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The effect of using high strength flowable system as repair material

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ABSTRACT

The maintenance and the repair of concrete structures have become more needed in the field of Civil Engineering. The selection of repair materials for concrete structures requires an understanding of the material behavior. Therefore, this research is conducted to provide a clear indication and understanding of the behavior and structural performance in engineering construction. The combined system of substrate concrete with different mix proportions of flowable high strength system reinforced by hybrid fibers was used to study its mechanical properties. The experimental tests are: compressive strength, splitting tensile strength, flexural strength and pull-out test. It was found that the high strength flowing concrete (HSFC) provides the best performance when the compressive strength of the repaired system is needed, whereas the high strength flowable mortar (HSFM) has the best performance when the tensile strength of repaired system is required. The best value of pull out test was obtained from using the flowable high strength mortar reinforced with 1.5% steel fiber +0.25% palm fiber +0.25% Barchip fiber as the repair material, whereas, the least value of pull-out test was obtained from samples using epoxy.

1. Introduction

Many structures, especially those made of reinforced concrete, suffer from severe degradation after their construction due to many environmental causes (deicing salts, freezing and thawing, aggressive environment like earthquake) and a drastic increase of live loads. One of the major problems facing Civil Engineers today is to maintain and retrofit these structures [1,2].

In many instances, epoxy resins were used as repair materials to maintain concrete infrastructures. Epoxy resins are very expensive as a repair material. In addition, thermal aging is accelerated when epoxy resins are exposed to high temperature and humidity. However, this results in a drastic increase of costs for the maintenance of concrete structures. Hence, alternative repair materials that are economic while possessing good thermal resistance compared to epoxy resins are needed [3].

The strengthening, the maintenance and the repair of concrete structures have gained more recognition in the field of Civil Engineering. The selection of repair materials for concrete structures requires an understanding of the material behavior in uncured and cured conditions for the anticipated service life and exposure.

Hassan et al. [4] investigated the compatibility of cementitious, polymer and polymer-modified (PMC) repair materials. They concluded that the high shrinkage strain of cementitious repair mortars affects their compatibility with concrete and indirectly increase the permeability at the interface of the combined system. They also reported that the mismatch between the elasticity modulus of concrete and the epoxy mortar was found to reduce the load carrying capacity of the combined system. For the design of an efficient repair, it was recommended that the repair material should have a higher modulus (>30%) than the concrete substrate.

This study was conducted to study the use of high strength flowable mortar or concrete reinforced by steel fibers or hybrid fibers as repair materials. Therefore, the combined system of normal concrete "which is proposed here as substrate concrete" and the flowable high strength concrete reinforced by fibers representing the repair materials was generated.

2. Materials and mix proportions

2.1. Materials

The cement used in concrete mixtures was ordinary portland cement type I from Tasek Corporation Berhad. Silica fume was obtained from Scancem Materials Sdn. Bhd. and was used as partial replacement of cement. The chemical compositions of ordinary portland cement and silica fume are given in Table 1.

The superplasticizer (SP.) was Conplast SP1000 obtained from Fosroc Sdn. Bhd. and was used to establish the desired workability of mixes. The fine aggregate was natural sand, with fineness modulus of 2.86 and maximum size of less than 5 mm. The palm fiber was supplied by Fibre-X (M) Sdn. Bhd, and their characteristics are shown in Table 2. The synthetic fiber (Barchip) was obtained from

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Table 1
Chemical composition of ordinary portland cement and silica fume.

Constituent	Ordinary portland cement % by weight	Silica fume % by weight
Lime (CaO)	64.64	1.0% (max)
Silica (SiO_2)	21.28	90% (max)
Alumina (Al_2O_3)	5.60	1.2 % (max)
Iron oxide(Fe_2O_3)	3.36	2.0% (max)
Magnesia (MgO)	2.06	0.6%(max)
Sulfur trioxode (SO_3)	2.14	0.5%(max)
N_2O	0.05	0.8%(max)
Loss of ignition	0.64	6% (max)
Lime saturation factor	0.92	–
C3S	52.82	–
C2S	21.45	–
C3A	9.16	–
C4AF	10.2	–

Table 2
Physical properties of palm fiber.

