by crushing large size rocks. In China, the rapid increase in the natural aggregates consumption every year due to the increase in the construction industry means that the aggregate reserves are being depleted rapidly, particularly in some mountainous regions and coastal regions. It has been estimated that the concrete industry of China consumes 5–7 billion tons annually of natural aggregates. Such large consumption of natural aggregates has been causing destruction of the environment. Therefore there is an urgent need to find and supply alternative substitutes for natural aggregates by exploring the possibility of utilization of industrial by-products and waste materials in making concrete [2–4].

IOTs as secondary resources have been of great importance to all countries in the world. At present, the major utilization ways of IOTs includes [5–10]: land reclamation; recycling of useful metal, such as Fe, Co, Ni and Cu [11]; and production of building materials directly, such as cement clinker and mineral admixture, glass ceramics, using as sand for concrete and as siliceous materials for autoclaved aerated concrete, etc. [12–18]; back filling materials [19]; and using as soil modifier and magnetization fertilizers [20].

The utilization of IOTs and waste rock (WR) as raw ingredients in the concrete production is the focus of this paper. Past studies have reported the possible use of tailings as fine aggregate in normal and ultra-high performance concretes and its effect on different mechanical properties of concretes with various replacement levels of natural aggregate [21–24]. This paper aims to investigate the feasibility of using IOTs and waste rock (CWR) as fine and coarse aggregates in the production high strength concrete (HSC). Experimental investigations focus on the performance features of HSC containing IOTs and CWR in terms of workability, mechanical properties and durability. The performance characteristics of HSC with IOTs and CWR are compared to the HSC with natural aggregates. Additionally, the microhardness of interfacial transition zone (ITZ) between cement paste and aggregate was examined to interpret the macro performance of the concrete.

2. MATERIALS AND METHODS

2.1 Materials

The binders used in the production of HSC were ordinary Portland cement (OPC), with a strength class of 52.5 in accordance with Chinese National Standard GB 175–2007 [25], and ground blast-furnace slag (GBFS) with a Grade S95 in accordance with Chinese National Standard GB/T18046–2008 [26] and silica fume (SF). The chemical composites of the binders are given in Table I.

The mixing water was potable tap water. A polycarboxylate-based superplastizer (SP) provided by Mapei Ltd., was used in HSC for all mixes. The solid content, pH, and specific gravity of admixture were 29.4%, 6.1, and 1.10 g/cm^3.

Two types of aggregates were used to make the concrete, including natural aggregates and mine waste aggregates. IOTs and river sand (RS) were used as fine aggregates. Crushed waste rock (CWR) and limestone (CLS) were used as coarse aggregates, with 5 to 20 mm continuous gradation. RS was originally excavated from middle reaches of Yangtze river. CLS was purchased from a local crushing plant. The IOTs and the CWR used in this study were obtained from Beijing Miyun Iron Ore Mining Company. The chemical analysis (Table 1) indicates that IOTs and CWR are primarily comprised of silica with alumina and iron oxide. The mineral phases of IOTs and CWR were examined by X-ray diffraction (XRD), which showed that the two mine waste aggregates were mainly comprised of quartz, minor mineral phases includes albite, anorthite, chlorite, pyroxene, hornblende and magnetite (Fig. 1.).

