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Comparative Study on Compressive Strength of Concrete Using Novel Pumice with 40% Silica Fume and Metakaolin Conventional Concrete

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Abstract

The main goal is to compare lightweight concrete with conventional concrete and to explore the feasibility of using novel pumice stone as a partial substitute for coarse aggregates in M30 concrete grade. Groups were prepared at the composition of 50% cement and replacing 40% silica fume, 10% metakaolin is kept constant in this concrete. The independent t-test computation is done using 80% G-power. M-sand was utilized as the fine aggregate, whereas pumice was used as the coarse aggregate. Metakaolin and silica fume are procured from scientific companies and pumice are arranged from online traders. To determine the compressive strength, a total of 36 cubes were manufactured in two groups. This study shows the statistically significant difference between the t-test on an independent sample of p value is 0.000 ($p < 0.05$). The group data for a sample group made up of coarse aggregate made up of 40% silica fume, 10% metakaolin, and 40% pumice stone. Mean (34.3311, 43.0000), standard deviation (1.65492, 0.56454), standard error mean (0.39007, 0.13306). The result of a 28-day test for compressive strength on concrete of grade M30 is 34.33 N/mm^2, on average. The average result for the M30 grade concrete with pumice stone and partial replacement of modified concrete is 37.65 N/mm^2. Pumice stone, partly modified silica fume, and metakaolin enhanced the compressive strength of concrete by 8.25% as compared to normal concrete, measured by weight of cement. It shows better performance with greater economic effects than conventional concrete.

Keywords

Novel pumice stone, Metakaolin, Silica fume, Compressive strength, Lightweight concrete, M30 grade

Introduction

Natural lightweight aggregate and synthetic lightweight aggregate are the two different varieties [1]. Due to its lower density than typical coarse aggregate and ease of availability, pumice aggregate is employed. By using M30 mix, both nominal concrete and lightweight aggregate concrete are cast [2]. By performing different destructive and non-destructive tests, it was found that lightweight concrete with pumice aggregate outperformed traditional, suggesting it as a potential substitute [3]. Properties of cement are shown in table 1.

The continuous growth in construction activity has increased demand for natural aggregates [4]. Because of the continuing depletion of natural resources, it is imperative to develop some replacement materials that will serve the same purpose as natural aggregates [5]. The physical properties of the fine aggregate are listed in table 2. The coarse aggregate's physical characteristics are displayed in table 3. By doing this, it will be possible to utilize quarry dust effectively rather than allowing it to go to waste and endanger the environment [6]. Comparing

Table 1: Physical properties of cement.

S. No.	Name of the test	Result
1	Fitness	90 microns
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 of fine aggregate	Result
1	Size	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.	Name of the test	Result
1	Size	20 mm
2	Sieve analysis	20 mm
3	Water absorption	3.14%
4	Specific gravity	2.68

the chemical properties of cement, metakaolin, and silica fume is shown in table 4.

Google Scholar has 1190 findings from the last five years of study. Notwithstanding our practice with various composite materials, concrete still plays a significant part in the modern building business. Cement, fine and coarse aggregate make up the construction material known as concrete [7]. Coarse aggregate is one of the components of concrete that gives it more volumetric stability and durability. Because it is less expensive than cement, it immediately contributes to the economy of concrete. So, it is best to employ as much excellent aggregate as feasible. Both the fresh concrete and the cured concrete should exhibit the desired qualities when the aggregate is good [8]. Pumice stone has been chosen as the substitute material for coarse aggregate in light of the literature assessment [9]. Pumice stone is a naturally occurring lightweight aggregate that may be used to create lightweight concrete since it is both light and robust [10]. Its lightness is a result of gas that was released when molten lava burst from the earth's crust's depths [11]. Due to its desirable qualities, pumice stone is a particularly sought-after material as a light rock and has been utilized as a building material in civil engineering for ages all over the world [12].

Table 4: Comparison of chemical properties of cement, metakaolin and silica fume.

Contents	Cement	Metakaolin	Silica fume
SiO_2 (%)	20.1	54.9	93.38
CaO (%)	63.5	0.06	0.67
Al_2O_3	4.9	41.7	0.15
Fe_2O_3	3.6	1.07	0.21
MgO	1.2	0.84	0.10
TiO_2	-	0.36	-
MnO_2	2.9	-	1.28
LoI	1.7	1.03	1.46
Specific gravity	3.15	2.44	2.25
Color	gray	white	Grey to off-whitish
Bulk density (kg/cc)	830	900	1300

Pumice aggregate concrete has the advantage of being up to one-third lighter than traditional sand-and-gravel concrete, which is a substantial benefit. Its quality helps to lower the price of structural steel, which in turn lowers job expenses [13]. Lighter equipment can handle larger amounts of concrete with less damage to the machinery. In structures where dead load is a deciding factor, adding floors may be possible by reducing the dead weight on trusses, girders, and slabs. Pumice concrete's lightweight lessens the live strain on falsework and forms [5]. Contemporary scientists have discovered that pozzolan, or fine-grained pumice, is the key to the durability of the Pantheon and other Roman constructions, and that it is responsible for the manageable weight of the Pantheon's enormous, unreinforced concrete dome (known as pozzolana to the Romans). Pumice sand, pumice rock, and Portland cement are the main ingredients in contemporary pumice concrete formulas [5].

