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Experimental Analysis of Vermiculite Concrete with Supplementary Cementitious Materials: Assessing the Synergistic Effects of Fly Ash and Silica Fume

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Abstract

Fly ash and silica fume are mineral admixtures that are used in the production of M30 grade concrete, which is composed of cement, fine aggregate, coarse aggregate, vermiculite, and potable water. Water-to-cement ratio (w/c) has been established at 0.45. In this experimental investigation, concrete cubes and split tensile cylinders will be used with varying quantities of vermiculite: 0%, 20%, 40%, 60%, 80%, and 100%. The compression and split tensile strength of vermiculite concrete specimens are analyzed after 7, 14, and 28 days of curing, revealing a substantial increase in strength. Instead of sand, vermiculite is employed as the primary infill in concrete. The self-weight of the structure will be reduced by utilizing fine aggregate in place of vermiculite. This leads to a decrease in the cost of construction.

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Curing; Fly Ash;
M_{30}; Silica Fume;
Strength Properties;
Vermiculite.

Introduction

Lightweight concrete is a type of concrete which includes expanding agent that increases the volume of the mixture. Vermiculite is an inert material was described in 1824 for an occurrence in Millbury, USA. The vermiculite is a group of hydrated laminar mineral which are aluminum –iron – magnesium silicate, resembling mica in an appearance.[2] It is formed by weathering of hydrothermal alteration of biotite or phlogopite.[3] Vermiculite is chosen to replace

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specific properties such as it is lighter in weight, improved workability, fire resistance, resistance to cracking and shrinkage.[4] It will not undergo any chemical reaction when it is mixed with concrete as it is inert in nature and also it is an eco- friendly nature5. Concrete block having an density range of approximately 300 to 2000 kg/m^3. Vermiculite light weight concrete block can be effectively used in construction industry for reducing the self-weight of masonry wall.[6] Workability of vermiculite concrete increases with increase in percentage of supplementary cementitious materials.[7]

Literature Review

The Study by Vishal S. Ghutke and Pranita S. Bhandari in 2014 Explores the Influence of Silica Fume on Concrete

Ordinary Portland cement has traditionally been used to construct civil structures. Silica fume is a non-metallic, non-hazardous industrial byproduct. It is ideal for use in concrete mixes and increases concrete qualities such as compressive strength. The major goal of this study is to figure out what replacement percentages are best for Indian conditions. Various qualities of concrete employing silica fume have been studied to achieve the goal. Further, a comparison of conventional concrete and concrete having silica fume is made to establish the best replacement a certain percentage Compressive strength improves up to a particular proportion when cement is replaced with silica fume (10 percent replacement of cement by silica fume). However, if more silica fume is used to replace cement, the strength is reduced. The impact of silica fume on a variety of other concrete qualities has also been studied. This document is an excellent resource for novices who want to learn about the effects of Silica Fume on concrete.

The Study by Vinod Goud and Niraj Soni, Published in October 2016, Investigates the effects of using Fly Ash as a Partial Replacement for Cement in Concrete

Consequently, thermal power plants generate fly ash, which constitutes an enormous environmental threat. Industrialization and urbanization are two processes that have expanded globally in recent decades. In addition to the necessity of these phenomena, it is imperative to conduct research on their adverse impacts on the global environment and daily life. The most significant adverse consequence of these global operations has been the production of substantial quantities of industrial refuse. Consequently, the challenges associated with their safe management and disposal have emerged as a critical evaluation for environmentalists and scientists. An additional concern is the necessity of land, materials, and resources to facilitate infrastructure development. Thermal power facilities generate a substantial quantity of solid refuse as a byproduct.

The Study by T. Subramani and K. S. Ramesh, Conducted in May 2015, Focuses on Partially Replacing Cement with Fly Ash and Completely Replacing Natural Sand with Manufactured Sand (M Sand) in Concrete

Natural sand supplies are becoming exhausted as a result of the rapid increase in construction activity, and good quality sand may need to be transported across long distances, raising construction costs. Natural sand isn't usually of the highest quality. As a result, it's critical to use an alternate ingredient to partially replace natural sand in concrete while retaining its quality. Quarry sand is one such substance that can be utilised as a fine aggregate in place of sand. The objective of the present investigation is to substitute natural sand with Quarry sand as a fine aggregate. The compressive strength of the water-cured specimens is assessed at 7, 14, and 28 days. Split Tensile Strength, Flexural Strength Currently, we are conducting a test. We were able to ascertain the strength of a concrete by substituting fly ash for a portion of the cement and m sand for the entire sand using these ingredients.

