Experimental Research on Mechanical Properties of Recycled Aggregate Concrete with Different Modification Methods

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Keywords: recycled aggregate; recycled concrete; modified process; mechanical properties

Abstract. The recycled aggregates were modified by sodium silicate, cement grout, cement mixed with superfine fly ash grout and polymer emulsion. The influence of the modified recycled aggregates to the mechanical properties of the concrete was studied. The results indicated that the recycled aggregates can reduce the compressive strength, split tensile strength and elasticity modulus. The modified process of the recycled aggregates can enhance the mechanical properties of the concrete. The early split tensile strength and elasticity modulus were preferably enhanced by sodium silicate. The cement grout and cement mixed with superfine fly ash grout can significantly improved the later mechanical properties.

Introduction

A large amount of old buildings were demolished with the rapid development of the urbanization. More and more construction waste was produced. In 2014, more than 1.5 billion tons of construction waste was produced in our country. The number will continue to increase in the future. The reasonable utilization of the construction waste can not only bring great economic values, but it also can alleviate the pressure on finding new disposal sites to manage the wastes. The constructions waste was machined by sorting, crushing and screening, which can be used in concrete to replace the natural aggregates. That is the main application of the constructions waste.

The recycled aggregates have defects, such as higher porosity and more microcracks. A number of technical indicators of recycled aggregates could not reach the requirements of natural aggregates. A great deal of test and research work were made by the scholars at home and abroad. They have a lot of different conclusions through the modification of recycled aggregates[1~4]. In this paper, the recycled aggregates were modified by sodium silicate, cement grout, cement mixed with superfine fly ash grout and polymer emulsion. The influence of the modified recycled aggregates to the mechanical properties of the concrete were studied.

Materials

Cement:Ordinary Portland cement from Jidong cement company limited, type P•O 42.5 according the Chinese Standards GB175-2007. The compressive strength of the cement is 28.3MPa and 48.4MPa at 3-day and 28-day, respectively.

Fine Aggregate: Local well-graded natural sand with a fineness modulus of 2.71. Its apparent density and fraction passing 75μm sieve were 2650kg/m^3 and 1.3%, respectively.

Coarse Aggregate(NA): Local crushed limestone, with maximum size of 31.5mm with a apparent density of 2680kg/m^3.

Recycled Aggregate(RA):The recycled aggregates were obtained by crushing waste concrete. The strength grades and curing age of the waste concrete was C30 and 15 years, respectively. The physical properties of NA and RA are given in Table 1.

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Table 1 Physical properties of NA and RA

Type	Apparent density [g/cm^3]	Bulk density [g/cm^3]	Voidage [%]	Crushing value [%]	Water absorption [%]
NA	2.68	1.59	40.7	7.2	0.6
RA	2.41	1.43	40.0	16.1	3.94

Water Reducing Agent: Naphthalene series high range water reducing agent, the water reducing ratio is 22%.

Superfine Fly Ash:The water demand ratio is 94% and the specific surface area is 1200cm^2/g.

Soluble silicate: The modulus of the liquid soluble silicate is 3.0.

Polymer emulsion: SBR, the solid content is 50% and the density is 1.02g/cm^3.

Modified Process

The recycled aggregates were modified by dipping treatment. Specific chemical grouts were used, that can bond the microcracks, fill the pore and change the surface composition of the aggregates. In this experiment, the recycled aggregate were modified by sodium silicate, cement grout, cement mixed with superfine fly ash grout and polymer emulsion. The technical indicators of the modified recycled aggregates are given in Table 2.

Table 2 The technical indicators of the modified recycled aggregates

modified material	Apparent density [g/cm^3]	Bulk density [g/cm^3]	Voidage [%]	Crushing value[%]	Water absorption [%]
sodium silicate	2.59	1.47	43.2	11.9	1.08
cement grout	2.57	1.47	42.8	11.5	1.47
cement mixed with superfine fly ash grout	2.53	1.44	43.1	12.9	1.41
polymer emulsion	2.48	1.40	43.5	14.1	0.85

Mix Proportions

Mix proportion design of the concrete according to the specification for mix proportion design of ordinary concrete(JGJ55-2011). The designed strength grade of the natural aggregate concrete(N1) is C30 and the targeted slump is 140~160mm.

N1 had a constant water/binder (w/b) of 0.56, a cement content of 345 kg/m^3 and a sand ratio of 41%. The recycled aggregates were used at the level of 100% of the coarse aggregates. R1 represents the unmodified recycled aggregate concrete, RG1~RG4 represent the recycled aggregate concrete that modified by sodium silicate, cement grout, cement mixed with superfine fly ash grout, polymer emulsion, respectively. All the mixtures achieved similar slumps of 140~160mm though adjusting the quantity of water reducing agent. The mixture proportions are given in Table 3.

