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Investigation of Flexural Behaviour of Geopolymer Concrete using Recycled Coarse Aggregate

S. Vishnuvardhan[1], C. Sivalingam[2], Dr. M. Lenin Sundar[3], Ms. S. Sasikala[4]
[1]*(Structural Engineering,, Sri Krishna College of Technology, Coimbatore, India)*
[2]*(Structural Engineering, Sri Krishna College of Technology, Coimbatore, India)*
[3] *(Department of Civil Engineering,, Sri Krishna College of Technology, Coimbatore, India)*
[4]*(Department of Civil Engineering,, Sri Krishna College of Technology, Coimbatore, India)*

Abstract: The thesis is mainly concerned with the investigation of geopolymer concrete with the primary aim of addressing the economic, financial and environmental issues associated with the production and use of ordinary Portland cement. Manufacture of Portland cement is known to produce a much higher volume of carbon dioxide gas into the atmosphere, therefore finding a suitable alternative can bring a desirable solution to mitigate the environmental problems caused by the cement production. The thesis gives a review of geopolymer concrete and critically analyses the economic and environmental benefits of geopolymer concrete over Portland cement concrete**.** Geopolymer concrete products are known to have far better durability and strength properties than Portland cement properties. These properties are investigated in the laboratory and verified. Finally the thesis looks at the factors which may hamper the use of geopolymer concrete as an alternative to Portland cement concrete. It is believed that in some countries, the geopolymer concrete does not comply with some regulatory standards, in particular those that define minimum clinker content levels or chemical composition in contents. The issues are investigated and addressed by the thesis. Steel fibres are added with geopolymer concrete to investigate the behavior of geopolymer concrete. Experimental results show that steel fibres improves the compressive and tensile strength of geopolymer concrete.

Keywords: Geopolymer, Steel fibre, Portlandcement, Durability, Tensile Strength.

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1. Introduction

Geopolymer concrete has emerges a new engineering material with the potential to form an important aspect of environmentally sustainable construction and building products industry. Geopolymers are alkali-activated aluminosilicates, with a much lower carbon dioxide emission than ordinary Portland cements. Industrial aluminosilicates waste materials such as coal ash and blast furnace slag are activated by alkali to form geopolymers. As reported by Duxson et al, geopolymers demonstrate improved strength and chemical properties in addition to many other characteristics which are potentially valuable.

Depending on the raw material chosen and processing conditions, geopolymer concrete exhibit a diverse variety of properties, including high compressive strength, low shrinkage, fast or slow setting, acid resistance, fire resistance and low thermal conductivity. The manufacture of geopolymer concrete is carried out using the usual concrete technology methods. The geopolymer paste binds loose aggregates and un-reacted materials together to form geopolymer concrete. The concrete can be produced with or without the use of admixtures. As in the case of OPC, the aggregates occupy 75-80% by mass of geopolymer concrete. Geopolymeric materials made from coal ash can have better chemical and mechanical properties than ordinary Portland cement products. Early researches have shown that geopolymers can be produced cheaply and can be made when naturally occurring materials are mixed with NaOH and water

The manufacture of Portland cement requires the burning of large quantities of fuel, such as coal. The heating of limestone along with the impurities contained in it to produce cement results in high emissions of pollutants including greenhouse gas such as carbon dioxide, carbon monoxide, sulphur dioxide and nitrogen oxides. Excessive carbon dioxide in the atmosphere causes the greenhouse effect which eventually leads to global warming. Geopolymer concrete is therefore expected to provide an appropriate alternative for Portland cement as a binder to mitigate these negative environmental impacts of OPC. The geopolymer concrete can be produced without the need for large quantities of fuel, making it much more energy efficient and obviates much of the environmental pollutants associated with traditional Portland cement production.

Unlike other technologies, there is not yet a significant bulk of research focused attention on understanding the relationships between composition, processing, microstructure and the properties of geopolymer concretes. Fly ash based geopolymer concrete would be used for studies in this thesis.

