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Journal on Structural Engineering

State-of-the-art and State-of-practice in Structural Engineering

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Format for Citing Papers

Author surname, initials (s.) (2018). Title of paper. i-manager's Journal on Structural Engineering, 7(3), xx-xx.

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RESEARCH PAPERS

EDITORIAL

Structural Engineering is a combination of applied mechanics, materials science and applied mathematics so as to understand and predict how structures support and resist self-weight and imposed loads. The current issue of i-manager's Journal on Structural Engineering presents interesting topics on Boundary Conditions on Modal Analysis of Aluminum Plates using Digital Image Correlation Technique, Fiber Reinforced Concrete Column to Explosive Loading, Open Ground Storey Buildings, Conical Elevated Water Tanks under Varying Water Percentage in Conical and Cylindrical Parts, and Fibre Reinforced Alkali- Activated Concrete.

Durga Charan et al. have performed the Boundary Conditions on Modal Analysis of Aluminum Plates using Digital Image Correlation Technique. The authors have analyzed the dynamic response of rectangular and circular plates under all edges fixed conditions and all edges free boundary conditions of natural frequencies. The mode shapes are determined using ANSYS software and the Digital Image Correlation (DIC) technique is used as an electro dynamic shaker. The result shows that the natural frequencies of all edges fixed boundary condition plate have been found higher than the frequencies for all edge free boundary condition plate.

Sudhindra Yeri et al. have implemented a design of the Behavior of long carbon fiber reinforced concrete column to analyze the explosive loading and exterior column, which become critical as explosive load sometimes while exceeding the designed lateral seismic load. The adequacy of column reinforced according to IS 13920-2016 in resisting the blast load is numerically simulated. The results from the design of LCFRC columns reduce surface damage, cracking of concrete, deflection and the column reinforced according to IS 13920-2016 and LCFRC column showed greater resistance to explosive load.

Pramodini Naik and Satish Annigeri have presented a study on seismic evaluation and modeling techniques for open ground storey. Three building models representing the lateral stiffness of the building were considered, namely OGS bare frame (model 1), OGS within fill stiffness consideration in the upper storey's (model 2), building with infill stiffness consideration in the upper storey's and modeling additional infill stiffness in the corner bays of OGS (model 3) and also four scenarios are analyzed for modeling the lateral load and nonlinear hinge properties. The results observed from the model 3 - scenario 4 is a better modeling strategy among the three models studied.

Syed Shafahaduddin Quadri and his co-author Sawant have investigated a behavior of combined conical elevated water tank under varying water percentage in conical and cylindrical parts by performing dynamic analysis i.e. Response Spectrum method. The static and dynamic analysis of combining conical elevated water tanks is carried out by using a computer program, i.e. STAAD.Pro. The experimental studies have concluded that the total twenty numbers of models were made for empty tank and full tank condition, where these models are provided with ten numbers of columns along with the periphery of a circle with five staging level and connected by using Cross Staging pattern.

Sonal Thakkar et al. have presented a study about mechanical properties of fibre reinforced alkali activated concrete as one of the sustainable solutions in place of Ordinary Portland Cement Concrete. To understand the behaviour of fibre reinforced alkali-activated concrete, mechanical properties like compressive strength, flexural strength, split tensile strength, modulus of elasticity, and bond strength were investigated. From the analysis it is concluded that, the fibre reinforced alkali activated concrete has high early strength, which is due to geopolymerisation process between fly ash and sodium based activators.

I express grateful thanks to the authors, reviewers and all readers of i-manager's Journal on Structural Engineering.

Enjoy Reading!

Warm regards,

Ramya R.
Junior Associate Editor
i-manager Publications

MECHANICAL PROPERTIES OF FIBRE REINFORCED ALKALI-ACTIVATED CONCRETE

By

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ABSTRACT

In the modern era, where sustainable concrete is a buzzword, all efforts are made to find a substitute of cement. Fly ash based alkali-activated concrete is one of the sustainable solutions in place of Ordinary Portland Cement Concrete. This concrete uses industrial waste as one of the constituents in the concrete and thus offers sustainable solution to waste disposal and also has very high early strength. Present investigation studies the effect of polypropylene fibres in alkali-activated concrete. To understand the behaviour of fibre reinforced alkali-activated concrete, mechanical properties like compressive strength, flexural strength, split tensile strength, modulus of elasticity, and bond strength were investigated. Comparison of these results was carried out with fibre reinforced Ordinary Portland Cement concrete to evaluate the behaviour of fibre reinforced alkali-activated concrete. It was observed that with the addition of polypropylene fibres, 7 days strength in compression increased by 72%, in flexure by 35%, in modulus of elasticity by 42%, and in bond by 10% compared to Ordinary Portland Cement concrete with fibres. Thus, for high early strength alkali-activated concrete with polypropylene fibre becomes more suitable.

