Impact of Coconut Husk Microcrystalline Cellulose on the Properties of Geopolymer Lightweight Concrete

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Geopolymer composite is an alternative to ordinary Portland cement. It has potential to avoid CO_2 emissions to the atmosphere and to save raw materials during its manufacture. Flyash-based geopolymer concrete is altered by adding ground granulated bast-furnace slag (GGBS) to improve its fresh and hardened properties. Thermal ash aggregate is used as coarse aggregate to reduce geopolymer concrete density, improve strength, and conserve natural aggregate. Along with this matrix, coconut husk microcrystalline cellulose (MCC) is added to enhance its performance. In a M40 grade flyash and GGBS-based geopolymer concrete, MCC was used to replace fly ash at 1% to 5% levels. The geopolymer composites were tested for slump, compression, split tensile, water absorption, and acid resistance to determine the way coconut husk MCC interacts with lightweight concrete. An inclusion of 3% MCC with geopolymer composites improved 2% slump, 6% of compressive and split tensile strength. About 1.6% of water absorption was reduced in GPC matrix with 3% of MCC. Meanwhile 3% of MCC in geopolymer concrete improved, 4% of weight and 7% of strength under acid exposure. The research strongly supported utilizing MCC in geopolymer concrete to render it more sustainable and eco-friendlier.

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INTRODUCTION

To obtain the necessary raw materials to produce Ordinary Portland Cement (OPC) it is necessary to devastate the environment along with the emission of CO_2 into the atmosphere (Imbabi *et al*. 2012). In this modern world, geopolymer concrete (GPC) is a well-known substitute for OPC in construction work (Rahmawati *et al*. 2021). Fly ash, sodium hydroxide, sodium silicate, fine aggregate, and coarse aggregate are often used to make geopolymer composite (Roopchund *et al*. 2022). When not cured in hot air, fly ash-based GPC often needs a very long setting time and it develops a very poor compressive strength (Shilar *et al*. 2022). A complete or partial addition of ground granulated bast-furnace slag (GGBS) to flyash-based GPC shortens the setting time and increases the compressive strength (Subash *et al*. 2021). Calcium oxide content in GGBS decreases the setting time and increases the strength of GPC (Rajalekshmi *et al*. 2023; Silva *et al*. 2020). However, the introduction of geopolymer concrete in hot air curing can be avoided by adding GGBS. Geopolymer concrete uses both the industrial wastes as a powder material. Researchers have observed numerous pores in the hardened geopolymer microstructure (Hilal *et al*. 2022). These pores may be produced due to the space left within the concrete by the evaporated H_2O molecules produced during polymerization (Singh *et al*. 2023). At the same time, GGBS in this matrix emits heat within the concrete at the time of reaction. To hold the water and to reduce the heat, a material is required (Ahmad *et al*. 2023).

Coconut husk is among the agricultural by-products from which microcrystalline cellulose (MCC) can be obtained. India accounts for 31.45% of the global coconut production. Using coconut husk MCC, the moisture can be absorbed and can be dried later when the heat produced within the concrete (Sakuri *et al*. 2020). Natural cellulose, an ecofriendly material can be used in concrete matrix to enhance the curing effect internally (Ge *et al*. 2023). This internal moisture may prevent shrinkage and the development of minor thermal cracks within and over the surface of concrete.

Low density geopolymer concrete is created by adding lightweight aggregates, foaming agents, *etc*. to create lightweight concrete structures (Wu *et al.* 2021). Natural aggregates for concrete may be replaced by lightweight manufactured aggregates to reduce pollution, save money, and to protect the environment (Al-Obaidi *et al*. 2022). This homogeneous synthetic aggregate usage in concrete also reduces fly ash-related pollution in the atmosphere. Thermal ash Aggregate (TA), an artificial aggregate, is more resilient to external stresses (Lloyd *et al*. 2010). TA is a coarse aggregate that is used to achieve light weight geopolymer concrete with good strength and workability because of its consistent size and shape. The durability of light weight GPC is further increased with addition of TA ensured (Anuradha *et al*. 2012).

