

Comparative Study On Load Carrying Capacity Of Short Concrete Columns Confined With Cement Based Vs Geopolymer Based Ferromesh Composites

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ABSTRACT

Strengthening short concrete columns is a critical aspect of the structural rehabilitation, particularly for increasing load-carrying capacity under axial compression. This paper evaluates the axial load carrying capacity of short circular concrete columns confined using cement and geopolymer-based ferromesh composites. Twenty-eight plain short circular concrete columns were cast and tested under concentric axial loading. The primary variables considered were the number of ferromesh layers (one, two, and three) and the confinement matrix type. Cement concrete and geopolymer concrete were used as confinement matrices. When compared with ferromesh unwrapped cement concrete confined short concrete columns, ferromesh wrapped cement concrete and geopolymer concrete confined short concrete columns were to be effective. Cement based concrete confinement increases the ultimate load by 7.10%, 16.93%, and 30.90%, for one, two and three layers respectively, whereas in the case of the geopolymer based concrete confinement, 3.39%, 14.80%, and 30.30% increment was attained. The ferromesh wrapping effect was seen in the increased peak stress and ultimate strain, which indicated improvement in ductility. The failure mode analysis indicated a distinct change in behavior, from brittle splitting failure in ferromesh unwrapped columns to crushing with distributed microcracking in the ferromesh wrapped columns, indicating a more controlled failure mode.

Keywords: Short Concrete Columns; Ferromesh Wrapping; Confinement; Cement Concrete; Geopolymer Concrete; Strength; Axial Compression.

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1. INTRODUCTION

Columns are vertical, which transfers forces from the superstructure to the foundation. In real-life scenarios, the various things such as the use of the wrong mix proportions, lack of proper compaction, inadequate curing, environmental factors, overloading, or insufficient designing have the potential to deteriorate the performance of these components. Such factors lead to early-age cracking, increased porosity, and gradual loss of load-carrying capacity [1]. When these issues are overlooked, the structural element is subjected to an early-stage failure under axial load; thus, the safety of the structure is severely compromised.

As the growth in infrastructure is fast and the aging of the existing buildings, strengthening and rehabilitation of concrete structures become an important part. Strengthening methods such as steel jacketing, reinforced concrete jacketing, and fiber-reinforced polymer (FRP) wrapping are traditional ones. These methods enhance the strength but are not cost-effective; they are labor-intensive, and cause major change in shape of the member. Among these, external confinement techniques offer a better solution by enhancing the compressive strength of concrete without much increase in cross-sectional dimensions.

Ferrocement jacketing is one of the popular choices among different confinement methods due to its simple structure, low-cost design, and wide range of application possibilities. Ferrocement is a material technique consisting of several layers of thin wire mesh closely placed and embedded in a high-strength cement mortar. The distributed mesh reinforcement serves the purpose of increasing tensile strength, reduction in cracks, and enhancing the energy absorption capacity of the material. It was experimentally demonstrated that ferromesh wrapping can substantially enhance the axial strength, ductility, and crack distribution in circular concrete columns [2–4]. Comparative investigations between ferrocement and FRP confinement systems reveal that ferrocement provides competitive structural enhancement while maintaining lower cost and improved crack control performance [5,6].

From a structural aspect, there are significant environmental issues with traditional ferrocement, as it relies on ordinary portland cement (OPC) as a binder in the mortar matrix. Cement is one of the major sources of carbon dioxide (CO₂) emissions, and therefore, the cement industry ranks among the top global warming contributors [7]. As construction activities grow, the environmental impact of OPC production is bound to increase. There is essential to find low-carbon

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alternative binders that can achieve similar mechanical performance.