Keywords: Fibre Reinforced Alkali-activated Concrete, Fibre Reinforced Ordinary Portland Cement Concrete, Fly Ash, Mechanical Properties, Polypropylene Fibres, Fibre Reinforced Cement Concrete (FRCC).

INTRODUCTION

Cement concrete is most popular and widely used construction material in the modern world due to excellent mechanical properties, good fire resistance, and ease with which it is available. Cement production is highly energy intensive process and requires a huge amount of natural resources. Estimates indicate that one tonne of cement production liberates approximately, one tonne of carbon dioxide gas in the atmosphere while consuming 1.5 tonnes of natural resources (Scrivener & Kirkpatrick, 2008). Progress of any nation is today judged by therate of growth of infrastructure in that country. In developed countries, huge power is generated through coal-based thermal power plant which fulfils approximately 80% of their power requirements. Coal power plant produces a waste by the product called fly ash in huge quantity. It is estimated that approximately 50% of fly ash is effectively utilised either by the cement industry or for making fly ash bricks, etc., while the rest being disposed as landfill. Similarly, there are many industrial wastes whose effective disposal is need of the hour. Since concrete is one of the most widely used materials in building construction, fly ash obtained from the thermal power plant, when used as one of the ingredients replacing cement will prove to be an ideal solution for saving natural resources. In the modern world, there is an urgent need to develop alternative technology, which will reuse and recycle industrial waste and simultaneously will not compromise on mechanical properties and durability property of concrete. Alkali-activated concrete or geopolymer concrete is one of them.

Geopolymer concrete developed by Davidovits is one such attempt to use industrial waste as by-product (Davidovits, 1994). Alkali-activated concrete uses industrial wastes like fly ash, slag, rice husk ash, red mud or any material rich in Si and Al ions as they are source materials, which are activated with the alkaline solution like combination of sodium hydroxide and silicates (Davidovits, 1994; Hardjito et al., 2004; Hardjito & Rangan, 2005). Alkali-activated concrete has shown excellent durability properties compared to Portland cement concrete regarding acid resistance and sulphate resistance (Bakharev, 2005a, 2005b) and as it uses industrial waste, it leads to sustainable development.

While, it is a well-known fact that concrete has a very good compressive strength, but exhibits low tensile strength and hence is brittle. Structures subjected to alternate drying and wetting, pavement, marine conditions require the concrete to be crack free for an enhanced life cycle. Therefore, addition of fibres in concrete acts like a crack inhibitor and increases tensile load carrying capacity of concrete. There is huge database of the effect of fibres on ordinary cement concrete, but use of fibres on alkali-activated concrete is limited. The use of steel fibres in alkali-activated concrete have been studied by various researchers (Ganesan et al., 2013, 2015; Sakulich, 2011). Bernal et al. (2010) have studied the effect of addition of steel fibres in slag activated with water glass solution and found that there was an increase in split tensile strength. Also, modulus of rupture increased for alkali-activated concrete with slag. Reed et al. (2014) have studied the effect of fibres in geopolymer concrete at ambient curing with fly ash and found that compressive strength and ductility increased with the addition of fibres. Puertas et al. (2003) have studied the effect of polypropylene fibres on mortar made from fly, slag, and combination of fly ash and slag. Activation was done with sodium-based activators for 0.5% and 1% dosage of fibres. It was observed that nature of the matrix was the main factor, which influenced strength.

Studies revealing effect of polypropylene fibres on mechanical properties of alkali-activated concrete are sparse, hence was chosen as the field of investigation. Moreover, huge availability and effective utilisation of fly ash is one of the aims and hence fly ash was chosen as source material. This investigation is aimed to study the effect of polypropylene fibres on mechanical properties of alkali-activated concrete with fly ash as source material. Comparative studies of fibre reinforced alkali-activated concrete and the fibre reinforced Ordinary Portland Cement Concrete was carried out to understand the effect of fibres in strength development mechanism. To compare both grades of concrete and dosage of fibre are kept same.

1. Experimental Programme

1.1 Materials

Source of Low calcium class F fly ash was from the Ukai Thermal Power Plant. Table 1 shows the physical and chemical properties of fly ash. The alkaline solution consisted of a mixture of sodium hydroxide and sodium silicate. Sodium hydroxide was obtained in the form of flakes with 98% purity and was dissolved in tap water depending on the concentration of the solution, expressed in terms of Molarity (M) (Bakharev, 2005a).

