

Experimental Investigation on Concrete Properties Using Starcrete as Partial Replacement of Cement

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Abstract— This research work aimed a experimental investigation on concrete properties using starcrete to find the optimum percentage. The objective of the study was to compare the performance of starcrete concrete with that of conventional concrete and to determine the optimum percentage of starcrete replacement that provides desirable strength characteristics. Material testing was conducted on both conventional and starcrete mixes to determine basic properties such as consistency, setting time, specific gravity, and aggregate characteristics. The dimension of cubes $150 \times 150 \times 150$ mm, cylinders 150×300 mm, and prisms $150 \times 150 \times 700$ mm were cast and tested to determine compressive strength, split tensile strength, and flexural strength at different Ages

Index Terms — cubes, Cylinder, Prism, starcrete, conventional concrete, compressive strength, split tensile strength, flexural strength, optimum percentage.

I. INTRODUCTION

Concrete is the most widely used construction material in the world due to its versatility, strength, and durability. However, the production of ordinary Portland cement (OPC), which is the primary binder in conventional concrete, is energy-intensive and contributes significantly to global carbon dioxide emissions. To achieve sustainable construction and reduce the environmental impact of cement production, there is an increasing focus on developing eco-friendly and alternative binders. One such innovative material is Starcrete, a starch-based binder that utilizes natural and industrial by-products to create sustainable concrete. A sustainable and eco-friendly materials have led to the development of alternative binders that can partially or fully replace cement in concrete. Starcrete is typically composed of potato starch combined with supplementary materials

such as fly ash or quarry dust, forming a geopolymer-like matrix capable of binding aggregates. The starch acts as a natural polymer that enhances bonding and strength development when mixed with suitable pozzolanic material.

Incorporating Starcrete into concrete not only reduces cement consumption but also promotes the use of renewable and waste materials, aligning with the goals of sustainable and green construction. Fly ash acts as a pozzolanic and filler material in Starcrete, contributing to the strength and binding capacity of the mix. When combined with potato starch the organic binder, fly ash reacts in the presence of water The silica (SiO_2) and alumina (Al_2O_3) present in fly ash react with calcium ions and the starch binder to form additional calcium silicate hydrate (C-S-H) and calcium aluminate hydrate (C-A-H) gels, improving the microstructure and durability of the composite.

. In most experimental studies, fly ash replaces 10% to 30% of the binder (cement) content in Starcrete mixes. At 10–20%, good workability and early strength are maintained. At 20–30%, better long-term strength and durability are achieved. Beyond 30%, the strength may reduce slightly due to slower pozzolanic reaction. Fly ash is incorporated along with potato starch to form the Starcrete binder, replacing a portion of cement in various percentages to determine the optimum mix based on compressive, split tensile, and flexural strength results

II. LITERATURE REVIEW

- 1) Dr Aled Roberts, et.al (2023): Researchers at the University of Manchester have developed an innovative material known as starcrete, composed of simulated Martian soil, potato starch, and a small amount of salt. This bio-based composite has

demonstrated a remarkable compressive strength of 72 MPa, which is more than twice that of conventional concrete (typically around 32 MPa), and significantly stronger than earlier extraterrestrial construction materials. These characteristics position starcrete as a promising alternative to traditional concrete, which contributes approximately 8% of global CO₂ emissions. Recognizing its potential for both extraterrestrial and terrestrial use, the research team has launched a startup to explore commercial applications of the materials

2) A Roberts, et.al (2022): Starcrete represents a groundbreaking advancement in extraterrestrial construction materials by leveraging locally available resources and low-energy processes. Developed using Martian and lunar soil simulants combined with potato starch and small quantities of magnesium chloride, Starcrete achieved compressive strengths up to 91.7 MPa, far exceeding traditional concrete used on Earth. Its simplicity, resource efficiency, and integration with life-support systems (e.g., food production) make it highly practical for early Martian or lunar settlements. Unlike previous biopolymer-based binders such as blood-derived proteins, starch is safe, edible, and sustainable. The use of statistical design methodologies allowed researchers to optimize parameters

