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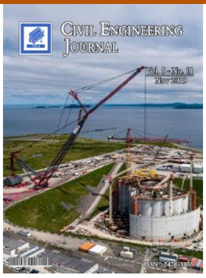

Reactive Powder Concrete with Steel, Glass and Polypropylene Fibers as a Repair Material

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Abstract

Repairing of reinforced concrete structures is currently a major challenge in the construction industry and is being put back into operation with a slight loss in load carrying capacity. Damage occurs due to many factors that reduce the strength of concrete structures and their durability. The aim of this paper is study the compatibility between three types of reactive powder concrete with (steel fibre, glass fibre and polypropylene fibre) as a repair materials and normal strength concrete as a substrate concrete. Compatibility was investigated in three steps. First: individual properties for substrate concrete were studied, these are (slump test, compressive strength, splitting strength, and flexural strength) also, for repair material these are (compressive strength and flexural strength) were determined by using standard ASTM test methods. Second: bond strength of composite cylinder for substrate concrete with different repair materials were evaluated by using slant shear test. Third: compatibility was investigated by using composite prisms of substrate concrete with different repair materials under two-point loading (flexural strength test). From the experimental results concluded, bond strength between reactive powder concrete with glass fibre as a repair material and normal strength concrete as a substrate layer is higher (17.38 Mpa) compared with RPC with steel fibre (13.13 Mpa) and polypropylene fibre (14.31 MPa). Also, it is more compatible due to flexural strength for composite prisms (having higher flexural strength (8.13 MPa). Compared with steel fibre (7.44 MPa) and polypropylene fibre (6.47 MPa). These results due to RPC with glass fibre have good workability with suitable flowability and glass fibre have higher tensile strength compare with other fibre.

Keywords: RPC; Bond Strength; Compatibility; Steel Fibers; Glass Fibers; Polypropylene Fibers; Slant Shear Test; Composite Prisms.

1. Introduction

Deterioration can define the process of degeneration or degradation of quality to an inferior state of a material. There are many causes of deterioration, which are physical, chemical, mechanical and reinforcement corrosion [1]. Any concrete structure when damaged must be repair to return its function. It is important to determine causes and the degree of the problem, so that repair adopted must be effective [2]. Repairing concrete can define replacing process, process or correcting deteriorated, damaged or faulty material, components or element of structure. The composite system consists of three components: substrate concrete (previous concrete), repair material (overlay) and bond region. Bond region means the interface and nearness of bond surface. The bond region must be able of resisting the stresses imposed on the composite system [3]. According to ACI 546-04, repair materials can classified into two basic categories, these are cementitious materials and polymer materials [4]. A new development of cement-based products is "reactive powder concrete (RPC)" because of RPC has extremely high strength, excellent toughness, excellent bond strength and higher durability, thus RPC as a repair mate has accomplished a lot of attention [5, 6].

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Compatibility is a term widely used in the field of concrete repair. Compatibility can describe as the evenness between the physical, chemical and electrochemical characteristics of a repair material and the substrate concrete that guarantees repair can bear whole stresses caused by variations in volume, chemical and electrochemical impacts without suffering or deterioration [7]. It is critical to study compatibility of repair materials at the same time with bond strength to well comprehend the performance of repair materials. There are no conventional techniques to determine whether repair materials are compatible with concrete substrates [8].

The aim of this research is to study bond strength and evaluate compatibility between RPC with different fibers as a repair material with normal-strength concrete as a substrate layer and find the best between them. Three types of repair material are used: RPC with steel fibers, RPC with glass fibers and RPC with polypropylene fibers. Slant shear test was used for assessing the bond strength and composite prism flexural test was used to investigate the compatibility between substrate concrete and repair material. Normal curing has been applied to both substrate concrete and repair material.

2. Materials and Methods

2.1. Materials

In this section, materials and its properties were illustrated as follow:

2.1.1. Cement

Ordinary Portland cement known to Karasta. This cement meets the IQS NO.5-1984 specification for Iraq and the EN 197-1:2011 CEM II / A-L 42.5 R, the international standards. Cement must be kept in a dry place in order to prevent exposure to atmospheric conditions.

