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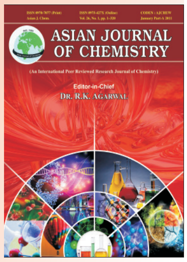

Study on Polymer Modified Self-Compacting Concrete Used for Repair of Concrete†

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This paper developed a polymer modified self-compacting concrete (PMSCC) by using non-air entraining acrylic latex, which is suitable for the replacement of old concrete. Test results show that polymer modified self-compacting concrete has good workability and stability and can achieve self-compacted without any vibration. Its slump flow is greater than 650 mm. Hardened concrete has the features of "low modulus of elasticity, high anti-crack ability and good durability". The simulation test shows that the interfacial bond strength between new and old concrete is higher than 1.56 MPa without any adhesives.

Keywords: Polymer modified, Self-compacting concrete, Replacement of concrete, Properties.

INTRODUCTION

For concrete repair, there are lots of materials and techniques could be selected, but people are most concerned about the durability of patching materials, bond strength between the old concrete and the patching material as well as the integrity of structure after repairing. Therefore, to determine the repair scheme must take account of the particularities of the projects and the adaptation of the plans[1]. Replacement with new concrete will not change the building structures and allows the patching materials to be in accordance with the constitutive relation and deformation properties in the maximum range to improve the integrity of structures. The building restores to its initial profile after repairing.

Polymer cement concrete (known as polymer modified concrete), due to the accumulation film formation effect of polymer material, has many properties been improved after adding polymer, such as tensile strength, bonding strength, water resistance and durability, *etc*., but its porosity must be reduced[2-4]. Therefore, we use a non-air entraining acrylic latex as the modifier. The concept of self-compacting concrete was first proposed by Japanese scholar Okamura in 1986[5]. Afterwards, self-compacting concrete became popular all over the world because of its unique construction superiority, good strength and durability. The paper is aiming at development a polymer modified self-compacting concrete used as replacement concrete for the old structure, using the improvement effect of polymer latex on cement based materials and the construction superiority of self-compacting concrete. It will be suitable for the replacement of large area freezing-thawing or erosion damaged hydraulic concrete, as well as the strengthening and reinforcement of the beams, columns and other building components with unsatisfied strength or density.

EXPERIMENTAL

Materials and concrete mix proportion: (1) Cement: ordinary Portland cement (P.O 42.5); (2) Mineral admixture: Class II and F style fly ash; (3) Fine aggregate: Limestone manufactured sand with fineness modulus of 2.63 and dust content of 18.7 %; (4) Coarse aggregate: natural gravel with maximum aggregate size of 20 mm; (5) Polymer: non-entraining acrylic emulsion with solid content of 47 %; (6) Fiber: 6 mm polypropylene fiber; (7) Chemical admixture: high-performance water reducing agent. Concrete mix proportions are shown in Table-1. There are three mix proportions including normal self-compacting concrete (SCC) and polymer modified self-compacting concrete (PMSCC-1 and PMSCC-2). Mold concrete samples without vibration. Curing Method is 7 days wet curing plus 21 days dry curing.

RESULTS AND DISCUSSION

Fresh concrete: The fresh concrete of PMSCC has good workability and stability. Its slump flow is over 660 mm and the extension time T500 is less than 2 s, which has reached SF2 class and VS2 grade level filling ability specified in

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TABLE-1
CONCRETE MIX PROPORTIONS (kg/m³)

No.	Water	Cement	Fly ash	Sand	Stone	Acrylic emulsion	Water reducer	Fibre
SCC	180	300	200	825	767	–	6.5	0.45
PMSCC-1	123	300	200	765	711	100	6.0	0.45
PMSCC-2	123	400	100	777	693	100	6.0	0.45

JGJ/T 283. It can be used for structures which have more reinforcement or buildings with high requirement for concrete appearance.

Hardened concrete: Test results of compressive strength, tensile strength and modulus of elasticity are listed in Table-2. Compared with SCC, at 28 days, compressive strength of PMSCC-1 which has only 9.4 % solid polymer (percentage of all binding materials, in mass) is 31.8 MPa reduced by 12.8 MPa, direct tensile strength is 3.19 MPa reduced by 0.02 MPa and modulus of elasticity is 23.1 GPa reduced by 7.5 GP. For the PMSCC-2, its compressive strength is 37.0 MPa reduced by 7.6 MPa, tensile strength is 3.63 MPa increased by 0.42 MPa and elastic modulus is 23.5 GPa reduced by 7.1 GPa. Thus, we confirm that adding polymer latex significantly reduces the brittleness of concrete and has a higher ratio of tensile strength and compressive strength.