Sodium silicate was in liquid form with 35.4% of SiO_2, 15.5% of Na_2O, and 45.9% of water. Sodium silicate had a ratio of SiO_2/Na_2O as 2.23 and a specific gravity of 1.58. Use of Naphthalene based super plasticiser was done for increasing the workability of alkali-activated concrete. In Ordinary Portland Cement concrete, ordinary Portland cement confirmed to IS:12269 specifications and was of Grade 53. The locally available coarse aggregate of 20 mm and 10 mm size was used to prepare both concrete. Fineness modulus of 20 mm aggregate was 7.3, while for

Sl. No.	Test Details	Test Results	Requirement as per IS 3812: 2003
1	Colour	Light Grey	-
2	Specific Surface Area	416.4 m^2/kg	Min. 320 m^2/ kg
3	Loss of ignition	1.1%	Max. 5% by mass
4	$SiO_2 + Al_2O_3 + Fe_2O_3$	93.0%	Min. 70% by mass
5	SiO_2	61.4%	Min. 35% by mass
6	Reactive Silica	34.7%	Min. 20% by mass
7	CaO	6%	
8	MgO	1.4%	Max. 5% by mass
9	SO_3	0.6%	Max. 3% by mass
10	Na_2O	0.6%	Max.1.5% by mass
11	Total Chlorides	0.03%	Max. 0.05% by mass
12	Retention on 45 micron sieve	21.1%	Max. 34% by mass
13	Pozzolanic Activity Index	88.2%	Min. 80% by mass

Table 1. Physical and Chemical Properties of Fly Ash

10 mm aggregate was found to be 6.03. Specific gravity was 2.7, and it confirmed to IS: 2386. The locally available river sand was used as fine aggregate in both concrete mixes and confirmed to provisions of IS: 383. The sand was having a specific gravity of 2.6 conforming to Zone II with a fineness modulus of 3.5. Polypropylene fibres were 12 mm in length and had a white coloured appearance with the specific gravity of 0.91.

1.2 Mix Proportioning of Concrete

Both concrete was designed for M25 grade of concrete with characteristic strength of 25 MPa at 28 days. For Ordinary Portland cement concrete mixture, a design based on IS: 10262 was adopted. Design for alkali-activated was carried out by assuming its density as 2400 kg/m^3. The guidelines given by (Hardjito & Rangan, 2005), were followed and after a lot of the variation of parameters like the amount of source materials, variation in molarity of sodium hydroxide, amount of sodium silicate to sodium hydroxide, etc., materials were proportioned to have the characteristic compressive strength of 25 MPa. The oven curing was done to alkali-activated concrete after one day rest period. Temperature of oven was kept at 60 °C. Table 2 shows the mix proportion used for the design of Ordinary Portland Cement Concrete and alkali-activated concrete with fly ash as source materials.

1.3 Selection of Fibre Dosage

Optimum dosage of 0.8% of polypropylene fibre was decided based on workability and strength criteria. Observations from past literature indicated that oven curing of one day in alkali-activated concrete lead to the development of very high early strength and therefore specimens were ever cured in one day.

Constituents	Ordinary Portland Cement Concrete	Alkali-activated Concrete
Cement (kg/m^3)	365	-
Fly Ash (kg/m^3)	-	428.6
Coarse Aggregate (20 mm & 10 mm) (kg/m^3)	1128	1170
Fine Aggregate (kg/m^3)	689	630
NaOH (kg/m^3)	-	68.6
Na_2SiO_3 (kg/m^3)	-	102.9
Admixture (kg/m^3)	2.5	8.6
Water (kg/m^3)	164	42.9

Table 2. Mixture Design of M25 Grade of OPCC and AAC

1.4 Specimen Preparation

Alkali-activated concrete requires alkaline solution which is a blend of sodium hydroxide and sodium silicate for present investigation. The solution of sodium hydroxide was prepared a day before casting by dissolving sodium flakes in water. Fly ash and aggregate were first dry mixed for 4-5 minutes in a pan mixture and then polypropylene fibres were added and further dry mixed for 2 minutes for alkali-activated concrete. Addition of alkaline liquid, water, and superplasticiser was done subsequently, and mixing was done further carried out for 5-6 minutes. The specimen were cast in moulds of respective test. Demoulding was done after one day and after this alkali activated specimens were wrapped with polyethene and placed in an oven for curing for 24 hours at 60 °C, and then kept at room temperature till the date of testing. After dry mixing of cement, fibres and aggregate, water was added according to mixture design to the prepared Ordinary Portland Cement Concrete specimens, which were water cured after the demoulding.

2. Mechanical Testing

Tests like compressive strength, split tensile strength, flexural strength, bond strength, modulus of elasticity, abrasion resistance, and impact energy were performed on FRAAC and FRCC.

Determination of compressive strength was done on compression testing machine with 2000 kN capacity on cubes of 150 mm × 150 mm × 150 mm as per IS: 516 for both concretes. Beams of the size of 100 mm × 100 mm × 500 mm were cast in accordance with the test procedure given in IS: 516 and tested on 100 kN flexure testing machine by application of two-point load test. Split tensile strength was determined on cylinder with size of 150 mm diameter and 300 mm height according to IS: 516, using compression testing machine having 2000 kN capacity. To evaluate Modulus of Elasticity (MoE), 150 mm diameter and 300 mm in height specimen was cast and extensometers were attached for recording the displacement. Universal testing machine of 1000 kN was used, where the load was continuously applied gradually to avoid shock loading on the specimen. Measurement of displacement was done at an equal interval of load and graph of stress v/s strain was plotted to determine MoE.

