PAPER • OPEN ACCESS

# Bond Strength Mechanism of Fly Ash Based Geopolymer Mortars: A Review

To cite this article: W W A Zailani *et al* 2017 *IOP Conf. Ser.: Mater. Sci. Eng.* **267** 012008

View the article online for updates and enhancements.

IOP Conf. Series: Materials Science and Engineering **267** (2017) 012008 doi:10.1088/1757-899X/267/1/012008

# Bond Strength Mechanism of Fly Ash Based Geopolymer Mortars: A Review

**W W A Zailani[2,1, a], M M A B Abdullah[2,1, b], R A Razak[2,1, c], M R R M A Zainol[3, d], M F M Tahir[1, e]**

[1] Center of Excellence Geopolymer and Green Technology (CEGeoGTech), School of Materials Engineering, Universiti Malaysia Perlis (UniMAP), P.O Box 77, D/A Pejabat Pos Besar, 01000 Kangar, Perlis, Malaysia.
[2] Faculty of Engineering Technology, Universiti Malaysia Perlis (UniMAP), P.O Box 77, D/A Pejabat Pos Besar, 01000 Kangar, Perlis, Malaysia.
[3] School of Civil Engineering, Universiti Sains Malaysia (USM), Engineering Campus, 14300 Nibong Tebal, P. Pinang, Malaysia

[a]warid.wazien92@yahoo.com, [b]mustafa_albakri@unimap.edu.my, [c]rafizarazak@unimap.edu.my, [d]ceremy@eng.usm.my, [e]faheem@unimap.edu.my

**Abstract.** Geopolymer possess many excellent properties such as high compressive and bond strength, long term durability, better acid resistance and also known as a "Sustainable Material" due to its low carbon emission and low energy consumption. Thus, it is a good opportunity to develop and explore not only for cement and concrete but also as geopolymeric repair materials. This reviews showed that good bonding properties between geopolymeric repair material and concrete substrate is important in order to acquire an enhanced resistance against penetration of harmful substances and avoiding respalling of the repair material by understanding the bonding behaviour. Bond strength depends to the properties of the repair materials itself and also the surface preparations of concrete substrate.

## 1. Introduction

Bonding strength is the major requirement of any successful repair material [1–3]. Thus, bond strength is one of the most important properties as concrete repair materials. Several studies have shown that the bond that exists between the repair material and concrete substrate is generally very weak in most of the repaired structures [4,5]. Several test methods such as pull off, splitting, flexural, and slant shear test have been proposed to evaluate the bond strength between repair materials and concrete substrate [6–8]. Thus, recent investigations in the field of geopolymers reveal a third category of mortars with high potential to be used in the field of concrete patch repair and slant shear test normally is used to study the bonding performance of repair material. Investigation on the utilization of high calcium fly ash geopolymer mortars containing OPC for use as repair material has been investigate and shows the strong bond at the interface zone.

The high calcium fly ash geopolymer mortar mixture not only gave sufficient high shear bond strength but also can be cured at room temperature because of the calcium in the system [9–13]. Thus, geopolymer becomes more practical for concrete repair and rehabilitation. The investigations have already been conducted in geopolymer field especially based on fly ash however, most of the

IOP Conf. Series: Materials Science and Engineering **267** (2017) 012008 doi:10.1088/1757-899X/267/1/012008

researchers covered the mixture development phase. Thus, it is a good opportunity to use some of their mixture formulation to develop this potential material as a new repair material. Therefore, the bonding mechanism between repair material and concrete substrate is reviewed in order to identify the factors that could improve the bond strength between geopolymer repair material and substrate.