2. Materials

A wide range of minerals and industrial by-products materials were investigated in the past to determine materials suitable for the manufacture of geopolymers. The source materials found to be suitable include natural minerals such as metakaolin, clays, etc which contains Si, Al and oxygen (O_2) in their chemical composition. By-products materials such as fly ash, silica fume, slag, rice-husk ash red mud, etc could also be used alternatively as the source materials

According to the research made by Davidovits (1999), it found that calcined source materials such as fly ash, slag exhibit much higher final compressive strength compared to the ones made using non-calcined materials such as metakaolin clays. However, it was found that when calcined (e.g. fly ash) and non-calcined (e.g. Kaolinite) materials are combined together; they result in a large improvement in compressive strength and reduction in reaction time.

Fly ash and slag are singled out from the from the by-product source materials to be the potential source materials for the manufacture of geopolymers.Fly ash is regarded as the better option between the two due to its high reactivity that originates from its finer particles. The spherical shape of flyash improves the workability of fresh concrete and its finer particle size acts as filler of voids in the concrete, thus produce dense and durable concrete. In addition to this, low-calcium fly ash is more advantageous than slag for geopolymer feedstock material

3. Properties and Application of Geopolymer Concrete

Application of geopolymer concrete technology is showing great promise to contribute positively to a sustainable concrete industry. Work conducted by Duxson et al (2007) indicated that, depending on the synthesis conditions (including nature of start materials), geopolymer concrete can be made to achieve the following properties:

1. High compressive strength gain
2.Good abrasion resistance
3. Rapid controllable setting and hardening
4. Fire resistance (up to 1000ºC) and no emission of toxic fumes when heated.
5. level of resistance to a range of different acids and salt solutions
6. Not subject to deleterious alkali-aggregate reactions
7. Low shrinkage and low thermal conductivity
8. Adhesion to fresh and old concrete substrate, steel, glass, ceramics
9. High surface definition that replicates mould patterns
10. Inherent protection of steel reinforcing due to high residual pH and low chloride diffusion rates.

It is essential to note that not all geopolymer concretes can possess these properties, but recipe and formulations can be manipulated to accomplish required specification.

3.1 Compressive Strength of Geopolmer Concrete

In comparison with Portland cement products, geopolymer concrete products possess high early strength and low shrinkage properties. They are usually resistant to freeze-thaw and have high thermal resistance qualities (Drechsler, 2005). Fig 4 shows the comparison in strength with time.

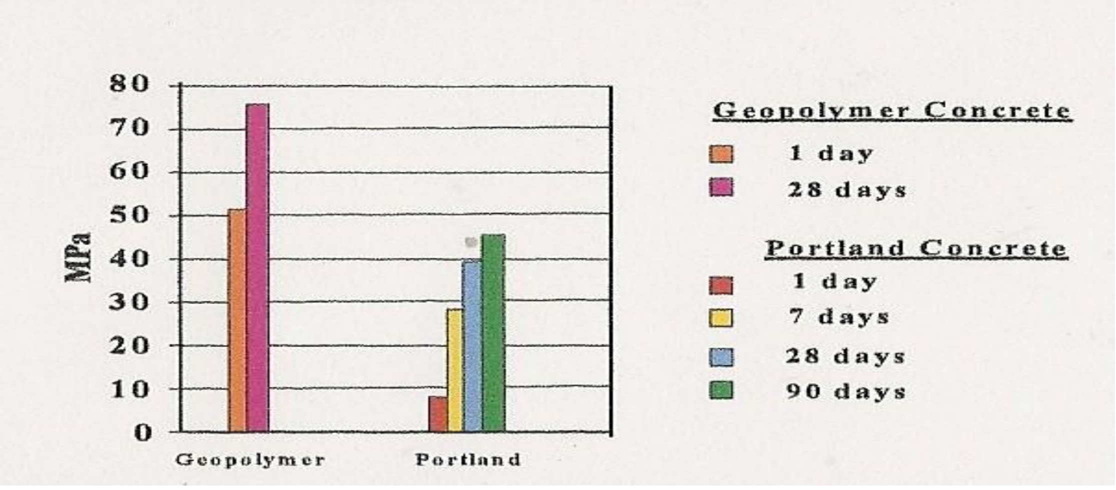

Fig 1: Geopolymer vs. Portland cement concrete strength comparison (Drechsler & Graham, 2005)**.**

