A Review and Laboratory Trials on the Development of Geopolymer Mortar from Ceramic Waste

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ABSTRACT

Concrete as a construction material, has been used and is still the most widely used material in the construction industry due to the easiness, its versatility, and the various advantages it has. But due to the massive use, concrete currently accounts for about eight percent of the carbon dioxide being emitted into the atmosphere, making it a major contributor to the climate crisis. The use of new materials has always been a challenge and a topic of vast inquisitiveness in the construction industry. Materials providing an improvement and conformance to increasing technical and ecological requirements play a crucial role in the sustainable development of resource- and energy-intensive cements and concretes. Over the past decades, an extensive resource base of natural and technogenic materials has been established for alkali-activated materials (AAMs) and is being continuously expanded with the rapid development of the alkali-activation theory and technology and the ongoing studies of many research groups around the world. In the ceramic industry, about 15-20 percent waste material is generated from total production and as of now there are no measures taken to recycle this waste or to utilise this effectively. The ceramic waste is also durable, hard and resistant to physical, chemical and biological factors. Combining all these factors and the idea of sustainability and AAM, the replacement of cement completely by ceramic waste appears to be a novel idea. Hence, this paper reviews the developments and possibility of using the ceramic waste as a binder material to form a geopolymer system. Preliminary laboratory trials made in this direction are also presented in the paper.

Keywords: Geopolymer, alkali activated materials, ceramic waste, binder materials, industrial waste, low cost, sustainable, aluminosilicates

1 Introduction

Although Portland cement based materials are still widely used for the construction, its production has started to diminish and the manufacturing of cement cause lot of environmental issues. For every one tonne of cement manufactured, nearly 1.7 tonnes of raw materials are consumed and in this process, about 0.8 tonnes of carbon dioxide is released to the atmosphere. It is a known fact that cement manufacturing industry alone contributes to about 6-7% of entire global carbon dioxide emissions. Also, the manufacturing consumes large quantities of rock extraction from quarry leading to their depletion and causing environmental issues. For protecting the environment and to have sustainable development, it is high time to develop new materials that can be used as an alternative to conventional cement or concrete. Geopolymer binder is one such innovative material that can be produced from aluminosilicate rich precursors activated by alkaline solution. They are amorphous and inorganic polymers consisting of repeating sialate monomer units (–Si–O–Al–O–). Industrial wastes rich in

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amorphous alumina and silica can be made use of in producing geopolymer systems. The common precursors used are kaolinite, feldspar, industrial by-products such as fly ash, slag, mining waste etc.

The reactivity of these precursor materials to form effective geopolymer depends on the chemical and mineralogical composition of precursors, fineness of materials, amorphous phase content etc. The precursor should be such that it should release aluminium easily on activation with the alkali activators (Provis and Deventer, 2009). The alkali activators commonly used are sodium hydroxide (NaOH), potassium hydroxide (KOH), sodium silicate (Na_2SiO_3) and potassium silicate (K_2SiO_3). Upon activation by the alkali solution, the aluminosilicate rich precursors get dissolved and free $[SiO_4]^-$ and $[AlO_4]^-$ tetrahedral units are released in solution. The tetrahedral units are alternatively linked to polymeric precursor by sharing oxygen atom, thus forming polymeric Si-O-Al-O bonds (Davidovits, 2015).

This paper explores the feasibility of using ceramic waste from industry as a precursor for making geopolymer binder systems. The ceramic waste material from industry was used as a binder material as it contained 37% alumina and 45% silica which are reactive and take part in the process of geopolymerisation. El-Dieb and Shehab (2014) studied the potential of ceramic waste powder in the preparation of geopolymer concrete by testing properties such as compressive strength, water absorption, electrical resistivity and microstructural analysis. The authors showed that ceramic waste powder can be used for preparing cementless concrete. Reig et al. (2017) used ceramic waste as aggregate and precursor. Huseien et al. (2018) suggested ternary system consisting of ceramic waste, slag and fly ash for alkali activated systems. Rakhimova and Rakhimov (2019) presented a comprehensive review of advancements in the alkali activated systems and new precursors which can be used for making such systems. Thus, based on the review of literature, it is seen that ceramic waste could be used as a potential precursor ingredient in making the geopolymer systems. The aim of this study is to take an advantage of their properties, due to silica and alumina being the main element contained in their compositions which are the most important elements to generate the aluminosilicate gel in geopolymerisation process and to study the method of the utilization of ceramic waste in order to avoid the waste disposal cost. In forming of the aluminosilicate bonds, the alkaline activated solution of sodium hydroxide and sodium silicate is required to activate the source materials. In addition, the geopolymer production can reduce the contaminant leachability by both physical adsorption or (encapsulation) and chemical (fixation) means to convert the waste into an environment friendly and sustainable product which can be used for construction purposes. This paper reviews the developments and possibility of using the ceramic waste as a binder material to form a geopolymer system. Preliminary laboratory trials made in this direction are presented in the sections below.