The present research examined the interaction of coconut husk MCC filler on the properties of geopolymer concrete, both in its fresh and hardened forms. The fly ash acted as a mineral powder in geopolymer concrete and it was partially replaced by GGBS. GGBS was added by replacing 50% of fly ash by its weight to make geopolymer concrete at room temperature and not only to improve its strength (Arfelis *et al*. 2023; Vydrina *et al*. 2023). Also, to reduce the pores and internal micro cracks, natural MCC was added. Recently, metakaolin, silica fume, and nano silica have been used as filler materials, but their use was found to be uneconomic (Rahmawati *et al*. 2021). Thus, this research utilized agricultural waste, namely natural coconut husk MCC as filler in GPC (Jakob *et al*. 2022; Khalili *et al*. 2023). The varying proportions of fly ash were substituted with MCC at 1%, 2%, 3%, 4%, and 5%. The arrived blends were subjected to the slump cone test, compressive strength test, split tensile strength test, water absorption test, and acid resistance test. The results are considered in this work with the aim to know the interaction of coconut husk MCC filler on the properties of geopolymer concrete along with lightweight aggregate.

MATERIALS AND METHODS

To understand the interaction of MCC on the performance of light weight GPC, the basic materials to make GPC were used. Flyash, GGBS, sodium hydroxide, and sodium silicate were the materials used to make geopolymer binder. GGBS and flyash were used as powders. Both powders are the byproduct of thermal power plant and the steel industry. The powders, namely flyash and GGBS, were purchased from Aastra Chemicals, India. The chemical and physical properties of flyash and GGBS are given in Tables 1 and 2. River sand was used as fine aggregate and thermal ash aggregate as coarse aggregate were used in this research. Zone II river sand was used with a specific gravity value of 2.65. The size of thermal ash aggregate fell between 10 to 20 mm. The fineness of TA was found to be 5.9. The bulk density of TA was 840 kg/m^3. The physical properties of the aggregates used in this research are given in Table 2. The TA used in this research is shown in Figure 1. Alkaline liquids, namely sodium silicate and sodium hydroxide, were used to produce geopolymer composite. Pellets purchased from the chemical shop were diluted in water to prepare a 10 M NaOH solution. The sodium hydroxide was prepared for the required molarity a day before casting. Glass silicate with 55% water content and a 45% solid content (Na_2O and SiO_2) was used in this research work. Sodium hydroxide pellets and sodium silicate gel are purchased from Astra Chemicals, India.

Tables 3 and 4 show, respectively, the solubility and physical properties of MCC. Figure 2 depicts the processes in the synthesis of MCC in a sequential order. In the visual example, Figure 3, the MCC from coconut husk is shown by scanning electron microscopy (SEM). According to the results of scanning electron microscopy (SEM), micro crystalline cellulose exhibited a variety of particle sizes, including both smaller and larger particles. MCC generally had a particle size distribution between 10 and 20 µm.

Since there is no codal provision available to compute the mix proportion of GPC, a simplified mix design from an article was used as a guide to compute it. This investigation used a geopolymer mix proportion of grade M40. Several aspects were taken into consideration at the time of designing this M40 geopolymer concrete mix (Subash *et al*. 2021; Jeffy Pravitha *et al*. 2023). The molarity of sodium hydroxide (NaOH) was 10 M. The liquid to powder ratio was 0.48. The ratio of alkaline liquid was 2.5. The maximum allowable size of the aggregate was 20 mm. Geopolymer concrete consists of many components in a certain ratio. For every cubic meter of geopolymer concrete, the quantities of fly ash, ground granulated blast furnace slag (GGBS), sodium hydroxide, sodium silicate, river sand, and graded 20 mm aggregate were 208.3, 208.3, 57.5, 172.5, 757.7, and 1158.0 kg/m^3, respectively. The mix percentage (kg/m^3) of geopolymer concrete per cubic meter is provided in detail in Table 5.

A NaOH solution with Molarity 10 concentration was made the day before. This was done because NaOH undergoes an exothermic reaction that causes a substantial amount of heat to be released. On the day of mixing, the process starts with the addition of fly ash, ground granulated blast furnace slag (GGBS), and MCC, followed by vigorous mixing along with aggregates. Next to create the geopolymer concrete, this mixture is blended with alkaline solutions, a mixture of sodium silicate and sodium hydroxide. The pan mixture was used to mix the materials to get geopolymer concrete. After proper mixing, the concrete was allowed to conduct a slump test and to cast the required specimens to conduct hardened concrete and durability tests.