The impact resistance was measured by dropping a hammer of 45.4 N weight from 457 mm height from the impact testing machine. The impact testing machine was developed using guidelines given in ACI 544.2 R. Coating of the specimen with the thin layer of petroleum jelly or heavy grease at the bottom was done. It was placed on the base plate within positioning lugs with the finished face upon the restrict movement of the specimen during testing. The hardened steel ball was placed on top of the specimen within the bracket. The number of blows (N1) required for the first visible crack of the specimen was recorded, and the number of blows (N2) required for the ultimate failure of the specimen was recorded.

Dorry abrasion testing was used to evaluate abrasive erosion of concrete under sand particles. It consists of a flat circular cast iron or steel disc of not less than 60 cm in diameter, which revolves in a horizontal plane about a vertical shaft. The arrangement was made for holding two test specimens in a diametrically opposite direction, and the specimens were placed in the vertical direction so that their lower ends were pressed with the prescribed pressure against the disc surface. A conventional funnel was also attached for continuously feeding a standard sand upon the disc. The distance from the centre of the disc to the centre specimen was 26 cm. The pressure was applied to the specimen by a disc, which revolved at the speed of about 28-30 rpm, i.e. nearly 16-18 minutes for 500 revolutions. Standard buzzard silica sand used had at least 75% passing 0.6 mm IS sieve, all passing 0.85 mm and retained on 0.3 mm sieve. The specimens were taken after abrasion and weighed again. The percentage loss in weight of concrete specimen was calculated by following mathematical equation:

$$\text{Percentage loss in weight} = \frac{100 \times (A-B)}{A} \quad (1)$$

where, A = Weight of concrete specimen before testing,

B = Weight of concrete specimen after testing

The bond test or pullout test was carried out to determine the bonding capacity between concrete and steel reinforcement. In this test, a cube of 150 mm with 12 mm diameter reinforcement in the middle was cast and used to evaluate the bond strength as per IS: 2770. Recording of the load was done at the relative slip of 0.002 mm at the free end of the concrete specimen. Determination of bond strength was as per value obtained from the failure load of bonding between concrete and steel reinforcement divided by the surface area of the embedded length of the bar. A dial gauge with least count of 0.00025 mm was used to determine the slip.

3. Results and Discussions

Fly ash when activated with alkaline activators like sodium hydroxide and sodium silicate, gets polymerised forming geopolymeric chain. It happens on account of bond formation between Silica and Alumina ions present in fly ash and alkali ions of activators. Due to the application of heat, overall reactivity of the system increases and as a result Alkali-activated concrete when heat cured has high early strength. Due to the inclusion of fibres, there is change in other mechanical properties also.

3.1 Optimum Dosage of Fibres

To determine the optimum dosage of fibre, different dosages like 0.4%, 0.6%, 0.8% and 1% of polypropylene fibres were taken for alkali-activated concrete. As high early strength was obtained in alkali-activated fly ash for seven days, strength was taken as criteria for deciding optimum dosage for alkali-activated concrete. As observed in Table 3, there was an increase in compressive strength with increase in fibre dosage. At 1% dosage of fibres, workability of concrete was affected greatly and increase in flexure strength was not significant. Therefore, 0.8% dosage of fibre was taken for alkali-activated concrete, and the same dosage was kept for ordinary Portland cement concrete so that comparison of behaviour can be studied.

3.2 Mechanical Properties: Compressive Strength

Figure 1 shows compressive strength results at 3, 7, and 28 days, respectively, with 0.8% of polypropylene fibres. Due to polymerisation process, alkali-activated concrete has achieved higher strength at an early age, i.e. 3 days and 7 days (Hardjito et al., 2004; Hardjito & Rangan, 2005). It was also observed that almost 80% of the compressive strength has been achieved in the 7 days for FRAAC. This indicates that due to polymerisation process, though early strength was achieved at 7 days, ordinary Portland cement

Fibre Dosage	Compressive Strength Results		Flexural Strength Results	
	Average Compressive Strength (MPa) at 7 days of FRAAC	Increment (%) in FRAAC w.r.t. Alkali-activated Concrete without Fibres	Average Flexural Strength (MPa) at 7 days of FRAAC	Increment (%) in FRAAC w.r.t. Alkali-activated Concrete without Fibres
0.0%	31.57	0.00	3.89	0.00
0.4%	31.64	+0.22	4.80	+23.40
0.6%	32.41	+2.66	5.21	+34.01
0.8%	33.07	+4.73	5.89	+56.02

Table 3. Compressive Strength and Flexural Strength of FRAAC

generally achieves 70% of its strength at 7 days due to hydration process. FRAAC has 103.1%, 72.1% and 6.3% increased compressive strength compared to FRCC at 3, 7, and 28 days as shown in Figure 2. Therefore, there is a huge increase in early strength in FRAAC which decreases at 28 days to 6.3%.