## 2. Reaction Mechanism at Interfacial Transition Zone

Bond strength requires an understanding of chemical reaction between the concrete substrate and repair materials. Geopolymer repair material which is able to transform and hardened rapidly at low temperatures through geopolymerization process able to cure at ambient temperature [6–8], to be an alternative to epoxy resins for structural retrofitting [4], high adhesion strengths even at early ages [9], and the cheapest solution for repair and rehabilitation [7,8]. Geopolymer is formed using precursors containing alumina ($Al_2O_3$) and silica ($SiO_2$) such as fly ash (FA) [17], kaolin [18], granulated blast furnace slag (GBFS) [19], and palm oil fuel ash (POFA) [20] activated with alkali solutions. The $Al_2O_3$ and $SiO_2$ in the precursor will dissolve and form a three-dimensional amorphous aluminosilicate network [21].

However, the sialate network of geopolymer which composed of tetrahedral anions $[SiO_4]^{4-}$ and $[AlO_4]^{5-}$ need positive ions such as $Na^+$, $K^+$, $Li^+$, $Ca^{++}$, $Na^+$, $Ba^{++}$, $NH^{4+}$, $H_3O^+$ to compensate the electric charge of $Al^{3+}$ in tetrahedral coordination as shown in Figure 1. When geopolymer is patch against the spalled of the reinforced concrete structure made from Ordinary Portland Cement (OPC), geopolymer is chemically bond to substrate due to the reaction products at the interface transition zone between OPC substrate [12,13].

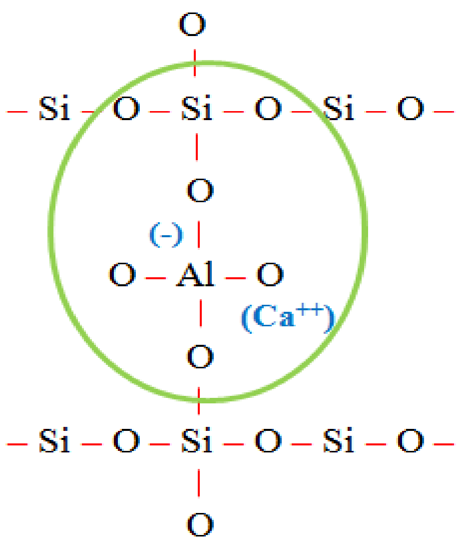


**Figure 1.** Schematic representation of the chemical bond at interface.

Calcium hydroxide or portlandite, which is available at the Ordinary Portland Cement (OPC) substrate surface, provides positive ion $Ca^{++}$ and this positive ion is required for the geopolymerization process. Theoretically, the $Ca^{++}$ will balance the negative charge of $Al^{3+}$ ions in geopolymer thus, promoting to the bond strength between geopolymer repair material and substrate. Thus, interfacial transition zone through Scanning Electron Microstructure (SEM) shows that geopolymer made from Tungsten Mine

IOP Conf. Series: Materials Science and Engineering **267** (2017) 012008 doi:10.1088/1757-899X/267/1/012008

Waste Mud (TMWM) is chemically bond to the concrete substrate as shown in Figure 2. Moreover, the increase in $Ca^{++}$ ion balanced the negative charge of $Al^{3+}$ ions, which leading to a dense interface zone is shown in Figure 3. Therefore, the microstructure images give clear picture in order to evaluate the bond strengths of geopolymer repair materials. Geopolymer made with TMWM and fly ash are good candidates as an alternative bonding material for repair works.

