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GEOPOLYMER AS REPAIR MATERIAL - A REVIEW

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Abstract — ***Cement is the world's most used construction binder material. Cement production emits large amounts of CO2 and consumes significant amount of energy. As a result, it is necessary to find a new concrete material to replace traditional Portland cement concrete, which is environmentally stressful, yet provides an effective building material. Geopolymer is an emerging alternative binder to Portland cement for making concrete. Geopolymer concrete is principally produced by utilizing industrial by-product materials such as fly ash, blast furnace slag, and other aluminosilicate materials. RCC structures undergo serious durability problems like spalling, erosion, wear, cracking, corrosion etc. years after the construction. Repair to damaged concrete are important not only to ensure the planned useful life, but also to provide good performance and security. This paper review the literature related to the studies conducted on geopolymer and repair materials.***

Keywords — Geopolymer concrete, Bond strength, Repair materials, Slant shear test, Cylindrical splitting test, Substrate

I. INTRODUCTION

Cement is the world's most used construction binder material. Cement production emits large amounts of CO_2 and consumes significant amount of energy. Production of one ton of Portland cement releases one ton of CO_2 into the atmosphere. The global cement industry contributes around 6% of all CO_2 emissions. It is a common viewpoint that finding an alternative material to the Portland cement is imminent. Some researchers have stated that CO_2 emission could increase by 50% compared with the present scope. Therefore, the impact of cement production on the environment issues a significant challenge to concrete industries in the future. As a result, it is necessary to find a new concrete material to replace traditional Portland cement concrete, which is environmentally stressful, yet provides an effective building material.

Promoting low-emission concretes is essential in order to face the crucial challenge to reduce the environmental impact of the construction sector and the concrete industry and to limit the impact of climate change. One way of reducing these CO_2 emissions is the use of blended cements in which a part of the Portland cement clinker is replaced with supplementary cementitious materials (SCMs). The most common SCMs used in high-volume applications are fly ash (FA) and ground granulated blast furnace slag (GGBFS). Fly-ash-based and GGBFS based blended cements are extensively used but limits are imposed on the OPC replacement. In most cases, blended cements still contain more OPC clinker than SCM. On the other hand, geopolymer is a new construction material which could be produced by the chemical action of inorganic molecules, without using any Portland cement. The geopolymer binder could be produced through chemical reaction between alumino-silicate materials such as fly ash or metakaolin that are rich in SiO_2 and Al_2O_3 and alkaline solutions such as Sodium Hydroxide or Sodium Silicate.

Fly ash is a suitable material for making geopolymeric binder because of its pertinent silica and alumina composition and low water demand. Low-calcium fly ash-based geopolymer concrete cured in high temperature has been reported to have good mechanical properties in both short and long term tests. The structural behaviour of heat-cured fly ash geopolymer concrete was found to be similar or superior to that of OPC concrete when tested for reinforced columns and beams, bonding and fracture properties.

The hardening mechanism for geopolymers essentially contains the polycondensation reaction of geopolymeric precursors, regularly aluminosilicate oxides, with alkali polysilicates yielding a polymeric silicon –oxygen aluminium framework.

II. LITERATURE SURVEY

A. GEOPOLYMER CONCRETE

Turner and Collins (2013) studied comprehensive carbon footprint estimates for both geopolymer and OPC concrete, including energy expending activities associated with mining and transport of raw materials, manufacturing and concrete construction. The CO_2 footprint generated by concretes comprising geopolymer binders and 100% OPC concrete were compared. The CO_2 footprint of geopolymer concrete is approximately 9% less than comparable concrete containing 100% OPC binder.

Suwan and Fan (2014) found out the influence of OPC replacement and manufacturing procedures on the properties of self-cured geopolymer. The self-cured GPC could be developed with OPC addition. The solidifying behaviour and early strength development of geopolymer cement was found to be influenced by the manufacturing procedure.