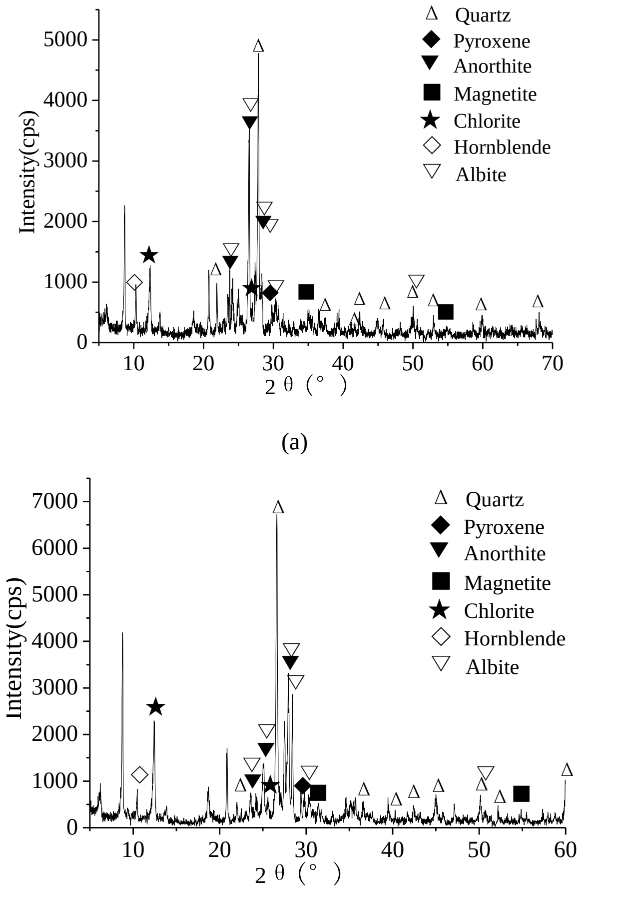


Fig. 1. XRD patters of mine waste aggregates. (a) Iron ore tailing sand (b) Crushed waste rock

Table I
Physical properties and chemical composition of raw materials

Composites	OPC	GBFS	SF	IOTs	RS	CWR	CLS
SiO_2(%)	20.71	34.56	94.32	55.03	73.88	56.27	0.85
Al_2O_3(%)	4.97	11.85	0.14	11.52	12.75	13.75	0.32
Fe_2O_3 (%)	3.26	0.64	1.29	9.27	2.38	8.50	0.20
MgO(%)	2.23	4.90	0.05	7.95	0.67	6.46	19.95
CaO(%)	59.88	43.46	0.06	5.82	1.59	4.19	32.36
SO_3(%)	2.72	1.18	0.43	0.38	0.043	0.14	0.027
Na_2O(%)	0.21	0.35	—	2.17	2.40	3.45	—
K_2O(%)	0.58	0.42	—	3.16	4.35	3.23	0.034
Loss(%)	3.62	0.25	3.4	3.20	1.16	2.31	45.97

2.2 Concrete Mixture Proportions

A total of four HSC mixtures were produced, which were designed to have a target 28 day compressive strength of 80MPa (C80 grade), using a water-to-binder ratio of 0.24 also 20% GBFS and 5% SF as a partial replacement for cement. In order to investigate the fresh and hardened properties of HSC made with mine waste aggregates and normal aggregates, binder and water content were kept constant in all mixtures. The dosage of SP was adjusted to obtain initial slump values in the range of 170–190 mm. The mix proportions of HSC chosen for this study are presented in Table II.

Table II
Concrete mixture proportion and slump

Combination of aggregates	Concrete mixture proportion (kg/m^3)						Water to binder ratio	SP dosage by weight of binder (%)	Slump (mm)
	Cement	GBFS	SF	Fine aggregate	Coarse aggregate	Water			
IOTs+CLS	420	112	28	648	1257	135	0.24	1.7	180
RS+CLS	420	112	28	648	1257	135	0.24	1.3	190
RS+CWR	420	112	28	648	1257	135	0.24	1.4	185
IOTs+CWR	420	112	28	648	1257	135	0.24	1.7	170

2.3 Preparation and Testing Procedure of HSC Mixes

All the HSC mixes were mixed in a horizontal rotating mixer. The slump of the fresh concrete was determined to ensure that it would be within the design value. The mixtures were then cast into molds and compacted using vibrating table. All of the specimens were demolded after 24 h and then cured in a standard curing chamber at a constant temperature of 20℃ (±2℃) and a relative humidity of greater than 95% until the testing age.

The mechanical properties for all of the HSC specimens were tested at the age of 7 and 28 days. The 150-mm cubes were cast for each mixture for compressive and splitting tensile strength tests, and the 150mm×150mm×550 mm and 150mm×150mm×300 mm prisms were cast for each mixture for bending tensile strength and compressive modulus of elasticity tests, respectively. The tests of all mechanical properties were conducted in accordance with the Chinese National Standard of GB/T 50081–2002 [27]. All the specimens were tested in a testing machine with the capacity of 3,000 kN. Three specimens of each mixture were tested and the mean value was obtained.

Rapid chloride permeability test (RCPT) was performed in accordance with the Test Method for Coulomb Electric Flux [28]. In this test, three cylindrical specimens of size 50 mm thick and 100 mm in diameter were subjected to DC voltage of 60 V across its thickness for a 6 h period between two cells containing 3% NaCl and0.3 N NaOH solutions. The number of coulombs that passed through each specimen was determined after a 6 hour testing period.