2.1.2. Fine aggregate

Normal sand from the (Al-Ekhaider region) was used. Fine aggregate grading is agreed with the Iraqi Specification (IQS No.45, /1984) (zone 2) for NSC and (zone 4) for RPC. In RPC, the nominal size ranges from 150 to 600µm due to the large grains size of aggregate is undesirable for sand, therefore it prepared by sieving. Physical properties of fine aggregate are shown in Table 1.

Table 1. The physical and chemical properties of fine aggregate

Properties	Test result	Limits of Iraqi specification No.45/1984
Specific gravity	2.65	-
Fineness modulus	2.6	-
Absorption	1.6%	-
Sulphate content	0.244%	≤ 0.5 %

2.1.3. Coarse aggregate

Round gravel with a maximum size of 14 mm was used in this study. The results showed that the coarse aggregate used in this study complies with the standard (IQS No. 45/1984) limits Size (5-14). Gravel must be washed to remove clay and salts and then stored in containers in a Saturated Surface Dry (SSD) condition before use it.

2.1.4. Silica fume

Densified micro silica from (CONMIX) Company localized in Sharjah, United Arab Emirates were used and chemical composition for silica fume used confirm with (ASTM C1240, 2015). Table 2 illustrated physical properties of silica fume used.

Table 2. Physical properties of silica fume used

Physical Properties	SF	Limit of Specification Requirements ASTM C-1240
Percent retained on 45µm (No.325) sieve, max, %	1.7	≤ 10
Specific Surface, Min, (m^2/g)	23	≥ 15

2.1.5. Admixture Type of “High Range Water Reducing (HRWR)”

The high-range water-reducing admixture used throughout the research (Hyperplast PC200). It satisfies (ASTM C494/C494 M, 2017). Table 3 demonstrates Hyperplast PC200’s primary characteristics.

Table 3. Hyperplast PC200's characteristics at 25 C°

Colour	Light yellow liquid
Freezing point	≈ -3C°
Specific gravity(s.g)	1.05±0.02
Air entrainment	Typically less than 2%
Colour	Light yellow liquid

2.1.6. Fibers

In this research, three types of fibers were used; Steel fibers (SF), glass fibers (GF) and polypropylene fibers (PPF). In this research, steel fibers or micro steel fibers are used. It was made in China. The research has used a glass fibers type alkali resistance. It was made in the UK. The experimental program used polypropylene fibers. Sika, Turkey, produced polypropylene fibers of this type. Figure 1 show the fibers used through the research. The properties for each fibre are listed in Table 4.

a) Steel fibers b) Glass fibers c) Polypropylene fibers

Figure 1. Fibers used in the research

Table 4. Fibers properties used through the research.

Property	**Value**		
	Steel fibers	**Glass fibers**	**Polypropylene fibers**
Length	13±1mm	13mm	12 mm
Diameter	0.2±0.05mm	14mm	0.032 mm
Aspect ratio (L_f/D_f)	65	857	375
Density	7800 Kg/m³	2680Kg/m³	910 kg/m³
Tensile strength	>2300 MPa	3500 MPa	600-700 MPa

Mix proportions used in preparing specimens for substrate concrete (NSC) were presented in Table 5.

Table 5. Quantity of materials used in NSC

Type of concrete	**Cement (kg/m³)**	**Sand (kg/m³)**	**Gravel (kg/m³)**	**W/C**	**Water (l/m³)**
NSC	424	731.4	934.4	0.49	212

Moreover, for repair materials, Reactive Powder Concrete (RPC) with 1%steel fibers and 0.75% polypropylene fibers developed by Al-Sultan (2015) [9]**,** 2% glass fibers developed by Kushartomo and Ivan (2017) [10] that give convergence strengths. Table 6 shows the mix proportions for RPC with three fibers.