Nath and Sarker (2015) studied the use of OPC to improve setting and early strength properties of low calcium fly ash geopolymer concrete cured at room temperature. Inclusion of OPC as little as 5% of total binder reduced the setting time to acceptable ranges and caused slight decrease of workability. The early age compressive strength improved significantly with the addition of OPC.
Onutai et al. (2015) used an aluminium hydroxide waste and fly ash for preparation of geoploymer concrete. It demonstrated that slurry containing higher content of alumina was having a higher elastic modulus and setting time. The geopolymerization was found to be increased with the increase in the concentration of NaOH. The contents of the Al-waste in the geopolymer influenced the geopolymer strength when NaOH concentration was changed at different curing temperatures.

Jo et al. (2015) developed the optimum mix design procedure for fly ash geopolymer paste. The study showed that an ambient temperature-cured geopolymer paste could be prepared with a high volume flyash use (60%), low volume Portland cement replacement (40%), nanoSiO2 (0.04%), and alkali activation (1.71 M NaOH).

Wardhono et al (2015) studied the strength of alkali activated slag/flyash (AASF) mortar blends at ambient temperature.) Study shoes that the ability of slag and fly ash to replace ordinary Portland cement in concrete can potentially reduce the environmental impact over the production of CO2. AASF made by 100% slag shows the highest initial compressive strength. AASF mix made by 50% slag and 50% fly ash exhibits the highest compressive strength at 28 days. Study suggests that the blending of slag and fly ash could provide a solution for the need for heat in the curing of fly ash based-geopolymer concrete.

Kirubajiny et al (2016) conducted study on carbonation of blended slag flyash geopolymer in field condition after 8 years of exposure. Carbonation rate of geopolymer concrete highly depends on the mix design of materials. Geopolymer concrete with 70% fly ash and 30% GGBFS shows greater resistance against carbonation compared to geopolymer concrete with 75% fly ash and 25% GGBFS. It was also observed that permeation properties of geopolymer concrete are strongly related to carbonation rate. Higher carbonation geopolymer concrete contains high permeation whereas less permeation characteristics were identified in lower carbonated concrete.

Ali et al (2016) studied the effect of addition of cement on performance of fly ash based geopolymer concrete. The effect of solution resting time and curing condition on geopolymer were also studied. The study shows that inclusion of Portland cement increases compressive strength, tensile strength and modulus of elasticity. It was also reported that the workability slightly reduces with inclusion of cement in geopolymer concrete. It was found that increasing the temperature of curing increase the performance of geopolymer concrete up to 70℃.

Partha et al. (2016) studied the sorptivity and acid resistance of ambient cured geopolymer mortars containing nano-silica. The effect of nano-silica on the flowability, compressive strength of geopolymer mortars were also studied. Study shows that inclusion of nano-silica include the early strength of geopolymer mortars. Sorptivity of specimen with 2% nano-silica was less than that of specimen without nano-silica. The acid resistance of geopolymer mortars was improved with the inclusion of 2% nano-silica. The micro structures of specimen with nano-silica were found out to be more compact as compared to specimens without nano-silica.

Lateef et al. (2016) investigated about the effects of alkaline activator type, curing procedure and source of flyash on early strength compressive strength of geopolymer concrete. It was found that the geopolymer strength was directly affected by the source of flyash. It was also found that use of silica fume based activating resulted in higher compressive strength than sodium silicate based activation solution.

Yeonho et al. (2016) investigated the compressive strength after partially replacing sand with crumb rubber. Studies was done by replacing fine aggregate by an amount of 5%, 10%, 15% and 20% of volume by crumb rubber. Regression models were also proposed to identify the critical parameter and to find the effect of replacement of fine aggregate.

It was found that the compressive strength decreases with increase in rubber content. Larger reduction was found in geopolymer using activator solutions with lower sodium silicate to sodium hydroxide ratio.

Nguyen et al. (2016) conducted the theoretical and experimental study on mechanical properties of fly ash-geopolymer concrete. The measured values of the modulus elasticity of heat-cured low-calcium fly-ash-based geopolymer concrete, with compressive strength in the range 45–58 MPa, were different from those of conventional concrete. The Poisson's ratio of fly-ash-based geopolymer concrete with compressive strength in the range of 45–58 MPa, is from 0.16 to 0.21. These values are similar to the values of conventional concrete. The stress–strain relations of heat-cured fly-ash based geopolymer concrete in compression well match the formulation designed for Portland cement concrete. The obtained indirect tensile strength of fly-ash geopolymer concrete is greater than the values calculated using an expression designed for Portland cement concrete.