Geopolymers are recognized as a high-performance, low-carbon alternative to ordinary portland cement (OPC) in construction. The materials are prepared by alkali activation of aluminosilicate precursors, namely fly ash, ground granulated blast furnace slag (GGBS), and metakaolin. Different from the traditional hydration reaction of cement, geopolymerization produces a three-dimensional alumino-silicate network that leads to a dense microstructure and improved durability [8]. Review articles on alkali-activated binders attribute to them a lower carbon footprint, better chemical resistance, and greater stability over time than those of conventional cementitious systems [9]. Moreover, the durability studies of low-carbon construction materials confirm their adequacy for structural applications [10]. The research problem in this study is the dual requirement of improving axial load capacity of short concrete columns while simultaneously reducing the carbon footprint of conventional cement-based confinement systems. The present investigation is undertaken to evaluate the axial compressive behavior of short circular concrete columns externally confined with ferromesh using two different concrete matrices: conventional cement concrete and geopolymer concrete. It addresses the effect of the number of layers of ferromesh on the ultimate load-carrying capacity, axial deformation response, and failure modes. The baseline study performance was set by subjecting the control short concrete columns, which were unwrapped. This work presents a side-by-side comparison of cement-based and geopolymer-based confinement systems exposed to the same experimental conditions.

The main focus of the study is on short columns that are subjected to concentric axial compression loading. The geopolymer mix proportions are adopted based on established mix design methodologies [11,12], and materials are selected in accordance with commonly available industrial by-products.

The rehabilitation of old structures should not only consider the aspect of structural safety but also be in line with the environmental goals. This research attempts to identify the effect of combination of ferromesh wrapping and geopolymer concrete on strength enhancement of short concrete columns.

2. LITERATURE REVIEW

The effect of ferrocement jackets and the inclusion of tension steel on reinforced concrete (RC) beams were studied, the test results show enhancement in load carrying capacity and bending without breaking. Also, finite element modeling nearly shows the same results [13]. Performed compressive and split tensile tests on concrete cylinders confined with varying percentages of mesh and different casting procedures; the results show an enhancement in compressive and split tensile strength

[14]. Experiments on fly ash-based geopolymer recycled aggregate concrete exposed to elevated temperatures and revealed that compressive strength could be maintained up to 600°C, thus indicating the fire resistance as well as the environmental friendliness of the material [15]. A fly ash-based geopolymer concrete mix design method that was quite systematic. In they tested different strength grades from M20 to M40 and thus demonstrated that the predicted and experimental strengths matched very well [11]. Besides that, they analyzed the impact of sodium hydroxide concentration and heat curing on the strength development of geopolymer mortar [12]. When concrete columns are confined with ferrocement, which is adjusted with GGBS, the axial load capacity, ductility, and crack resistance ability are boosted substantially [16]. Industrial by-products such as GGBS and metakaolin, when used in ferrocement composites, apart from making them durable, make them corrosion resistant [17]. Making use of high-strength mortar and several layers of mesh can not only greatly increase the axial load-carrying capacity of the columns but also their ductility under confinement [18]. Validated and confirmed the findings that self-compacting concrete under the restraint of ferrocement demonstrated an improved stress-strain relationship [19]. Demonstrated that ferrocement could be a good material for thin-walled structures since it ensures uniform reinforcement distribution [20]. The flexural performance of geopolymer beams wrapped with a layer of ferrocement was significantly improved [21]. Examined different models for predicting how confined concrete performs and suggested improved ways to estimate strain [22].

3. METHODOLOGY

3.1. Experimental program

In this study, a total twenty-eight short concrete columns were cast to analyze the effect of ferromesh and two different kinds of concrete confinement on the load-carrying capacity of short concrete columns. Out of twenty-eight columns, twenty-four were wrapped with different numbers of ferromesh layers, and the remaining four were unwrapped and used as control short concrete columns. 0 (unwrapped), 1, 2, and 3 layers of ferromesh wrapping are considered. Two different kinds of confinement matrices were used, namely, cement concrete and geopolymer concrete.