Materials and Methods

Cement

Ordinary Portland cement was utilised as the cement for the vermiculite concrete. It immediately becomes one of the structural parts once it has been set. Furthermore, the type of cement has an impact on the workability of fresh concrete as well as its workability rate. The most significant component of concrete is cement, which acts as a bonding agent for the separate elements that lack pozzolanic properties. Cement is available in a variety of forms and chemical compositions. IS:456-2000 codal provision is taken into account for this experimental project.The properties of cement are as follows Specific gravity of cement -3.13, Initial setting time and final setting time are 27 minutes and 10 hours.

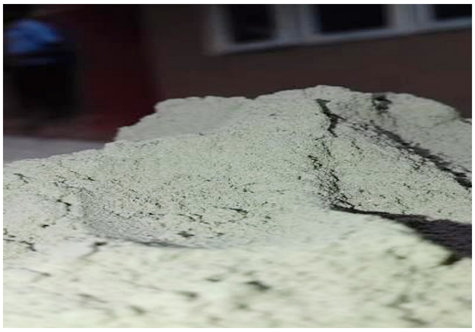

Fig.1: Cement

Table 1: Properties of cement

Parameter	Value
Specific gravity	3.13
Initial setting time	27 minutes
Final setting time	10hours

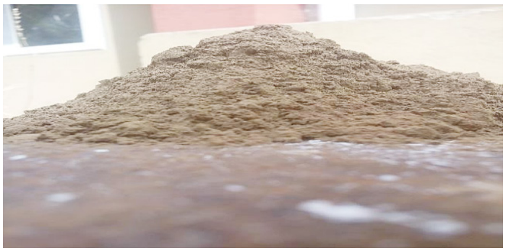

Fig. 2: Fly ash

Table 2: Properties offly ash

Parameter	Value
Specific gravity	2.5
Cohesion	Negligible
Compression	0.05–0.4
Optimum moisture content	18%-35%
Plasticity	Nonplastic

Table 3: Chemical composition of flyash

Chemical	Compostion
Percentage	
Silicondi oxide (SiO_2)	51.57
Aluminium oxide (Al_2O_3)	22.57
Ironoxide (Fe_2O_3)	14.91
Calcium oxide (CaO)	4.82
Lossonignition (LOI)	3.56

Flyash

Fly ash is a coal incineration by-product that is predominantly collectedfrom particulates that are discharged from coal-fired furnaces and thermal power facilities. It was purchased from Astrra chemicals, Chennai. Fly ash is frequently employed as a pozzolanic in the production of hydraulic cement and hydraulic gypsum, as well as a partial or complete substitute for Portland cement. It is also referred to as pulverized ash or discharge ash. It ensures an appropriate setting and safeguards concrete and plaster from chemical attacks and moisture. Fly ash particles typically exhibit a spherical shape with diameters ranging from 0.5 to 300 microns. The properties of fly ash vary significantly based on its type and source. This variability extends to its chemical composition, which influences its pozzolanic activity and other performance characteristics in concrete. Therefore, understanding the specific chemical composition of fly ash is crucial for optimizing its use as a supplementary material in concrete mixes.

