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Mechanical Characterization of Steel Fibre Reinforced Acrylic Emulsion Polymer Modified Concrete

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Abstract: A comparative study between acrylic emulsion Polymer Modified Concrete plain (PMC), reinforced with steel fibres (SFRPMC), Steel Fibre Reinforced Concrete (SFRC) and plain concrete was made. The fibres are 60 mm long and the fibre content was 0.010, 0.015 and 0.020%, respectively in volume. The steel fibres reinforcement was randomly dispersed into the matrix of acrylic emulsion polymer modified concrete. An increase in mechanical properties was observed as function of reinforcement and in addition of acrylic emulsion polymer. The comparison also showed that polymer modified concrete, plain and reinforced has a better performance than regular market concrete, suggesting that acrylic emulsion polymer modified concrete is a reliable alternative for construction industry.

Key words: SFRPMC, acrylic emulsion polymer, steel fibre, mechanical strength, matrix, Malaysia

INTRODUCTION

Concrete and steel were always considered the most important and the most commonly used structural materials. The development of new high-performance composite materials that are stronger and more durable than conventional materials (e.g., Portland cement concrete, steel, wood and masonry) is important to the construction industry (Rebeiz and Fowler, 1996).

The use of concrete in the construction is very old. The 1st concrete used in history is reported to the Greeks and Romans times. In 1756, John Sweaton in order to rebuild an important monument (Eddystone lighthouse), developed the first mortar. Portland cement appeared more >100 years later. Its name was given due to the resemblance of the color and quality of the hardened cement to portland stone (Reis, 2005).

Synthetic polymers revolutionized the way, new material was produced and made possible to produce cheaper and more flexible materials. Combining organic compounds at room temperature made possible the development of polymer-based materials with a wide variety of properties. Now-a-days, other materials can also be added or blended. New polymers with almost any desired properties could be developed. It is therefore, possible to design the best material for any given application (Cano *et al*., 1998). Polymer cement concrete is a modified concrete in which part (10-15% by weight) of the cement binder is replaced by a synthetic organic polymer. It is produced by incorporating a monomer, prepolymer-monomer mixture or a dispersed polymer (latex) into a cement-concrete mix. To effect the polymerization of the monomer or prepolymer-monomer, a catalyst is added to the mixture. The process technology used is very similar to that of conventional concrete. Therefore, polymer cement concrete can be cast-in-place in field applications whereas polymer impregnated concrete has to be used as a precast structure (Mason, 1981).

Modification of concrete with a polymer latex (colloidal dispersion of polymer particles in water) results in greatly improved properties at a reasonable cost. Therefore, a great variety of latexes is now available for use in polymer cement concrete products and mortars. The most common latexes are based on poly (methyl methacrylate) also called acrylic latex, poly (vinyl acetate), vinyl chloride copolymers, poly (vinylidene chloride), (styrene-butadiene) copolymer, nitrile rubber and natural rubber. Each polymer produces characteristic physical properties. The acrylic latex provides a very good water-resistant bond between the modifying polymer and the concrete components whereas use of latexes of styrene-based polymers results in a high compressive strength (Mason, 1981).

Generally, polymer cement concrete are made with polymer latex exhibits excellent bonding to steel reinforcement and to old concrete, good ductility, resistance to penetration of water and aqueous salt

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solutions and resistance to freeze-thaw damage. Its flexural strength and toughness are usually higher than those of unmodified concrete. The modulus of elasticity may or may not be higher than that of unmodified concrete, depending on the polymer latex used. For example, the more rubbery of the polymer, the lower of the modulus. Generally as the polymer forms a low modulus phase with the polymer cement concrete, the creep is higher than that of plain concrete and decreases with the type of polymer latex used in the following order: polyacrylate; styrene-butadiene copolymer; polyvinylidene chloride and unmodified cement (Mason, 1981).

In this research, the investigation carried out is to better understand the effect of the Acrylic Emulsion Polymer, water binder ratio and steel fibre on the polymer modified concrete. The polymer was acrylic emulsion polymer called as Tufcryl M176 product from Tufbond technologies is synthetic acrylic latex intended for manufacture of cement products. All these products have similar application as the polymer cement concrete under study, i.e., repairing of concrete structures.

EXPERIMENTAL PROGRAM

Previous studies done by researcher, considering an extensive experimental program supported by the Taguchi method (Taguchi *et al*., 2000), allowed an optimization of polymer modified concrete formulations that are now being used in the present research.