Nomenclature of columns: C01 in this, the first alphabet "C" represents the type of confinement concrete used (C = cement, G = geopolymer), the second number "0" represents the layers of numbers of ferromesh wrapped, and the third number "1" represents the number of the short concrete column. Following the same nomenclature scheme for all the twenty-eight short concrete columns. Based on the ferromesh layers wrapped and confinement matrix used, the short concrete columns were divided into seven different groups mentioned in the table below:

Table 1. Specifications of casting short concrete columns

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Group name	Column size before confinement (mm × mm)	Number of ferromesh layers wrapped	Type of concrete used as confinement	Column size after confinement (mm × mm)	Number of short concrete columns
A	100 × 450	0	Cement	150 × 450	4
B	100 × 450	1	Cement	150 × 450	4
C	100 × 450	1	Geopolymer	150 × 450	4
D	100 × 450	2	Cement	150 × 450	4
E	100 × 450	2	Geopolymer	150 × 450	4
F	100 × 450	3	Cement	150 × 450	4
G	100 × 450	3	Geopolymer	150 × 450	4

3.2. Material properties

3.2.1. Cement

Ordinary portland cement (OPC) 53 grade was used for casting of short concrete columns. The source of cement was Shree cement. The properties of cement have been tested as per IS 12269:2013 and IS 4031:1988 [23,24].

Table 2. Test conducted on cement

Name of material	Test conducted	IS code referred	Test results
Cement	Standard consistency	IS: 4031 (Part 4) - 1988	32%
	Initial setting time	IS: 4031 (Part 5) - 1988	150 minutes
	Final setting time	IS: 4031 (Part 5) - 1988	240 minutes
	Specific gravity	IS: 4031 (Part 11) - 1988	3.12

3.2.2. Fly ash

The class F fly ash (Grade 60) procured from the Eklahare Thermal Power Plant has been used. Its characteristics were determined as per IS 3812 (Part 1):2013 [25].

Table 3. Test conducted on fly ash

Name of material	Test conducted	IS code referred	Test results
Fly ash	Fineness of fly ash	IS: 3812 (Part 1) - 2013	6%

3.2.3. Ground granulated blast furnace slag (GGBS)

The GGBS incorporated is from JSW Cement Ltd. It is off-white in colour and has a fineness of 386 m²/kg.

3.2.4. Alkaline activator solution

The alkaline activator solution is vital in geopolymer concrete because it starts the chemical reaction between alumino-silicate materials like fly ash and GGBS. Here, sodium hydroxide (NaOH) and sodium silicate (Na₂SiO₃) solutions are used as the activators. A 13 molar (13M) NaOH solution is chosen, prepared by

mixing 520 grams of NaOH crystals in a liter of water [8,12].

3.2.5. Fine aggregate (sand)

Natural river sand from the Godavari River has been utilized in the present investigation as fine aggregate. The sand is clean, has good gradation, and is free from too much contamination like clay and organic matter. The whole selection and testing of fine aggregate were performed by referring to IS 383:1970 to check the suitability of fine aggregate for concrete making [26–28].

Table 4. Test conducted on fine aggregate

Name of material	Test conducted	IS code referred	Test results
Fine aggregate	Fineness modulus	IS: 383 - 2016	3.17
	Grading zone	IS: 383 - 2016	Zone I
	Specific gravity	IS: 2386 (Part 3) - 1963	2.73

3.2.6. Coarse aggregate

20 mm and 10 mm sizes crushed angular coarse aggregates were used [27,28].

Table 5. Test conducted on coarse aggregate

Name of material	Test conducted	IS code referred	Test results
	Particle shape, size	IS: 383 - 2016	Angular, 20 mm

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Coarse aggregate – 20 mm	Specific gravity	IS: 2386 (Part 3) - 1963	2.77
Coarse aggregate – 10 mm	Particle shape, size	IS: 383 - 2016	Angular, 10 mm
	Specific gravity	IS: 2386 (Part 3) - 1963	2.68

3.2.7. Wire mesh

Galvanized iron (GI) wire mesh of 0.95 mm thickness with square openings was used for the wrapping.

3.2.8. Water

Potable clean water, free from impurities and harmful substances like acids, alkalis, oils, salts and organic matters were used [29].

