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PREPARATIONS OF COMPOSITE CONCRETES USING IRON ORE TAILINGS AS FINE AGGREGATES AND THEIR MECHANICAL BEHAVIOR

PRIPRAVA KOMPOZITNIH BETONOV Z UPORABO FINIH AGREGATOV IZ ODPADKOV ŽELEZOVE RUDE IN NJIHOVE MEHANSKE LASTNOSTI

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Experiments were conducted to determine the utilizability of iron ore tailings from Lingxiang town near Huangshi City in Hubei province of China as a fine aggregate replacement for regular sand in concrete. The mix design was carried out for concrete with 35 grade. The sand was replaced with (0, 10, 20, 30, 40, 50 and 60) % iron ore tailings, respectively. The results show that the workability of fresh concrete reduced with the increasing of the iron ore tailings. And the workability can decrease significantly when the iron ore tailings are more than 40 %. Twenty eight days compressive strength and split flexible strength of the hardened concrete specimens exceeded 35 MPa and 5 MPa, respectively, and they reached the maximum when there was 30 % iron ore tailings. Their flex-compression ratio was 1/6 and 10 % higher than that of the control group that used sand as the fine aggregate. The crack resistance of the iron ore tailings concrete was studied at the same time, and the microstructure was observed with an SEM.

Keywords: iron ore tailings, fine aggregate, compressive, flex-compression ratio, crack resistance

Avtorji so izvajali preizkuse, da bi ugotovili ali so lahko odpadki železove rude iz Lingxianga pri mestu Huangshi v provinci Hubei na Kitajskem kot fini agregat ustrezna zamenjava za običajni pesek v mešanici za beton. Pripravili so mešanico betona kvalitete 35 (s tlačno trdnostjo 35 MPa). Pesek so nadomestili z (0, 10, 20, 30, 40, 50 in 60) % odpadkov železove rude. Rezultati preizkusov so pokazali, da se je obdelovalnost betonov zmanjševala s povečevanjem vsebnosti odpadkov železove rude. Pri vsebnosti nad 40 % odpadkov železove rude se je obdelovalnost betona drastično zmanjšala. Osemindvajsetdnevna tlačna in upogibna trdnost utrjenih vzorcev betonov je presegla 35 MPa oz. 5 MPa in maksimalne vrednosti so bile dosežene pri betonu, kateremu je bilo dodanih 30 % odpadkov železove rude. Ta beton je imel razmerje med upogibno in tlačno trdnostjo 1:6, kar je bilo 10 % več kot kontrolna skupina, ki je vsebovala samo pesek kot dodatek finega agregata. Istočasno so ugotavljali odpornost izdelanih betonov proti pokanju in opazovali njihovo mikrostrukturo z vrstičnim elektronskim mikroskopom (SEM).

Ključne besede: odpadki železove rude, fini agregati, razmerje med tlačno in upogibno trdnostjo, odpornost proti pokanju

1 INTRODUCTION

Ore tailings are the largest solid wastes of the mining and mineral industries. In China, the amount of ore tailings was up to 14.6 billion t at the end of 2013, and Iron Ore Tailings (hereinafter referred to as IOT) is about 50.88 %.[1] As the largest amount of ore tailings, the utilization of IOT is very difficult, and its low utilization causes the environmental problems of farmland occupation, vegetation destruction, and water pollution.[2,3] M. A. Onitiri et alinvestigated the effect of particle size and particle loading of iron-ore-tailing-filled epoxy and polypropylene composites on the stiffness and tensile strength.[4] They found that the stiffness increased with the content of IOT. S. Ullas et al. made masonry units with a mixture of soil, sand and cement with the replacement of 25 %, 50 % and 100 % IOT.[5] They found the wet compressive strength, water absorption, initial rate of absorption, and linear elongation had no desirable degradation. T. I. Ugama and S. P. Ejeh examined the IOT from Itakpe mines near Okene in Kogi state of Nigeria as a fine aggregate replacement of sand (RS) for the mortar used for masonry.[6] A. Shettima et al. also used IOT as fine aggregate to prepare concrete.[7–10] The tested result shows that 28 d compressive strength, indirect tensile and flexural strength values of comparable to control the mix when the combination of IOT and river sand is therefore 20 % IOT and 80 %. S. Zhao et al. used IOT to replace natural aggregate to prepare ultra-high-performance concrete.[11] It was found that 100 % replacement of IOT could significantly decrease the workability and compressive strength. When there was no more than 40 % IOT replacement, the mechanical property of the 90 d standard cured specimen was comparable to that of the control group and that were steam cured for 2 d (days). The compressive strength decreased by 11 %, and the flexural strength increased by 8 %. X. Huang et al. used IOT to prepare greener engineered cementious composites (ECCs) with a tensile ductility of 2.3–3.3 %, tensile strength of 5.1–6.0 MPa and compressive strength of 46–57 MPa at the 28th day.[12] Y. Hou investigated the characteristics of mineral admixture with IOT powder

