Preparation of UHPC with cement replaced by rich-silicon iron ore tailing powder[1]

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Abstract: In order to study the influence rule and mechanism of iron ore tailing powder(IOTP) replacing cement in UHPC, the influences of different specific surface area and dosage of IOTP replacing cement on its strength and liquidity were tested. Moreover, the pore structure and hydration products morphology of UHPC were tested by MIP and SEM, respectively. The results show that IOTP can increase the liquidity of UHPC, when alternative content of IOTP is less than 10%, proper specific surface area of IOTP can improve the strength, pore structure and hydration products structure of UHPC. However, when alternative content of IOTP is more than 15%, it shows up an inverse pattern.

Introduction

IOT is the major component of industrial solid waste. According to incomplete statistics, there are more than 10 billion tons of ore tailing discharged around the world every year, the stock of ore tailing in China is more than 10 billion tons and nearly one half is IOT. However, it is growing at a rate of 500 million tons every year[1]. The stored IOT causes many sorts of environmental pollution, moreover, some IOT ponds are at risk of dam break[2-5].

Wen NI found a certain amount of IOTP could improve the porosity of composite gelled material and lower the proportion of big pore[6]. Xueying MA through test showed IOTP after mixed with slag powder could improve the working performance, mechanical property and durability of the concrete[7]. Beixing LI found the rich-silicon IOTP mainly played a physical filling effect in concrete after curing in 90°C water[8]. The research of Xiaoyan HUANG showed IOTP used as mineral admixtures preparation high ductility fiber reinforced cement matrix composites was feasible, under the same mineral admixture content, the strength of IOTP ECC performance was lower than the fly ash ECC, but showed a stronger tensile ductility[9].

UHPC as a new type of building materials, with its excellent performance has attracted much attention, many scholars have carried out a lot of study about UHPC. Results show that porosity of UHPC is very low, inner structure is compact, but poor workability[10-15]. Combining with its high production cost and consistency, IOT is difficult to deal and has certain activity, the research tries to prepare UHPC with IOTP replacing cement, and explores its influences on the strength, liquidity, hydration products and pore structure of UHPC.

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Experimental

Materials

(1) The 52.5 ordinary Portland cement is from Huaxin, its physical properties and chemical composition are shown in table 2 and table 3. The IOT is from Miyun area, its main chemical composition is SiO2 and it belongs to rich-silicon IOT, the main mineral composition are quartz, feldspar minerals and magnetite, all of them are shown in table1, table 2 and figure 1. The SiO2 content of inert quartz sand is more than 90%. The water is tap water from Wuhan city. Grinding agent is melamine and quality content is 0.035%.

(2) Fly ash, specific gravity is 2.36g/cm2, specific surface area is 7200cm2/g, water requirement ratio is 93%. white beads, particle size distribution is 0.1μm~ 5μm, natural state of apparent density is 0.67g/cm3. Gray silicon ash, specific surface area is 22.4cm2/g, the average particle size is 0.2μm, water requirement ratio is about 113%. Their components are shown in table 2. Cylindrical copper coated steel fiber, the diameter is 0.2 mm, length is 12mm to 14mm, tensile strength is 2900MPa, the elastic modulus is 200GPa, density is 7.8 g/cm3. Liquid poly carboxylic acid water reducing agent and its water reducing rate is about 30%.

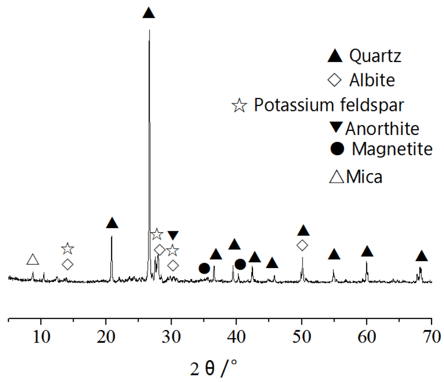


Fig 1 The XRD pattern of IOT

Table 1 Particle size distribution data of IOTP

Specific surface area/$m^2 \cdot kg^{-1}$	<1um /%	1-10 μm/%	10-30.2 μm/%	>30.2 μm/%	D_{10} / μm	D_{50} / μm	D_{90} / μm
394	3.93	39.74	32.82	23.51	1.403	12.611	49.906
588	6.64	41.65	30.23	21.48	1.257	10.755	47.515
801	7.50	44.02	29.27	19.01	1.150	9.273	44.122
1013	8.78	45.06	27.62	18.00	1.037	8.171	42.756