Geopolymer are produced using similar batching processes to Portland cement products. However, there is a major difference between geopolymer concrete and Portland cement in the binder (Nguyen, 2009). As reported by Drechsler et al (2005), Hardjito (2004) found out that the use of Super-plasticisers or increment in water contents improve the workability of the geopolymer concrete which result in high slumps of up to 240mm still achieving excellent strength without any indication of aggregate segregation.

Ultimate compressive strength and setting times of geopolymer concrete were found to be dependent on curing temperature, water content, type of alkaline activator and composition of source materials. Hardijito also found out that the presence of compounds other than silica and alumina, e.g. calcium iron oxides, decreases setting times (Drechsler, 2005).

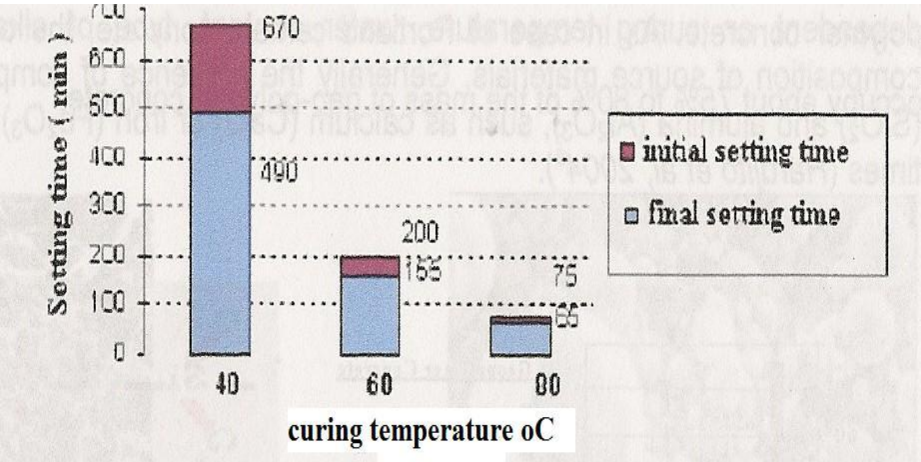

Fig 2 below shows the effect of temperature on setting time of a geopolymer concrete

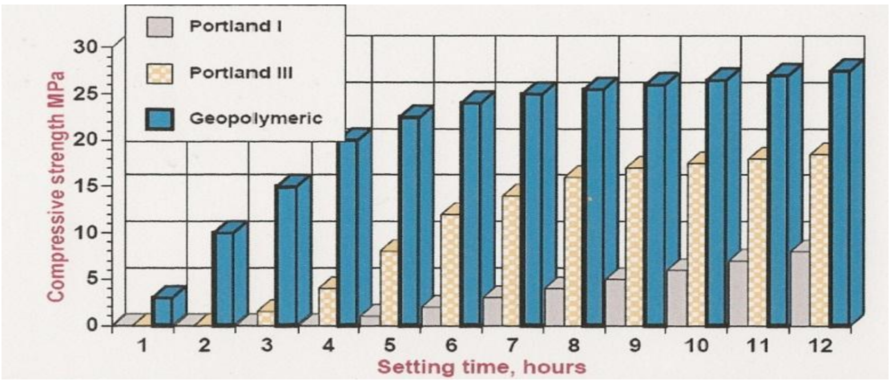

Fig 3: Effect of curing temperature on setting time of a geopolymer concrete (Nguyen, 2009).