2 Materials and Methods

Ceramic waste was collected from a nearby ceramic industry, Kerala Ceramics Limited in Kundara, Kollam, wherein ceramic waste was produced as an industrial bye product. The ceramic waste powder (Figure 1) appeared to be fine and white in colour. The fineness upon sieving through IS sieve 90 µm was only 3%. The specific gravity of the ceramic powder measured using Le Chatelier flask was only 2.43. Hence, the ceramic powder collected without any further processing was used as the binder in the preparation of geopolymer mortar. Sodium hydroxide and sodium silicate were used as activators by preparing the alkaline solution.

The alkaline solution to binder ratio by weight was fixed as 0.50 and the sand to binder ratio for the mortar was fixed as 1.50 respectively. The ratio of Na_2SiO_3/NaOH solutions by weight was 2.50. Manufactured sand passing 2 mm IS sieve was used as fine aggregate in the study. Fosroc Conplast SP 430 (sulphonated naphthalene based) Superplasticizer at a dosage of 3% by weight of binder was used as chemical admixture for improving the fresh properties of the mortar. Sodium hydroxide solution of 10M was used for the study. For 1 kg NaOH solution, 314 g of NaOH is added to 686 g distilled water.

The prepared mortar specimens were cubical of side 5 cm. At first, the ceramic powder was mixed dry with the fine aggregate. 80% of alkaline solution was added to the dry mix and mixed well in Hobart mixer (Figure 2). After 2-3 minutes of mixing, admixture was added to the remaining 20% alkaline solution, and this was added to the mortar mix, and mixed well for another 2-3 minutes. The fresh mortar was then filled in the moulds, hand compacted. After 24 hours, the specimens were demoulded and subjected to ambient air curing (Figure 3). Similar set of specimens were subjected to heat curing by placing in digital oven at 70 °C for 24 hours (Figure 4).

Figure 1. Ceramic powder used in the study for preparing geopolymer mortar

Figure 2. Preparation of geopolymer mortar using Hobart mortar mixer

Figure 3. Air cured specimen

Figure 4. Oven cured specimen

3 Results and Discussion

Both paste and mortar systems were tested. The initial and final setting time of geopolymer paste (subjected to air curing) was measured using Vicat apparatus as per IS 4031: Part 5 (2005). The mortar specimens were tested for compressive strength and hardened bulk density after 7 days of casting (i.e. after 24 hours of oven curing at 70 °C followed by ambient air curing). These results are discussed below.

3.1 Setting time of geopolymer paste

The initial setting time of paste is considered as the time elapsed between the times that the water is added to the paste mix, to the time that the paste starts losing its plasticity. The final setting time is the time elapsed between the moment the water is added to the paste, and the time when the paste has completely lost its plasticity and has attained sufficient stiffness to resist certain definite pressure. The time taken by initial setting needle to penetrate a distance of 5±0.5mm from the bottom of the mould was taken as the initial setting time and the time when the annular ring of the final setting needle fails to make the impression on the paste was recorded as the final setting time of the paste (IS 4031: Part 5, 2005). Additionally, the penetration of needle (from the top surface of mould) was measured every 15 minutes, and a graph (Figure 5) was plotted between the penetration from surface and the elapsed time. It is observed that the paste has not started setting till 135 minutes, and thereafter started stiffening. The initial setting time and final setting time of ambient air cured geopolymer paste was 165 minutes and 240 minutes respectively and the setting times were acceptable.

