MANUFACTURINGTECHNOLOGY ANDMECHANICAL PROPERTIES OF MODIFIED RECYCLED AGGREGATE CONCRETE

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ABSTRACT*: Wastes seriously affect people's living environment, such as concrete generated during the demolition of buildings. Waste concrete is usually treated as road filler by simple crushing. The usage is too simple, which is not conducive to saving resources. In this paper, the preparation process of recycled concrete modified by basalt fiber and Nano-silica was introduced. The mechanical properties, such as axial compressive strength and elastic modulus at 28 days were studied by static load test. The results show that the basalt fiber has different influences on the axial compressive strength and elastic modulus of recycled aggregate concrete. When the replacement rate is 50%, the optimum basalt fiber content corresponding to the maximum values of axial compressive strength and elastic modulus at 28 days is 2 kg·m^{-3}. When the replacement rate is 100%, the optimum BF content is 2 kg·m^{-3} and 1 kg·m^{-3}, respectively. When the replacement rate is no more than 50%, the optimum Nano-silica content is 6%, and when the replacement rate exceeds 50%, the optimum Nano-silica content is 8%in terms of axial compressive strength and elastic modulus. The results show that the recycled concrete made by the manufacturing technology can be applied to engineering practice.*

KEYWORDS*: manufacturing technology; recycled aggregate concrete; basalt fiber; Nano-silica; mechanical properties*

1 INTRODUCTION

Recycled coarse aggregate (RCA) contains more old mortar, whose performance is different from natural coarse aggregate (NCA),see (Li,2007). Fiber can improve the deformation and failure characteristics of RAC, and increase the splitting tensile strength, flexural strength, toughness and cracking resistance of RAC, see(Chen, 2003; Liu, 2017; Chen, 2014). The reinforcing effect of fiber on RAC splitting tensile strength is significantly higher than that of its compressive strength. The splitting tensile strength of RAC increases with the increase of fiber content, see(Yang, 2013; Zhou, 2017).The splitting tensile strength and the flexural strength of RAC with 1.8% steel fiber content can be increased by 60% and 40% respectively when compared with non-dosing steel fiber content, see(Zhang,2014). Nano-silica (NS) has smaller particle size and can be dispersed in the internal voids of concrete, see(Hosseini,2014; Gao, 2017). It can effectively improve the impermeability and corrosion resistance of concrete. The mechanical properties of concrete can be improved by adding appropriate NS, see (Marijonas, 2014;Nili, 2015).

In order to give full play to the bridging effect of fibers, enhance the friction and pull-out of the fiber, adding ultra-fine fly ash to the fiber-recycled aggregate concrete can strengthen the interface between the fiber and the matrix, which is beneficial to the reinforcement of the fiber, and the mechanical properties are improved (Leordean Dan; Radu, S. A.; Fratila D. et al., 2015). At the same time, Nano-SiO2 can refine the pore size of concrete and improve the interfacial transition zone (ITZ) properties of RAC, see(Zhang, 2014; Vivian, 2005).The compressive strength and splitting tensile strength of NAC are improved by adding the appropriate amount of basalt fiber (BF) and NS, see(Zhu, 2016). The optimum content of BF and NS is 1.2% and 3kg·m^{-3}, see (Fathi, 2017). However, there are few reports on the modified recycled aggregate concrete (MRAC) by adding BF and NS. In order to expand the application scope of RAC, the new recycled concrete manufacturing technology was introduced, and BF and NS are used as reinforcement materials in RAC. Through the static load test, mechanical properties of MRAC, such as the cube compressive strength, axial compressive strength, elasticmodulus, splitting tensile strength and flexural strength at 28 days were analyzed with the variation of replacement rate, BF content and NS content.

2 MANUFACTURING TECHNOLOGY

2.1 Raw material processing

The cement was the ordinary Portland cement produced by Jiaozuo Danyang Cement Company (P.O 42.5), and its performance index is shown in Tab. 1. BF was produced by Haining Anjie Composite Materials Co., Ltd., and its performance indicators are shown in Tab. 2 (provided by the manufacturer). NS was provided by Nangong Ruiteng Alloy Material Co., Ltd., and its performance index is shown in Tab. 3 (provided by the manufacturer). The XRD test pattern of NS is shown in Figure 1.

Figure 1 shows that the particle size of nano-SiO2 particles was about 20 nm. The fine aggregate was medium-sized river sand with a fineness modulus of 2.46 and an apparent density of 1996 kg·m^{-3}.