B. FACTORS AFFECTING CONCRETE-CONCRETE BONDING

Behfarnia et al. (2005) studied the bond between repair materials and concrete substrate in marine environment. The effect of initial curing periods and surface preparation was studied. It was found that the bond strength of repair materials can be considerably increased with surface roughening and acid etching method is the most effective method among the four methods implemented in the study. Initial curing shows considerable effect on bond strength of repair materials, longer periods of initial curing, higher bond strength will be developed in repair materials. It was also found that the bond strength of repair materials reduces in crude oil environment but with use of a proper percentage of microsilica in composition of repair material the damaging effect of crude oil was highly reduced. With use of microsilica in composition of repair concrete the reduction of bond strength due to sulphate attack was lowered.
Eduardo et al. (2006) studied the influence of added concrete compressive strength on adhesion to an existing concrete substrate. This study evaluated the bond strength between two concrete layers of different ages, considering two different mixtures of added concrete, with different strengths. This study shows that the compressive strength influence the concrete to concrete bond strength and also shows that the shear strength at interface can be improved by casting added concrete at later times.

Beushausen (2010) studied the influence of concrete substrate preparation overlay bond strength. This study identified that a saturated, surface-dry substrate concrete has generally no beneficial influence on overlay bond strength. In many instances, the use of substrate surfaces prepared to what is commonly considered the optimum moisture condition resulted in significantly lower bond strength, compared with non-preconditioned substrates. This phenomenon was ascribed to better mechanical interlock, which exists when the fresh overlay material can flow into the unsaturated cavities and pores of the substrate. Bonding agents were found to enhance bond strength only when an overlay of low workability was applied. For overlays with workability characteristics of conventional concretes (slump values between 70 and 110 mm), bonding agents were found to have no noticeable influence on bond strength. This relates to the circumstance that overlays of sufficient fluidity can fill the pores and cavities of the substrate without the help of a bonding agent.

Tayeha et al. (2013) evaluate the bond strength between normal concrete (NC) substrate and ultra-high performance fiber concrete (UHPFRC) repair material. Slant shear tests were performed to quantify the bond strength in shear, split tests conducted to evaluate the bond strength in indirect tension. The study showed that UHPFC exhibits excellent interlocking with the surface of NC substrate, and then gives bond strength greater than the strength of NC. Most of the failure in the split cylinder tensile strength test and slant shear strength was through the NC substrate specimen which indicated the bond strength between UHPFC and NC substrate is stronger than the cracking strength of the NC. The bond strength between the UHPFC and substrate was found to influence by surface treatment of the substrate. In the study, the highest bond strength was found to be for the sand blasted surface.

Rashid et al. (2015) conducted experimental and analytical investigations on the behaviour of interface between concrete and polymer cement mortar. The study suggests that overlay transition zone is the weakest zone in the composite specimens. Prediction formula for interfacial tensile strength was proposed in this paper and it shows close agreement with the experimental results.

C. BONDING OF GEOPOLYMERIC MATERIALS

Shuguang et al. (2008) studied the bonding and abrasion resistance of slag based geopolymeric material. The study shows that geopolymeric material shows higher bonding property and also the abrasion resistance of geopolymer were higher than cement based repair materials.

It was also found that the early strength of geopolymer concrete is higher than cement based repair materials at 1st day, 3rd day and 7th day. But after 28th day the strength of geopolymer concrete is less than that of cement based concrete.

Under microstructure analysis it was found that the steel slag was almost fully absorbed to take part in alkali activated polymerisation reaction in geopolymer.

Prabir (2011) studied the bond strength of reinforcing steel embedded in flyash based geopolymer concrete. Pull out test was used to determine the bond strength of geopolymer concrete and OPC concrete with reinforcing steel. Geopolymer concrete and OPC concrete shows similar cracking pattern under pull out test. Study also found that bond strength of geopolymer concrete was higher than that of OPC concrete.

Zhang et al. (2012) studied the potential application of geopolymers as protection coatings for marine concrete. Setting time, permeability, anticorrosion, bond strength and volume stability were used as parameters to evaluate the applicability of geopolymer concrete as a repair material under marine environment. It was found that the geopolymer coatings set within 4 hours, bond strongly with concrete and able to resist the shock due to tide. It was also found that geopolymer concrete with GGBFS shows lesser permeability and higher corrosion resistance than normal concrete.