Fig2 and **3** above shows that compressive strength of geopolymer concrete is dependent on curing time and curing temperature. As the curing time and curing temperature increase, the compressive strength also increases.

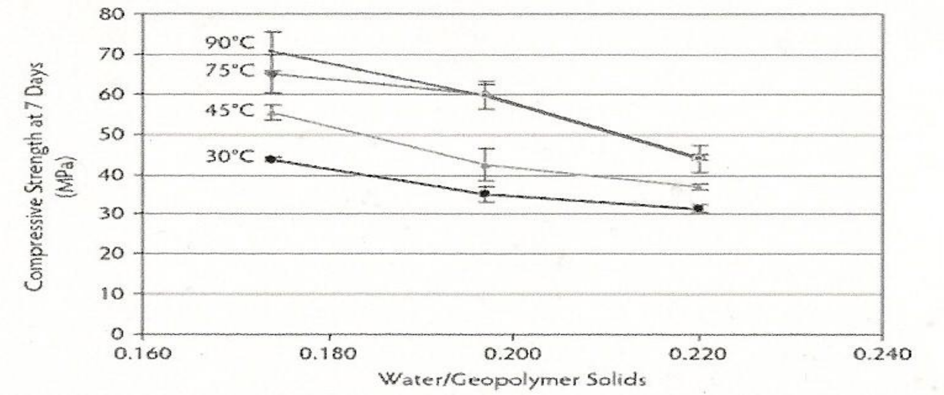

Fig 4: Effect of water-to-polymer solid ratio by mass of on compressive strength of geopolymer concrete (Nguyen, 2009).

4. Materials Properties

Materials used for this study are cement, natural fine and coarse aggregate and water.

4.1Coarse aggregate

Nominal size of recycled coarse aggregate used for this study is 20 mm. The properties of coarse aggregate are given below.

4.2Fine aggregate

River sand is used as fine aggregate for making the concrete. The properties of fine aggregate are given below.

Table 1. Sieve Analysis of Coarse aggregate
Total weight taken: 5kg (20 mm size recycled aggregate)

IS sieve Designation	Weight retained (g)	Percentage retained	Cumulative Percentage retained	Percentage Passing
80mm	**0**	**0**	**0**	**100**
63mm	**0**	**0**	**0**	**100**
40mm	**0**	**0**	**0**	**100**
20mm	**165**	**3.3**	**3.30**	**96.7**
16mm	**502**	**10.04**	**13.34**	**86.66**
12.5mm	**771**	**15.42**	**28.76**	**71.24**
10mm	**910**	**18.20**	**46.96**	**53.04**
4.75mm	**2652**	**53.04**	**100**	**0**

Table.2 . Grading limits of Coarse aggregate as per IS 383-(1970).

IS sieve Designation	Percentage passing for single sized aggregate 20 mm nominal size	Percentage passing for graded aggregates of 20 mm nominal size
80mm	**-**	**-**
63mm	**-**	**-**
40mm	**100**	**100**
20mm	**85-100**	**100**
16mm	**-**	**-**
12.5mm	**-**	**-**
10mm	**0-20**	**25-55**
4.75mm	**0-5**	**0-10**
2.36mm	**-**	**-**

Table. 3. Sieve analysis of fine aggregate
Total weight taken = 2kg

IS Sieve designation	**Weight retained(g)**	**Percentage retained**	**Cumulative percentage retained**	**Percentage Passing**	**Remarks**
4.75mm	0	0	0	100	FALLS ON ZONE II
2.36mm	60	3.00	3.00	97.00	
1.18mm	275	13.75	16.75	83.25	
600µ	532	26.60	43.35	56.65	
300µ	910	45.50	88.85	11.15	
150µ	223	11.15	100	0	

Table .4. Grading limits of fine aggregate as per IS 383-(1970).