The sulfate resistance was tested in accordance with the Test Method for Resistance of Concrete to Sulphate Attack [28]. In the test, twelve 100 mm×100 mm×100 mm cubic specimens were made for each mixture and cured in a curing chamber for 28 days. Then, six of them were exposed to wetting-drying cyclic sulphate testingmachine for two periods of 120 and150cycles. Each exposure cycle consisted of 15 hours full immersion in a 5% sodiumsulfate solution, then 1hourair drying and 6 hours oven drying at 80±5℃ as well as 2 hours cooling to ambient temperature. The sulfate solution was periodically refreshed every 15 cycles. After 120 and 150 cycles of exposure, the specimens were removed from the exposure tank and their surfaces were cleaned with dry cotton tore move weak reaction products and loose materials from the specimen. The compressive strength of the specimens was measured. The remaining six specimens were stored in a water curing tank at 20±2℃ up to 120and 150 days to compare strength values. Sulphate resistance was evaluated by determining the corrosion coefficient of compressive strength (K_f) of the specimens using Equation (1).

$$K_f(\%) = \frac{f_{cn}}{f_{c0}} \times 100 \tag{1}$$

Where f_{cn} is compressive strength of specimen after exposure to wetting-drying cyclic sulphate corrosion for n-cycleandf_{c0} represents the compressive strength of the specimen immersed in water for the period which is same as the n-cycle of wetting-drying cyclic sulphate corrosion.

Freeze-thaw cycles test was conducted on three prism samples(100 mm×100 mm×400 mm) for each mixture after 28 days of curing in accordance with the Test Method for Rapid Freezing and Thawing [28]. A maximum number of 300 freeze-thaw cycles was selected to stand for a typical freeze-thaw exposure on the concrete material throughout the structure life. The amount of freeze-thaw damage was evaluated by measuring the mass and fundamental transverse frequency of concrete prisms every 50 cycles of freeze-thaw exposure. Based on the fundamental transverse frequency, the relative dynamic modulus of elastic was calculated as the ratio of the dynamic modulus at a certain number of freeze-thaw cycles to the initial value before test began [28].

The specimens for the interfacial transition zone (ITZ) microhardness test were cut into the rectangle slices of 50 mm (length) ×30 mm (width) ×10mm (thickness). The test surface of the specimens containing the ITZ between aggregate and mortar was polished. Based on Standard Test Method for Micro Indentation Hardness of Materials [29], a Vickers indenter (Type HV-1000Z) was used to determined the microhardness in the ITZ between the aggregates and binder pastes.

3. RESULTS AND DISCUSSION

3.1 Physical and Mechanical Characteristics of Mine Waste Aggregates

In order to ascertain various physical and mechanical properties of mine waste aggregates, the following experiments were carried out in accordance with the Chinese National Standards of GB/T 14684–2011 [30] and GB/T 14685–2011[31]: Sieve analysis for coarse and fine aggregates; elongation and flakiness index; aggregate crushing value; bulk density and water absorption; packing density and percentage voids; sodium sulfate soundness; harmful matter content; aggregate shape parameters et al.

Particle grading curves of four aggregates are presented in Fig. 2. The gradation curve of the IOTs and RS presented in Fig. 2.(a) shows that they meet specifications requirements for concrete sand with gradation zones II [30] and have the same fineness modulus. However, the IOTs have higher content of fines (＜0.15 mm) and larger amount of coarse particles (＞2.36 mm). It seems from Fig. 2.(b) that CWR and CLS almost have the same grading.

The test results of physical and mechanical properties for four aggregates are summarized in Table III. Table III shows that the measured soundness loss for IOTs was 7.8% compared with 5.5% for RS. This suggests that the replacement of IOTs for RS would lead to decrease in the freeze-thaw durability of the concrete. Similarly, CWR has a higher soundness loss than CLS. Additionally, the particle shape parameters were determined by digital image processing (DIP).The results presented in Table 3 show that the RS has a near–round shape, while IOTs have an angular shape and rougher surface texture as a result of crushing and grinding. This suggests that IOTs would demand more paste volumes than those required by RS in the concrete mix. Therefore it is expected that the paste content in concrete matrix will increase as the IOTs replace for RS which consequently will lead to a decrease in the workability of the concrete. The particle shape parameters of CWR are similar to those of CLS.