Tanakom et al. (2015) studied the effect of sodium hydroxide and sodium silicate solutions on bond shear bond strength of flyash - granulated blast furnace slag geopolymer. It is found that the bond strength of geopolymer concrete depends on the type of alkaline activator solution and compressive strength of geopolymer concrete. It is also observed that the reaction product of geopolymer depends on source of material and alkali activator solution.

Zhang et al. (2015) studied the bond strength of geopolymers at ambient and elevated temperatures. The study shows that geopolymers exhibit slightly lower bond strength than that of epoxy resin at room temperature, however geopolymers retain much higher bond strength in 100– 300 ^{0}C. Addition of small quantity of short carbon fibers in metakaolin or flyash will not improve the bond strength of geopolymers at ambient temperature, but greatly improve bond strength at 100–300 ^{0}C through crack control mechanism. Addition of short carbon fibers provides better crack control in geopolymers than that of short basalt fibers.

Alanazi et al. (2016) studied the bond strength of PCC pavement repairs using metakaolin- based geopolymer mortar. Splitting test and a slant shear test are performed to characterize the bond strength of the geopolymer and conventional cement mortar interfaces. Effect of curing time, degradation of bond strength when exposed to acid and bonding behaviour of the metakaolin geopolymer with other repair materials were analysed. It was found that curing time affects the interface bond strength. Curing temperature was found to influence the strength of metakaolin geopolymer. It is found that the failure initiated and progress through the mortar, which indicates bond at interface formed of geopolymer and cement substrate is excellent.

III. CONCLUSION

From this literature survey, following conclusions were made

- *The CO_2 footprint of geopolymer concrete is less than compared to concrete containing 100% OPC binder.*
- *Geopolymer concrete containing higher content of alumina will have a higher elastic modulus and setting time.*
- *The acid resistance and Sorptivity of geopolymer mortars was improved with the inclusion of 2% nano-silica. The micro structures of specimen with nano-silica was also found out to be more compact as compared to specimens without nano-silica.*
- *Increasing the temperature of curing will increase the performance of geopolymer concrete up to 70℃.*
- *It was found that the geopolymer strength was directly affected by the source of flyash. It was also found that use of silica fume based activating resulted in higher compressive strength than sodium silicate based activation solution.*
- *The compressive strength of geopolymer concrete decreases with increase in rubber content.*
- *The stress–strain relations of heat-cured fly-ash based geopolymer concrete in compression well match the formulation designed for Portland cement concrete.*
- *The inclusion of Portland cement will increases compressive strength, tensile strength and modulus of elasticity of geopolymer concrete. The workability of fresh geopolymer concrete slightly reduces with inclusion of cement.*
- *The self-cured GPC could be developed with inclusion of OPC.*
- *The solidifying behaviour and early strength development of geopolymer concrete was found to be influenced by the manufacturing procedure.*
- *The overlay transition zone is the weakest zone in the composite specimens.*
- *The bond strength of repair materials can be considerably increased with surface roughening.*
- *The compressive strength of substrate and repair material influence the concrete to concrete bond strength.*

- *The bond strength between the repair material and substrate was greatly influenced by surface treatment of the substrate.*
- *Geopolymeric material has higher bonding property and also the abrasion resistance of geopolymer is higher than cement based repair materials.*
- *Geopolymer concrete and OPC concrete shows similar cracking pattern under pull out test.*
- *Geopolymer concrete with GGBFS shows lesser permeability and higher corrosion resistance than normal concrete.*
- *The bond strength of geopolymer concrete depends on the type of alkaline activator solution and its compressive strength.*
- *Addition of small quantity of short carbon fibers in metakaolin or flyash will not improve the bond strength of geopolymers at ambient temperature, but greatly improve bond strength at 100–300 ^{0}C through crack control mechanism.*
- *Addition of short carbon fibers provides better crack control in geopolymers than that of short basalt fibers.*
- *Curing time affects the interface bond strength of metakaolin geopolymer repaired concrete and curing temperature will influence the compressive strength of metakaolin geopolymer.*

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