3.3. Mix design

Three different mix designs were used, in which two mixes are of cement-based concrete and one is of

geopolymer-based concrete. Cement based-concrete was designed by following the standard design procedure [29,30]. Geopolymer-based concrete was designed as per previous research recommendations [11,31].

Cement-based concrete (mix 1) - The designated strength of concrete was 30 MPa (1 MPa = 1 N/mm²), 50 mm workability was adopted, 20 mm size angular coarse aggregates were used.

Table 6. Cement based concrete – Mix 1

Cement (kg/m ³)	Fine aggregate (kg/m ³)	Coarse aggregate (kg/m ³)	Water (kg/m ³)
413.33	725.69	1151.69	186.00
1.00	1.75	2.78	0.45

Cement-based concrete (mix 2) - To prepare the cement based concrete mix having a workability of 100 mm, coarse angular aggregates of 10 mm size were used, adopting a maximum water-cement ratio.

Table 7. Cement based concrete – Mix 2

Cement (kg/m ³)	Fine aggregate (kg/m ³)	Coarse aggregate (kg/m ³)	Water (kg/m ³)
490.00	866.84	817.59	220.48
1.00	1.76	1.66	0.45

Geopolymer-based concrete (mix 3) - Fly ash and GGBS are binder constituents in geopolymer concrete having equal proportions. NaOH and Na₂SiO₃ were used as alkaline activator solutions, with a solution-to-binder ratio of 0.35. A 13M concentration NaOH solution was used. Natural sand is used as fine aggregate, and angular coarse aggregate of 10 mm size were used.

Table 8. Geopolymer based concrete – Mix 3

Fly ash (kg/m ³)	GGBS (kg/m ³)	NaOH (kg/m ³)	Na ₂ SiO ₃ (kg/m ³)	Fine aggregate (kg/m ³)	Coarse aggregate (kg/m ³)	Extra water (kg/m ³)
202.50	202.50	70.88	70.88	670.63	1273.21	39.41
1.00		0.35		1.65	3.14	0.09

3.4. Short concrete column casting procedure

Casting of inner core 100 mm: Prepared twenty-eight circular molds, each 100 mm in diameter and 450 mm in height. Smoothened top and bottom edges to achieve proper finishing. Cleaned the inner surface and oiled it for easy demolding after casting. Prepared the concrete as per mix design – 1 quantity. Compaction is done to remove any air voids present inside the concrete. Do the same procedure with all twenty-eight short concrete columns. After 24 hours of casting, separate the formwork from the columns and place them in the curing tank for three days. After the curing process, chipping was done on all the short concrete columns. It creates a stronger bond between the inner concrete core, the ferromesh and the confined concrete.

The ferromesh was wrapped tightly around the inner core surface as per the group specifications mentioned in

the experimental program Table 1. To ensure proper confinement and uniform load distribution, care was taken that during the wrapping process, a 10 mm clear cover on both the top and bottom ends of each column was kept.

Casting of outer core 50 mm: Prepared twenty-eight circular molds, each 150 mm in diameter and 450 mm in height.; followed the same procedure for cleaning and oiling. Mix - 2 was used for unwrapped short cylindrical concrete columns and cement concrete confined columns, while Mix - 3 was used for geopolymer confined columns. After 24 hours, demolding was done; cement concrete-confined columns were placed in water for curing, and geopolymer concrete-confined columns needed ambient curing [12]. All specimens were cured for 28 days.

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Fig. 1. Ferromesh wrapped short concrete columns



Fig. 2. Ferromesh unwrapped cement concrete-confined short concrete columns [control columns]



Fig. 3. One-layer ferromesh-wrapped cement concrete-confined short concrete columns



Fig. 4. One-layer ferromesh-wrapped geopolymer concrete-confined short concrete columns



Fig. 5. Two layers of ferromesh-wrapped cement concrete-confined short concrete columns



Fig. 6. Two layers of ferromesh-wrapped geopolymer concrete-confined short concrete columns

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Fig. 7. Three layers of ferromesh-wrapped cement concrete-confined short concrete columns



Fig. 8. Three layers of ferromesh wrapped geopolymer concrete-confined short concrete columns

3.5. Experimental setup

All samples were tested under axial compression using a universal testing machine (UTM) as per standard code [32]. The load was increased slowly and continuously until the column failed.



