BOND PERFORMANCE OF SUSTAINABLE REPAIRING MATERIALS WITH STEEL REINFORCEMENT

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Abstract- Owing to the notable benefits of cement concrete such as flowability, high compressive strength, temperature resistance and economy, it is being used extensively in construction industry. However, concrete structures may deteriorate due to excessive loading, aging or various environmental factors. Repairing of concrete structures is an effective approach to avoid structural collapse. Several types of repairing materials have been explored at laboratory scale as well as at industrial scale. Two recent repairing materials are; polymer cement concrete (PCC) and geopolymer concrete (GPC). Both types of repairing concrete were used in this work and their bond strength with steel reinforcement was evaluated through pullout test. Conventional concrete was also used as reference specimen and results of pull out strength were compared with it. Experimentation revealed that all three types of specimens exhibited similar bond behavior. The experimental results were also compared with the existing code. Moreover, a relationship was proposed for prediction of bond strength and it showed close correspondence with experimental observations as well as with CEB-FIP code.

Keywords- Polymer concrete, Geopolymer concrete, Bond strength, Pullout test.

1 INTRODUCTION

Concrete is a widely used structural material with its ability to resist higher compressive loads. Due to various environmental and loading effects, reinforced concrete members deteriorate resulting in shorter age as expected. This is due to the lack of implementations in repair [1]. It is important to provide an appropriate solution for the deteriorated structures, in order to fulfill their intended use and to complete their service life. Repairing of concrete structures is a suitable solution for deteriorated structure, economically as well as environmentally, than to demolish it completely [1, 2]. Usually, spalling of concrete occurs thus indicating a substantial chance of failure and ultimate collapse. Such type of structural damages cannot be repaired by externally bonded fiber reinforced polymeric sheets. So, cementitious repair is required. Different novel repair materials and techniques can be used nowadays to increase the load bearing capacity of the members. Polymer cement concrete (PCC) and geopolymer concrete (GPC) are two common materials being used as a repair material [3, 4]. These materials have high strength and better adhesion. Also, they can resist thermal and environmental effects in a better manner as compared to conventional concrete. Polymer cement mortar can be prepared by adding polymers as an admixture [5, 6]. The particles of latex, when dispersed in water, forms rigid layer with minimal voids in it. Thus, contributing to the strength of PCM [7]. Geopolymer materials are also being employed in construction industry mainly due to the current interest in sustainable development. It has received attention as an alternative to the ordinary portland cement concrete (OPC) thus reducing high carbon dioxide emissions as well as the landfill costs. High silicon or aluminum materials of geological origin or industrial by products are employed as geopolymers. Geopolymers can be prepared from either from calcined or non-calcined sources. Higher compressive strength can be achieved by incorporation of calcined sources such as metakaolin, fly ash, slag as compared to those synthesized from kaolin clay; a non-calcined source [8, 9]. Several researchers have prepared geopolymer concrete by using industrial waste products such as fly ash, slag etc. Fly ash is widely being used in the production of geopolymer mortars and concrete. Class F fly ash contains more than 70% of silicon, aluminum and iron oxides which makes it pozzolanic in nature [10]. Thus, making it favorable for the use in concrete [11]. The use of fly ash in GPC results in the formation of sodium aluminum silicate hydrate (NASH) while two hydration products are formed by using slag in geopolymer concrete i.e. NASH and calcium silicate hydrate (CSH) [12]. The use of these industrial by-products in concrete not only makes it favorable for a cleaner environment but also helps to achieve higher strength and less permeability. It has been reported that the increase in amount of geopolymer binder results in the improvement of mechanical properties as in the case of conventional concrete [12].

Reinforcing bars are provided in concrete structures to compensate for tensile stresses. Different types of reinforcing bars; steel or fiber reinforced polymer, plain or deformed, are being used in reinforced concrete (RC) structures. However, steel bars are used as the most common type of reinforcement. Concrete has the ability to maintain a strong bond with steel bars. Bond stress depends on various factors such as concrete compressive strength, development length of steel rebar, diameter of rebar, bar type etc. Bond between concrete and rebar is maintained mainly by chemical adhesion and mechanical interlock. This bond is attributed to three types of forces; adhesion forces, shear forces, friction forces. Bond strength of steel reinforcing bars with GPC has been evaluated and reported to be higher than that of steel reinforcing bars OPC [13, 14]. However, bond strength of PCC has not been reported yet.

Since, PCC and GPC are widely being used as the most suitable and sustainable repair materials and also as basic structural materials in some countries, therefore it is significant to investigate the bond strength performance of these repair materials with reinforcement. Relationships for bond stress have not been developed for PCC and GPC. The present study aims to study the bond behavior of PCC and GPC with steel reinforcement, to compare their bond behavior with OPC and to establish a relationship between bond strength and compressive strength.

2 METHODOLOGY

2.1 Materials

Ordinary concrete (OPC) was prepared in the laboratory in order to compare the results with PCC and GPC. Materials employed in the production of concrete were easily available from local market. The properties of cement, sand and aggregate are mentioned in Table 1.

