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Strengths and flexural strain of CRC specimens at low temperature

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ABSTRACT

Crumb rubber concrete (CRC) is made by adding rubber crumbs into conventional concrete. This study undertakes an experimental study on the cubic compressive strength, axial compressive strength, flexural strength and splitting tensile strength of CRC specimens at both ambient temperature 20 °C and low temperature −25 °C. The flexural stress–strain responses were also recorded. The averaged size of rubber crumbs used in the study is about 1.5 mm. Four levels of rubber contents are investigated, which are 0%, 5%, 10% and 15% by volume, respectively. The mix design aimed at 40 MPa of compressive strength and 100 mm of slump for all the CRC specimens. The results show that CRC increases its magnitude in strengths when temperature decreases, which is similar to the case of conventional concrete, but still exhibits ductility in low temperature. The conclusion from this study is that CRC may be more beneficial in its application in low temperature environments than in ambient temperature environments.

1. Introduction

It has been widely observed that basic properties of Portland cement concrete such as compressive strength, split tensile strength and modulus of elasticity are temperature dependent [1–3]. One study reports that when temperature drops from 20 °C to −10 °C and −30 °C, the corresponding compressive strength is increased by 29% and 54%, respectively [4]. The reason for such increase is believed to the attribution of water–ice transformation that fills the large capillary pores when temperature drops from above freezing point to under freezing point, and the increase in strengths depends mainly on the moisture content and to "a lesser extent on the characteristic of the mix (e.g., water/cement ratio, air content)" [5]. One experimental work reveals that the increase in strengths at low temperatures varies almost linearly with the water concern of the concrete mixture [6].

Like most solid materials, concrete contracts or shrinks when temperature decreases. This means that in microscopic level, the average equilibrium distance between atoms in concrete is reduced, giving rise to the increase of the attractive forces between atoms. Macroscopically, this means that under below freezing temperature, concrete now is "harder" or more resistant to deform and more brittle as well [7].

Crumb rubber concrete (CRC) is a mix of conventional concrete with rubber crumbs, which are produced by shredding and commutating used automobile tires. Early studies by Eldin and Senouci [8] and Fedroff et al. [9] explored the effect of rubber chips on the compressive and flexural strength of CRC mixes. Their findings are that adding rubber chips will reduce both compressive and flexural strengths but increase the deformation capacity. Freeze–thaw durability of CRC was investigated by Savas et al. [10] and one of the conclusions from the study is that CRC with "10% and 15% of crumb rubber by weight of cement exhibited durability factors higher than 60% when tested according to ASTM C666 Procedure A". CRC also shows a much better crack resistance capability than conventional concrete, and one explanation is that rubber crumbs in CRC can function as distributed mini expansion joints within concrete [11]. Topçu and Demir [12] pointed that "in terms of durability, use of concrete with the optimum amount of rubber aggregate to produce concrete, that is 10% in volume, is economical and good for recycling. This concrete also shows adequate performance with respect to durability problems that may occur because of environmental conditions".

It has been widely recognized that CRC is more ductile than conventional concrete, though defining "ductility" can take many approaches. One observation is that the rapture pattern for conventional concrete is brittle, but for CRC it may first come to yield

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and then to break [13]. The result of a split strength test shows that the time gap, from the time of applying loading on the CRC specimens to the time the specimens fail, is more than tripled in comparison to the case of conventional concrete, while the split tensile strength for the former is only 45% of the latter [14]. In Ganjian et al.'s [15] exploration, the flexural strength of CRC reaches 4.8 MPa and 3.8 MPa with 5% and 10% of aggregates being replaced by rubber particles in weight, respectively. But he did not measure the flexural strain of concrete specimens. In Turatsinze and Garros's [16] flexural test of CRC, they find that there is a drop in the flexural strength but the flexural strain and the absorbed energy is significantly increased. Here the energy is defined as the area under the stress–strain curve. Zhu and his students [17] conducted various four-point bending tests including CRC in ambient temperature, and the ultimate flexural strains for CRC specimens can reach in the range of 600×10^{-6}. For the same test, the measured value of conventional concrete is about 150×10^{-6}. In addition, the stress–strain responses for CRC specimens are curved and while those for conventional concrete is basically linear. In Zheng et al.'s [18] study, they state that CRC has higher ductility performance than that of conventional concrete on the basis that the brittleness index values (the ratio of compressive strength to flexural strength) of CRC are lower than those of conventional concrete.