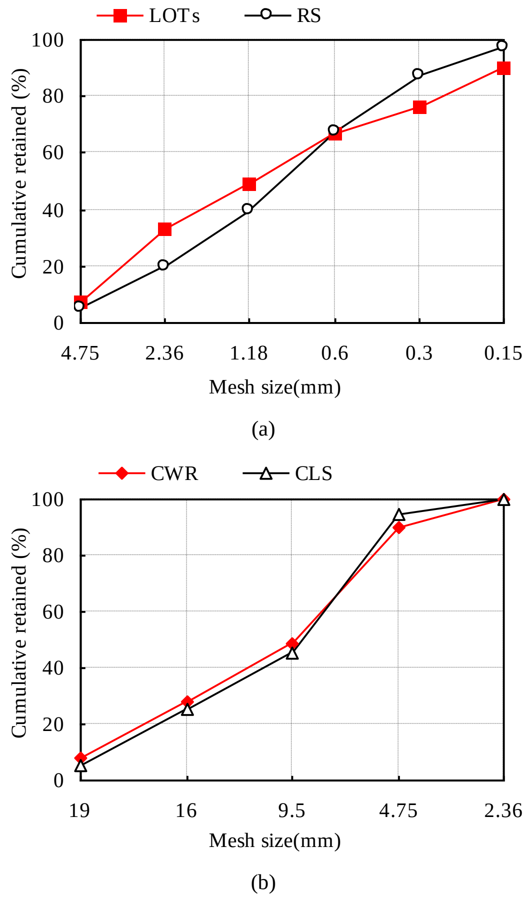


Fig. 2. Grading of fine and coarse aggregates.(a) Fine aggregates and (b) Coarse aggregates

Table III
Physical and mechanical properties of aggregates

Parameters	IOTs	RS	CWR	CLS
Bulk density (g/cm^3)	2.783	2.614	2.870	2.803
Absorption (%)	0.81	1.3	0.32	0.48
Crushing value (%)	14.0	15.9	7.8	6.6
Flakiness and Elongation index (%)	—	—	4.0	2.6
Silt content (%)	—	2.0	0.4	0.55
Clay lump (%)	0.9	0	0	0
Microfines passing the75 µm sieve (%)	4.2	—	—	—
Methyleneblue value (g/Kg)	0.57	0.30	—	—
Fineness modulus	3.01	3.02	—	—
Loose packing density (kg/m^3)	1619	1530	1534	1516
Void ratio of random close packing (%)	41.8	41.5	46.6	45.9
Sodium sulfate soundness loss (%)	7.8	5.5	7.1	4.7
Roughness (s)	15.7	13.1	—	—
Shape parameters of aggregate samples				
Roundness	0.80	0.88	0.79	0.80
Aspect ratio	1.52	1.36	1.49	1.42
Fullness ratio	0.92	0.97	0.91	0.91

Alkali silica reaction (ASR) is known to cause serious deterioration problems in concrete using aggregates containing amorphous silica, and therefore, the ASR potential of IOTs and CWR was determined before using them as alternative aggregates in HSC. Accelerated mortar bar test as specified by the Chinese Standard DL/T 5151-2001 [32] was used to measure the ASR potential of IOTs and CWR. The mortar bars were immersed in a 1mol/L NaOH solution at 80℃ for 14 days. Fig. 3. shows the expansion test results of mortar bar specimens containing IOTs and CWR, respectively. The expansion rate of the IOTs mortar bars measured at 14 days is between 0.10% and 0.2%, indicating that the accelerated mortar bar test cannot judge the ASR potential of IOTs. In order to defend damage of ASR, the effect of GBFS on inhibiting ASR expansion of IOTs is studied. When the replacement amount of cement with GBFS is 20%, the expansion rate of the IOTs mortar bars measured at 14 days is decreased to 0.038%, which is far below the critical value of 0.1%, and the decrease ratio of expansion is 78.2%, which satisfies the requirement value of 75% [32], indicating that the replacement of 20% GBFS is effective in inhibiting the ASR expansion of IOTs. Therefore, IOTs can be used in the concrete when using GBFS as mineral addition. Moreover, the expansion rate of CWR mortar bars measured at 14 days is less than 0.10% (Fig. 3.), indicating that CWR is innocuous aggregate without concerns of ASR.