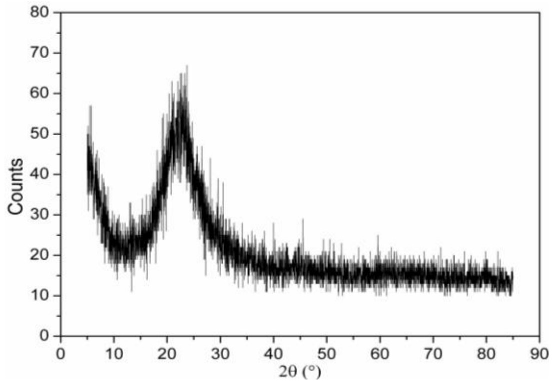

Fig. 1 XRD of NS

NCA was continuous graded gravel, and its physical properties are shown in Tab. 4. RCAwas artificially crushed from the waste concrete component of the structural laboratory of Henan Polytechnic University. Its strength grade of design was C30, and its physical performance index is shown in Tab. 4. Urban tap water was used.

Table 1 Performance indexes of cement

Soundness	Setting time/(h:min)		Compressive strength/MPa	Flexural strength/MPa
	Initial	Final	28days	28days
Meet to standard	2:34	3:47	49.3	8.2

Table 2 Properties of BF (Manufacturer provides)

Length /mm	Diameter /μm	Density /g·cm^{-3}	Elastic modulus /GPa	Splitting tensile strength/MPa	Fracture elongation /%
32	15	2.65	95～115	3300～4500	2.4～3.0

Table 3 Physical properties of NS particles(Manufacturer provides)

Particle size /nm	Specific surface area /m^2·g^{-1}	Purity /%	Bulk density /g·l^{-1}	PH
20	200±25	＞99.99	50	9

Table 4Physical properties of coarse aggregate

Aggregate type	Particle size /mm	Apparent density /kg·m^{-3}	Bulk density /kg·m^{-3}	Water content /%	Water absorption /%	Mud content /%	Crush value /%	Acicular content /%
NCA	5～20	1404	2739	0.1	0.8	0.7	10.7	4.13
RCA	5～20	1260	2460	1.5	6.07	2.4	15.2	9.23

2.2 Mix ratio design

In order to investigate the effect of the replacement rate, BF and NS content on the mechanical properties of MRAC, the replacement rate (r), BF content and NS content were used as control parameters. Among them, the replacement rate was the volume rate of RCA to the total coarse aggregate, and three kinds of changes were designed: 0%, 50% and 100%.Four kinds of changes of BF content were designed, such as 0 kg·m^{-3}, 1 kg·m^{-3}, 2 kg·m^{-3}, 3 kg·m^{-3}respectively.The NS content is the mass ratio of NS to cement, which was designed in the cases of 0%, 3%, 6% and 8% respectively. Based on the above factors, 48 kinds of concrete mix proportion were designed. In the specimen number the first three digits represent the recycled aggregate replacement rate, the next two digits represent the BF content, and the last two digits represent the NS content. For example, the number R0500106 indicates that the replacement rate is 50%, BF content is 1 kg·m^{-3}, NS content is 6%. Among them, the concrete with 0% replacement rate, 0 kg·m^{-3}BF content and 0% NS content was used as the reference concrete, and its mix number is R0000000. The reference concrete mix ratio is shown in Tab. 5. In order to reduce the influence of high water absorption of RCA on the performance of recycled concrete, RCA and NCA was soaked in water for 24 hours before the test, and dried to the saturated surface and then mixed.

Table 5 Mix proportions ofthe reference concrete

Mix no.	Mix proportions /kg·m^{-3}						
	Water	Cement	Sand	NCA	RCA	BF	NS
R0000000	210	425	548	1179	0	0	0

2.3 Specimens production

In order to uniformly disperse BF and NS in the concrete matrix, according to the literature, for example, (Mukharjee, 2014; Asprone, 2014), MRAC was mixed by the sectional feeding method. The main processes are as follows.

(1) Mixing RCA with the half of water for 2 minutes at a normal mixing rate;

(2) Rapidly stirring NS with the remaining half of the water for 2 minutes;

(3) Adding the NS slurry of the step (2) to the mixture of the step (1), and stirring at a normal rate for 2 minutes;

(4) Stirring the cement and BF at a normal rate for 2 minutes;

(5) Adding sand to the step (4), stirring at a normal rate for 2 minutes;

(6) Sequentially adding the mixture of the step (5), the remaining water (when RCA is not added) and the NCA to the mixture of the step (3), and stirring at a normal rate for 3 minutes.