Table 6. The mix proportion for RPC with three fibers as a repair material

RPC	**Cement Kg/m³**	**Sand Kg/m³**	**Silica Fume Kg/m³**	**SF %**	**GF %**	**PPF %**	**w/c ratio**	**Water Content Kg/m³**	**Super- plasticizer (by wt.of cementitious) %**
RPCS	950	1010	250	1%	-	-	0.17	204	6%
RPCG	950	1010	250		2%	-	0.17	204	6.5%
RPCPP	950	1010	250	-	-	0.75%	0.17	204	7.5%

2.2. Test methods

- Slump test was used to determine slump for substrate concrete NSC according to ASTM 143. For repair material (RPC with steel, glass and polypropylene fibre), flow table test was carried out according to ASTM C1437 to measuring workability for repair material.
- Compressive strength test: for substrate concrete (NSC), three cubes (150×150×150) mm samples were used to test compressive strength at age 28 days according to ASTM C39. For repair material (RPC with steel, glass and polypropylene fibre) three cubes with (50×50×50) mm were used to test compressive strength according to ASTM109.
- Splitting strength test: cylinders with dimension (150×300) mm were used to carry out splitting tensile strength according to ASTM C469.
- Flexural strength test: prisms with dimension (100×100×400) mm with clear span 300mm and for repair material (RPC with steel, glass and polypropylene fibre) prisms with dimension (100×100×300)mm with clear span 240mm were used to carry out flexural strength according to ASTM78.
- Slant shear test: bond strength of the repair materials with substrate concrete is determined by using the standard ASTM C 882 test. Composite cylinder specimens with dimensions (75×150) mm was prepared according to ASTM C882 as shown in Figure 2.
- Flexural strength test was used to evaluate compatibility between substrate concrete and repair material by using composite prisms with dimension (100×100×400) mm that have wide mouthed notch with dimension (200×100×10) mm lies at middle third of clear span as shown in Figure 3.
- After 28 days and before the repair material is placed on the substrate concrete, the slant surfaces of the substrate concrete specimen and the wide mouthed notch roughing by making horizontal and vertical groves with 3mm depth as stated by the study prepared by Diab et al. (2017) [11]. Then, casted by repair material and after 24 hrs. cured normal curing for 28 days, then tested.

Figure 2. Preparation and testing specimen of slant shear test

Figure 3. Preparation and testing specimen of composite prisms

3. Results and Discussion

3.1. Mechanical Properties

Mechanical properties for substrate concrete (NSC) and repair materials (RPC with different fibers) were presented in Table 7.

Table 7. Mechanical properties for substrate and repair material

Type of concrete	Slump (mm)	Compressive strength MPa	Splitting strength MPa	Flexural strength MPa
NSC	110	29.87	3.04	4.81
RPCS	112	116.36	-	12.69
RPCG	108	109.89	-	16.51
RPCPP	95	101.48	-	11.1

3.2. Slant Shear Bond Strength

The compression strength test with charging speed was 0.3 MPa/second was used to determine the compressive load needed to fail the composite cylinder at age 28 days and the bond strength is calculated by using Equation 1:

$$B_s = \frac{P}{A} \quad (1)$$

Where:

B_s: Bond strength (MPa)

P: Load at failure (N)

A: Area of inclined surface (area of an ellipse surface that equal to 9116 mm^2 (ASTM C882).

Table 8 shows results of composite cylinder bond strength tests and failure modes for each repair material type. ACI defined bond strength range in the "Concrete Repair Guide (ACI 546R)" selection of repair products.