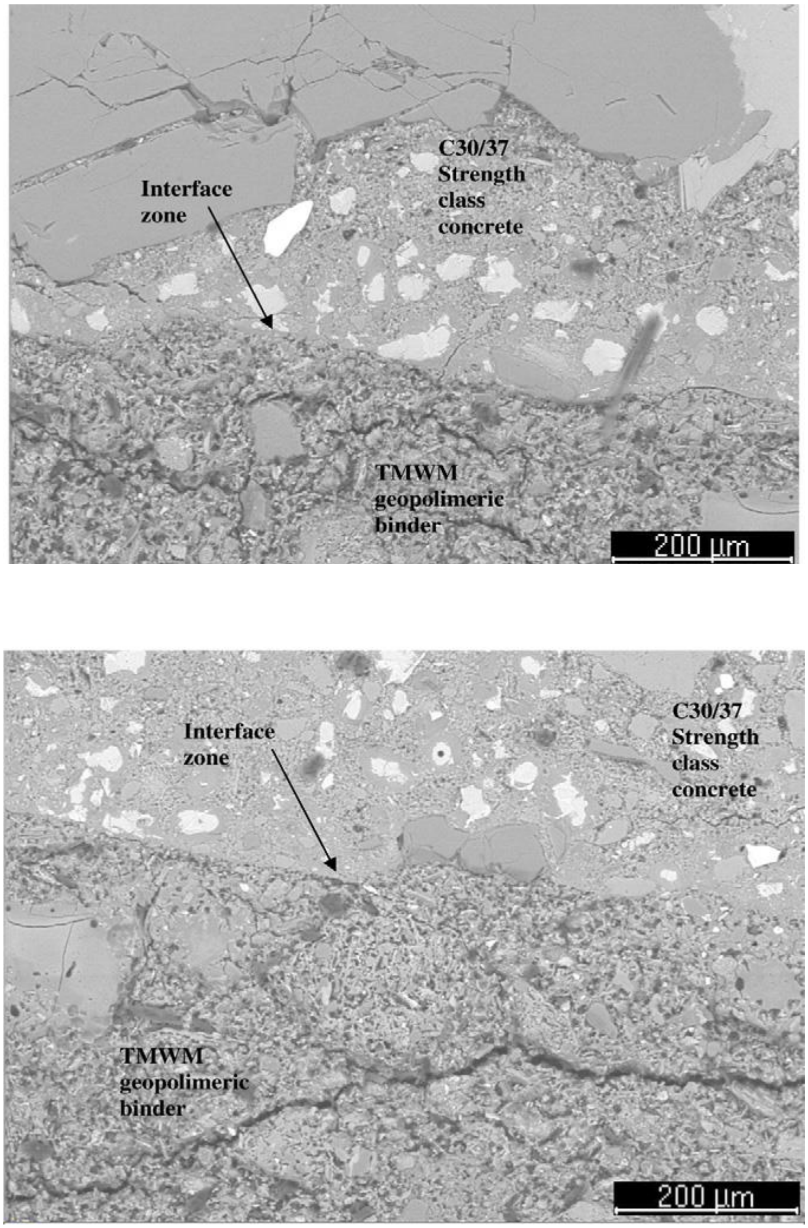


**Figure 2**. SEM micrographs of interfacial transition zone between geopolymer and substrate [8].

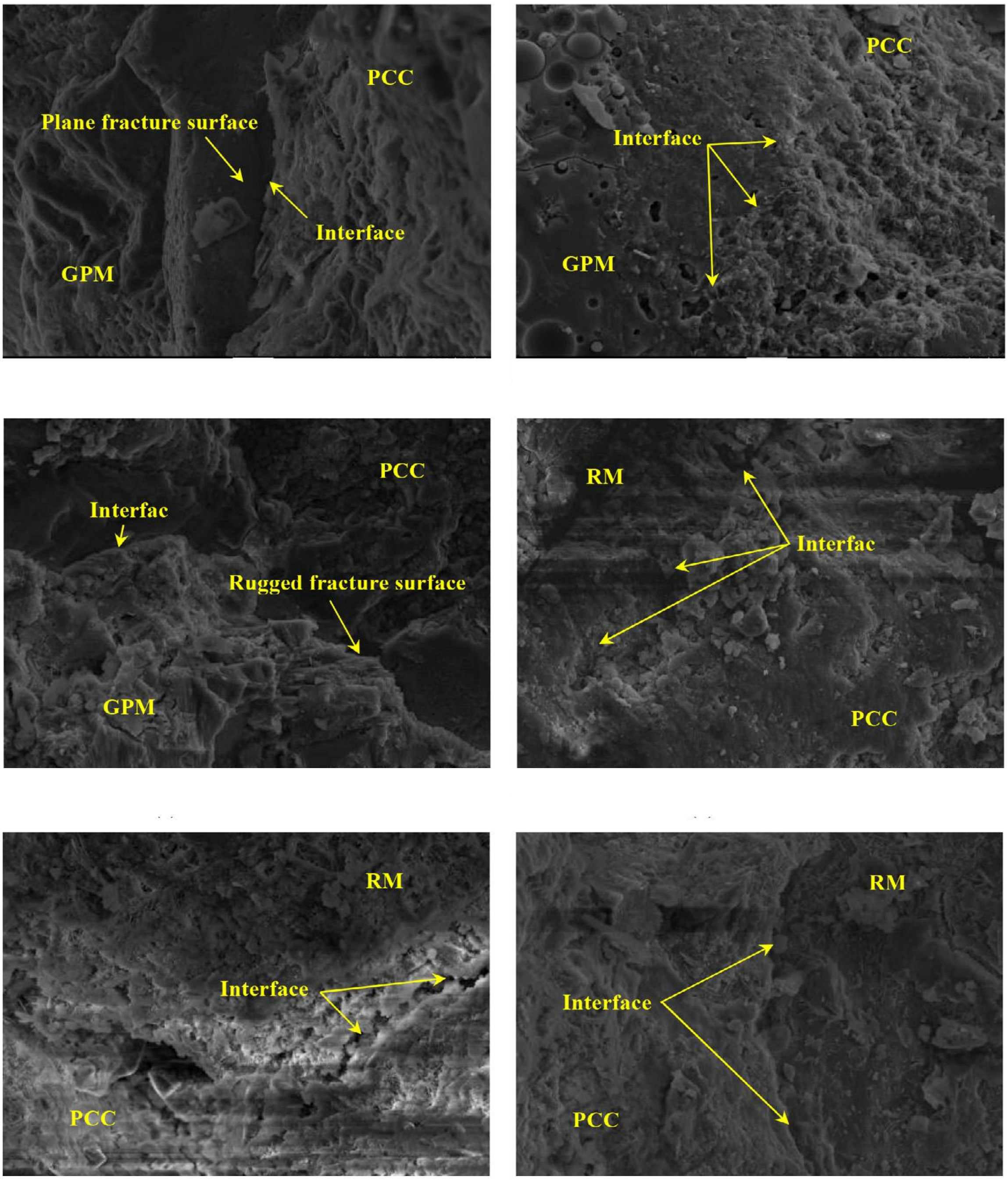


**Figure 3.** SEM micrographs of interfacial transition zone between concrete substrate (PCC) and geopolymeric binder (GPM) or repair material (RM) [9].

The microstructures image of these geopolymer (GPM), concrete substrate (PCC) and interface could be identified from unreacted fly ash, agglomeration of OPC and small line crossing along the interfacial, respectively. The negatively charged Al and tetrahedrally coordinated Al (III) atoms inside the network are charge-balanced by alkali metal cations such as $Na^+$ or $K^+$ (from alkaline activator) and $Ca^{++}$ (from Portland cement grains react with water). Thus, geopolymer which is rich in $Si^{4+}$ and

$Al^{3+}$ ions can react with $Ca(OH)_2$ at the surface of substrate leading to bonding strength development at the contact zone.

**3. Substrate Surface Treatment**

Surface treatment or surface roughness is an important parameter to put into consideration in order to enhance the bond strength between repair material and concrete substrate as shown in Figure 4 such as sand blasting, wire brushing, drill holes, acid etching, against metallic formwork, and grooves. The surface of the concrete structure or damaged concrete surface area is treated by increasing the roughness surface and it is believed that it wills courage the bond strength between an old concrete and repair material [3]. Recently, many researchers tried different types of surface roughness and identify the best method in terms of practicality and strength [11,19]. This is because the bond strength depends not only on the characteristics of the repair material but also on the surface roughness of concrete substrate.