IS sieve designation	**Percentage Passing by weight**			
	Zone I	**Zone II**	**Zone III**	**Zone IV**
10mm	100	100	100	100
4.75mm	90-100	90-100	90-100	95-100
2.36mm	60-95	75-100	85-100	95-100
1.18mm	30-70	55-90	75-100	90-100
600µ	15-34	35-59	60-79	80-100
300µ	5-20	8-30	12-40	15-50
150µ	0-10	0-10	0-10	0-15

4.1.1. Specific gravity of Fine aggregate:

Empty wt.of psychomotor : 774 g (w_1)
Empty + 1/3 of sea sand : 1265 g(w_2)
Empty + 1/3 of sea sand +water : 2112 g(w_3)
Empty + water : 1808 g (w_4)
Specific Gravity : $(w_2-w_1) / (W4-w1)- (w_3-w_2) = 2.62$

4.1.2. Specific gravity of coarse aggregate

The specific gravity of an aggregate is defined as the ratio of the mass of solid in a given routine of samples to the mass of an equal volume of water at the same temp.

Sp. gravity = C/ (B-A)

A = Mass of saturated surface CA in water
B= Mass of saturated surface dry CA in air
C= Mass of over dry CA in Air Specific gravity=2.80

5. Mix Design

One of the ultimate aims of studying the various properties of the materials of concrete, plastic concrete and hardened concrete is to enable a concrete technologist to design a concrete mix for a particular strength and durability. The design of concrete mix is not a simple task on account of the widely varying properties of the constituent materials, the conditions that prevail at the site of work, in particular the exposure condition, and the conditions that are demanded for a particular work for which the mix is designed.

Mix design can be defined as the process of selecting suitable ingredients of concrete and determining their relative proportions with the object of producing concrete of certain minimum strength and durability as economically as possible. The purpose of designing as can be seen is to achieve the stipulated strength and durability.

5.1. Concept of mix design

It will be worthwhile to recall at this stage the relationships between the aggregate and paste which are the two essential ingredients of concrete. Workability of the mass is provided by the lubricating effect of the paste and is influenced by the amount and dilution of paste. The strength of the concrete is limited by the strength of the paste, since mineral aggregates with rare exceptions, are far stronger than the paste compound. Essentially the permeability of concrete is governed by the quality and continuity of the paste, since little water flows through the aggregate either under pressure or by capillarity. Further, the predominant contribution to drying shrinkage of concretes is that of the paste.

Since the properties of concrete are governed to a considerable extent by the quality of paste, it is helpful to consider more closely the structure of the paste. The fresh paste is a suspension, not a solution of cement in water.

The more dilute the paste, the greater the spacing between cement particles, and thus the weaker will be the ultimate paste structure. The other conditions being equal, for workable mixes, the strength of concrete varies as an inverse function of the water/cement ratio. Since the quantity of water required also depends upon the amount of paste, it is important that as little paste as possible should be used and hence the importance of grading.

5.2. Requirements of concrete mix design

The requirements which form the basis of selection and proportioning of mix ingredients are:

a) The minimum compressive strength required from structural consideration
b) The adequate workability necessary for full compaction with the compacting equipment available.
c) Maximum water-cement ratio and/or maximum cement content to give adequate durability for the particular site conditions
d) Maximum cement content to avoid shrinkage cracking due to temperature cycle in mass concrete.

5.3. Standard mixes

The nominal mixes of fixed cement-aggregate ratio (by volume) vary widely in strength and may result in under- or over-rich mixes. For this reason, the minimum compressive strength has been included in many specifications. These mixes are termed standard mixes.

IS 456-2000 has designated the concrete mixes into a number of grades as M10, M15, M20, M25, M30, M35, M40 and M50. In this designation the letter M refers to the mix and the number to the specified 28 day cube strength of mix in N/mm^2. The mixes of grades M10, M15, M20 and M25 correspond approximately to the mix proportions (1:3:6), (1:2:4), (1:1.5:3) and (1:1:2) respectively.