Fig. 3: Silica Fume

Table 4: Properties of silicafume

Parameter	Value
Specific gravity	2.2
Cohesion	Negligible
Compression	0.05–0.4
Optimum moisture content	3%-6%
Plasticity	Nonplastic

Silicafume

Silica fume, also referred to as microsilica, is a byproduct generated during the production of silicon metal or ferrosilicon alloys. It was purchased from Astrra chemicals, Chennai.This ultrafine powder, composed of spherical particles less than 1 micron in diameter, is a highly effective pozzolanic material. When added to concrete, silica fume enhances both its mechanical and durability properties. It increases the compressive strength and abrasion resistance of the concrete, making it significantly more durable and less permeable. This reduced permeability also helps in protecting the concrete against aggressive chemicals and environments, thus extending its lifespan. In addition, silica fume plays a crucial role in strengthening the bond between the aggregate and cement paste in concrete, significantly enhancing cohesion. These beneficial properties have made silica fume a preferred material for high-performance concrete used in critical infrastructure projects such as bridges, tall buildings, and marine structures.

Table 5: Chemical composition of silica fume

Chemical Composition	Percentage
Silicondi oxide (SiO_2)	20.25
Aluminium oxide (Al_2O_3)	5.04
Iron oxide (Fe_2O_3)	3.16
Calcium oxide (CaO)	63.61
Potassium oxide (K_2O)	0.51
Lossonignition (LOI)	3.12

Fig. 4: M-Sand

Aggregates

M-SAND (Fine Aggregate)

Manufactured sand, often referred to as M-sand, serves as a substitute for natural river sand in the construction sector. It is produced by crushing hard granite stones into finely graded particles, thereby providing a viable alternative that meets the requirements for various concrete and construction applications. M-sand has several advantages over natural sand, making it a popular choice in the industry. One of the primary benefits of M-sand is its consistency in quality. Unlike natural sand, which can vary in texture and composition, M-sand is manufactured under controlled conditions, ensuring uniformity and better quality control. The pulverized sand has been cleansed and graded for construction purposes, and it is cubical in shape with grounded edges. Manufactured sand, also known as M-Sand, typically consists of particles smaller than 4.75mm in size. It serves as a viable replacement for natural river sand in construction applications. The primary drivers for its adoption include the ready availability of M-Sand and the cost-effectiveness achieved through reduced transportation expenses. These factors contribute to its increasing use in various construction projects, promoting sustainable and economically viable practices in the construction industry.It was purchased from Lakshmi agency, Madurai.

The cost of transportation from a distant river sand bank can be reduced by delivering manufactured sand to a nearby location, as it is composed of firm granite boulders. Consequently, the utilization of manufactured sand as a construction material can contribute to the reduction of construction costs.

Fig. 5: Coarse Aggregate

Coarse Aggregate

Coarse aggregate, essential in concrete production, comprises gravel, crushed stone, or recycled concrete typically larger than 4.75 mm. It plays a pivotal role in enhancing concrete strength, durability, and structural integrity. Selected for its size, grading, and quality, coarse aggregate fills voids between particles, optimizing concrete density. Its shape and texture influence workability and bonding with cement paste, impacting overall mechanical properties. Increasingly, recycled concrete aggregate is favored for sustainability, reducing environmental impact by conserving natural resources and minimizing transportation needs, highlighting its pivotal role in modern construction practices. To ensure a successful bond between the aggregate particles and the matrix, the utmost dimension of coarse aggregate that can be used in vermiculite concrete is 20mm of high-quality aggregate. The coarse aggregate particulates and matrix must be equidimensional.

Vermiculite

When heated, vermiculite, which is a hydrous phyllo silicate mineral, expands dramatically. Exfoliation is a regular occurrence in commercial furnaces when a mineral is heated to a high enough temperature. Vermiculite is created when biotite or phlogopite is weathered or altered hydrothermally. This natural mineral can be found in a variety of applications, ranging from construction to gardening. It's a popular name for hydrated laminar magnesium-aluminium-iron silicate, and vermiculite is a low-density substance with a density of 72–90 kg/m^3. It was purchased from Astrra chemicals, Chennai.

Fig. 6: Vermiculite

Water

The water should not contain acids, alkalis, or minerals. Water is an essential component of concrete, as it activates the cement emulsion, which provides the material with its strength. The purity and quantity of water must be meticulously assessed. Water is required to initiate the reaction between cement and other concrete constituents. The bonding property of cement is rendered ineffective in the absence of water. A building material is produced by the chemical reaction between cement and water, which phases the numerous minute surface imperfections of fine and coarse aggregate, bringing them closer together. Consequently, water is a critical component of concrete.