Table 3 Mixture proportions

Concrete	Component[kg/m^3]					Water reducing agent [%]	Slump [mm]
	Cement	Water	Fine aggregate	Coarse aggregate	Recycled aggregate		
N1	345	193	763	1099	-	0.8	155
R1	345	193	763	-	1099	1.2	140
RG1	345	193	763	-	1099	1.1	150
RG2	345	193	763	-	1099	1.0	145
RG3	345	193	763	-	1099	1.0	150
RG4	345	193	763	-	1099	1.1	155

Results of the Mechanical Properties

(1) Compressive strength

The cube crushing strength test results of the mixtures are showed in Table4 and Fig.1. It indicates that the modification of recycled aggregates has influence on the compressive strength of the concrete. The following conclusions can be drawn:

1)The comparison results of N1 and R1 indicate that the compressive strength of the unmodified recycled aggregate concrete were reduced 2.1MPa, 4.7MPa and 5.7MPa at 7-day, 28-day and 90-day, respectively. With the growth of age, the influence of the defects of the recycled aggregates such as higher porosity and lower interface strength with the cement stone is becoming more and more apparent. That is similar to some domestic and overseas scholars [4~6].

2)The modified process of the recycled aggregate can enhance the mechanical properties of the concrete, that will be more observably with the growth of age. The improvement range at 7-day, 28-day and 90-day are 5.0%、7.3% and 11.8%, respectively.

3)With the growth of age, the improvement of the cement mixed with superfine fly ash grout to the compressive strength of the recycled aggregate concrete is becoming more and more apparent. The compressive strength at 90-day is close to N1. But the early effect of RG3 to the strength is non-significant and similar to other modification methods, that may be due to the activity of fly ash is comparatively lower. The pozzolanic activity of the superfine fly ash is activated with the growth of age and the effect to the strength is becoming significantly. That is similar to some domestic and overseas scholars [4].

Table 4 Compressive strength

Concrete	Compressive strength[MPa]					
	N1	R1	RG1	RG2	RG3	RG4
7d	30.7	28.6	29.9	30.5	30.3	29.4
28d	38.4	33.7	36.2	36.3	37.5	34.6
90d	41.2	35.5	39.8	40.4	41.1	37.5

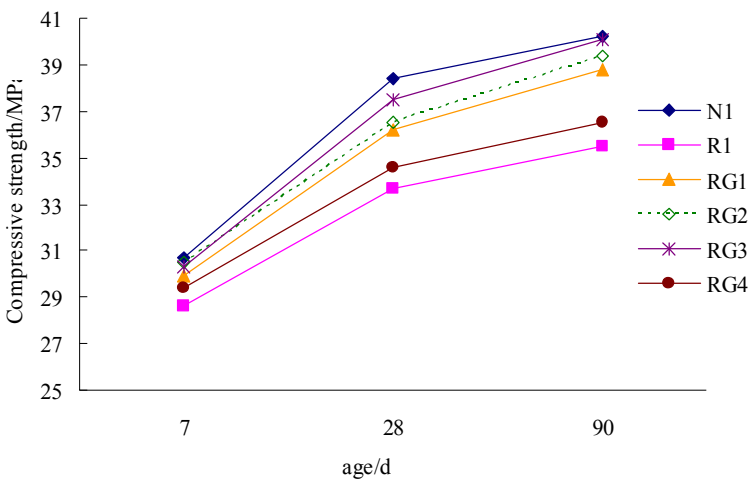

Fig.1. The Compressive strength of the concrete

(2) Split tensile strength

The split tensile strength test results of the mixtures are showed in Table5 and Fig2. The following conclusions can be drawn:

1) The split tensile strength of the recycled aggregate concrete is significantly decreased. The decreasing range at 7-day, 28-day and 90-day are 11.5%、17.9% and 20.7%, respectively. That has simlar rule to the compressive strength. It may be due to the pore and microcracks in the recycled aggregates, which play a greater influence when they withstanding tension. That is similar to some domestic and overseas scholars [3~5].

2) The modified process of the recycled aggregate can enhance the split tensile strength of the concrete. The RG1 at early age is just above the other modification methods. With the hydration of cement and activation of the pozzolanic activity of superfine fly ash, the effects of RG2 and RG3 raised gradually.