Fiber Properties	Quantity
Average fiber length (mm)	30
Average fiber width (μm)	21.13
Tensile strength (MPa)	21.2
Elongation at break (%)	0.04
Specific gravity	1.24
Water absorption%, 24/48 h	0.6

Table 3
Physical properties of synthetic fiber (Barchip).

Fiber properties	Quantity
Average fiber length (mm)	30
Average fiber width (mm)	0.52
Tensile strength (MPa)	550
Young's modulus (GPa)	8.2
Specific gravity	0.92
Melting point (°C)	150–165

Table 4
Physical properties of steel fiber.

Fiber properties	Quantity
Average fiber length (mm)	30
Average fiber diameter (mm)	0.56
(L/d) Aspect ratio	54
Tensile strength (MPa)	>1100
Ultimate elongation (%)	<2
Specific gravity	7.85

elasto plastic concrete and its characteristics are presented in Table 3. The steel fiber was supplied by Hunan Sunshine Steel Fibre Co. Ltd., and their mechanical properties are shown in Table 4.

Epoxy was used in this study as a repair material for the concrete. This material was produced by Manewtech Sdn Bhd, and was also certified to ISO 9001:2000.

2.2. Mix proportions

The mixes proportions of the different flowable mortar mixes are given in Table 5. A total of six mortar mixes were prepared using water-binder (cement + silica fume) ratio of 0.43 and silica fume replacement was 10%. The amount of cement, silica fume, sand and free water were kept constant. The incorporation of steel fibers was varied from 1.5% to 2.0% vol. to prepare the mixes M1–M3. The hybrid fibers of steel and palm fibers were used to prepare the mortar mixes (M4–M5). The hybridization of steel, palm and Barchip fibers are used to prepare mix M6.

On the other hand, the flowing concrete mixes design are given in Table 6. The six concrete were prepared as similar as the mortar mixes. Therefore, the incorporation of steel fibers (1.5%, 1.75% and 2%) was done to prepare the mixes C1–C3. Consequently, the hybrid fibers of steel and palm were used to prepare the concrete mixes (C4–C5), as well as, the steel, palm and Barchip fibers were used to prepare C6.

3. Test methods

The design of normal concrete and the mechanical properties are given in Table 7. The normal concrete is proposed here as substrate concretes that it needs to be repaired using different types of materials. The properties of density, compressive strength, splitting tensile strength and flexural strength were tested at the age of 90 days [5,6]. The specimens of that concrete were sawed or cored to prepare them to be connected with repair materials in one system. The three different materials are: high strength flowable mortar reinforced with fibers, high strength flowing concrete reinforced with fibers and the epoxy.

The test of compressive strength was implemented by casting cubes of 100 mm. The preparation of the cubes for testing the repair materials is given in Fig. 1. The figure shows the casting of the half cube in the mold with repair material, while the other half of the cube represents the substrate concrete.

Test of splitting tensile strength of repair materials was also implemented with the same assumption that half of the cylinder represents the substrate concrete while the other half should be cast with repair material to be connected into concrete in one system (see Fig. 2). The flexural strength test was implemented also depending on combining two substrate concrete portions by repair materials as shown in Fig 3.

Table 5
High strength flowable mortar mixes design.

Index	Cement (kg/m^3)	Silica fume (kg/m^3)	Water (kg/m^3)	SP (%)	Sand (kg/m^3)	W + SP/B	Steel fiber (%)	Palm fiber (%)	Synthetic fiber (Barchip) (%)	Flow (mm)	Compressive strength (MPa)	Splitting tensile strength (MPa)	Flexural strength (MPa)[a]
M1	550	55	260	2.2	1410	0.43	1.5	–	–	150	59.8	2.49	14.28
M2	550	55	260	2.2	1410	0.43	1.75	–	–	145	57.1	2.55	17.1
M3	550	55	260	2.2	1410	0.43	2.00	–	–	140	55.7	2.62	15.9
M4	550	55	260	2.2	1410	0.43	1.75	0.25	–	140	57.8	2.71	15.92
M5	550	55	260	2.2	1410	0.43	1.50	0.50	–	145	58.4	2.89	17.67
M6	550	55	260	2.2	1410	0.43	1.5	0.25	0.25	140	59.3	3.02	18.23

[a] The flexural strength test was achieved according to ASTM C348 using speciemen size of 40 mm × 40 mm × 160 mm.