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Experimental Study on Compressive Strength of Concrete Using Pumice with 40% GGBS and Metakaolin Comparing with Conventional Concrete

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Abstract

Aim: The objective is to compare conventional concrete by using M30 grade concrete mix, a novel pumice aggregate used to partially replace coarse aggregate to produce lightweight concrete.

Methodology: In our concrete, 10% metakaolin is kept constant while 50% cement and 40% ground granulated blast-furnace slag (GGBS) are replaced. This composition was used for all groups. Novel pumice stone has replaced coarse aggregate, while M-sand has replaced fine aggregate. The 18 cubes were arranged in a group based on the 28-day cure dates. In addition to novel pumice aggregate, metakaolin and GGBS are purchased from Scientific Company.

Results: The 18 cubes were arranged in a group according to the 28-day curing period. A total of 36 cubes were built in two groups in order to calculate the compressive strength. For typical concrete of grade M30 at 28 days, the average compressive strength test result is 30.28 N/mm^2. The result of the compressive strength test of concrete with novel pumice aggregate stone and partial replacement of GGBS and metakaolin by the weight of cement for group 1 and for 18 cubes for the M30 grade of concrete @ 28 days is 35.50 N/mm^2. According to an independent t-test analysis, $p = 0.000$, or less than $p = 0.05$ ($p < 0.05$), was found. As a result, the two groups show a considerable statistical difference.

Conclusion: The compressive strength of concrete of M30 grade at 28 days of compressive strength test results of concrete with novel pumice aggregate stone and partial replacement of GGBS and metakaolin by the weight of cement is increased.

Keywords

Novel pumice aggregate, Metakaolin, Ground granulated blast furnace slag, Compressive strength, Concrete, Lightweight aggregate, Conventional concrete

Introduction

The progression of concrete types, from conventional grades to high-strength varieties, marks a significant advancement in construction materials [1, 2]. Normal grade concrete, utilized extensively from grade 5 to 45 during the 1900s, provided sufficient strength for general construction needs [3-5]. This type typically comprised cement quantities under 380 kg/m^3, standard aggregates like granite, moderate water demands, and minimal superplasticizer usage.

However, starting around the 1960s, as innovative structural designs emerged requiring higher load capacities, there arose a demand for more robust concrete solutions [6]. Thus, high strength concrete (HSC) was developed, capable of withstanding load capacities ranging from 50 MPa to 90 MPa [7]. HSC necessitated altered mix proportions compared to normal grade concrete, typically involving increased cement content, elevated aggregates, reduced water content, and the integration of superplasticizers [8-10].

To achieve the desired characteristics of HSC, various additives and complementary materials have been introduced into concrete mixes [11]. These include silica fume, fly ash, metakaolin, and other pozzolanic substances [12, 13]. Silica fume gained prominence in HSC formulations due to its capacity to enhance strength when partially replacing cement. Fly ash, conversely, enhances fluidity and functions as a natural admixture in HSC mixes [14]. Moreover, fly ash can serve as a cost-effective substitute for superplasticizers, as it can be used in higher concentrations.

Metakaolin, derived from the heat treatment of kaolin, has been employed as a cement substitute since the early 1990s, contributing to enhanced strength and durability properties in HSC compositions [15-17]. Construction materials such as concrete are common and widely used. Cementitious materials have been well studied at the macro or structural level without fully understanding their properties at the micro level. It might be possible to improve the properties of concrete by better understanding its structure and behavior at the micro/nanoscale. In concrete with a high cement content and low w/c ratio, nano-silica addition increased compressive, splitting, and flexural strengths significantly. In concrete containing nano-silica, water permeability was reduced due to the microstructure being more uniform and compact, resulting in a reduction in water permeability [18].

In the case of cracks caused by pore pressure accumulation, carbon nanotubes (CNTs) can act as nano-reinforcements. As well as their high thermal conductivity, CNTs were regarded as beneficial. Through their ability to conduct heat, carbon nanotubes reduced thermal inertia in the incumbent matrix. Additionally, CNTs were found to help scatter thermal stresses as well. When CNTs are used as a thermally stable reinforcement, they can significantly increase the tensile strength of concrete at ambient and elevated temperatures [19]. HSC can be improved mechanically by using nano-silica if it is used efficiently. There was a reduction in mass loss and a decrease in residual compressive and tensile strengths with nano-silica present [19].

In summary, the transition from normal grade to HSC reflects the quest for stronger and more enduring construction materials, necessitating the adoption of innovative technologies and the incorporation of various additives and complementary substances to achieve desired performance attributes.

Materials and Method

The experiment was undertaken in Saveetha School of Engineering's Concrete Laboratory, which is part of the Civil Engineering Department. The project was to be fabricated in M30 design concrete cubes. Concrete cubes moulded in the standard size of 150 x 150 x 150 mm were prepared to find out the compressive strength of concrete.