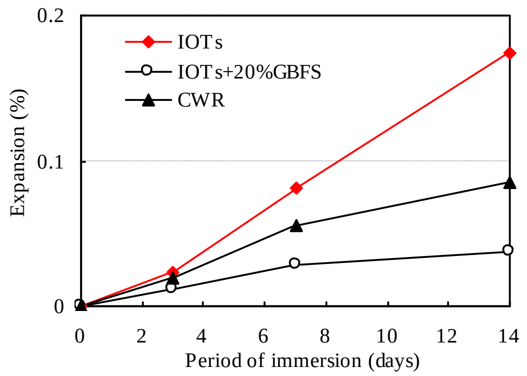


Fig. 3. Expansion of mortar bars as a function of immersion period

3.2 SP Dosages of Concrete at Constant Workability

The fresh concrete test results are presented in Table II. For each mixture with different fine or coarse aggregate, the SP dosage percent by weight of total binder was adjusted in order to achieve constant slump values between 170 and 190 mm. Table II shows that the a higher dosage of SP were needed in the concrete mixtures prepared with LOTs and CWR to overcome the adverse effect of shape and texture of grains, compared with the concrete mixtures prepared with RS and CLS. The results from previous study indicated that the workability of concrete mixtures made with IOTs increased substantially as the IOTs content increased due to its high microfines content and the rough surface in comparison with river sand [21].

3.3 Mechanical Properties of Concrete

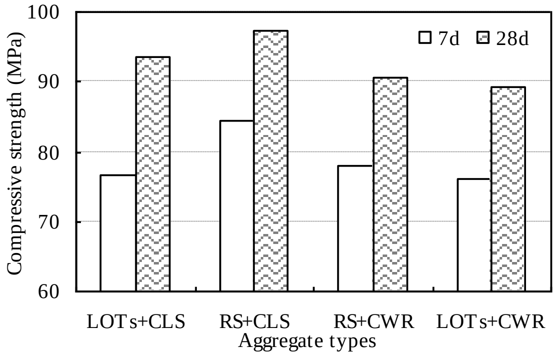
3.3.1 Strength

Fig. 4. is the test results of the compressive, flexural and slitting tensile strengths for all mixtures at 7 and 28 days. Fig. 4.(a) indicates that the combination of different types of coarse and fine aggregate has a significant effect on compressive strength of concrete. The highest compressive strength was achieved for the aggregate combination of RS and CLS while the lowest compressive strength was achieved using the aggregate combination of LOTs and CWR. After 28 days of curing, the compressive strength of all the four concrete specimens prepared with LOTs and CLS, RS and CLS, RS and CWR, and LOTs and CWR was 93.5, 97.2, 90.7 and 89.2 MPa, respectively. The above results indicate that LOTs and CWR are relatively low quality aggregates, but can be used successfully to prepare a C80 grade HSC. The 7-day compressive strengths showed similar trend to the 28-day compressive strengths as shown in Fig. 4.(a).

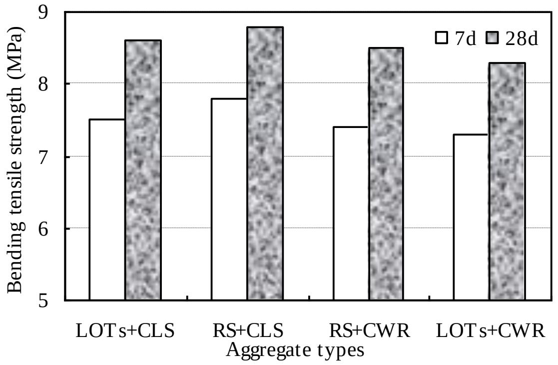
When a HSC is subjected to compressive loads, the failure usually passes through the paste–aggregate interface or through the aggregate [33]. In both modes of failure, the quality of aggregate significantly influences the mode of failure of concrete under compression. First, the surface texture of an aggregate has a significant influence on concrete compressive strength [34]. The rough surface of the IOTs could improve the strength of the bond between the aggregate particles and paste, which is beneficial to strength development. On the other hand, however, the stiffness and hardness of the IOTs were on average lower than those of the RS [22], which could also contribute to the strength decrease. Based on the experimental results shown in Fig. 4.(a), we can see that, generally, the strength impairing effect outweighs the strength-beneficial effect. Secondly, since the CWR aggregates are known to be weaker than the CLS aggregates the low load carrying capacity of concrete prepared with CWR aggregates is understandable. As shown in Table II, the crushing value of CWR aggregates was more than that of CLS aggregates. The higher strength of CLS aggregates, contributes to increased compressive strength of concrete prepared with the aggregates. Another point to be noted is that higher absorption of aggregate eliminates the accumulation of water in the fresh matrix in the vicinity of the aggregate; as a result, the ITZ in the aggregates with higher absorption is denser [35]. On the other hand, the mineralogy and the strength of coarse aggregates may control the ultimate strength of concrete, particularly in a HSC [36].