3.3 Flexure Strength

The flexural strength for FRAAC and FRCC at 3, 7, and 28 days, respectively is shown in Figure 3, which show increases in flexural strength increase from 3.0 MPa to 5.9 MPa, while in case of FRCC increase was significant from 2.2 MPa to 5.2 MPa at 3 to 28 days.

3.4 Split Tensile Strength

As observed in Figures 4 and 5, the split tensile strength increased from 2.68 MPa at 3 days to 5.36 MPa in case of FRAAC while in case of FRCC, split tensile strength was 1.28 to 4.27 MPa at 3, 7, and 28 days. Thus, higher split tensile strength was observed in FRAAC compared to FRCC at 3 and 7 days. Figure 6 shows that for the early age of 3 days

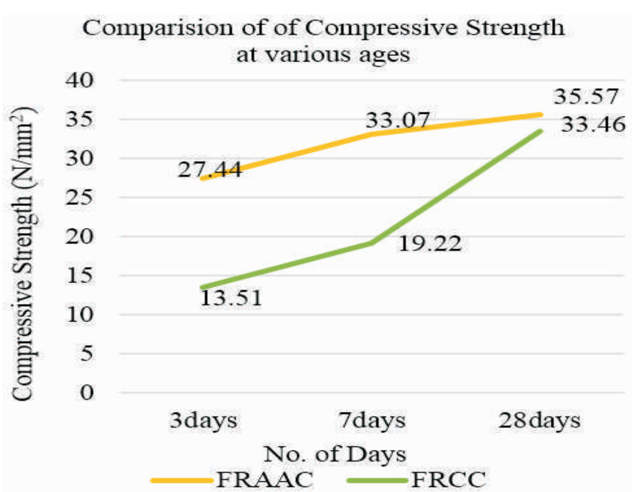

Figure 1. Compressive Strength at Various Ages for FRAAC and FRCC

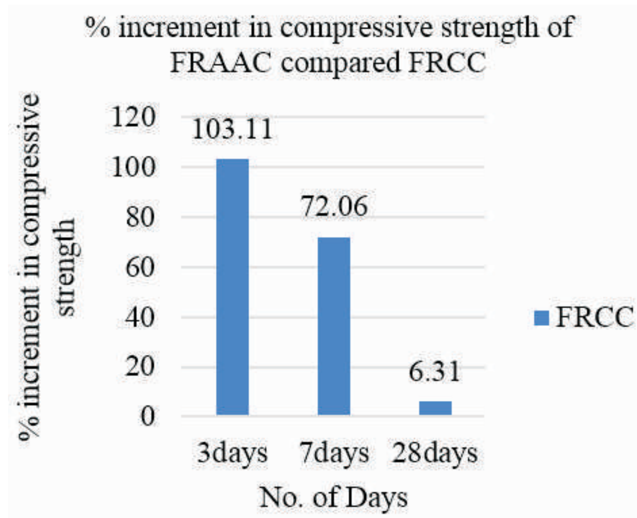

Figure 2. Percentage Increase in the Compressive Strength of FRAAC Compared to FRCC at Various Ages

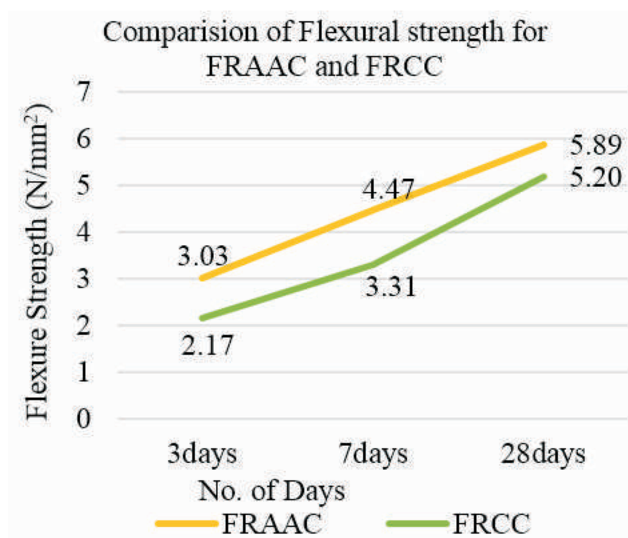

Figure 3. Flexure Strength for FRAAC and FRCC Concrete Mixes at Various Ages

and 7 days, there, was 109.4% and 60.74% increase respectively in split tensile strength compared to FRCC. Thus, inclusion of fibres in alkali-activated concrete tremendously increased the early age split tensile strength