Novel pumice aggregate stone (8 - 12 mm thickness), figure 1 shows materials used. Metakaolin in powder and GGBS in powder form. The cement of the highest quality is made up of the normal cement content of argillaceous and calcareous materials, as well as other materials like gypsum. M-sand that has been sieved to a fineness of 4.75 microns is used to make fine aggregate.

(a) (b) (c)

Figure 1: Materials **(a)** GGBS, **(b)** Metakaolin, and **(c)** Pumice stone size of 8 to 10 mm.

Table 1 displays all of the attributes. The physical characteristics of the M-sand are derived in table 2, while the physical characteristics of the novel pumice aggregate are shown in table 3. The M30 design was made with the ratio of 1:0.75:1.5 is cement:fine aggregate:coarse aggregate, respectively.

Using cubes with a standard size, compressive strength was determined. The comparison of the characteristics of cement, metakaolin, and GGBS is derived in table 4. The casting of concrete cube specimens is depicted in figure 2. Novel pumice's qualities are displayed in table 5. A total of 72 cubes were casted with 18 cubes for each mix design.

After the casting progress, the cubes were kept for 24 h and demolded, and the curing period was taken to the compression strength of 28 days. Figure 3 shows the curing of concrete specimens. After the curing process completed, the specimen was taken. The compression testing machine was utilized to calculate the resisting strength in N/mm^2. The ultimate load was taken and calculated by using the stress formula

Table 1: Physical properties of cement.

S. No.	Properties	Result
1	Fineness	90 micron
2	Specific gravity	3.1
3	Standard consistency	30%
4	Initial setting	30 min
5	Final setting	600 min

Table 2: Physical properties of fine aggregate.

S. No.	Properties	Result
1	Size of sample	4.75
2	Sieve analysis	2.59
3	Water absorption	3%
4	Specific gravity	2.65

Table 3: Physical properties of coarse aggregate.

S. No.	Properties	Result
1	Size	20 mm
2	Sieve analysis	20 mm
3	Water absorption	3.14%
4	Specific gravity	2.68

Table 4: Comparison the properties of cement, metakaolin, and GGBS.

Contents	Cement	Metakaolin	GGBS
SiO_2 (%)	20.1	54.9	35.26
CaO (%)	63.5	0.06	38.77
Al_2O_3	4.9	41.7	8.2
Fe_2O_3	3.6	1.07	1.23
MgO	1.2	0.84	4.1
TiO_2	-	0.36	-
MnO_2	2.9	-	11.7
LOI	1.7	1.03	0.74
Specific gravity	3.15	2.44	2.77
Color	Grey	White	Off Whitish
Bulk density (kg/cc)	830	900	1060

Figure 2: Casting of concrete.

Table 5: Properties of pumice.

S. No.	Properties	Values
1	Specific gravity	2.75
2	Water absorption	2.27%

Figure 3: Testing of concrete.

and known about the maximum load resistance by the concrete cube specimen.

Statistical analysis

The statistical report generated through the SPSS software and analyzed the results. The mean was also computed for compressive strength. Represents a group of statistics for a sample group of 40% of GGBS and 10% metakaolin and novel pumice aggregate stone as coarse aggregate. Mean (30.28, 35.50). There is a statistically significant difference and p = 0.000 as it is lesser than p = 0.05. Figure 4 shows the chart derived from SPSS software for compressive strength of a sample group of 40% of GGBS and 10% of metakaolin and novel pumice aggregate stone as a coarse aggregate mixture of concrete and conventional concrete.

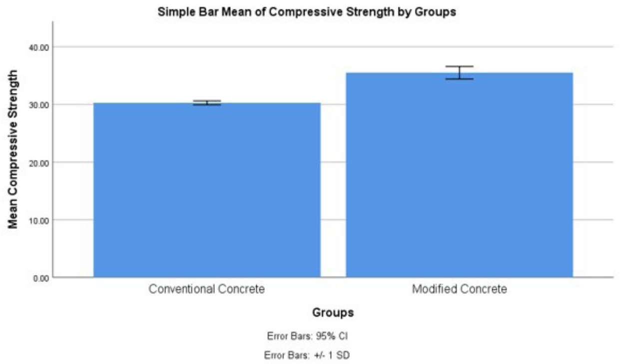

Figure 4: Bar chart analysis of mean compressive strength of sample group of 40% of GGBS and 10% of metakaolin and pumice stone as coarse aggregate mixture of concrete and conventional concrete. X-axis shows the comparison of conventional concrete and modified concrete. Y-axis shows the compressive strength test results. Lightweight concrete shows better accuracy compared to conventional concrete. The confidence interval (CI) was taken as 95% and ± 1 standard deviation.

Results

The average 28 days of compressive strength test result of conventional concrete is 30.28 N/mm^2. Table 6 shows the compressive strength result of conventional concrete.