Fig. 4.(b) and (c) show the flexural and splitting tensile strength of four concrete specimens prepared with different aggregates. The flexural strength increased as the compressive strength increased. As can be seen in Fig. 4.(b) the flexural strength of the concrete prepared with RS and CLS aggregates was the highest, followed by that of LOTs and CLS aggregate, and RS and CWR aggregate concretes. The least flexural strength was noted in the concrete specimens prepared with LOTs and CWR aggregates. The trend of splitting tensile strength values

obtained from different aggregate samples is similar to the flexural strength results. The splitting tensile strength was equal to 75–78% of the flexural strength.



(a)



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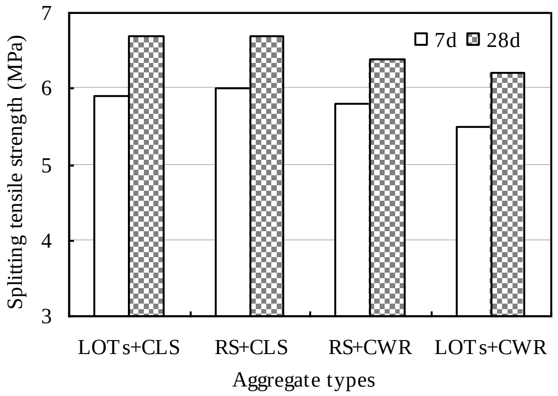

(c)

Fig. 4. Mechanical properties of hardened concretes (a) Compressive strength; (b) Flexural strength and (c) Splitting tensile strength

3.3.2 Elastic Modulus

The elastic properties of concrete are known to be influenced by elastic properties of the constituent materials and nature of the interfacial zone between aggregates and paste [37]. Due to the inherent stiffness and large volume fraction it occupies in concrete, the aggregate exerts the major influence on the elastic modulus of concrete. Not only aggregate stiffness, but also aggregate type, affects the elastic modulus. For HSC, the characteristics of coarse aggregate could be significantly important in determining the elastic properties of concrete, which was attributed to the highly dense paste structure and paste–aggregate bond. As is apparent from the data in Fig. 5., the modulus of elasticity was higher for the concretes containing RS and CLS aggregates than the concrete prepared with LOTs and CWR aggregates. After 28 days of curing, the modulus of elasticity of four concretes prepared with LOTs and CLS, RS and CLS, RS and CWR, and LOTs and CWR was 48.4, 51.8, 46.3and 45.3 GPa, respectively. The lower values of modulus of elasticity of LOTs and CWR aggregate concrete may be attributed to the soft nature of the two aggregates.

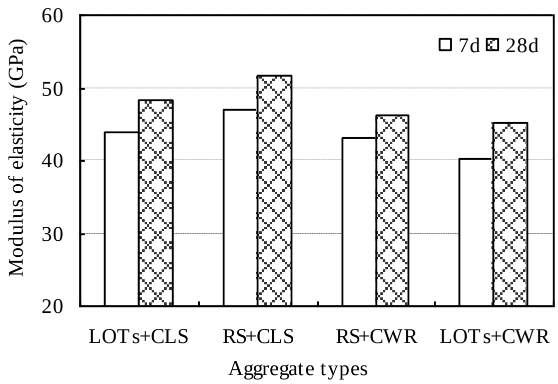

Fig. 5. Modulus of elasticity of hardened concretes

3.4 Durability of Concrete

3.4.1 Resistance to Chloride Ion Permeability

From the results of the RCPT test (Fig. 6), all the values of charge passed in coulombs were less than 100 and hence the chloride ion permeability is negligible as per ASTM C1202-12 [38]. The important observation is that, the concrete using the LOTs and CWR aggregates has slightly higher charge passed than that of using the normal aggregates, the aggregate type has adverse effect on the chloride ion permeability of concrete.