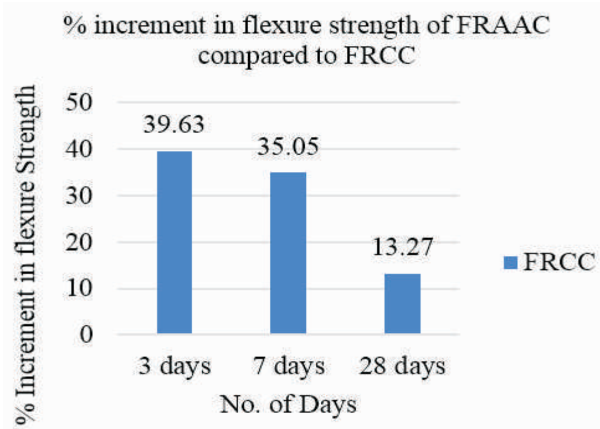

Figure 4. Percentage Increase in the Flexure Strength of FRAAC Compared to FRCC

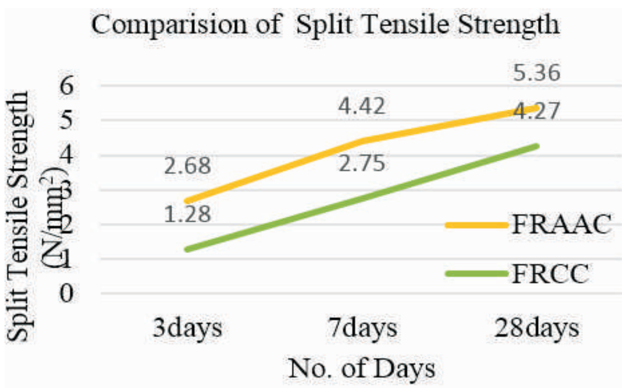

Figure 5. Split Tensile Strength for FRAAC and FRCC Concrete Mixes at Various Ages

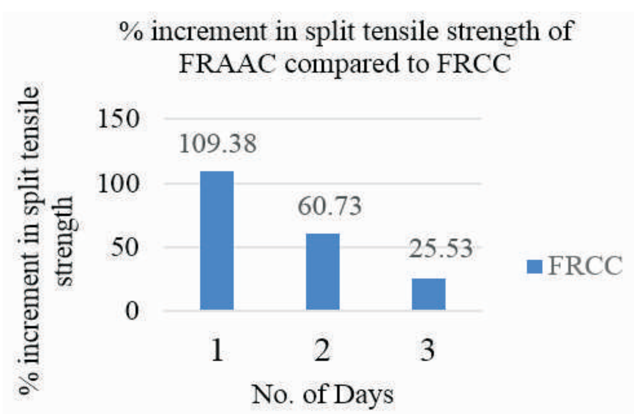

Figure 6. Percentage Increase in the Split Tensile Strength of FRAAC Compared to FRCC

compared to FRCC while at 28 days, the difference in strength is 25.5%. This would enable the early use of concrete without significant tensile stress generation.

3.5 Modulus of Elasticity

The Modulus of Elasticity (MoE) was conducted at the age of 7 and 28 days. Table 4 shows MoE for FRAAC and FRCC by taking an average of three specimens. It was observed that the MoE of FRAAC was 42.3% higher while at the age of 28 days, it was 5.39% higher compared to the FRCC.

3.6 Impact Energy

The impact resistance measures the energy absorption capacity of concrete. The number of blows required for first visible crack and final failure of concrete specimens cured for 28 days was represented in Figure 7, and the average results of six specimens were taken as the final results.

Sample calculation of impact energy at first crack is derived below:

n = Number of blows = 26, H = Height of hammer = 457 mm, g = 9810 N/mm^2

$t = \sqrt{\frac{2 \times H}{g}}$ = 0.3052 sec, V = velocity of the hammer = g x t = 9810 x 0.3052 = 2994.38

$m = \text{Mass of hammer} = \frac{W}{g} = \frac{44.5}{9810} = 0.00453\ \text{kg}$

Type of Concrete	FRAAC		FRCC	
Age	MoE (Mpa)	Average MoE (Mpa)	MoE (Mpa)	Average MoE (Mpa)
7 days	16698 18502 17736	17645	12235 11652 13320	12402
28 days	26728 27530 27981	27431	24892 26962 26225	26027