Table 2 The basic physical properties of cement

Water requirement of Normal consistency/%	Setting time/min		Compressive strength/MPa			Flexural strength /MPa		
	Initial	Fianl	3d	7d	28d	3d	7d	28d
27.6	104	176	30.0	48.5	55.2	5.7	8.8	9.5

Table 3 The chemical composition of cement and IOT(%)

Name	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	SO_3	Na_2O	K_2O	Loss
Cement	19.95	5.06	3.34	2.54	63.30	2.29	0.14	0.53	1.09
IOT	65.27	7.46	11.80	5.27	3.80	0.24	/	/	2.13
Fly ash	55.77	31.77	3.88	0.61	2.59	0.60	/	/	1.03
Bead	60.21	15.92	8.02	2.41	6.04	0.37	/	/	0.19
Silicon ash	94.32	0.14	1.29	0.05	0.06	0.43	/	/	3.40

UHPC mortars preparation

The mortars moulded at 100mm×100mm×100mm, 100mm×100mm×400mm molds, room temperature should be kept at 20±2°C, relative humidity should be not less than 50%, then the forms are removed after 1d, specimen are putted into water heated to 90 °C for 48 h (temperature 15°C/h or less), and then blocked in the oven which temperature was 20±2°C, relative humidity were more than 90% cured to certain age. Table 4 is the the mix of UHPC.

Table 4 Mix of blank UHPC

Water-binder ratio	Binder-sand ratio	Binding materials				Water reducer
		Cement	Bead	Fly ash	Silicon ash	
0.16	1:1	60%	15%	15%	10%	1.5%

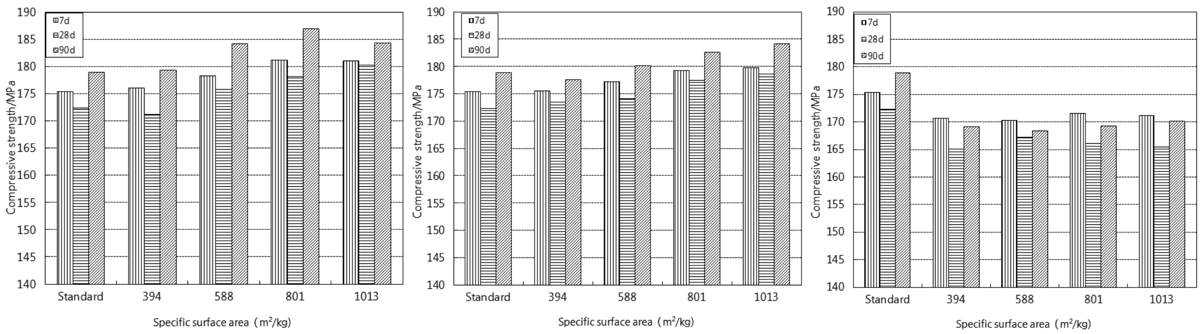
Note: copper coated steel fiber volume content is 2.0%.

Characterization

The model of SEM equipment is JSM-5610LV and made by Japanese Electronics Corporation. Samples preparation method: samples are from center area of mortars and hydration stopped by anhydrous ethanol, samples are dried in 40°C condition till to constant weight. The pore structure is tested by Autopore III9420 made by America, measuring range is 0.003um~360um, maximum working pressure is 414MPa. Samples preparation method: samples are from center area, hydration stopped by anhydrous ethanol and dried in the condition below 90°C till to constant weight before test.

Results and discussion

Strength



(a) 5% (b) 10% (c) 15%

Fig.2 The influence of IOTP content on strength

Figure 2 is about the influences of different specific surface area and content of IOTP to replace cement on the 7d, 28d and 90d strength.