2. Aims

CRC's basic properties at room temperature have been well studies, but few studys in public literature have been seen about those properties at low temperature. So those basic properties of CRC need to be evaluated before considering CRC's application in low temperature environment. Therefore, this study undertakes an experimental investigation in this regard. Cubic compressive strength, splitting tensile strength, flexural strength, and modulus of elasticity for CRC specimens at four levels of rubber contents at −25 °C are tested with an appropriate comparison to the cases of ambient temperatures. −25 °C is considered "mild cold". There are a few studies on testing concrete at much lower temperatures like −50 °C or −70 °C [4]. Some studies even go further down to −160 °C [1], of course, now with the application aiming to liquefied gas storages. The temperature −25 °C is chosen in this study because it represents the coldest day in the region of Tianjin, China and the intended application of this study is in roadway construction.

Enhanced ductility is preferred for concrete applications, but whether it remains true for CRC at low temperature is largely unknown. To find whether this is true or not for CRC quantitatively is another aim of this investigation.

3. Experimental work

3.1. Materials and mix design

Crumb rubbers used in the study is made by shredding waste tires. Particles size analysis of the crumb rubbers was carried out using the sieve method. The results are shown in Fig. 1. It indicates that the averaged particle is 1.5 mm or somewhere between Sieve #14 and Sieve #15. This size is widely used in asphalt-rubber and many studies in CRC. Rubber particles that are finer than this size will increase manufacturing cost significantly and larger than this size may appear too coarse for concrete mixes. Densities of all the materials used in concrete mixes were measured and listed in Table 1. The cement used in this study is called Grade #42.5, which is widely used in China. The chemical composition of the cement is listed in Table 2 and the standard strength test based on ASTM-C109 for the cement is given in Table 3 with the ratio of water: cement: sand being 0.5:1:3(by mass). Water reducer is provided by Sika Co. Ltd. in Tianjin China. Coarse and fine aggregate gradations are given in Table 4. Four CRC mixes are carried out with rubber crumbs taking 0%, 5%, 10% and 15% in volume respectively. Here, 5%, 10%, 15% in volume means 50, 100, 150 kg of rubber is added in per cubic meter of CRC, respectively. Four standardized tests were planned and they were: cubic compressive strength test, splitting tensile strength test, flexural strength test, and the modulus of elasticity of the specimens. The cubic compressive strength and slump for those four mixes are designed to target at 40 MPa and 100 mm respectively, and the reason for choosing 40 MPa and 100 mm is that the two numbers are considered "common" or "typical" in the sense they are neither extremely high nor extremely low. The water/cement ratio (by mass), water reducers, and other parameters are manipulated to reach the target. The mix proportions and the measured slump are listed in Table 5.

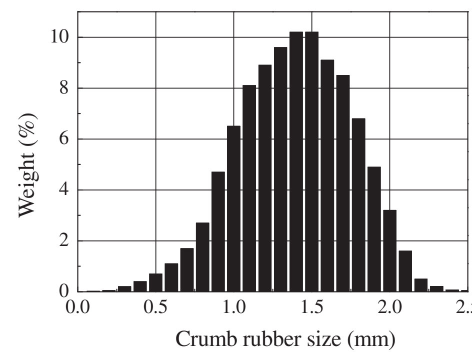

Fig. 1. Sieve analysis of crumb rubber.

Table 1
Material density, kg/m^3.

Material	Rubber	Cement	Water	Sand	Gravel	Water reducer
Density	1050	3100	1000	2400	2500	1100

Table 2
Chemical composition of Grade #42.5 Cement.

Chemical compound	SiO_2	$A1_2O_3$	CaO	MgO	SO_3	Fe_2O_3	Ignition Loss
Percentage, %	22.60	5.03	63.11	1.46	2.24	4.38	1.18

Table 3
Standard test results of Grade #42.5 cement with the ratio of water: cement: sand being 0.5:1:3(by mass).

Time	3-day	7-day	28-day
Compressive strength, MPa	17.3	31.8	47.8

Table 4
Gradation of coarse and fine aggregates.

Coarse aggregate						
Sieve size, mm	25	20	15	10	5	0
Sieve retained, %	0	16.8	14.5	20.2	31.6	16.9
Passing percentage, %	100	83.2	68.7	48.5	16.9	0
Fine aggregate						
Sieve size, mm	2.5	1.25	0.63	0.315	0.16	0
Sieve retained, %	0	25.2	22.9	15.3	14.3	22.3
Passing percentage, %	100	74.8	51.9	36.6	22.3	0

Table 5
Mix proportions of CRC, kg/m^3.

Type	Rubber	Cement	Water	Sand	Gravel	Water reducer	Slump (mm)
A	0	295	168	837	1083	0	110
B	50	336	168	575	1168	3.36	86
C	100	480	168	416	1070	4.80	90
D	150	600	168	312	935	6.00	100