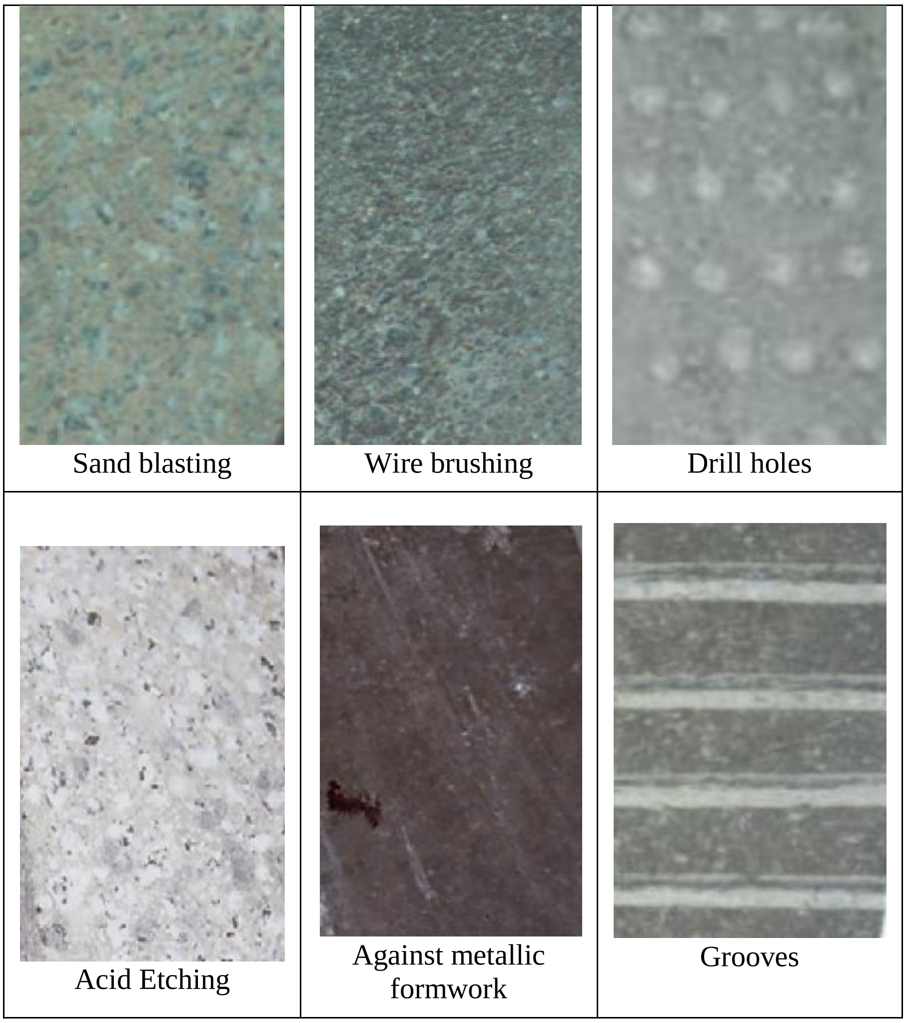


**Figure 4.** Different surface preparation of the concrete substrate.

Bond strength between the repair materials and substrate depends on the surface treatment of the substrate, as the surface treatment increases the bond strength increases [24]. Geopolymer possess very high bond strength however, some researchers believed that it is not affected by increasing the surface roughness of the concrete substrate [8]. The surface substrate that is rich in calcium hydroxide but lack exposed course aggregates which could contribute to improve bond strength due to silica dissolution from the aggregate surface. However, it is believed that surface treatment will have a significant impact to the bonding between repair material and concrete substrate although, the calcium hydroxide is reduced at the interface but this required for further analysis.

