HIGH TEMPERATURE HEAT RESISTANCE OF CONCRETE CONFINED WITH CFRP USING FIBER REINFORCED GEOPOLYMER BONDING AGENT

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Rehabilitation and improvement of concrete structures by strengthening is an environmentally sustainable option compared to demolition and building of new structures. Epoxy resin is typically used as the bonding agent to strengthen concrete structures by using FRP. However, a major drawback of epoxy resin is that it loses bond strength by melting at high temperatures. Geopolymer is an alternative binder that possesses high resistance to elevated temperatures. This paper presents the results of CFRP confined concrete cylinders using 0.2% short PVA fiber reinforced geopolymer paste as the bonding agent. Concrete cylinders of 45 MPa were wrapped with one or two layers of CFRP and exposed to temperatures of 200, 400 and 800°C for 90 minutes and then tested for compressive strength. The specimens exhibited failure by tearing the CFRP fabric. The percentage of increase of strength by the CFRP wrapping at 800°C was 86% for one layer with fiber, 51% for one layer without fiber, 65% for two layers with fiber, and 73% for two layers without fiber. While strength of the cylinders increased with the increase of CFRP layers, the addition of PVA fiber did not have an obvious benefit to the strength enhancement. No melting, though cracks were observed in fiber reinforced geopolymer due to high temperature exposures.

Keywords: Geopolymer paste, CFRP confinement, PVA fiber, Workability, Compressive strength, Fabric tearing.

1 INTRODUCTION

As a construction material, concrete often requires rehabilitation or improvement due to damage during service, increase of load rating or deterioration by exposure to harsh environment. Compared to total demolition and rebuilding, rehabilitation and improvement of structures by strengthening is considered a more environmentally sustainable option. Utilizing fiber reinforced polymer (FRP) in the form of reinforcement bars, plates, sheets, or fabric wrapped around concrete members has gained popularity to strengthen concrete structures due to their high strength, high corrosion resistance, and ease of application.

There are a variety of different FRP materials that can be used for strengthening concrete structures such as carbon fiber reinforced polymer (CFRP), basalt fiber reinforced polymer (BFRP), and glass fiber reinforced polymer (GFRP). Depending on the given application, a suitable FRP material can be used based on each material’s distinct property. These FRPs are generally bonded to concrete using epoxy resin as a bonding agent. This process initiates an easy and quick in-situ installation with minimal disturbance to the surroundings compared to other repairing and upgrading methods. However, since commercially available epoxies have a glass transition
temperature in the range of 60°C to 82°C (ACI Committee 440 2017), epoxy bonded FRP confinement suffers from reduced bond strength and mechanical properties when exposed to elevated temperature for an extended duration (Urbaniak 2018). The loss of bond strength of epoxy at elevated temperatures consequently reduces the ability of the epoxy to transfer the force between concrete member and FRP material. This is a significant limitation of epoxy resin because in case of fire the FRP strengthening becomes ineffective due to loss of bond strength.

Geopolymer binder, produced by the reaction of aluminosilicate materials with an alkali may be considered as a potential alternative bonding agent for FRP strengthening. Geopolymers have ceramic-like properties which possess good thermal resistance and bonding properties (Kong and Sanjayan 2008, Sarker and McBeath 2015).

Bond strength of fly ash geopolymer to bond CFRP fabric to concrete surface was found not affected by high temperature of 400°C (Sarker et al. 2017). Also, the addition of short carbon fibers to the geopolymer paste was shown to enhance bond strength retention at elevated temperatures (Zhang et al. 2015). It was also found that the compressive strength of concrete cylinders wrapped with carbon fiber fabric increases incrementally with the increase of carbon fiber fabric layers (Zhang et al. 2016).

Considering the loss of bond strength of epoxy resin at high temperature, the development of alternative bonding agents with high resistance to elevated temperature would benefit maintaining the strength of FRP strengthened concrete structures during an accidental fire or for structures that require to resist high temperatures during the service life. Therefore, this study investigated the residual compressive strength of concrete confined by CFRP fabric using short fiber reinforced geopolymer as the bonding agent after high temperature exposures.

2 MATERIALS AND METHODS

2.1 Materials

Concrete cylinders of 100 mm diameter and 200 mm height were used for compressive strength test with and without CFRP wrapping. The ingredients of concrete were 360 kg/m³ of OPC with a water to cement ratio of 0.4, 676 kg/m³ of sand and 1220 kg/m³ of coarse aggregates.