The mixture formed by the above process was loaded into a plastic test mold, vibrated by a vibrating table for 4 minutes, transported to the floor of the curing room of which the temperature was 20±1 °C, and then covered with a plastic film. After 24 hours, the molds were removed, and the specimens were maintained in a constant temperature water tank. The specimens were taken out one day before the test and dried to the surface. Two groups of 100mm * 100mm * 100mm cube specimens were designed under each working condition, of which one group was subjected to the compression and the other group was subjected to the splitting tensile at 28 days; two groups of 100mm*100mm*300mm prism specimens were designed, of which one group was subjected to the axial compression and the other group was subjected to the elastic modulus at 28 days; one group of 100mm*100mm*400mm prismatic specimens was subjected to the flexural strength at 28 days. Each group had 3 pieces of specimens, and the mean value was analyzed.The above test procedures were carried out in accordance with the Standards for Testing Methods for Mechanical Properties of Ordinary Concrete (GB/T50081-2002)(Chinese Standard).

3 MECHANICAL PROPERTIES

The statistical values of 28-dayaxial compressive strength(f_{cp})and elastic modulus(E_c) of MRAC are shown in Tab.5.

3.1 Axial compressive strength

The statistical results of the 28-day axial compressive strength (f_{cp}) of MRAC are shown in Tab.6. It can be seen from Tab.6 that the axial compressive strength of ordinary RAC decreases with the increase of the replacement rate. The axial compressive strength of NAC is 33.23 MPa, and the axial compressive strength of RAC at 100% replacement rate is only 19.29 MPa, which decreases by 42.0%. After adding NS, the 28-day axial compressive strength of MRAC decreases with the increase of the replacement rate. After adding BF, the replacement rate corresponding to the maximum axial compressive strength of the MRAC varies with the BF content. When the BF content is 1kg·m^{-3} 2kg·m^{-3} and 3kg·m^{-3}, the replacement rate corresponding to the maximum axial compressive strengths are 50%, 0%, and 0%, respectively.

It can be seen from Tab.6 that the axial compressive strength of NAC decreases with the increase of BF content. The axial compressive strength of the MRAC at 50% replacement rate increased from 21.76 MPa (BF content is 0kg·m^{-3}) to 25.65 MPa (BF content is 2kg·m^{-3}), and then with the increase of BF content, the axial compressive strength decreased to 22.19 MPa (BF content is 3kg·m^{-3}). The variation of axial compressive strength with BF content of the MRAC at 100% replacement rate is the same as that of a 50% replacement rate, and the BF content corresponding to the maximum axial compression strength is also 2 kg·m^{-3}, see (Zhao, 2017). It can also be seen from

Tab.6 that when the replacement rate is 0% and 50%, the NS content corresponding to the maximum axial compressive strength of MRAC is 6%, and when the replacement rate is 100%, the NS content corresponding to the maximum axial compressive strength of MRAC is 8%.

From Tab.6, the ratio of the axial compressive strength to the cube compressive strength at 28 days can be obtained. In the NAC, the ratio is between 0.680 and 0.875, which is slightly larger than that of MRAC which is between 0.675 and 0.816. The research shows that the ratio of the axial compressive strength to the cube compressive strength of RAC is slightly larger than that of NAC, see (Hou, 2013;Shi, 2012). The reason may be that the brittleness of the NAC is larger, the cracking load of the lateral deformation is smaller, and the restraining effect of the bearing surface is reduced, which in turn causes the cube compressive strength to be slightly higher than the axial compressive strength, resulting in the ratio of the axial compressive strength to the cube compressive strength of NAC is higher.

Tab. 6 The fitting value and experimental value of axial compressive strength / Mpa