## 4. Conclusion

As conclusion, previous researchers proved that geopolymer can be used as repair materials and bond strength between repair materials and substrate is important to meet the requirement and effectiveness of the repair works. Therefore, the recommendation is to study the possibility of using the geopolymer as a repair material for a long term durability. Since one of the most critical factors affecting excellent repair material is the bond strength between a repair material and an existing concrete, a comprehensive analysis and study is required to understand the reaction and bond mechanism between geopolymer and concrete substrate.

## 5. Acknowledgments

The author would like to express his gratitude to the Center of Excellence Geopolymer & Green Technology (CEGeoGTech) for funding the research project.

## 6. References

[1] Sumesh M, Alengaram U J, Jumaat M Z, Mo K H, and Alnahhal M F 2017 *Construction and Building Materials* **148** 62–84
[2] Singh B, Ishwarya G, Gupta M, and Bhattacharyya S K 2015 *Construction and Building Materials* **85** 78–90
[3] Momayez A, Ehsani M R, Ramezanianpour A A, and Rajaie H 2005 *Cement and Concrete Research* **35** 748–757
[4] Pacheco-Torgal, Abdollahnejad Z, Miraldo S, Baklouti S, and Ding Y 2012 **36** 1053–1058
[5] Espeche A D and Lee J 2011 *Construction and Building Materials* **25** 1222–1235
[6] Momayez A, Ehsani M R, Ramezanianpour A A, and Rajaie H 2005 *Cement and Concrete Research* **35** 748–757
[7] Alanazi H, Yang M, Zhang D, and Gao Z 2016 *Cement and Concrete Composites* **65** 75–82
[8] Pacheco-Torgal F, Castro-Gomes J P, and Jalali S 2008 *Construction and Building Materials* **22** 154–161
[9] Phoo-Ngernkham T, Sata V, Hanjitsuwan S, Ridtirud C, Hatanaka S, and Chindaprasirt P 2015 *Construction and Building Materials* **98** 482–488
[10] Nie Q, Hu W, Ai T, Huang B, Shu X, and He Q 2016 *Construction and Building Materials* **125** 905–911
[11] Nath P and Sarker P K 2015 *Cement and Concrete Composites* **55** 205–214
[12] Somna K, Jaturapitakkul C, Kajitvichyanukul P, and Chindaprasirt P 2011 *Fuel* **90** 2118–2124
[13] Temuujin J, Riessen A, and Williams R 2009 *Journal of Hazardous Materials* **167** 82–88
[14] Khan M Z N, Nuruddin F A, Hao Y, and Hao H 2016 *Construction and Building Materials* **125** 809–820
[15] Nath P and Sarker P K 2014 *Construction and Building Materials* **66** 163–171
[16] Duan P, Yan C, and Luo W 2016 *Construction and Building Materials* **124** 69–73
[17] Al Bakri A M M, Kamarudin H, Bnhussain M, Nizar I K, Rafiza A R, and Zarina Y 2012 90–97
[18] Yun Ming L, Yong H C, Al Bakri M M, and Hussin K 2016 *Progress in Materials Science* **83** 595–629
[19] Islam A, Alengaram U J, Jumaat M Z, and Bashar I I 2014 *Materials and Design* **56** 833–841
[20] Zarina Y, Mustafa Al Bakri A M, Kamarudin H, Nizar I K, and Rafiza A R 2013 *Reviews on Advanced Materials Science* **34** 37–43
[21] Davidovits J 1994 *First International Conference on Alkaline Cements and Concretes* 131–149
[22] Phoo-ngernkham T, Sata V, Hanjitsuwan S, Ridtirud C, Hatanaka S, and Chindaprasirt P 2015 *Construction and Building Materials* **98** 482–488

[23] Tayeh B A, Abu Bakar B H, Megat Johari M A, and Voo Y L 2013 *Procedia Engineering* **54** 554–563
[24] Tayeh B A, Abu Bakar B H, Megat Johari M A, and Voo Y L 2012 *Construction and Building Materials* **36** 538–548