3) N.A. Mohd, et.al (2016): The study represents a comprehensive study on the properties and potential of starch as a natural and eco-friendly binder. Starch, an abundant organic compound composed of D-glucose polysaccharides, is extracted from plants such as tubers, seeds, and roots where it serves as an energy reserve. It possesses good ductility, adhesion, and self-curing ability and is non-hygroscopic, meaning it resists water absorption and prevents swelling. The performance of starch as a binder largely depends on its amylose (linear polymer) and amylopectin (branched polymer) content. However, native starch has limitations like high water sensitivity and poor viscosity control, which can be improved by physical, chemical, or enzymatic modifications. Thus, starch-based binders provide an eco-friendly and cost-effective alternative to synthetic polymers, supporting the development of green materials and promoting sustainability in various industries

4) Sarath Chandra Kumar, et.al (2011): Fly ash acts as a partial replacement for cement, leading to reduced cement consumption and environmental benefits such as lower CO₂ emissions. The study highlights that incorporating fly ash improves the workability of concrete due to its fine spherical particles, which reduce water demand and enhance flowability. It also delays the initial setting time slightly, allowing better handling and placement, but achieves higher long-term strength compared to conventional mixes. The research shows that the compressive strength of fly ash-blended concrete initially develops more slowly than that of pure cement concrete. However, at later ages, the strength surpasses that of the control mix due to ongoing pozzolanic reactions. Fly ash also refines the microstructure by filling voids and reducing permeability, resulting in improved resistance to sulphate attack, chloride penetration, and alkali-silica reaction. Fly ash gains strength more slowly at early ages but achieves higher long-term strength (after 28 days) compared to normal concrete, especially when 20–30% cement is replaced.

5) C. Marthong, et.al (2012): The paper investigates how the partial replacement of Ordinary Portland Cement (OPC) with fly ash affects the mechanical and durability properties of concrete. Fly ash, a by-product from thermal power plants, possesses pozzolanic properties due to its silica and alumina content, which react with calcium hydroxide from cement hydration to form additional cementitious compounds. The study used three grades of OPC—33, 43, and 53—and replaced cement with fly ash in proportions of 10%, 20%, 30%, and 40% by weight. Tests were conducted on mortar cubes, concrete cubes, and beams to evaluate compressive strength, shrinkage, and durability under sulphate attack. The results revealed that adding fly ash significantly improves the workability of concrete due to its fine and spherical particles, which act as a lubricant and enhance flowability. However, early-age strength decreases with increasing fly ash content, especially at higher replacement levels (above 30%). This is because the pozzolanic reaction of fly ash is slower compared to cement hydration. Despite this, long-term strength (at 90 days) improved notably, especially for mixes with 20% fly ash, where the strength approached that of conventional concrete.

III. STARCRETE AND CONVENTIONAL MIXES

Starcrete is an emerging sustainable binder that was originally developed for construction applications in extraterrestrial environments such as the Moon and Mars. The material was designed to minimize dependence on Earth-based resources by utilizing locally available raw materials, thereby reducing transportation requirements and overall energy consumption. Due to its promising mechanical performance and eco-friendly nature, Starcrete has recently attracted interest for terrestrial construction applications as a partial replacement for cement.

Starcrete is a bio-composite material in which potato starch functions as the primary binding agent. When combined with suitable supplementary materials such as fly ash or quarry dust, the starch forms a stable binding matrix capable of holding aggregates together effectively. In certain formulations, a small quantity of salt is introduced to enhance intermolecular bonding within the starch structure, leading to improved strength characteristics. The interaction between the organic polymer (starch) and pozzolanic materials contributes to the formation of a dense microstructure, which improves the mechanical performance of the composite.