Table 1-Properties of concrete constituents

Cement (Paidaar cement)		**Coarse Aggregate (Sargodha crush)**		**Fine Aggregate (Ravi Sand)**	
Specific gravity	3.15	Fineness	2.65	Fineness Modulus	2.4
Consistency	31%	Specific gravity	6.03	Specific gravity	2.61
Fineness	8%	Loose bulk density	1289 kg/m^3	Bulk density	1330 kg/m^3
Initial setting time	105min.	Rodded bulk density	1584 kg/m^3		
Final setting time	2hrs. - 5min.	Water absorption	0.99%		

Polymer cement mortar was provided by Imporient Chemicals in two-component form. Component A included cement, sand and polymeric fibers. Component B was latex to be mixed in component A in the prescribed ratio. Coarse aggregate was added in addition. PCC was cured for 28 days. Wet curing was carried out for first 7 days with jute bags and then the specimens were ambient-cured for next 21 days , as it has been reported to be the most suitable method [5]. The properties of structural repair mortar provide by the manufacturer are mentioned in APPENDIX 1. GPC was produced in the laboratory by using a combination of fly ash and slag as binders. These binders were obtained from DG cement plant in Pakistan and their properties are mentioned in Table 2. Sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) were used as alkaline activators in a ratio of 1:2.5. Sodium hydroxide was prepared in the laboratory at 12M concentration by dissolving pellets into distilled water 24 hours prior to casting. GPC was cured for 7 days under ambient conditions to get desired normal strength requirement.

Table 2 Chemical composition of binders for GPC

Material	**Oxides**							
	SiO_2	Al_2O_3	CaO	Fe_2O_3	MgO	K_2O	Na_2O	SO_3
Flyash	56.34	23.08	9.02	6.43	1.70	0.56	0.28	-
Slag	37.42	13.25	40.85	1.92	1.63	0.01	0.42	0.64

Reinforcement was provided by steel reinforcing bars. Deformed bars of diameter 14mm with yield strength of 453 MPa were used to determine the bond strength between three types of repairing concrete and reinforcement. This diameter of bar was selected because it is commonly available and is being used in real applications.

2.2 Preparation of specimens

Cube specimens were prepared for pullout testing and compression testing. Cube size for pullout specimens was 150 × 150 × 150 mm while that for compression testing was 100 × 100 ×100 mm.

A hole with diameter slightly greater than that of the steel bar was punched in the center of the base plate of steel cube mould, so that the steel bar can pass through it easily. A steel plate, with a hole at the center and the diameter same as that in the base plate, was clamped to the upper portion of steel cube mould in order to fix the steel bar. Steel bars were wrapped with PVC pipe to maintain the bonded length of five times diameter of bar ($5d_b$) as shown in Figure 2.

Casting and curing procedure of OPC followed the standard ASTM C192 [15]. Molds were cleaned and oiled prior to casting of specimens and steel bar was then fixed in the center of the mold. Ingredients were first weighed according to the mix design as presented in Table 1. Dry mixing of cement and half of the fine aggregate was carried first. After that; coarse aggregate, other half of fine aggregate and water was mixed for about five minutes. Concrete was poured in three layers and each layer was compacted by using vibrating table. The surface of specimens was then smoothened by steel trowel. Samples were demolded after 24 h and jute bags were used for curing. PCC was prepared by machine mixing of the two components provided by the manufacturer and coarse aggregate was added in addition. Similarly, GPC was prepared by machine mixing of binders, alkaline activators and coarse aggregate and its mix design is presented in Table 4.

Table 3-Mix design of OPC

Ingredients	**Amount (kg/m^3)**
Cement	368
Fine Aggregate	552
Coarse Aggregate	1105
Water	165

Table 4-Mix design of GPC

Ingredients	**Amount (kg/m^3)**
Flyash	384
Slag	128
Cement	128
NaOH	183 (12M)
Na_2SiO_3	457
Fine Aggregate	640
Coarse Aggregate	1280

Figure 1: Specimen Preparation

2.3 Testing of specimens

Compression test was performed on the prepared cubic specimens of 100 ×100 × 100 mm following the standard ASTM C39 [16]. Compression test was performed in order to relate bond strength with compressive strength. Specimens for compressive strength were tested at the same age as that of pullout test. Compressive load was applied on the cubes by using Universal testing machine (UTM). Pullout specimens were tested according to the standard ASTM D7913 [17]. Specimens were adjusted in the pullout assembly. Dial gage was attached to the unloading end of steel bar in order to measure relative slip. Figure 2: Testing of specimens

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Figure 2: Testing of specimens

3 RESULTS AND DISCUSSIONS

Compressive strength and bond strength were calculated from the experimental loads. Pullout failure mode was observed for all specimens. Bond stress-slip relationship was plotted for the specimens. Similar behavior was obtained for all three types of specimens with an increasing line with a minor slippage at first stage, then a decreasing trend and ultimately constant stress zone with a significant slip. This trend is plotted in Figure 3. Similar bond behavior of GPC has been reported in another study [18]. However, it has been reported that despite of similar bond behavior and stress-slip relationship, GPC shows slightly higher bond strength depending upon the amount of flyash or source of binders. Also, GPC can achieve relatively higher bond strength at early age due to heat curing, but for ambient curing results of GPC are quite similar to those of OPC. Bond strength for PCC has not yet been reported by any other study.