Table 8. Results of slant shear test bond strength

Type of substrate concrete	Repair material (RPC with fibers)	Bond strength MPa at 28 days	Failure mode	Bond strength at 28 days MPa (ACI 546R-14)	Comparison with ACI
	Steel	13.13	Substrate layer	14-21	Not acceptance
NSC	Glass	17.38	Substrate layer	14-21	Acceptance
	polypropylene	14.31	Substrate layer	14-21	Acceptance

3.2.1. Effect of Flow for Repair Material

From the results can conclude when the repair material had a good flow (easy to flow), noticed the voids at interface zone very little due to repair material can inter into the groves and voids and fill it easily that will lead to strong bond strength. When the flow of repair material little, repair material cannot inter to the groves and voids because it was restricting and will reduce bonding strength. Figure (4 -A) show effect of good flow on bond strength and Figure (4-B) show influence of little flow on bond strength. These results agreed with Marco (2014) and Dawood and Ganim (2017) studies [12, 13]. From Figure 5 showing RPC with polypropylene fibre have lesser flow due to it reduced workability and make it more restricted thus reduced flowability, therefore it cannot inter to the groves easily without compaction. But, addition steel and glass fiber improve workability and can inter to the groves without compaction.

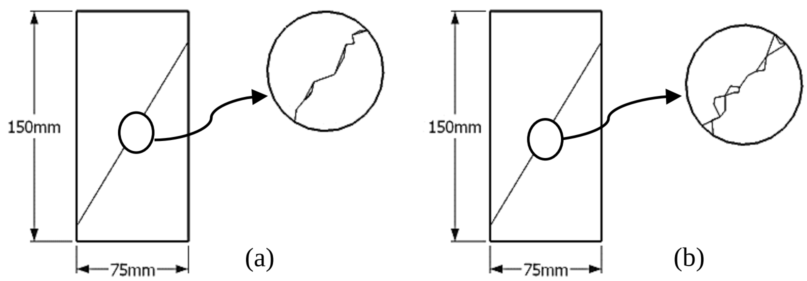

Figure 4. The Influence change of flow on bond strength a) Good Flow; b) Little Flow

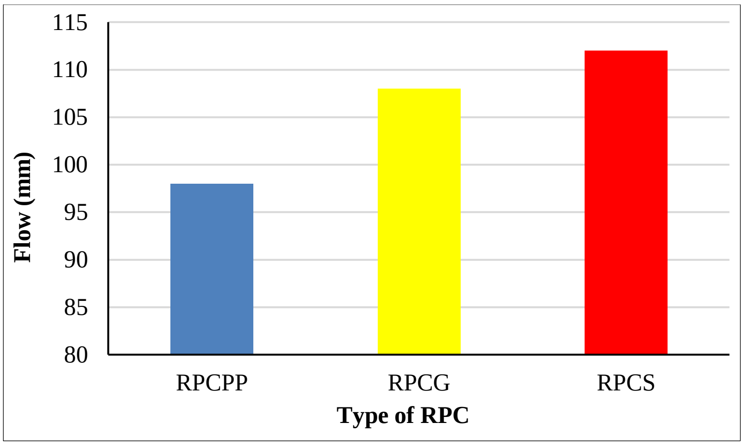

Figure 5. Flow for RPC with different fibers (SF, GF, and PPF)

3.2.2. Effect of Variance in Compressive Strength between Substrate Layer and Repair Material

Bond strength between substrate concrete and repair material increase with increasing compressive strength for substrate layer. This occur when the substrate be strong, it can resisting stresses result from applied load for long period (i.e. when the compressive strength for repair material /compressive strength for substrate concrete more than one, the failure occurs at substrate layer. If the ratio less than one, failure occurs at repair material). Figure 6 shows slant shear failure for NSC with SF,GF and PPF.This agreed with previous study [13, 14]. Thus can concluded bond strength increase when increased compressive strength of substrate concrete.

Figure 6. Slant shear failure for NSC with SF,GF and PPF

3.2.3. Effect of Fibers Types

Addition of fibers have a great effect on the slant shear bond strength. From Figure 7 concluded when add steel fibers to reactive powder concrete, it gives less bond strength than glass and polypropylene fibers because of SF is stiff material with less bend-ability. Therefore, when placing RPC with steel fibre on substrate concrete, steel fibers may be still straight or with little bent and it cannot inter the groves that found in substrate layer. Another reason, when steel fibers bent may be leave cavities inside bending steel fibers at bond zone that lead to reduced bond strength. While glass fibers and polypropylene fibers were had ability to bent and inter the groves and do not lock spaces between them, therefore gives higher bond strength.