The compressive strength test result of concrete with novel pumice aggregate stone and partial replacement of GGBS and metakaolin by the weight of cement is 35.50 N/mm^2 for average result of group I and for 18 cubes. Table 7 shows M30 grade concrete 28 days of compression strength test result of concrete with novel pumice aggregate stone and partial replacement of GGBS and metakaolin by the weight of cement.

There is a statistically significant difference and p = 0.000 as it is lesser than p = 0.05. Table 8 shows results of the independent samples t-test for a sample group of 40% of GGBS and 10% of metakaolin and novel pumice aggregate stone as coarse aggregate. Table 9 Shows the group statistics derived from the SPSS statistical analysis.

Discussion

By observing above results it is understood that using novel pumice aggregate stone as a coarse aggregate and GGBS into fine aggregate [9]. The independent samples t-test from the SPSS software the compressive between the group 1 and group 2 was calculated by the Levene's test variances F is 20.664, significance is 0.000 and t value is -19.475 and df value is 34 and 20.418. The mean difference is -5.22611 and standard error difference is 0.26835. The independent t-test analysis done through the SPSS statistical software and the significance of two tailed test results was p = 0.000 i.e., less than p = 0.05.

Table 6: M30 grade of concrete at 28 days at compressive strength test result of conventional concrete.

S. No.	Strength (KN)	Compressive strength (N/mm²)	Mean compressive strength (N/mm²)
1	683	30.34	30.28
2	690	30.67	
3	681	30.25	
4	672	29.87	
5	685	30.45	
6	670	29.78	
7	696	30.92	
8	693	30.78	
9	675	29.98	
10	687	30.52	
11	673	29.92	
12	686	30.47	
13	688	30.58	
14	672	29.87	
15	684	30.38	
16	672	29.87	
17	679	30.16	
18	680	30.21	

Table 7: Represents the compressive strength of M30 grade of concrete using pumice with 40% GGBS and metakaolin.

S. No.	Strength (KN)	Compressive strength (N/mm²)	Mean compressive strength (N/mm²)
1	758	33.69	35.50
2	804	35.73	
3	807	35.87	
4	809	35.96	
5	832	36.98	
6	812	36.09	
7	787	34.98	
8	762	33.87	
9	780	34.67	
10	820	36.44	
11	784	34.84	
12	767	34.09	
13	843	37.47	
14	770	34.22	
15	809	35.96	
16	814	36.18	
17	816	36.27	
18	805	35.78	

Table 9: Represents group statistics for a sample group of 40% of GGBS and 10% of metakaolin and pumice stone as coarse aggregate.

	Group	N	Mean	Std. deviation	Std. error mean
Compressive strength (N/Mm²)	Conventional concrete	18	30.2789	0.34573	0.08149
	Lightweight concrete	18	35.5050	1.08475	0.25568

A variety of waste aluminosilicate materials have been successfully transformed by geo-polymerization into mining and construction materials with improved chemical and physical characteristics, such as fire and acid resistance [10].

Limitations of the novel pumice, a thin aggregate that is utilised in building. Lightweight concrete is often used in precast and prestressed construction. The lightweight component used in concrete is called novel pumice [13]. A type of lightweight concrete that dates back to the beginning. The cause of it is volcanic activity. The most important characteristic of lightweight concrete is low heat conductivity [7].

Future Study

IS 10262:2019 places a limit on the amount of GGBS that can be used in the production of self-compacting cement since using more GGBS would result in stiffer concrete, an earlier setting time, and uniformity loss. Thus, the objective of the current work is to present a unique mix design and development approach for fly ash-GGBS based SCAAC under ambient curing conditions [1].

Conclusion

For the creation of GGBS based in the current inquiry, a straightforward mix design technique has been presented. As comparison to ordinary concrete, the compressive strength of M30 grade concrete increased by a percentage after 28 days of testing when pumice stone was added, and some of the weight of GGBS and metakaolin was replaced with cement. It shows the incremental percentage of 20% and performance over conventional concrete.

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Table 8: Independent samples t-test results for sample group of 40% of GGBS and 10% of metakaolin and pumice stone as coarse aggregate: This study shows the statistical significance difference. And it was observed for compressive strength in an independent sample t-test p = 0.000 as it is lesser than p = 0.05.

Compressive strength	Levene's test for equality of variances		T-test for equality of means						
	F	Sig.	t	df	Sig. (2-tailed)	Mean difference	Std. error difference	95% CI of the difference: Lower	95% CI of the difference: Upper
Equal variance assumed	20.664	0.000	-19.475	34	0.000	-5.22611	0.26835	-5.77146	-4.68076
Equal variance not assumed	-	-	-19.475	20.418	0.000	-5.22611	0.26835	-5.78515	-4.66708

Conflict of Interest

None.

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