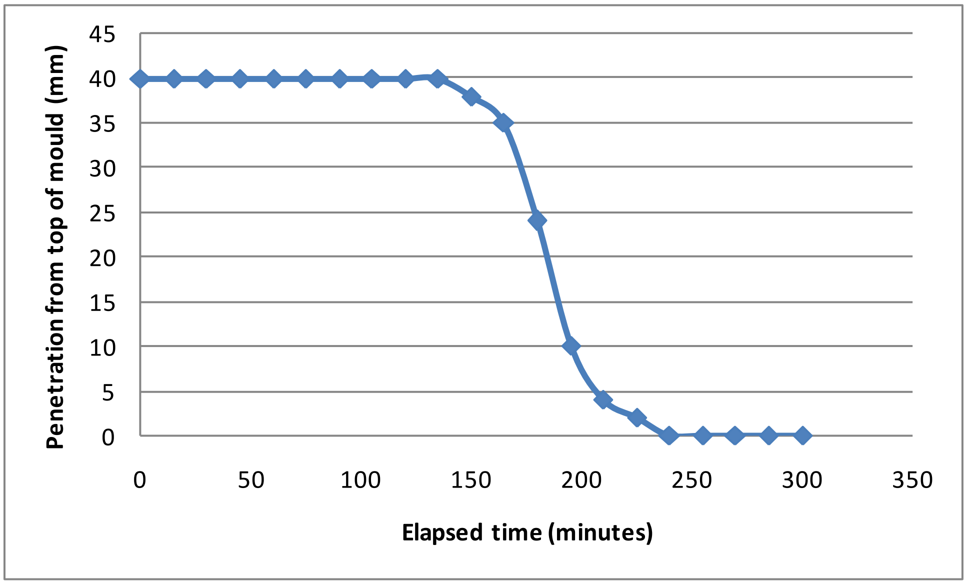

Figure 5. Stiffening process of geopolymer paste

3.2 Compressive strength of mortar

Table 1 shows the average 7 day compressive strength and hardened bulk density of geopolymer mortar subjected to ambient curing and heat curing (followed by air curing). It is seen that heat curing for 24 hours at 70 °C only improved the compressive strength marginally. The strengths attained were low. The reduced strength may be due to the fact that ceramic powder was used as binder in the as received form without any processing. It appears that the ceramic powder needs further heat processing in order to make it more reactive and apt as a precursor for geopolymer systems. Also, it is suggested to do X-ray diffraction and X-ray fluorescence tests on ceramic powder in order to determine its chemical composition. The bulk density of mortar subjected to air curing and heat curing was 2.3 and 2.21 g/cm^3 respectively. Both the low strength and bulk density results points out that these geopolymer mortars can be used for light weight applications.

Table 1. Hardened properties of geopolymer mortar

Property	Ambient air curing	Heat curing followed by air curing
Average compressive strength (MPa)	7 MPa	8 MPa
Hardened bulk density (g/cm^3)	2.30 g/cm^3	2.21 g/cm^3

4 Conclusion

Alkali-activated materials (AAMs) is a trending topic of modern research and is being continuously expanded with the developments in alkali activation theories, innovative use of new precursor materials, new sources for alkali activation etc. This paper reviews the developments and possibility of using the ceramic waste as a binder material to form a geopolymer or alkali activated binder system. Ceramic waste is considered as a new binder precursor apart from usual materials such as fly ash, slag etc. Based on the preliminary laboratory studies, it appears that the ceramic waste when used in as received form without any processing is not much useful in producing geopolymer system with enhanced properties. However, this may be used in the production of alkali activated mortar or concrete systems for light weight applications, non-load bearing structural components, partition walls etc. More in-depth studies are necessary in studying the potential of ceramic waste and the effect of any processing methods in improving the utilisation of ceramic waste in geopolymer systems.