The geopolymer paste was made using fly ash and GGBFS as the solid precursors and a combination of 10M sodium hydroxide with sodium silicate as the alkaline liquid. The sodium silicate to sodium hydroxide mass ratio was 2.5, and the GGBFS to fly ash mass ratio was 0.25. The mass ratio of the total alkaline solution to solid precursors was 0.45. Short Polyvinyl Alcohol (PVA) fiber was added to geopolymer paste at a dosage of 0.2% by volume. The length, diameter, density, tensile strength, and elastic modulus of the PVA fiber were 8 mm, 38 micron, 1.3 gm/cm³, 1600 MPa and 40 GPa, respectively. The CFRP was 230 g/m² woven unidirectional carbon fiber fabric with a tensile strength of 3600 MPa.

2.2 Preparation of Specimens and Testing

After one day of steam curing of the concrete cylinders, the surface was prepared by sandblasting. The loose materials were removed, and a profiled open textured surface was achieved to facilitate the bonding of CFRP, as shown in Fig. 1. The concrete specimens were fully wrapped in one layer and two layers of CFRP fabric using geopolymer paste with and without PVA fibers as the bonding agent. The geopolymemr paste was applied to the concrete cylinders in two layers. A layer of geopolymer paste was applied to the CFRP fabric and the concrete cylinder was rolled on it to get the fabric wrapped fully around the cylinder and another layer of geopolymer paste was then applied on top of the CFRP. A second layer of geopolymer paste was applied on the surface of the
CFRP fabric and rolled to ensure a uniform and smooth surface. The CFRP fabric had a 30% of the length overlapped at the end to enhance the wrapping.

Fig. 1. Concrete cylinders: (a) before sand blasting, (b) ready for CFRP wrapping after sand blasting.

The CFRP wrapped cylinders were stored for curing at room temperature for two days, followed by oven curing for 4 hours at 60°C. A set of the CFRP wrapped cylinders were kept at room temperature and the rest were exposed to elevated temperatures of 200°C, 400°C, 800°C in an electric furnace, as shown in Fig. 2. The specimens were heated for 1.5 hours after the target temperature was reached. Then the specimens were cooled down to room temperature naturally in the furnace by leaving the door open. The specimens were then tested for compressive strength. The average compressive strengths were determined from the results of three identical specimens for each case.

Fig. 2. Specimens in electric furnace.

3 RESULTS AND DISCUSSION
3.1 Physical Change in Specimens by High Temperature Exposure

After initial ambient curing, the CFRP wrapped specimens were stiff with no visible sign of cracks. However, after oven curing for four hours, some hairline cracks developed due to shrinkage and dehydration caused by dry heating. The liquid contained in the specimens tends to leave and reach
the surface during curing which results in the formation of the cracks seen in Fig. 3 (left). Wider cracks were observed in specimens with two layers of CFRP fabric compared to the specimens with one layer of CFRP fabric. In two layers CFRP confinement, inadequate geopolymer penetration formed a thin layer of geopolymer paste on the upper layer of fabric. This might lead to reduced bonding of the CFRP fabric to the underlying layer of geopolymer paste. The specimens with PVA fibers in the geopolymer paste was expected to reduce cracking when compared to the specimens without PVA fibers (Gao et al. 2017). However, the observed cracks indicate that the addition of 0.2% PVA fiber was not enough to eliminate the cracking of the geopolymer paste.

![Fig. 3. CFRP confined specimens: left side - after oven curing (a) two layers CFRP and geopolymer with no fiber, (b) one layer CFRP and geopolymer with no fiber, (c) two layers CFRP and geopolymer with fiber, (d) one layer CFRP and geopolymer with fiber; right side - after exposure to (a) ambient temperature, (b) 200°C, (c) 400°C, (d) 800°C](image)

No visual changes were observed in the CFRP confined specimens after exposure to 200°C and 400°C, as seen in Fig. 3 (right). At 800°C, the specimens became light brown, and some areas were observed to spall as high temperature causes a rapid rise of pore pressure within the geopolymer layer. This leads to the development of tensile stress and spalling of the geopolymer paste. No significant improvement in terms of cracking was observed in specimens with 0.2% of PVA fiber in the geopolymer paste after exposure to high temperatures. This can be due to the initial rapid dehydration and shrinkage cracks formed after oven curing beyond the PVA fiber’s crack retardation capacity.