Table 4. Modulus of Elasticity Results of FRAAC and FRCC at Different Ages

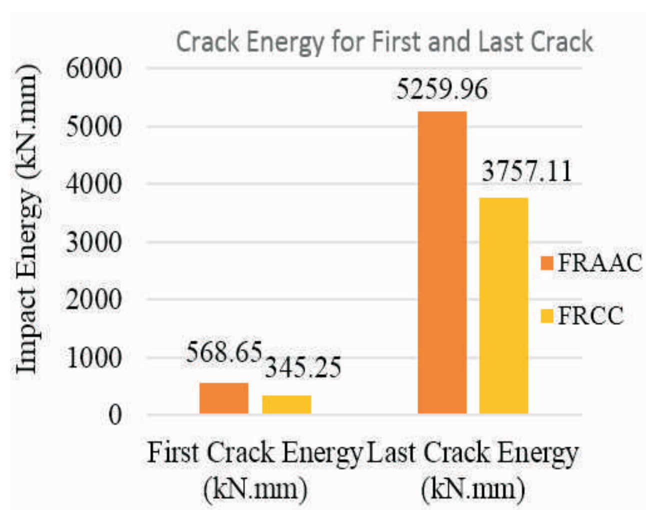

Figure 7. Crack Energy for Various Concrete

$$\text{Impact Energy (U)} = \frac{n \times m \times V^2}{2} = \frac{28 \times 0.00453 \times 2994.38^2}{2}$$
$$= 568.7 \text{ kN.mm}$$

FRAAC showed higher impact strength compared to the FRCC. Brittle failure was avoided due to incorporation of fibres as shown in Figure 8.

3.7 Abrasion Resistance

The abrasion test measures the wear and tear of the surface when subjected to repeated loading. This test was performed after 28 days and results are represented in Table 5. Initial weight before testing of specimens and final weight after testing of specimens was done. Average results of six specimens were taken.

Figure 9 shows tested FRAAC specimen samples. As observed from Figure 10, weight loss in FRAAC and FRCC was 13.6% and 15.8%, respectively indicating lesser weight loss in FRAAC compared to the FRCC. Thus, the inclusion of fibres in concrete increases resistance to abrasion.

3.8 Bond Strength

The bond strength is used to determine the reinforcement holding capacity of the concrete. This test was carried out at an age of 7 days and 28 days and results are represented in Table 6. The Load-slip curve of all concrete mixes at the age of 28 days is presented in Figure 11. As observed in Figure 11, load-slip curve for both the mixes are similar, but the failure load of FRAAC was higher compared to the FRCC. At 7 days, FRAAC bond strength was 36.64% higher while at the age of 28 days, the bond is 5.61% higher compared to the FRCC, which may be due to the inclusion of fibres which lead to the densification of concrete.

Figure 8. Impact Strength of FRAAC Specimen

Specimen	FRAAC		FRCC	
	Initial Wt. (A) (g)	Final Wt. (B) (g)	Initial Wt. (A) (g)	Final Wt. (B) (g)
1	308.9	267.66	295.36	242.60
2	306.55	260.22	298.88	243.01
3	307.12	269.58	306.21	256.35
4	311.18	265.28	292.35	259.36
5	309.95	270.05	303.36	263.56
6	304.22	263.88	302.39	250.20
Average	307.9	266.12	299.76	252.35

Table 5. Weight before and after Abrasion Test for FRCC and FRAAC

Figure 9. FRAAC Specimen after Abrasion Test

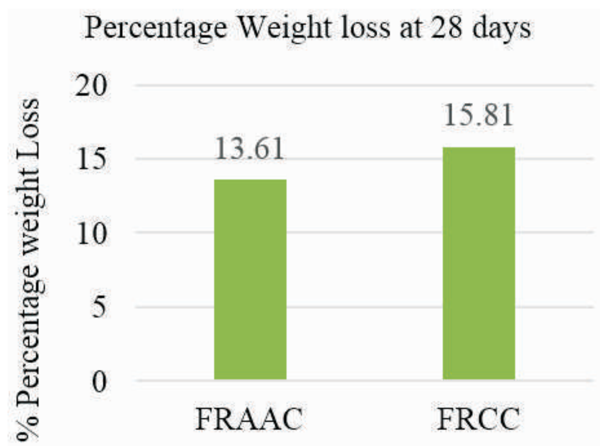

Figure 10. Percentage Weight Loss in FRAAC and FRCC

Conclusion

Thus, it can be observed that fibre reinforced alkali-activated concrete has high early strength, which is due to geopolymerisation process between fly ash and sodium based activators. In addition of fibres, the 7 day

Age	FRAAC		FRCC	
	Bond Strength (Mpa)	Avg. Bond Strength (Mpa)	Bond Strength (Mpa)	Avg. Bond Strength (Mpa)
7 Days	8.42		6.62	
	8.71	8.69	6.19	6.36
	8.96		6.29	
28 Days	13.87	14.31	13.19	13.55
	14.31		13.86	
	14.72		13.61	