Mix no.	Fitting value	Experimental value	Error /%	Mix no.	Fitting value	Experimental value	Error /%	Mix no.	Fitting value	Experimental value	Error /%
R0000000	29.81	33.23	0.115	*R0500000*	23.71	21.76	-0.082	*R1000000*	19.45	19.29	-0.008
R0000003	32.73	35.83	0.095	*R0500003*	25.32	23.11	-0.087	*R1000003*	21.00	20.36	-0.031
R0000006	34.29	37.06	0.081	*R0500006*	26.23	25.82	-0.016	*R1000006*	21.47	22.57	0.051
R0000008	32.15	35.44	0.103	*R0500008*	24.46	24.91	0.019	*R1000008*	22.44	23.40	0.043
R0000100	23.08	21.57	-0.066	*R0500100*	24.17	24.37	0.008	*R1000100*	19.26	20.75	0.077
R0000103	32.17	34.76	0.080	*R0500103*	24.54	25.47	0.038	*R1000103*	19.75	21.77	0.103
R0000106	33.93	36.69	0.081	*R0500106*	25.83	26.13	0.012	*R1000106*	20.95	23.36	0.115
R0000108	32.02	31.54	-0.015	*R0500108*	23.80	25.27	0.062	*R1000108*	21.49	23.64	0.100
R0000200	23.61	21.46	-0.091	*R0500200*	24.11	25.65	0.064	*R1000200*	20.21	21.54	0.066
R0000203	28.44	25.84	-0.091	*R0500203*	25.41	26.46	0.041	*R1000203*	20.89	22.53	0.078
R0000206	30.09	26.50	-0.119	*R0500206*	26.69	28.10	0.053	*R1000206*	21.55	22.66	0.052
R0000208	29.52	26.83	-0.091	*R0500208*	24.11	25.72	0.067	*R1000208*	25.39	23.14	-0.089
R0000300	22.77	24.37	0.070	*R0500300*	23.30	22.19	-0.048	*R1000300*	20.38	20.06	-0.015
R0000303	28.48	25.83	-0.093	*R0500303*	24.93	23.28	-0.066	*R1000303*	22.13	22.46	0.015
R0000306	30.44	26.39	-0.133	*R0500306*	25.12	24.92	-0.008	*R1000306*	22.94	22.51	-0.019
R0000308	29.87	26.67	-0.107	*R0500308*	24.75	22.87	-0.076	*R1000308*	26.08	23.30	-0.107

3.2 Elastic modulus

Elastic modulus is an important basic performance of concrete. The value of elastic modulus is greater, the stiffness and brittleness of concrete will be greater. The statistical results of elastic modulus (E_c) at 28 days are shown in Tab.7. It can be seen from Tab.7 that as the replacement rate increases, the elastic modulus of the MRAC decreases. The above changes are mainly due to the content of micro-cracks in RCA. With the increase of replacement rate, the ductility of MRAC increases and the brittleness of MRAC decreases. The addition of BF forms a crisscross network, which improves the overall performance and ductility of MRAC. With the increase of replacement rate, the content of closed micro-cracks in RCA increases, and NS particles can't effectively bridge the closed micro-cracks, so the elastic modulus decreases.

It can be seen from Tab.7 that the elastic modulus of MRAC showed a trend of increasing first and then decreasing with the increase of BF content. The BF content corresponding to the maximum value of the elastic modulus at the 50% and 100% replacement rates is 2kg·m^{-3} and 1kg·m^{-3}, respectively. The main reason is that when the BF content is too higher, BF tends to form a mass during the concrete mixing process, see(Asprone, 2014), the internal void content increases, the concrete compactness decreases, and then the elastic modulus decreases. The above results indicate that the proper addition of BF is beneficial to the improvement the elastic modulus of MRAC.

From the influence of the amount of NS, when the replacement rate is 0% and 50%, the NS content corresponding to the maximum elastic modulus of the MRAC is 6%. When the replacement rate is 100%, the elastic modulus increases with the increase of NS content, and the NS content corresponding to the maximum elastic modulus of the MRAC is 8%. The main reason is that when the replacement rate is lower, the agglomeration effect is enhanced by adding excessive NS, some NS particles are leached, and the RAC interior is relatively loose, see (Nazari, 2011).When the replacement rate is 100%, there are more pores in the RAC, NS particles can give full play to the pozzolanic effect and filling effect, and less NS particles can be leached, see (Fathi, 2017). Therefore, the MRAC is more compact with the increase of NS content, and then the elastic modulus can be improved.