Fig. 9. Experimental setup (Universal Testing Machine)

4. RESULTS AND DISCUSSION

4.1. Axial load-deformation results of short concrete columns under universal testing machine (UTM)

Table 9. Axial load–deformation results of short concrete columns under axial compression

Column id	Axial load (kN)	Axial deformation (mm)	Average axial load (kN)	Average axial deformation (mm)
C01	532.46	10.46		
C02	510.29	10.90		
C03	548.68	9.95	532.32	10.35
C04	537.84	10.07		
C11	574.12	10.75		
C12	559.85	10.98		
C13	581.27	10.43	570.33	10.74
C14	566.09	10.79		
C21	615.94	11.29		
C22	628.33	11.17		
C23	607.40	11.35	622.56	11.20
C24	638.56	10.98		
C31	713.25	11.54		
C32	682.37	11.83		
C33	704.08	11.62	696.98	11.69
C34	688.21	11.78		
G11	540.12	10.26		
G12	563.30	10.07	550.35	10.15

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G13	528.47	10.40		
G14	569.51	9.88		
G21	590.85	10.43		
G22	615.33	10.27		
G23	631.74	10.13	611.28	10.30
G24	607.19	10.35		
G31	709.26	10.67		
G32	688.40	10.85		
G33	700.59	10.59	693.66	10.76
G34	676.38	10.93		

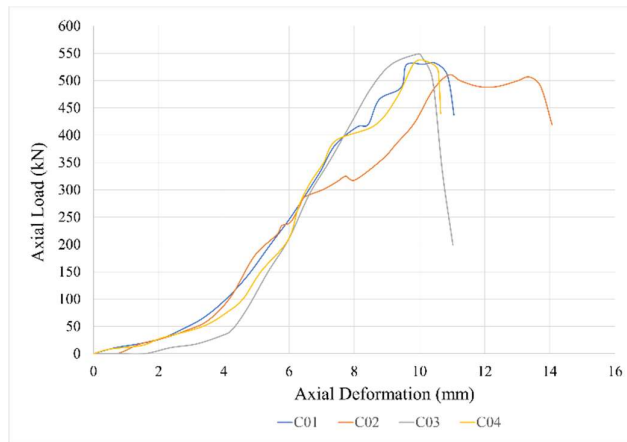


Fig. 10. Axial load-deformation behavior of ferromesh unwrapped short concrete columns confined with cement concrete

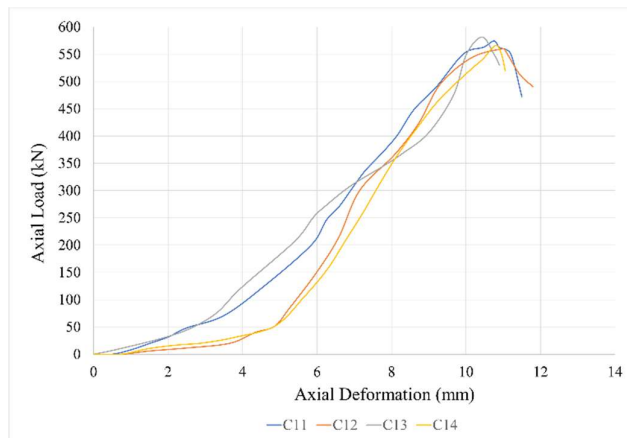


Fig. 11. Axial load-deformation behavior of one-layer ferromesh-wrapped short concrete columns confined with cement concrete

Comparative Study On Load Carrying Capacity Of Short Concrete Columns Confined With Cement Based Vs Geopolymer Based Ferromesh Composites