Table 6. Bond Strength of FRAAC and FRCC Concrete

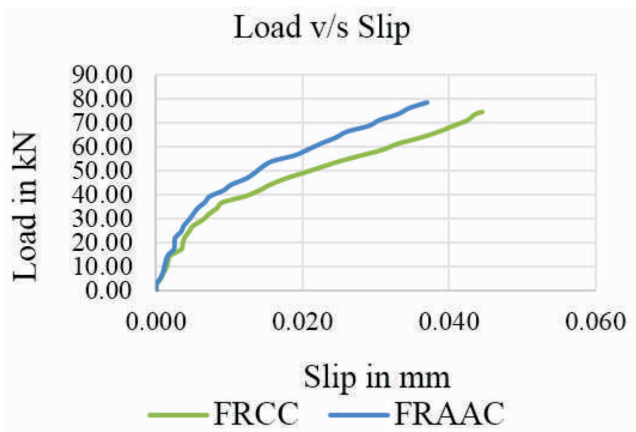

Figure 11. Load vs. Slip for FRAAC and FRCC

compressive strength increases to 72%, flexural strength increases to 35%, and split tensile strength to 61% compared to fibre reinforced Ordinary Portland Cement concrete. In 28 days, due to hydration process of cement, FRCC also gains sufficient strength and hence marginal increase in all mechanical properties was observed. Since impact strength and abrasion resistance of FRAAC are high, it can be suggested that fibre reinforced alkali-activated concrete can be used where early application of concrete is desired.

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References

[1]. **ACI: 544.2 R: (1986).** *Measurements of Properties of Fiber Reinforced Concrete.* American Concrete Institute Committee.

[2]. **Bakharev, T. (2005a).** Resistance of geopolymer materials to acid attack. *Cement and Concrete Research,* 35(4), 658-670.

[3]. **Bakharev, T. (2005b).** Durability of geopolymer materials in sodium and magnesium sulfate solutions. *Cement and Concrete Research,* 35(6), 1233-1246.

[4]. **Bernal, S., De Gutierrez, R., Delvasto, S., & Rodriguez, E. (2010).** Performance of an alkali-activated slag concrete reinforced with steel fibers. *Construction and Building Materials,* 24(2), 208-214.

[5]. **Bureau of Indian Standards. (1959).** *Method of Test for Strength of Concrete* (IS: 516-1959). New Delhi, India.

[6]. **Bureau of Indian Standards. (1963).** *Methods of Tests for Aggregates for Concrete* (IS: 2386-1963, Part 1). New Delhi, India.

[7]. **Bureau of Indian Standards. (1970).** *Specifications for coarse and fine aggregate from natural sources of concrete* (IS: 383-1970). New Delhi, India.

[8]. **Bureau of Indian Standards. (1987).** *Specifications for 53 grade Ordinary Portland cement* (IS:12269-1987). New Delhi, India.

[9]. **Bureau of Indian Standards. (1997).** *Indian Standard Methods of Testing Bond in Reinforced Concrete –Pullout Test* (IS: 2770-1997, Part I). New Delhi, India.

[10]. **Bureau of Indian Standards. (2009).** *Concrete Mix Proportioning – Guidelines* (IS: 10262-2009). New Delhi, India.

[11]. **Bureau of Indian Standards. (2013).** *Specifications for use of fly ash as Pozzolana and admixtures* (IS: 3812-2013, Part 1). New Delhi, India.

[12]. **Davidovits, J. (1994).** High-alkali cements for 21st century concretes. *Special Publication,* 144, 383-398.

[13]. **Ganesan, N., Abraham, R., & Raj, S. D. (2015).** Durability characteristics of steel fibre reinforced geopolymer concrete. *Construction and Building Materials,* 93, 471-476.

[14]. **Ganesan, N., Indira, P. V., & Santhakumar, A. (2013).** Engineering properties of steel fibre reinforced geopolymer concrete. *Advances in Concrete Construction,* 1(4), 305-318.

[15]. **Hardjito, D., & Rangan, B. V. (2005).** *Development and properties of low-calcium fly ash-based geopolymer concrete.* Research Report GC-1, Faculty of Engineering, Curtin University Report.

[16]. **Hardjito, D., Wallah, S. E., Sumajouw, D. M., & Rangan, B. V. (2004).** On the development of fly ash-based geopolymer concrete. *Materials Journal,* 101(6), 467-472.

[17]. **Puertas, F., Amat, T., Fernández-Jiménez, A., & Vázquez, T. (2003).** Mechanical and durable behaviour of alkaline cement mortars reinforced with polypropylene fibres. *Cement and Concrete Research,* 33(12), 2031-2036.

[18]. **Reed, M., Lokuge, W., & Karunasena, W. (2014).** Fibre-reinforced geopolymer concrete with ambient curing for in situ applications. *Journal of Materials Science,* 49(12), 4297-4304.

[19]. **Sakulich, A. R. (2011).** Reinforced geopolymer composites for enhanced material greenness and durability. *Sustainable Cities and Society,* 1(4), 195-210.

[20]. **Scrivener, K. L., & Kirkpatrick, R. J. (2008).** Innovation in use and research on cementitious material. *Cement and Concrete Research,* 38(2), 128-136.

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