From figure (a) can be known: when IOTP specific surface area was 394m2 /kg, the strength of UHPC almost did not change, when the IOTP specific surface area continued growing, the strength of UHPC appeared different degree of growth, and it reached the top value when the specific surface area of IOTP was 801m2/kg (except the 28d strength value). For 7d strength, four different specific surface area of IOTP, change value compared with standard sample was 0.72MPa, 2.88MPa, 5.75MPa and 5.56MPa, respectively. For 28d strength, the change value was -0.90MPa, 3.42MPa, 5.79MPa and 7.90MPa, respectively. For 90d strength, the change value was 0.43MPa, 5.33MPa, 8.01MPa and 5.42MPa, respectively. It was visible that when IOTP content was 5%, the impact of IOTP specific surface area on the strength was more obvious.

From figure (b) can be known: when IOTP specific surface area was 394m2 /kg, the strength of UHPC showed a little bit, but it appeared growing with the growth of IOTP specific surface area. The biggest change value of 7d, 28d and 90d strength was 4.30MPa, 6.34MPa and 5.23MPa, respectively. And it showed that the rate of contribution was inferior to when the IOTP content was 5%.

From figure (c) can be known: when the replacing content was 15%, the strength of UHPC decreased significantly and the influence of specific surface area was tiny. This may be because too much IOTP lead to lack of cement, the hydration products were hard to package aggregate, and the inner structure was not impact, all of these factors would greatly influenced the macroscopic strength.

Fluidity

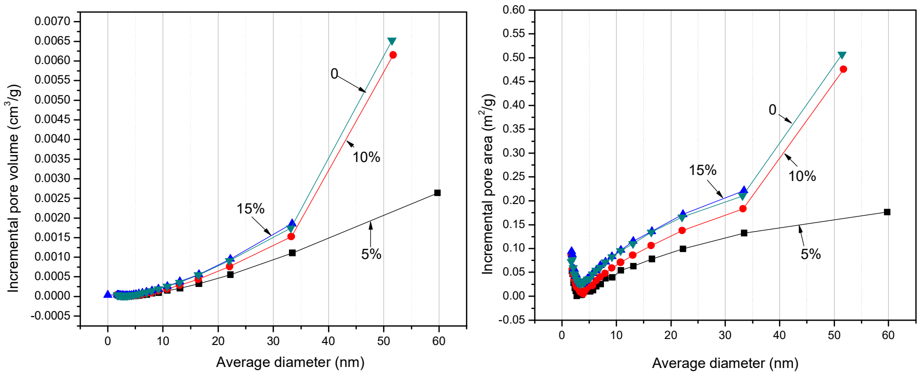
Table 5 The influence of cement replacement content on jump table fluidity

IOTP content	Jump table fluidity(mm)			
(%)	394m^2/kg	588m^2/kg	801m^2/kg	1013m^2/kg
0	190	190	190	190
5	198	207	201	195
10	220	227	220	213
15	254	260	256	248

Table 5 was about the influence of cement replacement content on jump table fluidity. From it we could see that when the specific surface area was the same, the jump table fluidity increased with the growth of IOTP replacing content. We also could see that when the IOTP content was the same, the jump table fluidity increased firstly and then decreased, the value reached the top point when the IOTP specific surface area was 588m2/kg. On the whole, the work performance of UHPC could be improved through mixing right amount of IOTP.

Pore structure

Figure 3 was about the influence of IOTP content on pore structure when the IOTP specific surface area was 801m2/kg . We could see that both the hole size-volume and hole size-area showed the same changing rule. The pore size distribution was the best when the replacing content was 5%, when the dosage increased to 10%, although the pore area and pore volume increased, but still lower than the standard sample. But when IOTP content increased to 15%, pore area and pore volume became further coarsening, value is greater than the standard sample. It showed the same law as strength, IOTP had enhancement effect to the strength when IOTP replacement content did not exceed 10%, when the replacement amount was 15%, IOTP had negative effect on strength and pore structure.