In conventional concrete, Ordinary Portland Cement (OPC) acts as the main binding material, and strength development primarily depends on cement hydration and the water-cement ratio. Although conventional concrete offers adequate compressive strength and durability, it is associated with high carbon emissions due to cement production. Additionally, conventional concrete exhibits brittle behavior and limited tensile strength.

The incorporation of Starcrete as a partial replacement for cement aims to reduce cement consumption while maintaining or enhancing strength properties. Fly ash used in Starcrete acts as a pozzolanic material, reacting with calcium hydroxide released during cement hydration to form additional cementitious compounds such as calcium silicate hydrate (C-S-H). The presence of starch further improves bonding between particles and reduces micro-voids within the matrix. As a result, Starcrete-modified concrete has the potential to offer improved strength performance along with significant environmental benefits when compared to conventional concrete.

IV. DIMENSIONS

For the experimental investigation, concrete specimens were cast in the form of cubes, cylinders, and prisms with standard dimensions. The cube specimens were prepared with a size of $150 \times 150 \times 150$ mm for compressive strength evaluation. Cylindrical specimens of 150 mm diameter and 300 mm height were cast to assess the tensile strength characteristics. In addition, prism specimens measuring $150 \times 150 \times 700$ mm were prepared to study the flexural behavior of the concrete. The use of these standard specimen sizes ensures consistency in testing and allows reliable comparison of the mechanical properties obtained from the experimental program.

V. EXPERIMENTAL INVESTIGATION

The experimental investigation comprised the collection of materials required for the preparation of both conventional concrete and Starcrete mixes. Material characterization tests were conducted for conventional and Starcrete constituents to evaluate their fundamental properties, and the obtained results were systematically compared. In addition, standard tests were performed on fine and coarse aggregates to assess their physical and mechanical characteristics, ensuring their suitability for concrete production. The outcomes of these material tests formed the basis for understanding the performance differences between conventional concrete and Starcrete in the subsequent experimental program. An M30 grade concrete mix was designed and adopted as the control mix for conventional concrete. The same mix proportions were maintained for all mixes to ensure consistency, and cement was partially replaced with Starcrete at levels of 10%, 20%, and 30% by weight of cement. Based on these mix designs, concrete specimens were cast in the form of cubes, cylinders, and prisms for evaluating the mechanical performance of both conventional and Starcrete-modified concrete. This methodology enabled a systematic assessment of the influence of varying Starcrete replacement levels on the strength characteristics of concrete.

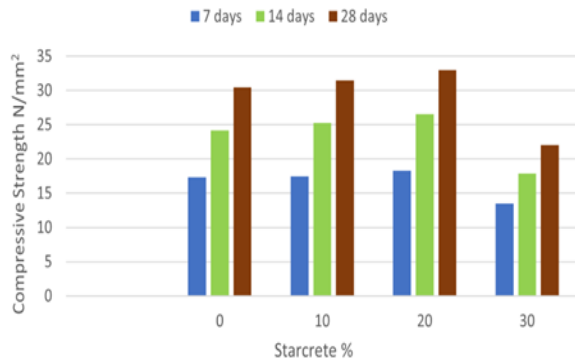
VI. RESULTS

The results section presents the outcomes of strength tests conducted on the cast specimens, including cubes, cylinders, and prisms. Compressive strength tests were performed on cube specimens, split tensile strength tests on cylindrical specimens, and flexural strength tests on prism specimens to evaluate the mechanical behavior of the concrete. The measured strength values obtained for conventional concrete and Starcrete-modified concrete at different replacement levels are reported and compared. These results provide a clear understanding of the influence of Starcrete incorporation on the strength performance of concrete.