Methodology

Compressive Strength Test

Once the curing period is complete, remove the specimen from the water and carefully dry its surface to remove excess moisture. Measure the specimen's dimensions accurately to the nearest 0.2 meters. Clean the bearing surface of the testing machine thoroughly. Position the specimen in the machine to ensure an even distribution of load across all sides, aligning it with the center of the base plate. Adjust the movable part of the machine gently until it touches the specimen's upper surface. Gradually apply the load at a rate of 140 kg/cm² per minute until the specimen fails, ensuring minimal disruption during testing. Record the maximum load and any unexpected failure characteristics observed during the test.

Compressive Strength of the cube =Load applied/ Area of Specimen.

Fig. 7: Compressiontest on Cube

Split Tensile Strength Test

Upon completion of the curing period, whether it be 7, 14, or 28 days, or at any specific age chosen for tensile strength testing, remove the specimens from the water and thoroughly dry their surfaces to remove any moisture. Subsequently, mark diametrical lines on both ends of each specimen to ensure accurate axial alignment before proceeding with testing. Afterward, record the specimen's dimensions and weight. Establish the compression testing machine to the intended compression range. Place the specimen on the plywood strip located on the lower plate. The specimen should be positioned so that the end lines are vertical and in the center of the lower plate. Position the additional plywood piece on top of the specimen. The upper plate should be lowered until it is near the plywood strip. At a rate of 0.7 to 1.4 MPa/min, without trauma.

Splitting Tensile Strength, t= 2 x (load applied) / (π x Length x Diameter)

Result and Discussion

According to the results, adding up to 40% vermiculite as a partial substitute for fine aggregate boosts compressive strength. After seven days of testing, the amount of vermiculite added is gradually decreased.

Fig. 7: Splittensileteston cylinder

Table 6: Compressive Strength of Concrete (28Days)

Mix Id	Fly Ash (%)	Silica Fume (%)	Vermiculite (%)	M-Sand (%)	Avg. Compressive Strength (N/mm²)
V0	20	10	0	100	28.54
V20	20	10	20	80	28.14
V40	20	10	40	60	31.24
V60	20	10	60	40	27.47
V80	20	10	80	20	23.45
V100	20	10	100	0	21.54

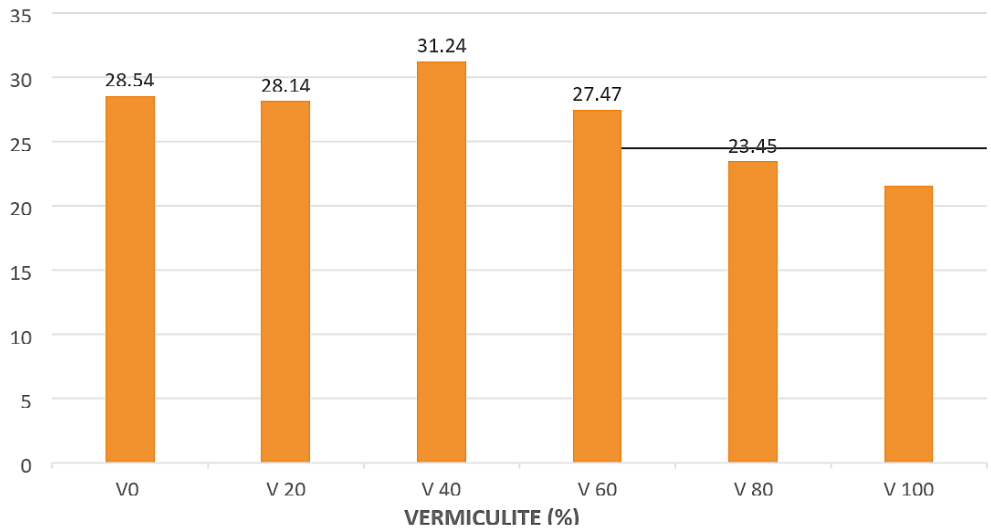

Fig 9: Graphical representation for compressive strength of concrete (28 days)

Where the results reveal that adding 20% vermiculite increases strength by 6%, and adding 40% vermiculite increases strength by 16%, which is the greatest value obtained by concrete. It shows that the use of 60 percent vermiculite results in a 2 percent drop over normal concrete, whereas 80 percent and 100 percent vermiculite results in a 12 percent and 30 percent decrease over conventional concrete.