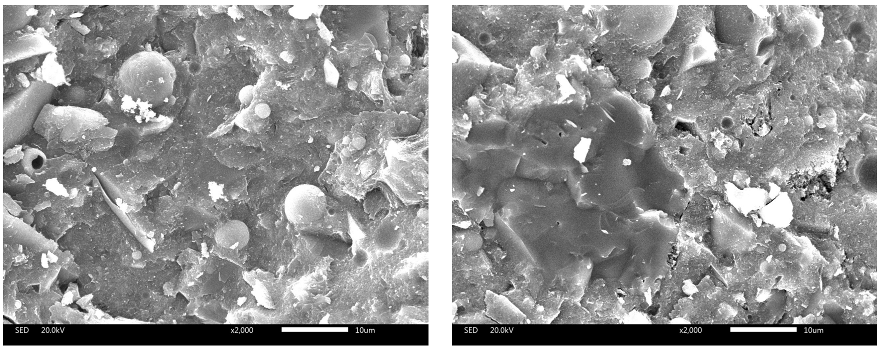
(a) Pore size-volume (b) Pore size-area

Fig.3 The influence of cement replacement content on pore size distribution

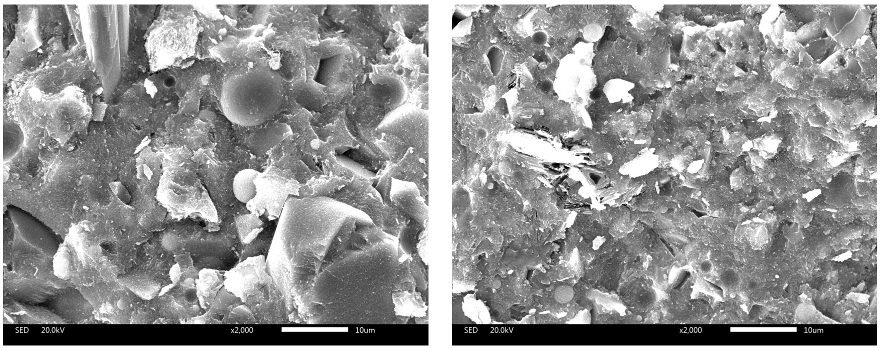
Morphology

Figure 4 was about the influence of IOTP content on hydration products morphology when the IOTP specific surface area was 801m2/kg, . CSH gel in figure (a) was evenly distributed, we could see some un-hydrated round particles, mainly for the beads, fly ash and silica fume.CSH gel distribution in figure (b) was not equal to standard sample, but for aggregate the wrapping effect was very good, it did not see obvious interface transition zone. With rod material in figure (c), there were some Ca(OH)2 at the lower right corner which between aggregate and CSH gel, at the same time, there was a crack at the lower left part of the picture. CSH gel in figure (d) was obvious thinner than the other three images, a clear crack almost throughout 1/3 length of the picture and more Ca(OH)2.

With the increase of IOTP replacing cement, the hydration products content and compactness of CSH gel would be worse. However, considering the strength, liquidity and pore size distribution, when the content was no more than 10%, it could improve the properties of UHPC, this is mainly because average particle size of IOTP was smaller than the cement particles, it played a better physical filling effect for UHPC and strengthen the "core effect". However, when the IOTP was too much (H particles increased and L particles decreased), with a certain porosity, the gel reduced to a certain degree (H/L ratio to a certain degree), L particles could not fill the porosity of H particles which would lead to strength reduced.



(a) Standard (b) 5%



(c) 10% (d) 15%

Fig.4 The influence of cement replacement content on SEM patterns

Conclusions

From the above research, it can be found that IOTP had a effective interaction on UHPC when cement replaced. When the IOTP content is less than 10% and controlling specific surface area, the strength, liquidity, pore size distribution and hydration products morphology of UHPC are better than standard samples. Especially, most of these values reach the biggest when the specific surface area of IOTP is 588m2/kg or 813m2/kg. Whereas, when the IOTP is more than 15%, most above properties are worse than standard samples no matter the specific surface area of IOTP.

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