The constituent materials used in the laboratory to produce steel fibre reinforced polymer modified cement concrete comprised portland cement (ordinary portland cement) fine aggregates, coarse aggregates, silica fume, free water, acrylic emulsion polymer and steel fibres. The chemical properties of ordinary portland cement are shown in Table 1.

Acrylic emulsion polymer (Tufcryl M176), product from Tufbond technologies is synthetic acrylic latex intended for manufacture of cement products. This material provides excellent water resistance. It increases the tensile strength of cement admixture. It is a fine particle size, good water resistance, excellent adhesion to concrete and excellent UV resistance. It is a milky white and has 43-46% non-volatile solids has 100 cps maximum of viscosity and 18°C of Tg. Steel fibre from stahlcon are made from cold drawn high tensile steel wires in accordance to ASTM A820, type 1 and shall have a minimum tensile strength 1100 N mm^{-2}.

Packaging SPEC	Papers
Type of packing	Paper (non-water soluble bag)
Weight per bag	20 kg bag^{-1}
Weight per pallet	1200 kg pallet^{-1}

Table 1: Binder properties

Normal or ordinary portland cement			
Oxide composition	Wt. (%)	Compound composition	Wt. (%)
CaO	0.63	C_3S	0.40
SiO_2	0.21	C_2S	0.30
Al_2O_3	0.06	C_3A	0.11
FeO	0.04	C_4A	0.11

Aspect Ratio (AR) is the ratio of fibre length against the diameter (l day^{-1}). The higher the AR and the volume concentration of the fibres, the better is the performance with respect to the flexural strength, flexural fatigue, toughness, abrasion, impact and crack resistance. Equivalent flexural ratio, Re, 3 is defined as the ratio between the equivalent flexural strength, fe, 3 and concrete strength, fct at which the 1st crack occurs. The design flexural strength, fa takes into account the plastic moment distribution after the concrete crack. The higher the Re, 3 values, the better the concrete performance.

Specification	
Codes	HE 0.75/60
Aspect ratio	80
Fibre length	60 mm
Equivalent diameter	0.75 mm
Pieces per kilogram	4,600
Deformation	Hooked end with round shaft

The mix proportions of steel fibre reinforced, acrylic emulsion polymer modified concrete are shown in Table 2. The mixes were prepared using a pan mixer and in accordance with BS 1881-1:1970. The viscosity of the concrete is evaluated through slump test. From each concrete, mix three 100 mm cube samples 28 days compressive strength and six cylinders of 100 mm in diameter and 200 mm in height for 28 days compressive strength and splitting tensile strength and three 100 mm in diameter and 500 mm in length for 28 days are collected. The specimens are demolded 24 h after casting and placed in water tank at 20±2°C.

The curing is done in accordance with BS 1181-111 1983 (Fig. 1-3). The slump test is carried out by using mini cone (diameters: 100, 200 and height 300 mm). Place the mixed concrete in the cleaned slump cone in four layers each approximately ¼ in height of the mould. Tamp each layer 25 times using tamping rod. Remove the cone immediately, rising it slowly and carefully in the vertical direction. As soon as the concrete settlement comes to a stop, measure the height of the concrete in cm. The difference between the height of slump cone and height of concrete after settlement is the slump. For each concrete mixes, the compressive strength, flexural strength, splitting tensile

Table 2: Mixture proportion of concrete

Codes	Acrylic emulsion polymer	Silica fume	Steel fibre	Water
	(kg m^{-3})			
SFRPMC-1	3.7	17.1	23.5	144.0
SFRPMC-2	3.7	17.1	23.5	144.0
SFRPMC-3	3.7	17.1	23.5	144.0
SFRPMC-4	9.0	20.6	48.4	144.0
SFRPMC-5	9.0	20.6	48.4	144.0
SFRPMC-6	9.0	20.6	48.4	144.0
SFRPMC-7	14.5	27.4	35.6	144.0
SFRPMC-8	14.5	27.4	35.6	144.0
SFRPMC-9	14.5	27.4	35.6	144.0
SFRPMC-10	3.7	20.6	35.6	171.4
SFRPMC-11	3.7	20.6	35.6	171.4
SFRPMC-12	3.7	20.6	35.6	171.4
SFRPMC-13	9.0	27.4	23.5	171.4
SFRPMC-14	9.0	27.4	23.5	171.4
SFRPMC-15	9.0	27.4	23.5	171.4
SFRPMC-16	14.5	17.1	48.4	171.4
SFRPMC-17	14.5	17.1	48.4	171.4
SFRPMC-18	14.5	17.1	48.4	171.4
SFRPMC-19	3.7	27.4	48.4	205.7
SFRPMC-20	3.7	27.4	48.4	205.7
SFRPMC-21	3.7	27.4	48.4	205.7
SFRPMC-22	9.0	17.1	35.6	205.7
SFRPMC-23	9.0	17.1	35.6	205.7
SFRPMC-24	9.0	17.1	35.6	205.7
SFRPMC-25	14.5	20.6	23.5	205.7
SFRPMC-26	14.5	20.6	23.5	205.7
SFRPMC-27	14.5	20.6	23.5	205.7