Table5 Split tensile strength

Concrete	Split tensile strength[MPa]					
	N1	R1	RG1	RG2	RG3	RG4
7d	2.35	2.08	2.17	2.14	2.11	2.13
28d	3.57	2.93	3.18	3.15	3.14	3.09
90d	4.11	3.26	3.45	3.52	3.57	3.38

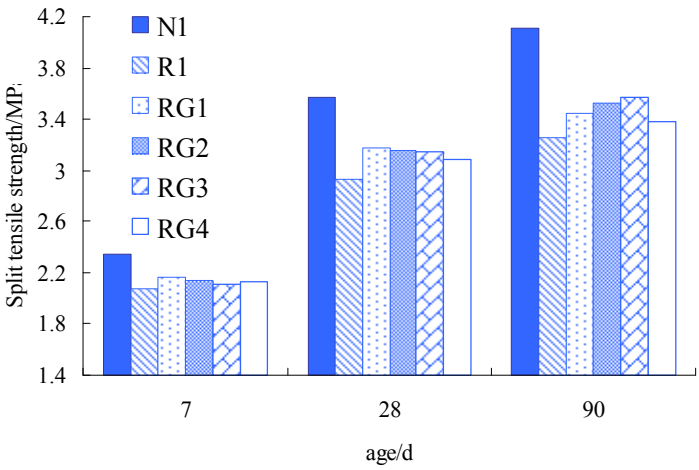

Fig.2. The split tensile strength of the concrete

(3)Elasticity modulus

The elasticity modulus test results of the mixtures are showed in Table6 and Fig3. The following conclusions can be drawn:

1) The elasticity modulus of the recycled aggregate concrete presents a significantly decreased, which is similar to the split tensile strength. The decreasing range at 7-day, 28-day and 90-day are 23.5%、26.0% and 26.7%, respectively. It may be due to the pore and microcracks in the recycled aggregates, which is easier to make concrete deformation. That is similar to some domestic and overseas scholars [7].

2) The modified process of the recycled aggregate can enhance the elasticity modulus of the concrete. The improvement range at 7-day, 28-day and 90-day are 5.6%、9.9% and 16.0%, respectively. It indicates that, the effects of the modified material such as filling pores are gradually increase, which will enhance the ability of the concrete to resist deformation. The early improvement of sodium silicate is superior to others. The later strength of the hydration products of RG2 and RG3 is increased and the influence to the elasticity modulus is also growing.

Table 6 Elasticity modulus

Concrete	elasticity modulus [10^4MPa]					
	N1	R1	RG1	RG2	RG3	RG4
7d	2.81	2.15	2.37	2.25	2.22	2.24
28d	3.15	2.33	2.59	2.61	2.56	2.48
90d	3.29	2.41	2.75	2.88	2.86	2.69

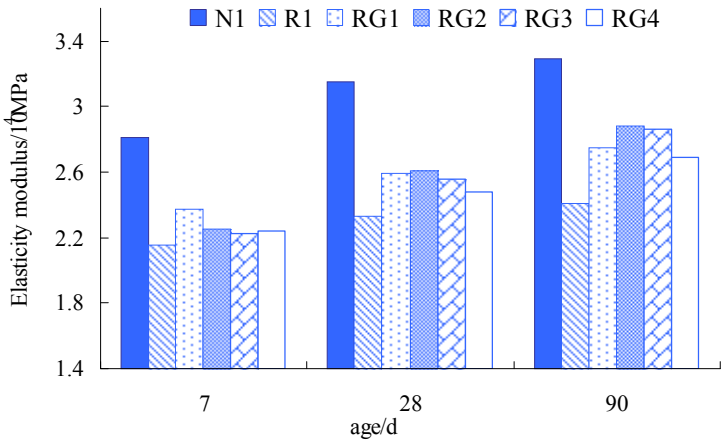

Fig.3. The elasticity modulus of the concrete

Conclusions

(1) The recycled aggregate can reduce the compressive strength, which decreases more with the growth of age. The modified process of the recycled aggregate can enhance the compressive strength of the concrete, that will be more observably with the growth of age.

(2) The early effect of these modification methods to the compressive strength are similar. With the growth of age, the compressive strength of the recycled aggregate concrete modified by cement mixed with superfine fly ash grout is higher than other modification methods.

(3) The split tensile strength of the recycled aggregate concrete is significantly decreased. The modified process of the recycled aggregate can reduce the effects of the replacement, that will be more observably with the growth of age. The early improvement of sodium silicate is superior to others. The later effects of cement grout and cement mixed with superfine fly ash grout are getting better.

(4) The elasticity modulus of the recycled aggregate concrete presents a significantly and greater decline, which is similar to the split tensile strength. The effects of different modification methods to the elasticity modulus are also similar to the split tensile strength.

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