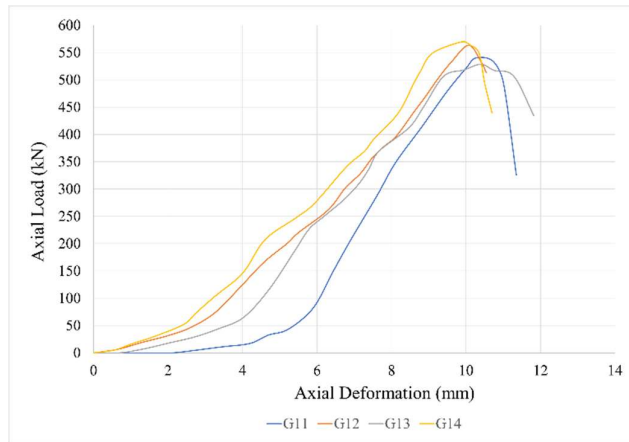


Fig. 12. Axial load-deformation behavior of one-layer ferromesh-wrapped short concrete columns confined with geopolymer concrete

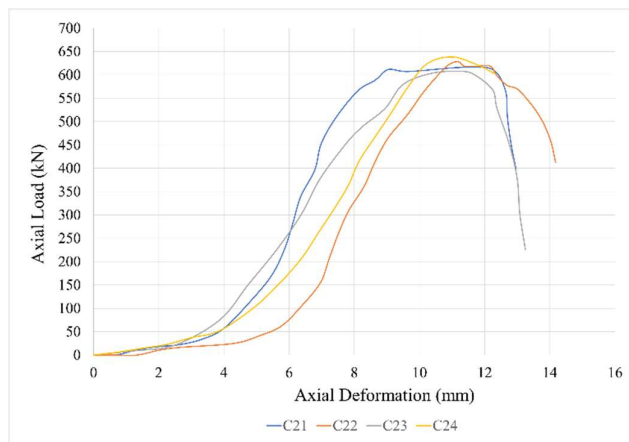


Fig. 13. Axial load-deformation behavior of two-layer ferromesh-wrapped short concrete columns confined with cement concrete

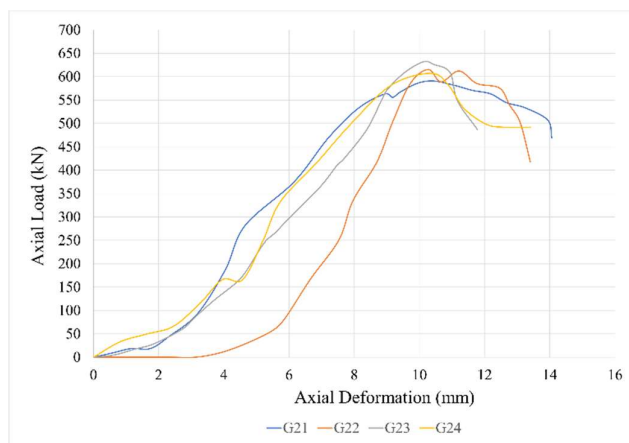


Fig. 14. Axial load-deformation behavior of two-layer ferromesh-wrapped short concrete columns confined with geopolymer concrete

Comparative Study On Load Carrying Capacity Of Short Concrete Columns Confined With Cement Based Vs Geopolymer Based Ferromesh Composites

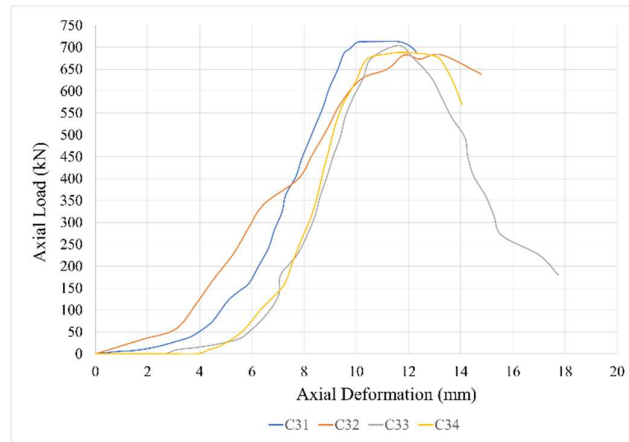


Fig. 15. Axial load-deformation behavior of three-layer ferromesh-wrapped short concrete columns confined with cement concrete