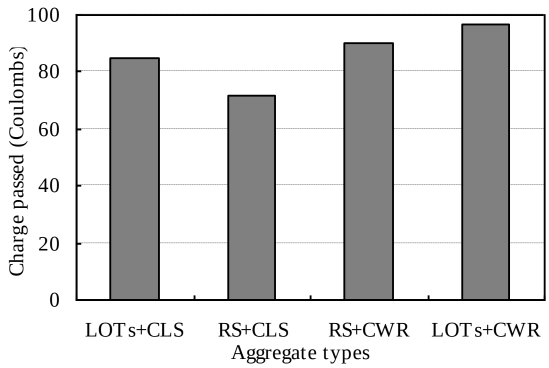

Fig. 6. Rapid chloride ion permeability of concrete

3.4.2 Resistance to Sulfate Attack

The corrosion coefficient of compressive strength (K_f) evaluated from wet-dry sulphate attack test for 120 and 150 cycles are presented in Fig. 7. From the results it could be observed that, the all K_f values obtained in four concrete specimens is between 80% and 85% after 150 time wet-dry sulphate cycles. As per GB/T50082–2009 [28], if the K_f value is up to 75%after n time wet-dry sulphate cycle attack, the sulphate attack grade is denoted by KSn. The important observation is that, the concrete using the LOTs and CWR aggregates have experienced a little more loss in compressive strengths after 120 and 150 wet-dry sulphate cycles when compared with the concrete using the RS and CLS aggregates. Hence, it could be noticed that the IOTs and CWR aggregate concrete got slightly worse resistance against sulphate attack than that of normal aggregate concrete.

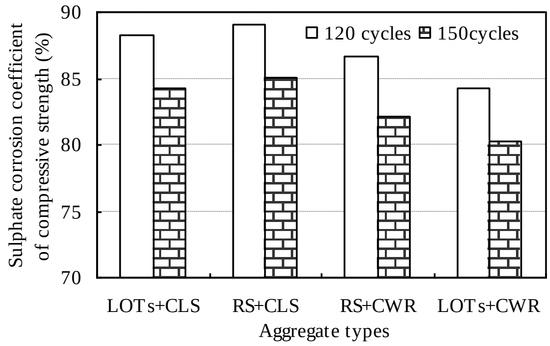

Fig.7. Deterioration of concrete submitted to the wet-dry sulphate attack

3.4.3 Freezing Resistance

Fig. 8. shows the trends of the percentage mass loss and relative dynamic modulus of elasticity (RDM) with the number of freeze-thaw cycles for four concrete specimens. As shown in Fig. 8., even after 300 freeze-thaw cycles the mass loss is between 0.18% and 0.38%, and the RDM is between 96% and 98%, which is still much larger than the benchmark 5% and 60%, respectively as defined by GB/T50082–2009 [28]. This indicated the four aggregate concretes achieved good freeze–thaw durability more than 300 cycles. By comparing the mass loss and RDM in Fig. 8., it can be observed that the concrete specimens containing IOTs and CWR aggregates showed slightly lower performance to freeze-thaw damage compared to the concrete containing RS and CLS aggregates. This phenomenon on one hand may be due to the fact that both the tensile strengths of IOTs and CWR concrete samples are lower than those of RS and CLS concrete samples, while on the other hand it may also be attributable to the higher mass loss of the IOTs and CWR aggregates subjected to five wet-dry sodium sulphate cycles compared to RS and CLS aggregates (shown in Table II), respectively.