Materials and Method

The experiment was conducted in the civil engineering department's concrete lab at Saveetha School of Engineering. Concrete cubes of the M30 grade concrete design were to be used in the project. To determine concrete's compressive strength, 150 x 150 x 150 mm concrete cubes of various sizes were made. Figure 1 and figure 2 depict metakaolin and silica fume, respectively. The usual cement composition of argillaceous and calcareous elements, as well as additional components like gypsum, make up the cement of the highest grade. The innovative pumice stone is seen in figure 3. A G-power

Figure 1: Silica fume.

Figure 2: Metakaolin.

Figure 3: Pumice stone size of 8 to 10 mm.

of 80%, alpha and beta values of 0.05 and 0.2, and 95% confidence interval (CI) are used. Applications of nanomaterials is also one prominent approach in the preparation of required concrete cubes.

To attain the desired compression strength, the cubes were maintained for 24 h after the casting process, demolded, and the curing period was extended to 28 days. In this project, cement that complied with the IS: 12269-2013 OPC 53 standard was employed. According to IS: 12089-1987 and Indian Standard Draft Code CED 2 (7921), respectively, silica fume and metakaolin were employed. All of the traits are displayed in table 5. The M30 design was constructed using a cement, fine aggregate, and coarse aggregate mix ratio of 1:0.75:1.5.

Pumice was employed as the coarse aggregate and M-sand as the fine aggregate in the novel pumice stone (8 - 12 mm thickness). Ground granulated blast furnace slag (Silica fume) and metakaolin in powder form are added to the concrete. By weight, 50% silica fume and 10% metakaolin were used to replace some of the cement. Fine aggregate is created from M-sand that has been sieved to a fineness of 4.75 microns. 18 cubes were produced for each combo design, for a total of 36 cubes.

Table 5: Physical properties of pumice stone.

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

A compression testing equipment was used to determine the compressive strength. One of the cube's faces was laid flat on the test setting and the cube was put on a flat surface. The weight was introduced progressively as the progression started. When that maximum weight is applied, the cube may entirely or partially break. Results for compressive strength were obtained using the ultimate load and the resisting area. Figure 4 shows concrete cube specimens that are 150 x 150 x 150 mm in size being cast. Concrete cube examples are shown in figure 5.

Once the curing process was complete, the specimen was collected to assess the compressive strength. Using the compression testing device, the compressive strength in N/mm^2 was determined. The concrete cube specimen's maximum load resistance was known, and the ultimate load was measured and calculated using the stress formula.

Statistical analysis

The results of the experiment were assessed using SPSS (Statistical Package for the Social Sciences) version 26 soft-

Figure 4: Casting of concrete.

Figure 5: Testing of concrete.

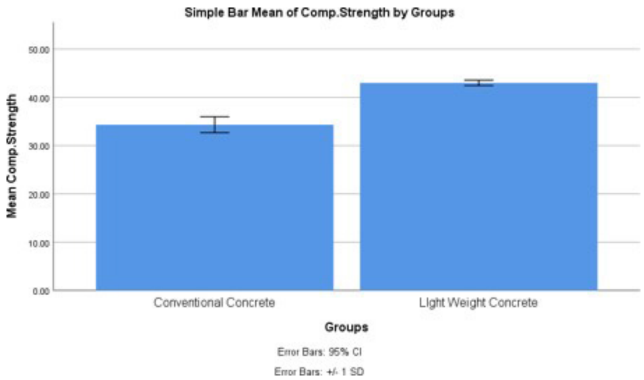

Figure 6: Bar chart analysis of mean compressive strength of sample group of 40% of silica fume and 10% of metakaolin and pumice stone as coarse aggregate mixture of concrete and conventional concrete. Lightweight concrete shows better accuracy compared to conventional concrete. Mean accuracy of detection = +/- 1 Standard deviation.

ware. To evaluate the statistical significance between the study and control groups, an independent sample t-test was applied. The factors that impacted compression strength, concrete grade, water/cement ratio, cement grade, and days of curing were all independent in the research; there were no dependent variables. This tool was also used to determine the mean, standard deviation, and standard error of the mean of compressive strength. Figure 6 shows the bar chart of comparison of conventional concrete and light weight concrete. There is a Statistical significance difference between the standard deviation is taken as +/- 1 standard deviation. P < 0.000 for an independent sample t-test, which is smaller than p < 0.05. Represents group statistics for a sample group of 40% of silica fume and 10% of metakaolin and pumice stone as coarse aggregate. Mean (34.3311, 43.0000), standard deviation (1.65492, 0.56454), and standard error mean (0.39007, 0.13306).