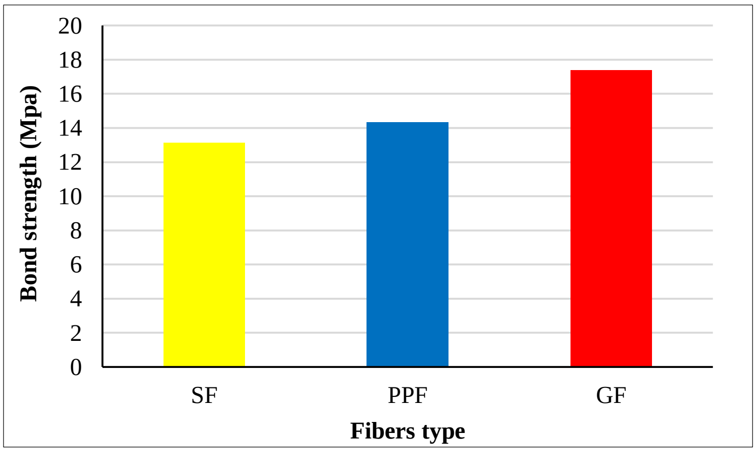

Figure 7. Effect of fibre on the slant shear bond strength

3.3. Compatibility between Substrate Concrete and Repair Material by Flexural Strength Test for Composite Prisms

Flexure test for composite beam would be suitable method to study the compatibility between repair and substrate material by using simple beam with loaded by two points loads are located at one –third of the clear span length from each support. Depending on failure modes, repair material can evaluate compatible or incompatible. Visually examined was used to evaluate tested specimens by compare it with Figure 8 and classified as compatible or incompatible (any case not represent 3, 4, 5 can be consider compatible [14-16]**.** Figure 9 shows the failure mode for composite prisms and Table 8 show the results of composite beams with normal curing and its failure modes. All specimens were tested at 28 days.

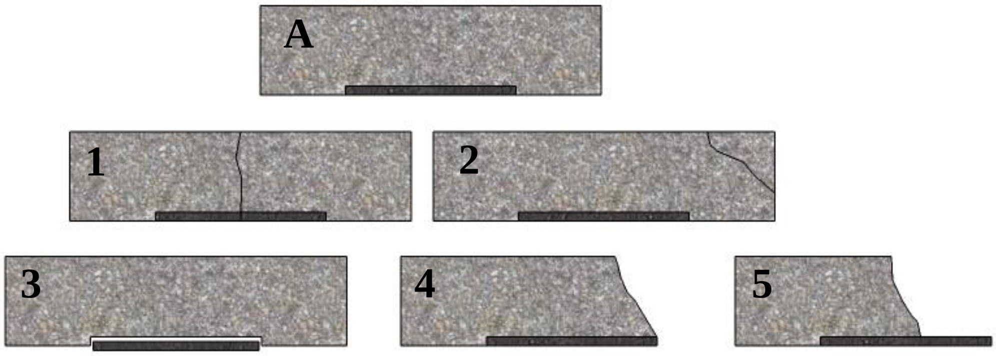

Figure 8. A) Composite prism used in the research
Compatibility evaluation (1, 2 Compatibility) (3, 4, 5 incompatibility)

