Preparation of UHPC with micro-bead replaced by rich-silicon iron ore tailing powder

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Abstract: In order to study the influence rule and mechanism of rich-silicon iron ore tailing powder(IOTP) replacing micro-bead in UHPC, the influences of different specific surface area and dosage of IOTP replacing fly ash 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 5% and specific surface area is higher than 801m²/kg can improve the strength, when specific surface area is 801m²/kg and alternative content of IOTP is no more than 10% can improve pore structure. However, when alternative content of IOTP is more than 15%, all of these properties are worse.

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 micro-bead, and explores its influences on the strength, liquidity, hydration products and pore structure of UHPC.

Experimental

Materials

(1) The 52.5 ordinary Portland cement is from Huaxin, its physical properties and chemical composition are shown in table 1 and table 2. The IOT is from Miyun area, its main chemical composition is SiO_2 and it belongs to rich-silicon IOT, the main mineral composition are quartz, feldspar minerals and magnetite, all of them are shown in table 2 and figure 1. The SiO_2 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/cm^3 , specific surface area is $7200\text{cm}^2/\text{g}$, water requirement ratio is 93%. white beads, particle size distribution is $0.1\mu\text{m}\sim 5\mu\text{m}$, natural state of apparent density is 0.67g/cm^3 . Gray silicon ash, specific surface area is $22.4\text{cm}^2/\text{g}$, the average particle size is $0.2\mu\text{m}$, 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/cm^3 . Liquid poly carboxylic acid water reducing agent and its water reducing rate is about 30%.

Fig 1 The XRD pattern of IOT

Table 1 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 2 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

Geopolymer preparation

The mortars moulded at $100\text{mm}\times 100\text{mm}\times 100\text{mm}$, $100\text{mm}\times 100\text{mm}\times 400\text{mm}$ molds, room temperature should be kept at $20\pm 2^\circ\text{C}$, 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 3 is the the mix of UHPC.

Table 3 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℃ condition till to constant weight. The pore structure is tested by Autopore ^{III}9420 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℃ till to constant weight before test.

Results and discussion

Strength

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 micro-bead on the 7d, 28d and 90d strength.

From figure (a) can be known: The strength increased with the growing of IOTP specific surface area. When the specific surface area was less than $588\text{m}^2/\text{kg}$, the strength of UHPC was lower than standard sample, but when the IOTP specific surface area was $801\text{m}^2/\text{kg}$ or $1013\text{m}^2/\text{kg}$, the strength of UHPC was higher than standard sample. For 7d strength with four different specific surface area of IOTP, change value compared with standard sample was -4.19MPa , -1.53MPa , 2.58MPa and 2.77MPa , respectively. For 28d strength, the change value was -3.92MPa .

-0.75MPa, 1.86MPa and 5.54MPa, respectively. For 90d strength, the change value was -5.17MPa, -3.68MPa, 0.43MPa and 1.68MPa, respectively. It showed that when IOTP dosage to binding material was 5%, the best IOTP specific surface area was 1013m²/kg.

From figure (b) can be known: When the replacing content was 10%, the strength of UHPC decreased significantly and the 7d strength was higher than 28d strength and 90d strength. For 7d strength with four different specific surface area of IOTP, change value compared with standard sample was -6.92MPa, -6.82MPa, -5.06MPa and -6.17MPa, respectively. For 28d strength, the change value was -8.23MPa, -7.25MPa, -4.71MPa and -6.29MPa, respectively. For 90d strength, the change value was -12.37MPa, -10.68MPa, -9.92MPa and -11.06MPa, respectively.

From figure (c) can be known: When the replacing content was 10%, the strength of UHPC decreased more significantly. For 7d strength with four different specific surface area of IOTP, change value compared with standard sample was -10.96MPa, -11.85MPa, -10.23MPa and -10.71MPa, respectively. For 28d strength, the change value was -11.11MPa, -10.42MPa, -9.86MPa and -10.559MPa, respectively. For 90d strength, the change value was -14.47MPa, -15.96MPa, -12.07MPa and -13.73MPa, respectively.

It showed that Only when the IOTP dosage to binding material was 5% and IOTP specific surface area was higher than 801m²/kg, the IOTP had a positive effect on strength.

Fluidity

Table 4 was about the influence of micro-bead 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.

Table 4 The influence of micro-bead replacement content on jump table fluidity

IOTP content (%)	Jump table fluidity(mm)			
	394(m ² /kg)	588(m ² /kg)	801(m ² /kg)	1013(m ² /kg)
0	190	190	190	190
5	193	210	204	203
10	202	223	215	211
15	219	237	226	220

Pore structure

Fig.3 The influence of micro-bead replacement content on pore size distribution

Figure 3 was about the influence of IOTP content on pore structure when the IOTP specific surface area was $801\text{m}^2/\text{kg}$. 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 was greater than the standard sample.

Morphology

Figure 4 was about the influence of IOTP content on hydration products morphology when the IOTP specific surface area was $801\text{m}^2/\text{kg}$. CSH gel in figure (a) was evenly distributed, we could see some un-hydrated round particles, mainly for the bead, fly ash and silica fume. CSH gel distribution in figure (b) was not equal to standard sample, but the difference was small. In figure (c), the dense of CSH decreased, some small openings and cracks could be seen. CSH gel in figure (d) was obvious thinner than the other three images.

With the increase of IOTP replacing micro-bead, 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.

Fig.4 The influence of fly ash replacement content on SEM patterns

Conclusions

From the above research, it can be found that IOTP had a effective interaction on UHPC when micro-bead is replaced. When the IOTP content is less 5% and its specific surface area is higher than 801m²/kg, the strength, liquidity, pore size distribution are better than standard samples. Especially, most of these values reach the biggest when the specific surface area of IOTP is 1013m²/kg. Whereas, when the IOTP is more than 10%, most above properties are worse than standard samples no matter the specific surface area of IOTP except hydration products morphology.

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