Results

The result of a 28-day compressive strength test on conventional concrete's M30 grade is an average of 34.33 N/mm². Table 6 displays the results of the 28-day compressive strength test on M30 grade conventional concrete. The average result for group 1 and 18 cubes for the M30 grade of concrete at 28 days of compressive strength test of concrete with pumice stone and partial replacement of silica fume and metakaolin by the weight of cement is 43.00 N/mm². The M30 grade of concrete at 28 days of compressive strength test results of concrete with pumice stone and partial replacement of silica fume and metakaolin by the weight of cement is shown in table 7. There is statistical significance difference for compressive strength in an independent sample t-test p < 0.000 as it is lesser than p < 0.05. Represents group statistics for a sample group of 40% of silica fume and 10% of metakaolin and pumice stone as coarse aggregate. Table 8 shows the independent t-tests comparison for compressive strength test results. Mean (34.3311, 43.0000), standard deviation (1.65492, 0.56454), and standard error mean (0.39007, 0.13306). Table 9 shows the group statistics derived from the SPSS statistical analysis.

Discussion

The optimum doses of silica fume and metakaolin in combination led to better performance to increase the strength, durability, and hardness respectively. This mineral admixture was the best alternate material for cement and reduced the CO_2 emission from cement industry. Silica fume enhances the performance and durability of cement-based systems and mix compositions [14]. Since metakaolin partially replaces cement in concrete, more C-S-H gel is produced, which interacts with $Ca(OH)_2$, one of the byproducts of cement hydration. The experimental investigation assessed the impact of metakaolin on a few concrete sample specimens' susceptibilities to corrosion.

To do this, a concrete pore solution was researched [15] concrete's strength and permeability will be considerably increased and decreased by the addition of silica fumes, increasing the material's durability. Pumice stone has been used

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

S. No.	Ultimate load of the concrete cube specimen (kN)	Compressive strength for 28 days (N/mm²)	Mean compressive strength (N/mm²)
1	590	30.67	30.28
2	672	34.31	
3	659	33.73	
4	680	34.67	
5	674	34.40	
6	685	34.89	
7	725	32.22	
8	689	35.07	
9	617	31.87	
10	693	35.24	
11	662	33.87	
12	653	33.47	
13	696	35.38	
14	699	35.38	
15	720	36.44	
16	650	33.33	
17	597	35.42	
18	746	37.60	

Table 7: M30 grade of concrete at 28 days of compressive strength test result of concrete with pumice stone and partial replacement of silica fume and metakaolin by the weight of cement.

S. No.	Ultimate load of the concrete cube specimen (kN)	Compressive strength for 28 days (N/mm^2)	Mean compressive strength (N/mm^2)
1	840	37.33	35.50
2	852	37.87	
3	820	36.44	
4	847	37.64	
5	800	35.56	
6	802	35.64	
7	780	34.67	
8	757	33.64	
9	760	33.78	
10	812	36.09	
11	840	37.33	
12	855	38.00	
13	865	38.44	
14	842	37.42	
15	874	38.84	
16	842	37.42	
17	854	37.96	
18	865	38.44	

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

		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	Upper
Compressive strength	Equal variance assumed	9.141	0.005	-21.034	34	0.000	-8.66889	0.41214	-9.50646	-7.83132
	Equal variance not assumed	-	-	-21.034	20.904	0.000	-8.66889	0.41214	-9.52622	-7.81156

Table 9: Represents group statistics for a sample group of 40% of silica fume and 10% of metakaolin and novel pumice stone as coarse aggregate. Mean (34.3311, 43.0000), standard deviation (1.65492, 0.56454), and standard error mean (0.39007, 0.13306).

	Groups	N	Mean	Std. deviation	Std. error mean
Compressive strength (N/mm^2)	Conventional concrete	18	34.3311	1.65492	0.39007
	Lightweight concrete	18	36.8061	1.58424	0.37341

in place of coarse aggregate [16]. The volcanic-derived rocks known as pumice stones may be found all over the world. Pumice stone, a naturally occurring lightweight aggregate, may be used to make lightweight concrete since it is both strong and light [17].

The use of substitute materials made from industrial waste has replaced some traditional materials. The physical, mechanical, and durability properties of concrete were investigated by comparisons between the compressive and tensile strengths of regular concrete and concrete that had pumice replaced in varying percentages, ranging from 5% to 30% [18]. The use of silica fume improves the cohesiveness of shotcrete and self-consolidating concrete, which is the future focus of this work. Engineers and specifiers may achieve their design and performance objectives, if not go above and beyond them, with the aid of silica fumes.

Conclusion

Within the parameters of this investigation, lightweight concrete (group 2) greatly outperforms traditional concrete in terms of strength (group 1). With a 25.25% improvement over the compressive strength of traditional concrete, the partial substitution of these innovative ingredients has produced superior results. As a result, the study's ultimate finding is that innovative pumice material may be used in place of natural aggregate to reduce concrete's self-weight.

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None.

Conflict of Interest

None.

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