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

Lamyaa Gh. Salim a*, Haider M. Al-Baghdadi a, Haitham H. Muteb a

*Department of Civil Engineering, University of Babylon, Collage of Engineering, Babylon, Iraq.

Received 15 July 2019; Accepted 03 October 2019

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 to 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].
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

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.

| 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.

| Physical Properties | SF | Limit of Specification Requirements ASTM C-1240 |
|---------------------|----|-----------------------------------------------|
| Percent retained on 45μm (No.325) sieve, max, % | 1.7 | ≤ 10                                          |
| Specific Surface, Min, (m²/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.
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.

![Fibers](image)

**Figure 1. Fibers used in the research**

| Property               | Value            |
|------------------------|------------------|
| Length                 | 13±1mm           |
| Diameter               | 0.2±0.05mm       |
| Aspect ratio (L/Df)    | 65               |
| Density                | 7800 Kg/m³      |
| Tensile strength       | >2300 MPa        |

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

![Mix proportions](image)

**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.

![RPC mix proportions](image)

**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.
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.

| 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:

\[ B_s = \frac{P}{A} \]  

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.

| 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 |
|---------------------------|----------------------------------|-----------------------------|--------------|-------------------------------------------|---------------------|
| NSC                       | Steel                            | 13.13                       | Substrate layer | 14-21                                     | Not acceptance      |
|                           | 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
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.

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.
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. Visual 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](image)

Compatibility evaluation (1, 2 Compatibility) (3, 4, 5 incompatibility)

![Figure 9. Result of composite beams of RPC with SF, GF and PPF with NSC](image)

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](image)

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 Compa>ptibility 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.

6. References

[1] A. S. Rodrigues, "Deterioration of Concrete" Journal of Civil Engineering and Environmental Technology, Vol. 1, p: 14-19, 2014.
[2] Anisuddin, Syed, and Syed Khaleeq. "Deterioration and rehabilitation of concrete structures in hot and arid regions." In 21st Annual ARCOM Conference, vol. 7, no. 9. 2005.
[3] Bakhsh, Keivan Neshvadian. Evaluation of bond strength between overlay and substrate in concrete repairs. Architecture and the Built Environment, KTH Royal Institute of Technology, 2010.
[4] Guide, Concrete Repair. "ACI 546R-04." (2004): 53.
[5] Lee, Ming-Gin, Yung-Chih Wang, and Chui-Te Chiu. “A Preliminary Study of Reactive Powder Concrete as a New Repair Material.” Construction and Building Materials 21, no. 1 (January 2007): 182–189. doi:10.1016/j.conbuildmat.2005.06.024.
[6] Karthik, S, and Karthik Sundaravadivelu. “Retrofitting of Reinforced Concrete Beams Using Reactive Powder Concrete (RPC).” IOP Conference Series: Earth and Environmental Science 80 (July 2017): 012038. doi:10.1088/1755-1315/80/1/012038.
[7] Emmons, P. H., and A. M. Vaysburd. "Compatibility Considerations for Durable Concrete Repairs." Transportation Research Record 1382 (1993): 13.
[8] Venkiteela, Giri, Matthew Klein, Husam Najm, and Perumalsamy Naidu Balaguru. “Evaluation of the Compatibility of Repair Materials for Concrete Structures.” International Journal of Concrete Structures and Materials 11, no. 3 (September 2017): 435–445. doi:10.1007/s40069-017-0208-5.
[9] S. M. B. Al-Sultan, "Effect of Methods of Curing and Types of Fiber on the Behavior of Reactive Powder Concrete Beams," M.Sc. Thesis, Civil Eng., 2015.

[10] Kushartomo, Widodo, and Richard Ivan. “Effect of Glass Fiber on Compressive, Flexural and Spliting Strength of Reactive Powder Concrete.” Edited by J.-W. Park, H. Ay Lie, H. Hardjasaputra, and P. Thayaalan. MATEC Web of Conferences 138 (2017): 03010. doi:10.1051/matecconf/201713803010.

[11] Diab, Ahmed M., Abd Elmoaty M. Abd Elmoaty, and Mohamed R. Tag Eldin. “Slant Shear Bond Strength between Self Compacting Concrete and Old Concrete.” Construction and Building Materials 130 (January 2017): 73–82. doi:10.1016/j.conbuildmat.2016.11.023.

[12] T. Marco, "Influence of Substrate Moisture Preparation on Concrete Overlay Bond Strength," M.Sc. Thesis, University of Cape Town, 2014.

[13] E. T. Dawood and T. W. Ganim, "Effectiveness of High Performance Mortar Reinforced With Fibers as a Repair Material" Challenge Journal of Concrete Research Letters vol. 8, (2017): 29-47. doi:10.20528/cjrcl.2017.02.001.

[14] R. Pattnaik, "Investigation into compatibility between repair material and substrate concrete using experimental and finite element method," Ph.D. dissertation, vol. Civil Dept., 2006.

[15] M. S. Hassan, Z. T. Hadad, and S. T. Kadhim, "Studying the Compatibility between Metakaolin Repair Materials and Concrete Substrate," Engineering and Technology Journal, vol. 28, (2010): 5857-5868.

[16] Arianmanesh, Sara, and Mohammad Reza Esfahani. "Investigation into Compatibility between Repair Material and Substrate Concrete." (2013): 1-13.