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Table 1: Chemical component of IOT and cement (%)

Name	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	Loss
IOT	73.85	5.92	15.4	0.48	1.20	/	1.00	1.05	5.87
Cement	21.05	6.05	3.64	63.98	2.68	0.23	/	/	3.24

Table 2: Size distributions of the used materials

Name	Sieve size (mm)	4.75	2.3 6	1.18	0.60	0.30	0.15	0.088
NRS	Cumulative percentage (%)	8.51	22.43	44.32	62.15	90.06	96.86	100
IOT		0	1.0	2.3	7.3	37.8	98.3	99.5

and ground slag in the proportion of 2:8, 4:6 and 6:4.[13] The results showed that the compressive strength of the concrete decreased with the percentage of IOT powder increasing, because of the low activity of the IOT. K. Shetty et al. prepared self-compacting concrete by partially replacing the cementitious material with red mud (RM) and partially replacing the sand with IOT.[14] The results showed that the compressive strength and flexural strength were more than the control mix. S. Jian et al. found that IOT could be used to manufacture construction materials due to the high content of iron, and the product required a lower sintering temperature and energy.[15] At present, the IOT has been widely used in other building materials, which solve the low level utilization of IOT all over the world.[16–21]

Our team makes efforts in the high-value utilization of IOT of Huangshi city, Hubei Porovince, China recent years.[22,23] This investigation aims to prepare high tensile-compressive strength concrete by changing the ratio of IOT that was used as fine aggregate and the replacement of regular sand.

2 EXPERIMENTAL PART

2.1 Materials

The ordinary Portland cement (42.5 grade) used in this study is from Huaxin Cement Co. LTD and its chemical components and physical properties are listed in **Table 1** and **2**, respectively. The IOT containing 15–20 % iron is obtained from Lingxiang Town of Huangshi City, Hubei Province, China. Its apparent density is 2.58 g/cm^3 with a fineness modulus of 0.36. The XRD pattern of IOT is given in **Figure 1**, the chemical component in **Table 1,** and the sieving analysis results in **Table 2**.

The coarse aggregate has a local source with a maximum size of 31.5 mm and the apparent density of 2.71 g·cm^{-3}. The fly ash used in this study was grade II and obtained from Xisaishan Thermal Power Plant Station of Huangshi. The polycarboxylate-based superplasticizer (SP) has about 35 % solid content and a water-reducing rate of about 40 %.

2.2 Instruments

The following instruments were utilized to perform different experiments in the research: X-ray fluorescence (XRF) was used for the chemical composition of IOT and cement using a Bruker (Billerica, MA, USA) XRF machine. X-ray diffraction (XRD) analysis was conducted using a Rigaku (Akishima-shi, Tokyo, Japan) XRD machine. Scanning electron microscope (SEM) analysis was performed by Supra 55 VP, ZEISS (Oberkochen, Germany). A compression machine (Jinan, Shandong, China) with 2000 kN capacity was used for compressive of specimens and a flexural machine (Cangzhou, Hebe) with 300 kN capacity for flexural and split tensile tests.