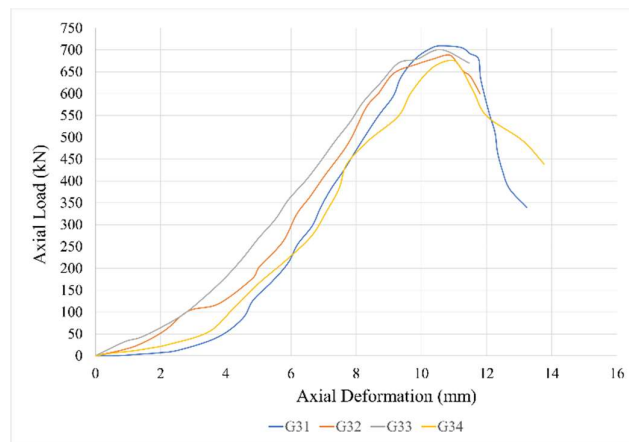


Fig. 16. Axial load-deformation behavior of three-layer ferromesh-wrapped short concrete columns confined with geopolymer concrete

4.2. Stress-Strain results of short concrete columns

Table 10. Stress-Strain results of short concrete columns under axial compression

Column id	Stress (N/mm ²)	Strain	Average stress (N/mm ²)	Average strain
C01	30.13	0.0232		
C02	28.88	0.0242	30.13	0.0230
C03	31.05	0.0221		
C04	30.44	0.0224		
C11	32.49	0.0239		
C12	31.68	0.0244	32.27	0.0239
C13	32.89	0.0232		
C14	32.03	0.0240		
C21	34.86	0.0251		
C22	35.56	0.0248	35.23	0.0249
C23	34.37	0.0252		
C24	36.14	0.0244		
C31	40.36	0.0256	39.44	0.0260
C32	38.61	0.0263		

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C33	39.84	0.0258		
C34	38.94	0.0262		
G11	30.56	0.0228		
G12	31.88	0.0224		
G13	29.91	0.0231	31.15	0.0226
G14	32.23	0.0220		
G21	33.44	0.0232		
G22	34.82	0.0228		
G23	35.75	0.0225	34.59	0.0229
G24	34.36	0.0230		
G31	40.14	0.0237		
G32	38.96	0.0241		
G33	39.65	0.0235	39.26	0.0239
G34	38.28	0.0243		

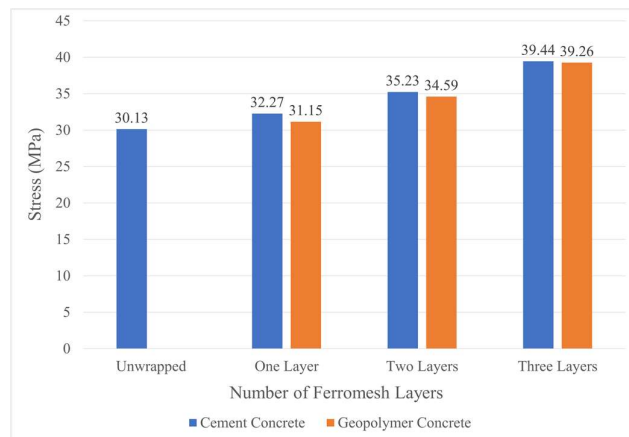


Fig. 17. Comparison of compressive strength of cement-based and geopolymer-based confined short concrete columns with varying mesh layers

The axial compression test results clearly reveal that ferromesh wrapping enhances the load-carrying capacity of short concrete columns. The average compressive strength of unwrapped cement concrete confined columns (control columns) was 30.13 MPa. The increase in strength due to ferromesh wrapping with cement concrete confinement was observed 7.10%, 16.93% and 30.90% for one, two and three layers, respectively. For geopolymer concrete columns, the percentage increase in strength was 3.39% for one layer, 14.80% for two layers, and 30.30% for three layers.