5.4. Results

Table 1: Workability of geopolymer concrete (without steel fibre)

Sl.No	Mix ratio	Molarity of NaoH solution	Slump (mm)
1	1:1.5:3	8 M	175
2	1:1.5:3	12 M	178

Table 2: Workability of geopolymer concrete (with 1% steel fibre)

Sl.No	Mix ratio	Molarity of NaoH solution	Slump (mm)
1	1:1.5:3	8 M	158
2	1:1.5:3	12 M	152

Table 3: Workability of geopolymer concrete (with 2% steel fibre)

Sl.No	Mix ratio	Molarity of NaoH solution	Slump (mm)
1	1:1.5:3	8 M	135
2	1:1.5:3	12 M	126

Table 4: Compressive strength of geopolymer concrete (without steel fibre)

Sl.No	Mix ratio	Molarity of NaoH solution	Failure load (kN)	Compressive strength (N/mm^2)	Average compressive strength (N/mm^2)
1	1:1.5:3	8 M	870	38.66	38.37
			855	38.00	
			865	38.44	
2	1:1.5:3	12 M	1015	45.11	45.04
			1005	44.67	
			1020	45.33	

Table 5: Compressive strength of geopolymer concrete (with 1% steel fibre)

Sl. No	Mix ratio	Molarity of NaoH solution	Failure load (kN)	Compressive strength (N/mm^2)	Average compressive strength (N/mm^2)
1	1:1.5:3	8 M	920	40.88	40.29
			910	40.44	
			890	39.55	
2	1:1.5:3	12 M	1055	46.88	46.96
			1075	47.77	
			1040	46.22	

Table 6: Compressive strength of geopolymer concrete (with 2% steel fibre)

Sl.No	Mix ratio	Molarity of NaoH solution	Failure load (kN)	Compressive strength (N/mm^2)	Average compressive strength (N/mm^2)
1	1:1.5:3	8 M	960	42.66	43.26
			970	43.11	
			990	44.00	
2	1:1.5:3	12 M	1125	50.00	50.29
			1140	50.66	
			1130	50.22	

Table 7: Split tensile strength of geopolymer concrete (without steel fibre)

Sl. No	Mix ratio	Molarity of NaoH solution	Failure load (P) (kN)	Split tensile strength($2P/\pi LD$) (N/mm^2)	Average split tensile strength (N/mm^2)
1	1:1.5:3	8 M	305	4.31	4.33
			310	4.38	
			303	4.28	
2	1:1.5:3	12 M	330	4.67	4.68
			340	4.81	
			322	4.55	

Table 8: Split tensile strength of geopolymer concrete (with 1% steel fibre)

Sl.No	Mix ratio	Molarity of NaoH solution	Failure load (P) (kN)	Split tensile strength($2P/\pi LD$) (N/mm^2)	Average split tensile strength (N/mm^2)
1	1:1.5:3	8 M	365	5.16	5.19
			360	5.09	
			376	5.32	
2	1:1.5:3	12 M	395	5.59	5.51
			385	5.44	
			388	5.49	

Table 9: Split tensile strength of geopolymer concrete (with 2% steel fibre)

Sl.No	Mix ratio	Molarity of NaoH solution	Failure load (P) (kN)	Split tensile strength($2P/\pi LD$) (N/mm^2)	Average split tensile strength (N/mm^2)
1	1:1.5:3	8 M	465	6.58	6.81
			480	6.79	
			500	7.07	
2	1:1.5:3	12 M	485	6.86	6.98
			505	7.14	
			490	6.93	

6. Conclusion

The introduction of geopolymer technology as a feasible technology for construction purposes will form a much better alternative for Portland cement. Geopolymer technology does not only contribute to the reduction of greenhouse gas emissions but also reduces disposal costs of industrial waste. Geopolymer concrete products exhibit far better properties including durability and compressive strength than Portland cement products. Geopolymer technology encourages recycling of waste and finally it will be an important step towards sustainable concrete industry. Results show that addition of steel fibres improves the compressive and split tensile strength of geo-polymer concrete.

7. References

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