2.3 Mix proportions and specimen preparation

2.3.1 Mix proportion

Concrete specimens were prepared with the partial replacement of iron ore tailings in this study. **Table 3** presents 7 kinds of concrete mix proportions, and the first mix was a controlled mix without iron ore tailings. The controlled mix was made for C35 grade. In the mixture, 10 %, 20 %, 30 %, 40 %, 50 % of fine aggregate (regular sand) were replaced with iron ore tailings, respectively.

2.3.2 Preparation and casting of specimens

The 150 mm × 150 mm × 150 mm cubes were casted for compressive strength and split tensile strength and 150 mm × 150 mm × 550 mm beams for flexural

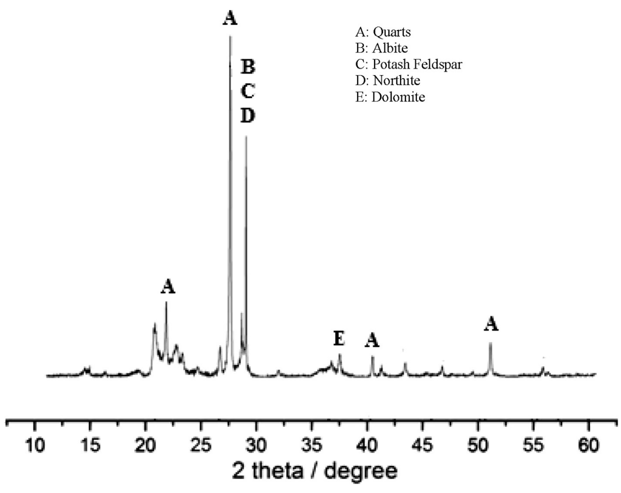

Figure 1: XRD pattern of IOT

Table 3: Concrete mix designation

Trial No.	Cement ($kg·m^{-3}$)	Fly ash ($kg·m^{-3}$)	IOT ($kg·m^{-3}$)	NRS ($kg·m^{-3}$)	CA ($kg·m^{-3}$)	SP ($kg·m^{-3}$)	W/B	Sp (%)
NC	367	53	0	672	1178	0.18	0.44	35.7
10 IOT	367	53	67.2	604.8	1178	0.18	0.44	35.7
20 IOT	367	53	134.4	537.6	1178	0.18	0.44	35.7
30 IOT	367	53	201.6	470.4	1178	0.18	0.44	35.7
40 IOT	367	53	268.8	403.2	1178	0.18	0.44	35.7
50 IOT	367	53	336.0	336.0	1178	0.18	0.44	35.7
60 IOT	367	53	403.2	268.8	1178	0.18	0.44	35.7

strength. After casting, all the test specimens were kept at room temperature for 24 h and then de-molded. Then these were cured in a standard room at about 20 °C with a relative humidity of about 95 % for a certain time.

2.3.3 Properties of fresh concrete and hardened concrete

The properties of fresh concrete such as slump and bleeding were conducted according to the Chinese Standard GB-T50080-2011.

2.3.4 Mechanical properties of hardened concrete

The compressive strength tests on cubes were performed on the 3rd, 7th and 28th day. The split tensile tests on the cubes and the flexural strength tests on beams were performed on the 28th day.

2.3.5 Cracking resistance of hardened concrete

The 25 mm × 25 mm × 280 mm beams were cast for cracking resistance, at which both ends copper heads were embedded. The specimens were added with some fiber and cured for 3 d under standard conditions after being de-moulded. The test was performed under the controlled conditions with a wind speed of 8 m/s, a temperature of 20±1 °C and a humidity of 60±5 %. The original lengths of these samples were measured on the 3rd, 7th, 14th, 28th and 60th day respectively. The numbers, width and length of the cracks on these specimen surfaces were all recorded.