Ultimate tension strain is in response to the ultimate deformation ability of concrete under tensile stress, which is tested according to DL/T 5150. Trying to increase the ultimate tension strain of concrete can reduce the cracks due to shrinkage or temperature stress. For the thin layer replacement concrete, trying to increase its ultimate tension strain could reduce the interface stress between old and new concrete and decrease the risk of cracking effectively. The results show that ultimate tension strain of PMSCC is significantly improved after adding latex. At 28 days, ultimate tension strain of PMSCC-1 is 147 millionths, which is increased by 26.7 % compared with SCC. Ultimate tension strain of PMSCC-2 is 179 millionths increased by 54.3 %.

Concrete durability tests were performed according to ASTM C 803, ASTM C 666 and ASTM C 1202. From the test results in Table-2, we confirm that PMSCC has good durability and corrosion resistance, which attribute to the following two reasons: Firstly, polymer particles can reduce the porosity of slurry, with significant effects especially for sealing connection pores. Secondly, the polymer film has good waterproof performance.

Autogenous volume change, although it may occasionally be an expansion, is usually shrinkage and is entirely a result of chemical reaction within the concrete and aging, which has a great effect on concrete anticrack ability. Test results show that, when 28 days, 90 days, the autogenous volume deformation of PMSCC-1 is expansion, while the autogenous volume deformation of SCC is shrinkage. Until 160 days, they are all getting to be shrinkage and the value is 4 millionths and 44 millionths, respectively. Obviously, PMSCC has less autogenous volume shrinkage than SCC (Fig. 1).

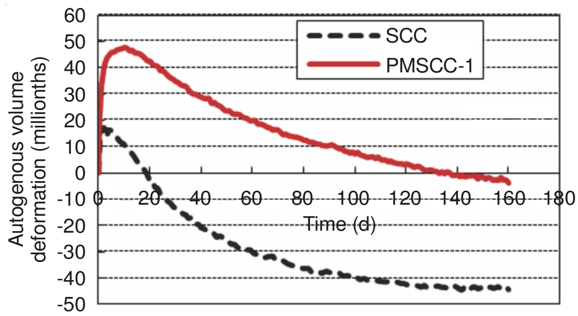

Fig. 1. Autogenous volume deformation of concrete at different times

Dry shrinkage of hardened concrete is usually occasioned by the drying and shrinking of the cement gel that is formed by hydration of Portland cement. Test results show that dry shrinkage of PMSCC-1 is 289 millionths at 28 days and is significantly less than the dry shrinkage of SCC (Fig. 2).

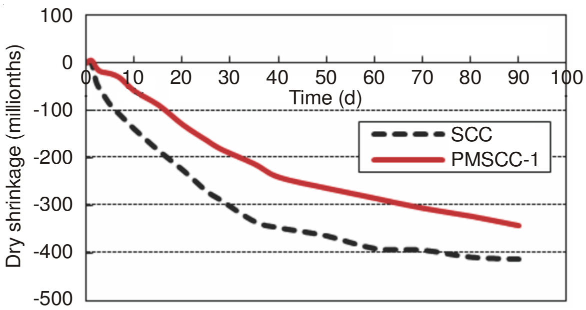

Fig. 2. Dry shrinkage of concrete at different times

For thin layer replacement concrete, trying to reduce the autogenous volume shrinkage and the dry shrinkage could significantly reduce its cracks and the interface shear stress between new and old concrete and improve the integrity of structures after repairing.

Regarding the modifying mechanism of polymer on cement mortar and concrete, the current consistent view is that the improvement is achieved through the film, which is formed by polymer with higher cohesive strength, within the cement paste or the transition zone between cement paste and aggregate. Cement hydration is performed simultaneously

TABLE-2
HARDENED CONCRETE PROPERTIES

No.	Compressive strength (MPa)		Tensile strength (MPa)		Modulus of elasticity (GPa)		Ultimate tension strain (millionths)		Permeability coefficient (m/s × 10^{-12})	DF	Ability to resist chloride ion penetration (coulomb)
	7d	28d	7d	28d	7d	28d	7d	28d	28d	28d	28d
SCC	25.0	44.6	2.57	3.21	25.5	30.6	111	116	0.5	90	–
PMSCC-1	22.1	31.8	2.27	3.19	18.1	23.1	137	147	0.7	95	–
PMSCC-2	29.0	37.0	2.90	3.63	20.1	23.5	170	179	0.3	97	820C