Tab 1: Compressive Strength Results

Percentage of replacement of Starcrete (%)	Compressive Strength (N/mm ²)		
	7 days	14 days	28 days
0	17.31	24.17	30.44
10	17.44	25.28	31.5
20	18.31	26.59	32.96
30	13.51	17.87	22.05

Fig 1: Graph for Compressive Strength Results

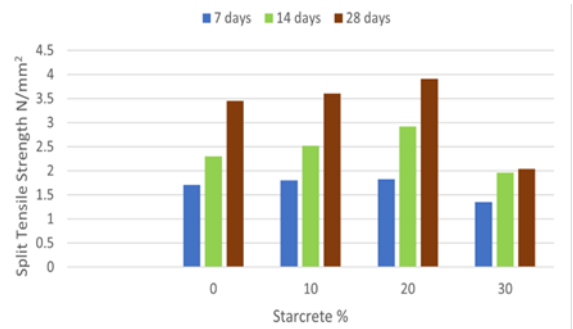


In the above results, the partial replacement of starcrete in concrete at various percentages has been discussed. It is seen that 20% replacement of starcrete in concrete gives more compressive strength

Tab 2: Split Tensile Strength Results

Percentage of replacement of Starcrete (%)	Split Tensile Strength (N/mm ²)		
	7 days	14 days	28 days
0	1.71	2.3	3.45
10	1.80	2.52	3.61
20	1.83	2.92	3.91
30	1.35	1.96	2.04

Fig 2: Graph For Split Tensile Strength Result

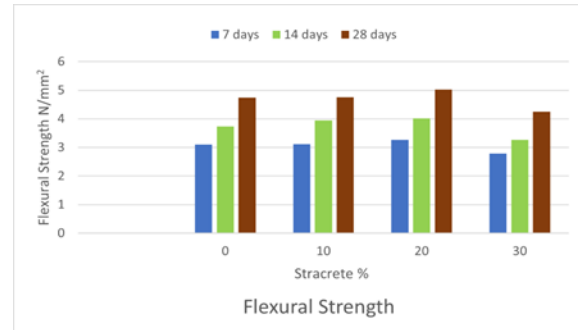


In the above results, the partial replacement of starcrete in concrete at various percentages has been discussed. It is seen that 20% replacement of starcrete in concrete gives more split tensile strength

Tab 3: Flexural Strength Results

Percentage of replacement of Starcrete (%)	Flexural Strength (N/mm ²)		
	7 days	14 days	28 days
0	3.10	3.73	4.74
10	3.11	3.94	4.76
20	3.27	4.01	5.02
30	2.78	3.26	4.25

Fig 3: Graph For Flexural Strength Result



In the above results, the partial replacement of starcrete in concrete at various percentages has been discussed. It is seen that 20% replacement of starcrete in concrete gives more Flexural strength.

VII.CONCLUSION

The following conclusions are drawn from the experimental investigation of concrete with partial replacement of cement by Starcrete by 10%, 20% and 30% are discussed. This study demonstrates the potential of incorporating Starcrete into conventional concrete as an effective approach to enhance environmental sustainability while maintaining

structural performance. At a 10% replacement level, the quantity of Starcrete is relatively low, resulting in limited development of the pozzolanic reaction of fly ash and the bonding effect of starch. Consequently, the concrete behaves similarly to conventional concrete, exhibiting only marginal improvements in strength. An optimum performance was observed at a 20% replacement level, where a balanced interaction between cement hydration products and the pozzolanic reaction of fly ash was achieved. At this level, starch acts as a natural polymer binder, improving particle adhesion and reducing microvoids, while fly ash reacts with calcium hydroxide released during cement hydration to form additional C–S–H gel. This enhanced particle packing, reduced porosity, and improved microstructure collectively resulted in maximum compressive, split tensile, and flexural strengths. However, at a 30% replacement level, the reduction in cement content led to an insufficient supply of calcium hydroxide for complete pozzolanic reactions, thereby limiting hydration and weakening the bonding mechanism. Additionally, the increased organic content from starch at this level may delay setting and hinder strength development due to reduced formation of crystalline C–S–H, ultimately resulting in a reduction in strength.

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