4.3. Failure modes and crack patterns



Fig. 18. Crack pattern and ultimate failure mode of ferromesh unwrapped short concrete columns confined with cement concrete under axial loading



Fig. 19. Crack pattern and ultimate failure mode of ferromesh-wrapped short concrete columns confined with cement concrete under axial loading



Fig. 20. Crack pattern and ultimate failure mode of ferromesh-wrapped short concrete columns confined with geopolymer concrete under axial loading

The ferromesh unwrapped short concrete columns failed in a brittle way when the axial compressive load was applied. No cracks could be seen at the beginning of the loading stage. When the load became the ultimate value, vertical splitting cracks appeared sharply, and then the concrete was crushed and the surface was spalled. The concrete was not laterally restrained, and the core was able to expand freely; therefore, the load carrying capacity was lost very suddenly, and there was no post-peak deformation. Ferromesh wrapped confined columns showed failure behavior changes that were more progressive as the number of ferromesh layers increased.

In one-layer ferromesh wrapped cement concrete confined columns, crack initiation was delayed compared to control columns. Fine vertical cracks formed at higher load levels with limited surface spalling. For two layers, crack spacing was reduced, and cracks were uniformly distributed. Crushing occurred gradually near peak load with improved stability. For three layers, failure was highly controlled. Crack widths

were minimal, and the concrete core experienced gradual crushing, while the mesh-maintained integrity even beyond peak load.

For geopolymer confined short concrete columns with one layer of ferromesh wrapped showed behavior almost similar to the cement-based columns; only crack formation was delayed, and there was less surface damage. Columns with two layers show postponement in core crushing with huge improvement in crack resistance. Among the geopolymer confined columns, three-layer wrapped columns gave the best results, showing very fine cracks, gradual failure, and increased post-peak stability.

4.4. Discussion

Ferromesh wrapping has a major impact on the axial compressive strength of the concrete. The ferromesh wrapping arrests the lateral expansion of the concrete core under compression. The gain in strength is in direct relation to the number of layers of the ferromesh, with

three-layer columns revealing close to 30% improvement for both cement and geopolymer concrete. Ferromesh wrapping is thus demonstrated as being highly effective through the change seen in unwrapped columns from brittle splitting to controlled crushing in ferromesh wrapped columns. Ferromesh wrapping effectively postponed the onset of cracks, lessened the crack width, and ensured that cracks were evenly distributed along the column height. Three-layer samples exhibited the most controlled mode of failure and showed no loss of the load-carrying capacity even after the maximum load was exceeded. The raise in peak strain clearly shows an improvement in ductility and toughness.

Cement-confined and geopolymer-confined concrete columns showed similar behavior. The single-layer geopolymer column's strength gain was slightly lower; however, the difference became almost zero in the case of two layer and three-layer configurations. As a result of the three-layer wrapping, both systems obtained almost 30% strength enhancement. This shows good bonding between ferromesh and geopolymer concrete that can generate enough confinement pressure. Based on its properties and lower environmental impact, geopolymer concrete can be considered as an alternative to conventional cement concrete for ferromesh-confined short concrete columns.

5. CONCLUSION

Ferromesh unwrapped short concrete columns failing are characterized by brittle failure with very limited deformation capacity and almost no post-peak resistance. The use of ferromesh wrapping boosted the axial load carrying capacity, ductility, and crack control through lateral expansion restraint and failure mode alteration from sudden splitting to controlled crushing with distributed microcracking. Adding more ferromesh layers brought about a marked improvement in strength and post-peak behavior, with two and three layers showing significant advancement over one layer. Geopolymer concrete has emerged as a very good confinement matrix, capable of matching the performance of cement-based confinement and, at the same time, providing a sustainable solution. The number of ferromesh layers played a more significant role in the structural performance. Geopolymer concrete presents a green alternative without sacrificing performance.

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