3 RESULTS AND DISCUSSION

3.1 Workability of fresh concrete properties

3.1.1 Slump

Table 4 shows the workability of fresh concrete and the slump loss after 60 min. It can be seen that the initial slump value increased with the increasing IOT content when the IOT replacement was less than 30 %, when the water content kept constant. The mixture with 30 % IOT content had the greatest slump of 195 mm and excellent cohesiveness and water retention. This was because the finer IOT powder in the concrete mixture increased the fluidity of the mortar, and thus the resistance to motion of the coarse aggregate decreased. However, the slump value decreased with the increasing of the IOT content when it was more than 30 %. This was because too much IOT with finer size powder could make the concrete mixture thicker. It is also shown in **Table 4** that the slump loss of the first 60 min was increased slightly with the increasing of the IOT content.

Table 4: Changes of the workability of the concrete mixture with IOT

Trial No.	Slump value (mm)	Cohesiveness	Water retention	Slump loss of 60 min (mm)
NC	160	general	general	50
10 IOT	165	general	general	55
20 IOT	180	good	good	55
30 IOT	195	excellent	excellent	60
40 IOT	175	excellent	excellent	60
50 IOT	130	poor	good	65
60 IOT	80	very poor	good	75

3.1.2 Bleeding

The amount of bleeding of concrete with different amounts of IOT versus time is shown in **Figure 2**. The bleeding tests indicated that the addition of IOT decreases the bleeding capacity and the bleeding rate, which had a positive impact. For example, for the mix with 30 % IOT, the bleeding capacity at 30 min reduced by 52 % and the bleeding rate by 48 %. The bleeding tests also showed that the bleeding rate was bigger within 30 min with an IOT content of less than 30 %. The reduction of bleeding rate and bleeding capacity

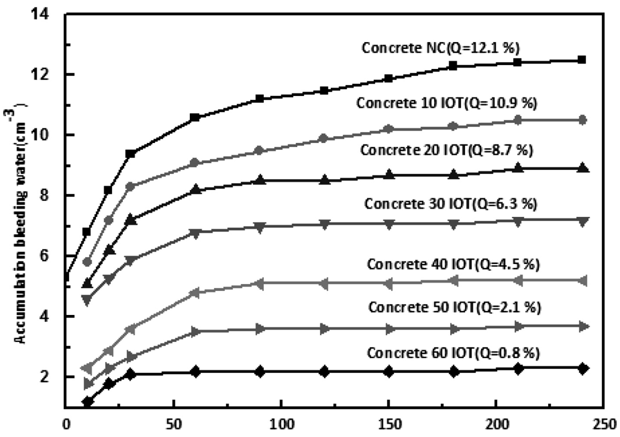

Figure 2: Cumulative bleeding curves of concrete with different IOT contents

should be attributed to the finer size of IOT with a specific surface, which reduced the content of free water in the system compared with the regular sand.

Considering the slump tests results, when the addition of IOT was more than 30 %, it caused an unfavorable influence on the compaction because of the thickness of the fresh concrete. It is clear that a 30 % IOT replacement has a significant effect on improving the workability of the fresh concrete from **Table 4** and **Figure 2.** At this level, comparing with the mix without IOT, the slump increased by 22 % and the bleeding capacity decreased by 45 %, respectively.

3.2 Properties of hardened concrete

3.2.1 Mechanical properties

The results of the mechanical property tests on the specimens are shown in **Figure 3** and **Table 5**, and the value is the average of three measurements. It can be seen from **Figure 3** that the compressive strength of the 3rd increases as the percentage of IOT increases to 50 %, the 7th to 40 %, the 28th to 30 %, and the 90th to 30 %. From **Table 5** it is clear that the tensile and flexural strengths at 28 d increase for the concrete with 30 % IOT, and the tensile-compressive strength ratio nearly showed the same. When the replacement of sand by IOT is 30 %, the compressive strength of concrete increases by about 30 % at the age of 28 d. The 28-days compressive strength and split flexible strength of the hardened concrete specimens all exceeded 35 MPa and 5 MPa, respectively, and they reached the maximum when there were 30 % IOT in the mix. When the replacement of IOT was more than 40 %, the strength reduced at the age of (14, 28 and 90) d. This is because of the smaller size of the IOT than the regular fine aggregate. From **Table 2**, the particles size of the IOT is mostly between 0.300 mm and 0.150 mm, when that of the regular sand is larger than 0.300 mm, so the IOT can mix with the other component uniformly. The small size of the IOT particles makes the hardened concrete denser by the filling effect, especially for crushed fine aggregate with more large material. Nevertheless, over-adding IOT results in fresh concrete thin even loose. So the strength of the concrete is very seriously affected by the degree of its compaction by bad workability, and this can be observed from **Figure 4**. In the hardened concrete microstructure with 60 % IOT, there are some cracks observed in the SEM.