When comparing the results of the 14-day test to the results of the 7-day test, the strength obtained gradually increases in compressive strength over the conventional specimens, but when comparing the results of the 7-day test, the strength obtained decreases. Vermiculite achieves the highest value of 40%, representing a rise of 11% above the conventional. After adding 40% vermiculite, the strength steadily decreases, similar to the 7-day test.

Each specimen exhibits a considerable gain in compressive strength over conventional specimens after 28 days of testing, however the results percentage decreases when compared to the 14-day test. Vermiculite 40 percent achieves the highest value, representing a 9.4 percent gain over standard concrete. After adding 40% vermiculite, the strength steadily decreases, similar to the 14-day test.

Table 7: Split tensile strength of concrete (28days)

Mix Id	Fly Ash (%)	Silica Fume (%)	Vermiculite (%)	M-Sand (%)	Avg. Compressive Strength (N/mm^2)
V0	20	10	0	100	4.20
V20	20	10	20	80	4.30
V40	20	10	40	60	4.41
V60	20	10	60	40	4.07
V80	20	10	80	20	3.99
V100	20	10	10	0	3.89

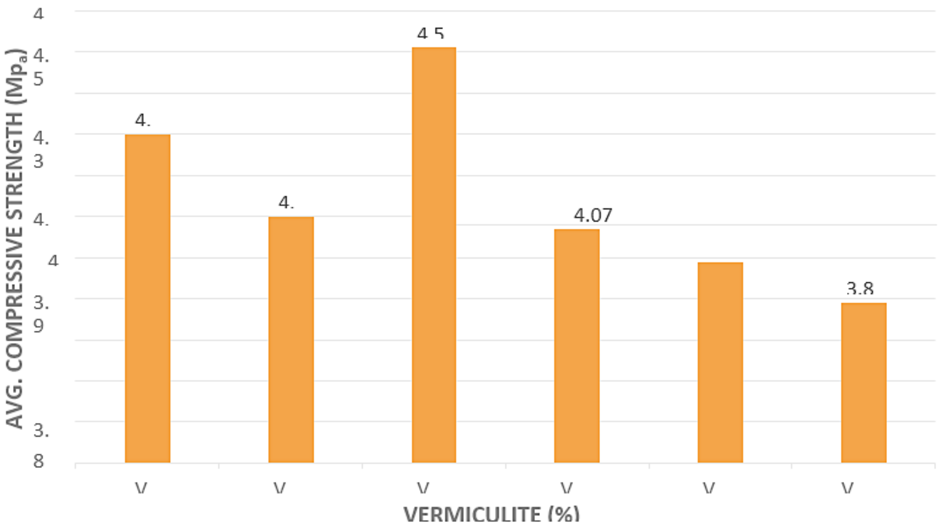

Fig 10: Graphical representation for split tensile strength of concrete (28days)

Conclusion

The combination of Vermiculite, silica fume, and fly ash leads in an increase in compressive strength of vermiculite concrete, with a maximum strength of 10% more than ordinary concrete after 28 days.The use of vermiculite leads in a considerable improvement in split tensile strength, with a maximum strength of 5.4 percent, compared to standard concrete.Vermiculite has a bigger impact on compressive strength but a lesser impact on split tensile strength in vermiculite concrete.As can be seen from the findings, adding more than 40% vermiculite causes a steady loss in all strength parameters due to the specimen's low self-weight, which results in a reduction in strength. We infer that non-structural elements such as bricks, blocks, and wall panels can be made using this vermiculite concrete.

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Conflict of Interest

The authors do not have any conflict of interest.

Data Availability Statement

The manuscript incorporates all datasets examined throughout this research study.

Ethics Statement

This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Informed Consent Statement

This study did not involve human participants, and therefore, informed consent was not required.

Clinical Trial Registration

This research does not involve any clinical trials.

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