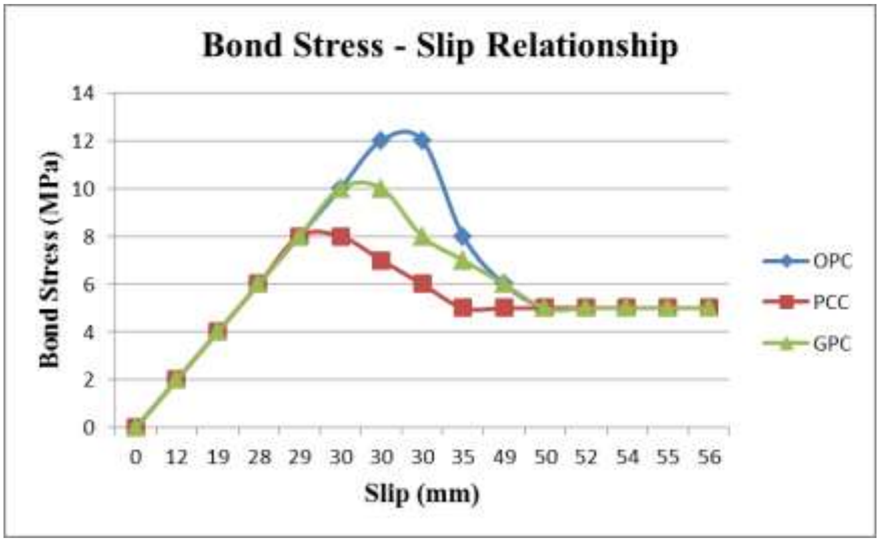

Figure 3: Bond stress - slip relationship

A relationship was developed (Eq. (A) between compressive and bond strength from the experimental results with coefficient of determination (R^2) value equal to 0.9.

$$\tau_{max} = 1.5(f_c')^{0.63} \quad \text{Eq. (A)}$$

where;
τ_{max} = Maximum bond strength (MPa)
f_c' = Compressive strength (MPa)

The obtained results were verified by using the relationship of bond stress specified by CEB-FIP 10 [19]. The relationship established by CEB-FIP Code is mentioned in Eq. (B).

$$\tau_{max} = 2.5\sqrt{f_c'} \quad \text{Eq. (B)}$$

Experimental results were in good agreement with those obtained by using the code. Upto 11% variation was observed between experimental and analytical results. Thus, PCC and GPC can be used as sustainable materials for cleaner production and already existing relationships for OPC can be used for PCC and GPC to estimate their bond strengths accurately. These repair materials require minimal maintenance and can be used effectively [3, 20].

4 CONCLUSIONS

The results of the experimentation revealed that all three types of prepared concrete exhibited similar bond behavior. This is because all materials are cementitious so the stress-slip curve showed the same trend. Thus, the analytical relations established for OPC can also be used for PCC and GPC. Moreover, the experimental results were verified by using the specified standard and a close correspondence was obtained between the relationship established in the present study through experimentation and the standard-specified relationship, thus approving the results.

5 APPENDIX

APPENDIX 1

Product Description	Repair Mortar SF is a two component fibre reinforced, cementitious polymer silica fume containing multipurpose patching and structural repair mortar.
Uses	For patching or structural repair of deteriorated concrete and mortar. It is suitable for exterior or interior, horizontal or vertical surfaces.
Advantages	Easy to mix, apply and finish Excellent adhesion to substrate Shrinkage compensated Low water absorption Non-corrosive, non-toxic
Test Standard	BS 1881 ; ASTM C 109
Technical Data:	
Form	Two components; Grey powder with Polymer Emulsion
Packing	22 kg powder: 3.0 Lit. Emulsion
Pot life	50-60 minutes at 25 ˚C
Density	Fresh mortar: 2.0-2.1 kg/Lit.
Yield	Approx 14 litres of wet mixture
Water absorption	< 0.01 ml/m^{2}sec (BS 1881, PART 208)
Flexural strength	7-9 N/mm^2 (28 days)
Adhesion	>2.0 N/mm^2 on concrete (BS 1881, PART 207)
Temperature	Minimum 5 ˚C Maximum 40 ˚C
Mixing	3 minutes electric mixing (500 RPM)

ACKNOWLEDGMENT

Imporient Chemicals and DG Khan cement plants are highly acknowledged for providing polymer cement mortar and fly ash, respectively. The careful review and constructive suggestions by the anonymous reviewers are gratefully acknowledged.

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