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A Review on Behaviour of Beam Column Joint Using EAF Steel Slag Concrete

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ABSTRACT

The amount of industrial waste generated and the overexploitation of quarries worldwide are becoming one of the serious environmental problem. Electric Arc Furnace (EAF) steel slag is currently used for asphalt concrete pavements in many countries but huge quantities of this material are still landfilled. Reusing the slag as recycled material in the construction industry not only helps in the reduction of the amount of waste disposed off but can also bring down the consumption of natural aggregates. EAF slag is the secondary product of the steel production process and is procured after the separation of molten steel from impurities. In this review paper, the impact of using EAF concrete on the structural behavior of internal beam-column joints and also the resisting mechanism of these joints are studied. A parametric study on the structural performance of EAF concrete compared to conventional concrete in terms of the load-carrying capacity, energy dissipation and strength attained by the joint in failure condition is made.

Keywords: Beam column Joint, EAF Concrete

1 Introduction

India is the second-biggest crude steel producer in the world. According to the data of the World Steel Association, crude steel production in India in 2019 was estimated at 111.2 million tons which resulted in 12 million steel slag tons. This leaves a certain remark in the enormous quantity of slag produced. The steel slag is generally discarded worldwide and is becoming an important problem due to the scarcity of land. The problem is further added as there are no adequate specific regulations or norms for the disposal and control of slag generation. EAF slag is obtained as a steel production process byproduct and when Electric Arc Furnace is used instead of Basic Oxygen Furnace (BOF). The advantages of using EAF compared to BOF is mainly of the following reasons: (i) material consumption of BOF process is higher, (ii) energy consumption of BOF process is 2.8 times greater than that of EAF process, (iii) low carbon emission as in EAF process and (iv) cost of production is lower.In Indian practice, a beam-column joint is not efficiently designed mainly due to economic considerations.

Beam-column joints are critical regions in the moment resisting RC frame, specifically considering combined loading conditions. During earthquakes, the failure of RC frames occurs primarily because of large shear in joints resulting in the entire breakdown of the structure. The design of the joints can be avoided as if the structure is mainly subjected to only gravity load. Adequate detailing and design of joints have to be ensured and controlled to improve the strength and ductility to resist large deformations caused due to earthquakes or wind. The review evaluates the replacement of conventional cement concrete with EAF steel slag and their effect in any structural member i.e. beam column joints.

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2 Need for the study

Beam column joints have a significant influence on the response of the structure. The analytical study conducted on the behavior of this joint gives a proper understanding of its structural behavior and also its importance in a structure subjected to gravity and earthquake loads. By incorporating EAF concrete in this study, the question of whether this sustainable construction technique is acceptable for a critical region like a beam-column joint can be explained. It also gives a better idea about the potential use of EAF steel slag as recycled aggregate in critical regions like beam-column joints thereby contributing to sustainable construction.

Fig 1. Stockpile of EAF steel slag (Source: www. ien.com)

3 Studies on EAF concrete

Manso et al. (2004) conducted experiments on concrete with fine and coarse aggregates replaced by EAF steel slag. The slag obtained was crushed and stabilized to make suitable mortars. Several mixes were designed to analyze their strength and properties. Durability and environmental behaviour were also found out by conducting accelerated ageing, soundness, and leaching tests. Results indicated that the durability of EAF concrete showed an acceptable behaviour against aggressive environments especially in the geographic region where the winter temperature hardly ever falls below 0°C.

Manso et al. (2006) conducted tests to evaluate the internal expansivity of the slag and its resistance to environmental agents, ice and moisture were made. The results showed that the EAF slag concrete performance was similar with conventional concrete in terms of strength and in terms of its durability. The high porosity of EAF slag is the main disadvantage when it comes to concrete making. The leaching test showed a cloistering effect of concrete on the products present in EAF slag which are toxic.

Rajan (2014) evaluated the strength of concrete of M20 mix made with steel slag with the replacement of fine aggregate. The replacement of sand with steel slag was carried out partially for variable percentages of 10%, 20%, 30%, 40% and 50% in weight of sand. Experimental studies like flexural strength test , compression test, tensile strength test and stress-strain test were carried out. The final results showed that the compressive strength, tensile strength and flexural strength increase with the increase in the percentage of steel slag up to 30% by weight of fine aggregate. The stress-strain graph showed that 30 % of steel slag replaced with M20 concrete is similar to traditional M20 concrete.