Fig. 1: Compressive test specimens

Fig. 2: Flexural test specimens

Fig. 3: Cube, cylinder and beam specimens

strength and modulus of elasticity are specified in the standard BS 1881-116:1983, BS 1881-118:1983, BS 1881-117:1983 and BS 1881-121:1983, respectively. All samples were conducted on curing 28 days.

RESULTS AND DISCUSSION

It has been observed that the compressive strength, flexural strength, splitting tensile strength is influenced by a large number of process parameters (factors) such as acrylic emulsion polymer, silica fume, steel fibre, water-cement ratio and aging (curing). In Table 3, the compressive strength, splitting tensile strength, flexural

Table 3: Test results of properties of fresh and hardened concrete

Performance parameter values	Compressive strength (MPa) Cube	Compressive strength (MPa) Cylinder	Flexural strength (MPa) (Beam)	Splitting tensile strength (MPa) (Cylinder)	Young's modulus (GPa) (Ec)
SFRPMC-1	13.95	12.65	1.24	1.08	17.98
SFRPMC-2	18.58	17.28	2.02	1.97	21.02
SFRPMC-3	29.13	21.51	3.55	2.37	23.45
SFRPMC-4	14.84	13.14	2.08	1.11	18.32
SFRPMC-5	31.42	19.67	3.34	2.65	22.42
SFRPMC-6	36.55	25.74	4.14	3.10	25.65
SFRPMC-7	15.58	14.68	2.56	1.58	19.37
SFRPMC-8	32.58	20.86	3.78	2.71	23.09
SFRPMC-9	38.63	30.88	4.55	3.28	28.09
SFRPMC-10	23.57	20.93	4.34	2.31	23.13
SFRPMC-11	36.51	30.39	5.51	3.05	27.87
SFRPMC-12	47.03	34.54	6.63	3.35	29.71
SFRPMC-13	28.38	21.74	4.65	2.35	23.57
SFRPMC-14	37.85	34.98	6.39	3.88	29.90
SFRPMC-15	51.23	43.88	7.61	4.70	33.49
SFRPMC-16	19.37	13.82	3.27	1.91	18.79
SFRPMC-17	24.05	21.90	3.76	2.50	23.66
SFRPMC-18	30.69	25.24	5.32	3.41	25.40
SFRPMC-19	15.46	13.29	2.82	1.61	18.43
SFRPMC-20	22.87	21.53	3.55	2.49	23.46
SFRPMC-21	28.21	23.92	5.01	3.09	24.73
SFRPMC-22	11.63	9.60	2.45	1.26	15.67
SFRPMC-23	17.11	12.94	2.60	1.79	18.19
SFRPMC-24	25.92	21.28	4.29	2.12	23.32
SFRPMC-25	3.32	3.43	0.58	0.47	9.37
SFRPMC-26	5.49	4.84	0.84	0.61	11.13
SFRPMC-27	8.64	7.80	2.93	1.15	14.12

Table 4: Compressive properties of plain, Steel Fibre Reinforced Concrete Polymer Modified Cocnrete (SFRPMC) and commercial concrete (28 days curing)

Test series	Compressive properties (MPa) average
Plain concrete grade 43	43.90
Plain concrete with silica fume	49.29
Steel Fibre Reinforced Concrete (SFRC)	53.08
Polymer Modified Concrete (PMC)	39.42
Steel Fibre Reinforced Acrylic Emulsion Polymer Modified Concrete (SFRPMC)	65.20
Master flow 211	50.86
Emaco S 88	45.12
Groutek S	44.62
Hagenpox	49.70

strength and modulus of elasticity of SFRPMC are in the range of 8.64-51.23 MPa for cubes, 7.80-43.88 MPa, 1.15-4.70 MPa, 2.93-7.61 MPa and 14.12-33.49 GPa, respectively. The highest compressive, splitting tensile strength, flexural strength and modulus of elasticity are obtained from SFRPMC-15 mix.