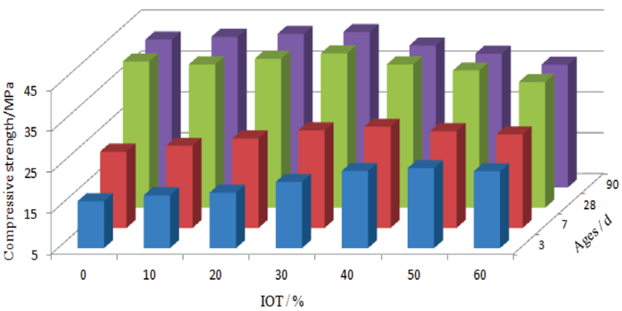

Figure 3: Compressive strength of hardened concrete with different IOT content at the age of (3,7, 28 and 90) d

Table 5: Mechanical properties of harden concrete

Trial No.	Compressive strength (MPa)				Tensile strength (MPa)	Flexural strength (MPa)	Tensile-compressive strength ratio
	3 d	7 d	28 d	90 d			
NC	16.5	23.7	40.8	41.2	3.8	5.2	0.093
10 IOT	17.9	25.1	40.1	41.9	4.2	5.7	0.105
20 IOT	18.6	26.9	41.5	42.6	5.1	6.5	0.123
30 IOT	21.2	28.9	42.8	43.1	6.7	7.3	0.156
40 IOT	23.9	29.8	40.1	39.8	6.3	7.2	0.157
50 IOT	24.6	28.7	38.6	37.8	4.5	5.6	0.117
60 IOT	23.8	27.9	35.8	35.1	3.7	4.8	0.103

3.2.2 Shrinkage

The shrinkage results are shown in **Figure 5**. The values are the average of three samples for each age. The results show that the IOT content of concrete has a detrimental effect on the shrinkage deformation. There is obvious shrinkage deformation increasing in early 28 d age in spite of the IOT replacement ratio. The gentle trends of shrinkage deformation were observed for the 30 % and 40 % replacement after 28 d, but a further increasing for the 50 %. Furthermore, the initial cracking

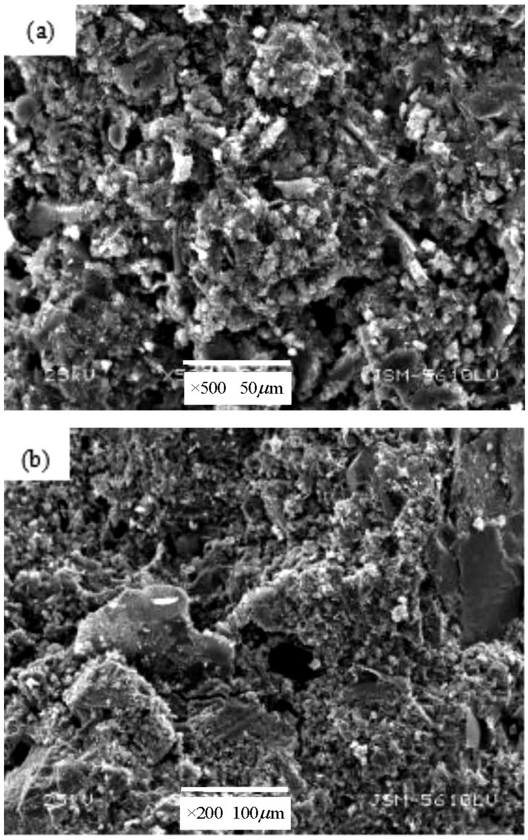

Figure 4: SEM micrographs of the hardened concrete of IOT: a) 30 % and b) 60 % at 28 d