TABLE-3
BOND STRENGTH BETWEEN NEW AND OLD CONCRETE

Sample diameter (mm)	Load (KN)	Pull strength (MPa)		Note
		Single	Average	
141.7	24.5	1.56	2.27	Sub-layer old concrete broken
	38.9	2.47		The interface of new and old concrete break off, there is aggregate at the broken surface
	30.6	1.94		
	49.3	3.12		The interface break, the broken section has the aggregate less than 20mm
93.6	16.0	2.33	2.26	The pull head and the concrete bonding surface broken
	15.6	2.26		
	18.4	2.67		
	12.3	1.78		Lower layer old concrete broken, there is aggregate greater than 40mm at the broken section

with the polymer, finally forming the interpenetrating network structure which cement paste and polymer film mutually intertwined[2,3]. For the polymer modified self-compacting concrete, its compressive strength is decreased, but the ratio of tension and compression is significantly increased; elastic modulus is significantly decreased, where plasticity is increased due to the formation of the polymer film and the plugging effect on connection gap in concrete. Frost resistance, permeability and the resistance to chloride ion penetration of concrete are all improved significantly. In addition, the modification can significantly reduce the autogenous volume deformation and the dry shrinkage of concrete because of the water retention property of polymer film. As conclusion, PMSCC used as replacement concrete has features of "self-compacted, high anti-crack ability, good durability", which could effectively reduce the interface stress between the new and old concrete and improve the integrity of repair structure.

Bond strength between new and old concrete: Using replacement concrete to repair and to reinforce damaged concrete structure, maximally guarantee the similarity of repair materials and old concrete in terms of performances and deformation, but the interfacial bond strength is often less than the bond strength of mortar. Therefore, people are more concerned about the bonding issue between new and old concrete. Here a examination was performed which is to simulate the repair of concrete beam and column with the PMSCC. Two concrete prisms with the size of 400 mm × 400 mm × 1600 mm, which suffered freeze-thaw damage, are selected as samples to be repaired. Remove the surface frosted concrete exposing fresh surface and clean with water. Install sheet steel form around the samples, assuring the repair layer thickness between 70 mm and 80 mm. Pour polymer-Modified self-compacting concrete (PMSCC-2) into the gaps between forms and concrete. Note that there is not any interface adhesives. Removed forms after 7 days. After maintenance 28 days conduct pullout tests to test the bond strength between new and old concrete. The test results and section position description are shown in Table-3.

For the diameter of 141.7 mm, the maximum pullout strength is 3.12 MPa, the minimum pullout strength is 1.56 MPa and the average value is 2.27 MPa. For the diameter of 93.6 mm, the maximum pullout strength is 2.67 MPa, the minimum pullout strength is 1.78 MPa and the average value is 2.26 MPa. Observation the pull sections: the minimum pull strength specimen is broken off at the locations of foundation concrete. In light of this, PMSCC has good bond strength with the foundation concrete, the interfacial bond strength is not less than 1.56 MPa and the average is above 2.26 MPa.

For the new and old concrete interface without planted-bar, the interface adhesion has three kinds: mechanical engaging forces, van der Waal's forces and chemical acting force[6]. PMSCC assure a high bond strength with the foundation concrete from the following three aspects: Firstly, polymer modified self-compacting concrete has a lot of bonding materials, the growth of hydration products which mix to the interspaces in the old concrete surface to form a dense structure, can significantly improve the mechanical engaging force of the new and old concrete interface. Secondly, the accumulation effect of the polymer particles can significantly improve the van der Waal's force of the interface. Thirdly, foundation concrete surfaces need no interface agent and the use of high cementitious materials of polymer modified self-compacting concrete and the incorporation of fly ash, can improve the chemical forces of the interface by the hydration reaction of adhesive materials between the old and new concrete.

Conclusion

In this paper we have successfully produced the polymer modified self-compacting concrete with non-entraining acrylic latex, which is suitable for the old concrete repair by replacement. Performances test and simulations experiment results show that the concrete has the features of "self-compaction, high plasticity, high anticrack ability, good durability and corrosion resistance" and has good bond strength with the foundation concrete.

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