The specimens after testing are shown in Fig. 4-6 Mechanical properties obtained from compressive tests performed on steel fibre reinforced acrylic emulsion and polymer-modified concrete from previous study are shown in Table 4. The results shown in Table 4 show that fibre reinforcement improves the compressive strength of SFRPMC by 48.5%. From Table 3, there is

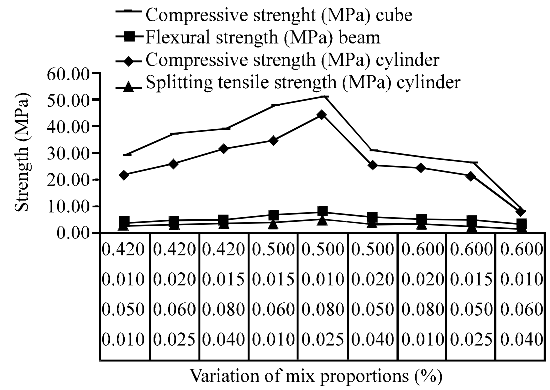

Fig. 4: Effect of mix proportions on specimens

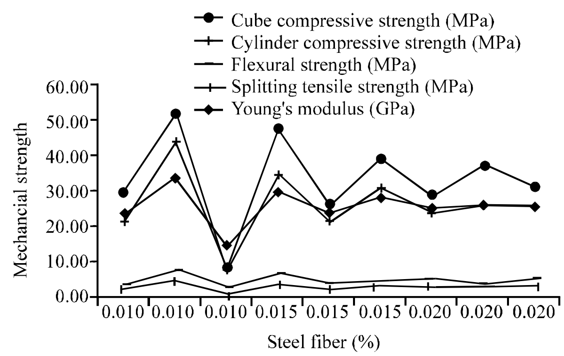

Fig. 5: Effect of steel fibres on specimens

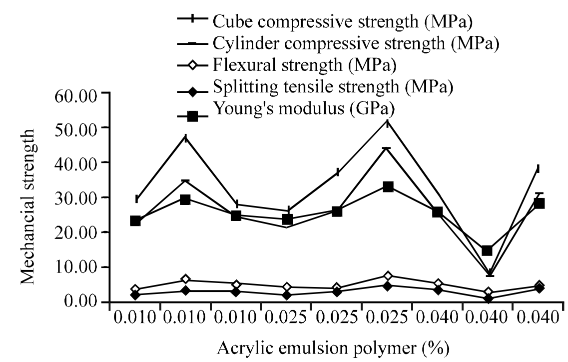

Fig. 6: Effect of acrylic emulsion polymer on specimens

slight difference between the test results due to random distribution of fibres. When compared to commercial concretes, plain acrylic emulsion polymer modified concrete exhibits lower compressive strengths values ranging from 11.7-22.5%. By Taguchi method, steel fibre percentages affect 11% from all mix proportions (acrylic emulsion polymer 14%, silica fume 12%, curing aging 24% and water-cement ratio 39%) to cube compressive strength. For cylinder compressive strength and modulus of elasticity, steel fibres gives only 8% effect from mix proportions.

Fig. 7: Steel fibre reinforced acrylic emulsion polymer modified concrete specimens after testing

About 13% of steel fibres percentages affect the flexural strength and 10% on splitting tensile strength of SFRPMC specimens. In addition to acrylic emulsion polymer, percentages affect the mechanical properties of SFRPMC in range 10-15% (Fig. 7).

CONCLUSION

The following results can be drawn concerning the properties of steel fibres reinforced acrylic emulsion polymer modified concrete formulations, considered in this research.

- As expected, steel fibres reinforcement affect the strength of acrylic emulsion polymer modified concrete. For the formulations studied, a considerable improvement in compressive strength (28.2-46.1% over that of the matrix) is observed
- Similarly, failure behaviour of the polymer modified concrete is altered by fibre reinforcement, resulting in a slightly ductile failure while unreinforced polymer modified concrete shows a brittle failure
- The mechanical properties of steel fibre reinforced acrylic emulsion polymer modified concrete observed in this study are higher compared to ordinary polymer modified concrete. Comparing plain polymer modified concrete to ordinary concrete, compressive strength is lower to existence of polymer properties compared to cement properties. When polymer modified concrete is reinforced, increase >100% is observed
- Acrylic emulsion polymer with fibre reinforcement proved to be excellent alternative to concrete available in the market

These results suggest that steel fibre reinforcement is a good choice to improve mechanical properties of polymer modified concrete, opening a door for more practical and representative applications including reinforcement of commercial concrete.

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