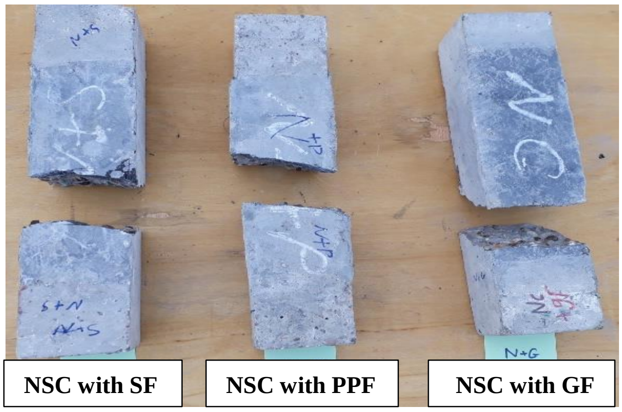

Figure 9. Result of composite beams of RPC with SF, GF and PPF with NSC

Table 9. Results of flexural strength of composite beams

Substrate concrete	RPC with fibers	Fr for NSC MPa	Fr for RPC MPa	Fr for composite beams MPa	Fr ratio	Failure mode
	steel		12.69	7.44	1.55	compatible
NSC	glass	4.81	16.51	8.13	1.69	compatible
	polypropylene		11.1	6.47	1.4	incompatible

3.3.1. Effect of Difference Flexural Strength

Flexural strength (flexural strength of composite prism/flexural strength of substrate prism) ratio was used to evaluation the load carrying capacity of specimens with respect to substrate layer. In case of flexural strength ratio greater than 1.0, the load carrying capacity for repair material is more than that of the substrate concrete layer. Therefore, the failure mode is lies at the middle-third for composite prisms and due to repair material was strong, the crack goes toward the edge of notch where failure occur. Then, repair material can be assumed to be compatible with substrate layer. In case of flexural strength ratio less than 1.0, that mean repair material was weak and failure mode lies at middle third of composite beams because the flexural strength of repair material is equal or less than flexural strength of substrate layer.

3.3.2. Effect of Different Types of Fibers

From Figure 10, glass fibers were had ability to bent and inter the groves and do not leave spaces between them, therefore gives higher bond strength, glass fibers have higher tension strength therefor it bears high stresses. Also, RPC contain silica fume that interact with $Ca(OH)_2$ product from cement hydration for substrate concrete and produce additional C-S-H that bind repair material with substrate concrete (i.e. improve bond between fibers and concrete). RPC with steel fibers (RPCS) gives results slightly reduce from RPCG due to steel fibers not easy inter to the groves. For prisms repair by RPCPP gives lowest flexural strength for composite prisms due to polypropylene fibers have lower tension strength compare with steel and glass fibers.

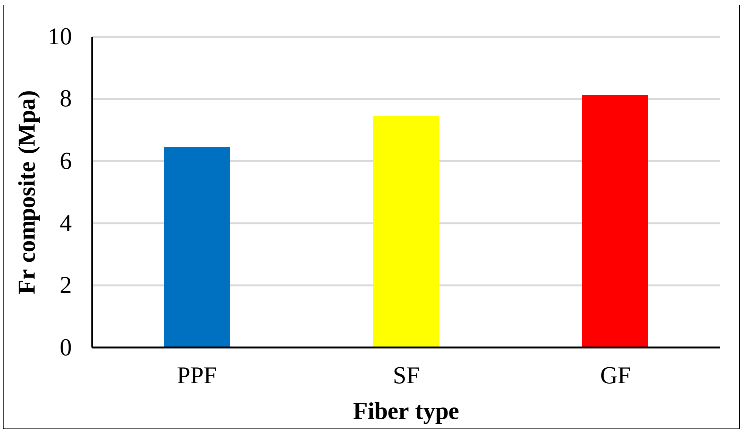

Figure 10. Effect of fibre on the flexural strength of composite prisms

4. Conclusions

- Adding fibers to RPC improve bond strength between substrate concrete and repair material.
- When use of fibers in RPC increased the flexural strength of composite material. However, RPC with glass fibers show best performance compared with steel and polypropylene fibers.
- Glass fibers improve workability for RPC compare with steel and polypropylene fibers.
- RPC with glass fibers more compatible with NSC substrate concrete.
- When using RPC with glass fibers for repairing have benefits health.
- For slant shear bond strength and Compatibility of composite prisms, compressive strength and flexural strength respectively for substrate concrete has a greater effect on bond strength and its Compatibility.

5. Conflicts of Interest

The authors declare no conflict of interest.

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