The relationship between the elastic modulus and the axial compressive strength at 28 days can be obtained from Tab.7, as shown in Eq. 1.

$$E_{c,28d} = 0.4545 \cdot f_{cp,28d}^{1.1954} \quad (1)$$

Tab. 7 The fitting value and experimental value of elastic modulus / Gpa

Mix no.	Fitting value	Experimental value	Error /%	Mix no.	Fitting value	Experimental value	Error /%	Mix no.	Fitting value	Experimental value	Error /%
R0000000	29.95	31.31	0.045	*R0500000*	18.05	17.23	-0.045	*R1000000*	15.63	15.32	-0.020
R0000003	32.77	33.70	0.028	*R0500003*	19.40	17.92	-0.077	*R1000003*	16.67	17.27	0.036
R0000006	34.12	34.62	0.014	*R0500006*	22.15	20.27	-0.085	*R1000006*	18.86	19.30	0.024
R0000008	32.35	31.36	-0.030	*R0500008*	21.22	19.74	-0.070	*R1000008*	19.69	19.40	-0.015
R0000100	17.86	20.29	0.136	*R0500100*	20.68	21.11	0.021	*R1000100*	17.06	17.82	0.045
R0000103	31.60	32.14	0.017	*R0500103*	21.80	21.32	-0.022	*R1000103*	18.06	19.48	0.078
R0000106	33.72	33.44	-0.008	*R0500106*	22.47	22.08	-0.018	*R1000106*	19.66	19.82	0.008
R0000108	28.14	27.39	-0.027	*R0500108*	21.59	20.46	-0.052	*R1000108*	19.93	20.29	0.018
R0000200	17.76	19.74	0.112	*R0500200*	21.98	21.62	-0.016	*R1000200*	17.83	17.57	(0.015
R0000203	22.17	23.33	0.052	*R0500203*	22.81	22.55	-0.012	*R1000203*	18.82	18.85	0.002
R0000206	22.85	25.88	0.133	*R0500206*	24.51	23.80	-0.029	*R1000206*	18.95	18.75	-0.011
R0000208	23.19	24.06	0.037	*R0500208*	22.05	21.49	-0.025	*R1000208*	19.43	19.32	-0.006
R0000300	20.67	19.40	-0.062	*R0500300*	18.48	18.80	0.017	*R1000300*	16.38	17.65	0.077
R0000303	22.16	21.20	-0.043	*R0500303*	19.57	19.21	-0.018	*R1000303*	18.75	18.52	-0.012
R0000306	22.74	22.02	-0.032	*R0500306*	21.24	19.91	-0.063	*R1000306*	18.80	19.47	0.035
R0000308	23.03	21.92	-0.048	*R0500308*	19.16	17.64	-0.079	*R1000308*	19.59	19.52	-0.004

From Eq. 1, the error between the fitted value and the experimental value of elastic modulus can be obtained, as shown in Tab. 7. It can be found that the fitted value is close to the experimental value, and the error is between ± 13.6%.

According to the above analysis, the NS content corresponding to the maximum value of each mechanical property of MRAC under different replacement rates and BF content can be obtained, as shown in Tab.8.

Table.8 NS content corresponding to the maximum value of each mechanical index

r/%		**0%**				**50%**				**100%**			
BF/kg·m^{-3}		0	1	2	3	0	1	2	3	0	1	2	3
NS/%	f_{cp}	6	6	8	8	6	6	6	6	8	8	8	8
	E_c	6	6	6	6	6	6	6	6	8	8	8	8

As can be seen from Tab.8, when the replacement rate is 50% and 100%, the NS content corresponding to the maximum of axial compressive strength and elastic modulus is the same. The above results indicate that the composite enhancement effect of BF and NS on MRAC is related to the replacement rate and the type of loading. In practical engineering, the amount of NS and BFof MRAC can be prepared according to the main load types of components in Tab.8, so as to realize the recycling of resources.

4 CONCLUSIONS

With the increase of the replacement rate and BF content, the failure morphology changes from brittle to plastic.With the increase of NS content, the brittle failure characteristics are enhanced.

The axial compressive strength of MRAC decreases with the increase of the replacement rate. The axial compressive strength of MRAC with 50% and 100% replacement rate has the same change rule as the change of BF content, and the BF content corresponding to the maximum 28-day axial compressive strength is 2 $kg \cdot m^{-3}$.When the replacement rate is 50% and 100%, the NS content corresponding to the maximum of the axial compressive strength is 6% and 8% respectively.The elastic modulus decreases as the replacement rate increases. The BF content corresponding to the maximum of elastic modulus with 50% and 100% replacement rate is 2 $kg \cdot m^{-3}$ and 1 $kg \cdot m^{-3}$, respectively. The NS content corresponding to the maximum of elastic modulus of MRAC with 50% replacement rate is 6%. The elastic modulus of MRAC at 100% replacement rate increases with the increase of NS content, at this time, the optimal NS content is 8%.

The recycled concrete made by the technology introduced in this paper can be applied to engineering practice.

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