### 3.2 Failure Modes of Specimens Under Compression

The majority of the specimens exhibited failure due to CFRP fabric tearing. The compressive force caused the concrete core to expand laterally and tensile stress to be developed in the CFRP fabric due to Poisson’s effect. When the induced tensile stress was greater than the tensile strength of the CFRP fabric, the CFRP failed following by crushing of the concrete (Zhang et al. 2016, Salman and Salman 2021). No CFRP confined specimens failed at the overlap area which indicates the 30% overlap is sufficient as the stress was transferred successfully over the area.

### 3.3 Residual Compressive Strengths of CFRP Confined Cylinders

The mean unconfined compressive strength of the concrete at 25°C was 45.9 MPa. The residual compressive strengths of unconfined concrete after exposure to 200, 400 and 800°C were 41.8, 34.2 and 3.7 MPa, respectively. The percentage increase of the residual compressive strengths by CFRP fabric confinement relative to the unconfined strength after exposure to different temperatures are plotted in Fig. 4. The enhancement of compressive strength increased with the number of CFRP layers up to 400°C exposure. At 800°C, the concrete cylinder with one layer of CFRP fabric
confinement showed better strength retention than two layers of CFRP confinement. The possible source of discrepancy in this result might occur due to inconsistent application and thickness of geopolymer paste.

CFRP confinement resulted in greater strength enhancement at higher temperatures compared to low temperatures. As the temperature increases, the strength of the concrete decreases but the strength of CFRP confinement remains unaffected because of lower thermal expansion of CFRP fabric than the concrete itself. Thus, the surface of the concrete cylinder remains prestressed by the CFRP fabric which effectively confines the concrete cylinder. Furthermore, geopolymer paste bonds the concrete cylinder well to the CFRP fabric due to its high thermal resistance. For these reasons, the CFRP confinement showed a higher percentage of strength increase for specimens at higher temperature compared to low temperature.

![Percentage strength increase of CFRP wrapped cylinders after high temperature exposure.](image)

The percentage increase of compressive strength is higher in specimens without PVA fiber in the geopolymer paste compared to specimens with fiber. The addition of fiber reduced the workability of the geopolymer paste which also reduced the penetration of geopolymer paste through the CFRP fabric and as a result reduced the bond strength of the geopolymer paste.

Elmegbr et al. (2019) conducted a similar experiment where 40 MPa concrete cylinders were wrapped with two layers of BFRP fabric using geopolymer paste without fiber as the bonding agent. It was found that the compressive strength was increased by 17% at ambient temperature and 15% after exposure to temperatures from 65°C to 350°C. Compared to BFRP, CFRP confinement had a higher strength enhancement which are 35% at ambient temperature and 50% at 400°C. As CFRP fabric has a tensile strength of 3600 MPa, which is greater than BFRP fabric (1600 MPa), the CFRP confined specimens were able to resist greater tensile stress than BFRP fabric confined cylinders, which resulted in higher compressive strength.

4 CONCLUSIONS

Concrete cylinders of 45 MPa unconfined compressive strength were wrapped by one or two layers of CFRP fabric using geopolymer paste with or without the addition of 0.2% PVA fiber as the bonding agent and tested after exposure to 200, 400, 800°C. Based on the results, the following conclusions are drawn:
- Short PVA fiber of 0.2% by volume of the paste was found not enough to eliminate shrinkage cracks of geopolymer paste subjected to dry heat curing.
- The geopolymer paste bonding agent remained mostly intact after high temperature exposures.
- Failure of the cylinders was characterized by tearing of the confining CFRP followed by crushing of concrete.
- Increase in the layers of CFRP fabric confinement generally increased the strength enhancement of concrete cylinders.
- The presence of fibers in the geopolymer paste appeared to decrease the strength enhancement of CFRP confinement. This is attributed to the effect of fibers to reduce the penetration of geopolymer paste bonding agent through the CFRP fabric.

References

ACI Committee 440, Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures (ACI 440.2R-17), American Concrete Institute, Farmington Hills, MI, 2017.