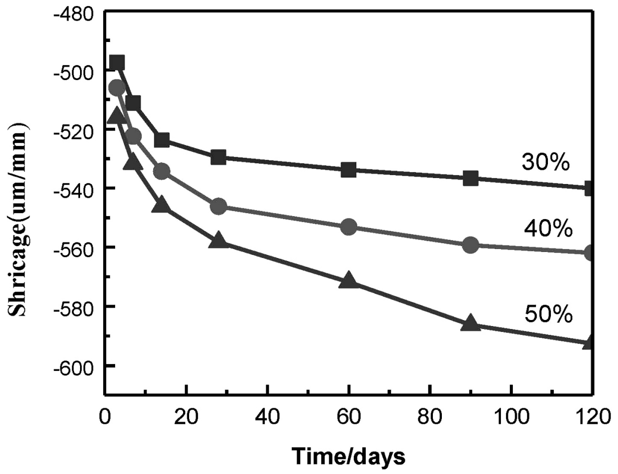

Figure 5: Shrinkage curve of samples with IOT 30 %, 40 % and 50 % at different time

time was (48.3, 36.8 and 25.2) h for IOT 30 %, 40 % and 50 %, respectively. This can be ascribed to two factors: more IOT replacement and finer particles of IOT. On one hand, the former factor can reduce the strength of concrete, which decreases the restriction to shrinkage deformations. On the other hand, the more added water can compensate the finer particles of IOT, which leads to thicker fresh concrete and an increase of the shrinkage deformations for more IOT replacement.

The results of cracking resistance of the concrete with 40 % IOT replacement were listed in **Table 6.** For the samples with 40 % IOT replacement, the shrinkage value is small, 553.1 μm/m, at the age of 60 d. Its initial crack time is 36.8 h, and there is no evident change for the shrinkage value, as well as for the crack number, the width and the length after 28 d. During the whole experiment, only very fine cracks were observed on the surface. All the results showed that the cracking resistance grade of the samples was ascribed to the second grade according to the Chinese national standard of GB50164.

Table 6: Cracking resistance of 40 % IOT replacement

Items	Age (days)						
	3	7	14	28	60	90	120
Crack numbers	1	1	2	2	3	3	4
Maximum crack width (mm)	0.1	0.2	0.3	0.8	0.9	1.0	1.1
Total crack length (mm)	30	35	46	48	68	72	73
Weighting crack length (mm)	0.2	0.2	0.3	0.4	0.5	0.6	0.6
Total cracking area (mm^2/m^2)	181	331	577	728	852	876	902

4 CONCLUSIONS

This study focuses on exploring whether IOT can be used as a fine aggregate replacement for regular sand in concrete. The following conclusions can be drawn:

1) The replacement of some regular sand with IOT can improve the workability of the fresh concrete by compensating the aggregate grading, while the slump and bleeding of fresh concrete was the best with a 30 % replacement of IOT.

2) Due to the small particle size of the IOT, which is less than 300 μm, the compressive strength of the hardened concrete increases because the IOT powder can fill the small pores existing in the hardened concrete. When the replacement of IOT is 30 %, the flex-compression ratio is almost 1/6. Over-adding of the IOT results in some cracks in the hardened concrete microstructure, which decreases its compressive strength.

3) The harden concrete of less than 40 % IOT replacement has good durability because of the high compressive strength to restrict the shrinkage deformations. The cracking resistance of the hardened concrete with 40 % IOT replacement is ascribed to the second grade according to the Chinese national standard of GB50164.

4) The IOT can be utilized to prepare concrete as fine aggregate with good workability of fresh concrete and good performance of the hardened concrete, and the maximum amount is a 40 % replacement of regular sand.

Acknowledgments

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