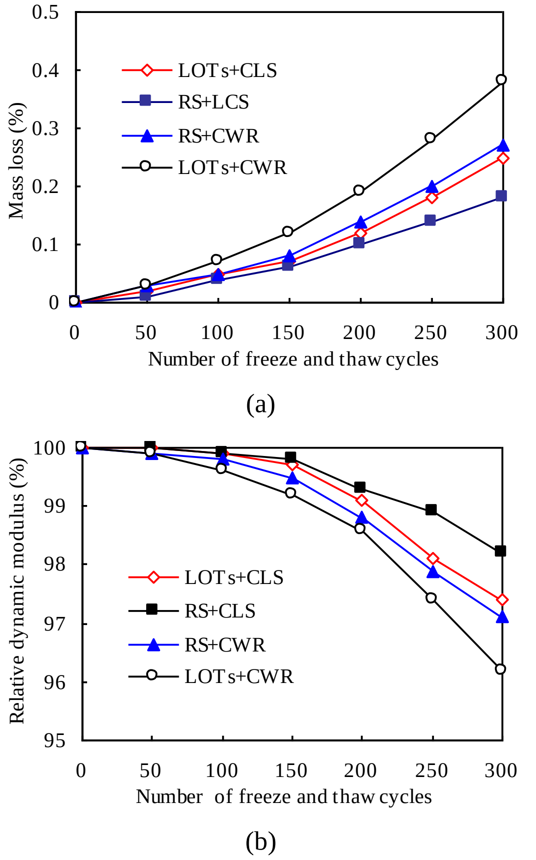

Fig. 8. Freeze-thaw test results of concrete. (a)Mass change and (b) Relative dynamic modulus vs. cycles of freezing and thawing

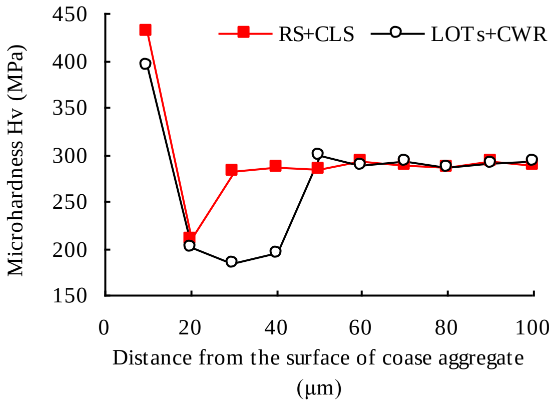

Fig. 9. Vickers microhardness distribution at ITZ of concrete with different aggregates

3.5 Microhardness of concrete

The microhardness of the ITZ with varied distance away from different aggregates at the age of 28 days is shown as Fig. 9. In the case of normal RS and CLS aggregates, the interfacial microhardness value falls down to nadir gradually at the point of 20μm away from aggregate surface, then it rises up and becomes stable. It gives evidence that the range of the weak zone (ITZ) is about 30μm. In the case of IOTs and CWR mine waste aggregates, the microhardness value was the lowest in the ITZ at a distance of 20–40μm, with the value increasing upon moving away from the ITZ, which then remained constant from a distance of 50μm. It gives evidence that the range of the weak zone (ITZ) is about 50μm. It also needs be noted that the microhardness value in the ITZ between mine waste aggregates and binder paste is less than that between natural aggregates and binder paste. It also explains why the mechanical properties and resistance to chloride ion penetration of HSC with mine waste aggregates are inferior to those with natural aggregates.

4. CONCLUSIONS

In this study, the feasibility of using IOTs and CWR as fine and coarse aggregate in HSC was investigated. Based on the experimental results, several conclusions can be drawn：

1) The two mine waste aggregates of IOTs and CWR included seven inert phases with quartz as main mineral. The IOTs is able to cause ASR and the ASR expansion is effectively inhibited by 20% GBFS replacement of cement.

2) The mine waste aggregates lowered the flow ability of fresh concrete which presents some disadvantages compared with normal aggregates. The mine waste aggregates require a higher dosage of superplasticizer to overcome the adverse shape and texture of particles.

3) It is feasible to produce a C80 grade HSC using IOTs and CWR as alternative aggregates. In the case of the same water/binder ratio, the mechanical behavior of HSC made with mine waste aggregates is generally below those of the control concrete made with normal aggregates, and the impact of CWR as coarse aggregates on the mechanical properties of concrete is more significant compared with IOTs as fine aggregates.

4) The HSC produced using the mine waste aggregates are slightly lower in resistances to sulphate attack and freeze-thaw than the HSC with normal aggregates due to the high soundness loss of the mine waste aggregates. The mine waste aggregates have slight adverse effect on the chloride ion permeability of HSC.

5) The width of the ITZ in the HSC with mine waste aggregates is about 50 μ m and larger than that with normal aggregates. The bond between cement paste and mine waste aggregates is weaker than that between cement paste and normal aggregates.

6) It is not adequate to clarify the effect mechanism of mine waste aggregates on mechanical and durability characteristics of HSC by ITZ microhardness, which needing further research.

ACKNOWLEDGEMENTS

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