Table 1. Chemical Properties of Mineral Admixtures

Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	SO_4	MgO	Loss of Ignition
Fly Ash	70	12	11	4	-	-	-	3
GGBS	35	13	4	40	-	-	8	-

Table 2. Physical Properties of Materials

Material	Fly Ash	GGBS	River Sand	TA
Specific Gravity	2.35	3.2	2.65	2.10
Moisture content (%)	nil	nil	nil	nil

Fig. 1. Thermal ash aggregate

Fig. 2. Manufacturing process of MCC

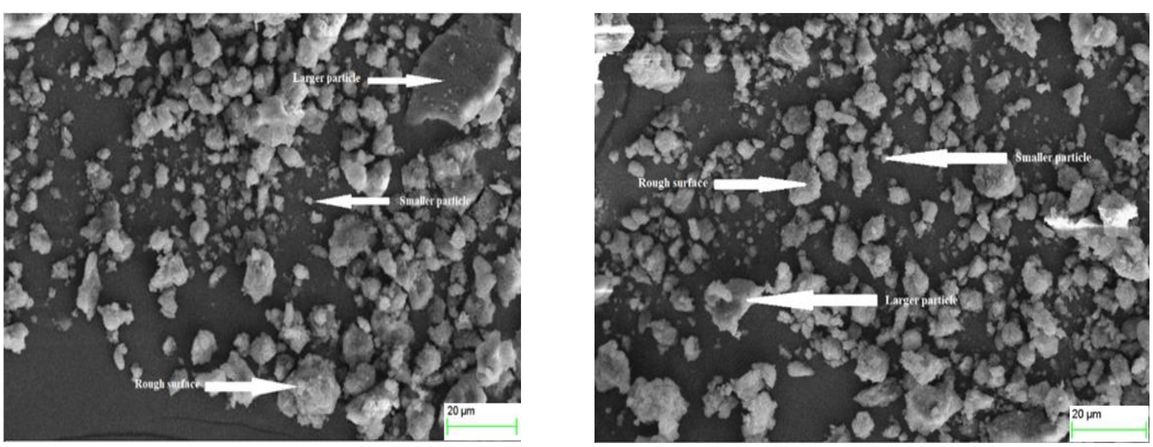

Fig. 3. SEM micrograph of coconut husk MCC

Table 3. Comparison of Solubility Tests of Microcrystalline Cellulose

Solvent	Microcrystalline cellulose
Acetone	Completely insoluble
Distilled water	Partially soluble
1% HCl	Insoluble
1% NaOH	Partially soluble

Table 4. Physical Properties of Microcrystalline Cellulose

Properties	Values
True density	1.52
Moisture content	6.21%
Hydration capacity	3.16%
Swelling capacity	48.7%

Table 5. Mix Proportion of Geopolymer Concrete (kg/m^3)

Mix ID	Flyash	GGBS	MCC (%)	Micro crystalline Cellulose	NaOH	Na_2SiO_3	River Sand	TA
Mix 1	208.33	208.33	0	0	57.50	172.50	757.74	1158.05
Mix 2	206.27	208.33	1	2.07	57.50	172.50	757.74	1158.05
Mix 3	204.17	208.33	2	4.17	57.50	172.50	757.74	1158.05
Mix 4	202.08	208.33	3	6.26	57.50	172.50	757.74	1158.05
Mix 5	200.02	208.33	4	8.32	57.50	172.50	757.74	1158.05
Mix 6	197.94	208.33	5	10.42	57.50	172.50	757.74	1158.05

The determination of the workability or consistency of the concrete mix is conducted in accordance with the guidelines outlined in the Indian Standard IS 1199-1959. The slump test is a rapid and convenient method for assessing the workability of concrete. The mixed geopolymer concrete is introduced into the slump cone, and after raising the cone, the slump value is recorded, while also observing the manner of failure. Compressive Testing Machine was used in carrying out the tests. According to IS516-1959, the compressive strength of geopolymer concrete mixes was evaluated by casting nine numbers of concrete cubes measuring 150 millimeters on a side, 150 millimeters on a side, and 150 millimeters on a face for each mix. These results are displayed in Table 3. The concrete received the appropriate compaction because of the filling of three levels. After a day had passed, the cast samples were taken out of the molds and allowed to cure in the open air until the day of the testing. A thermometer was used to determine the temperature of the room. After 7 and 28 days of curing at room temperature ambient, cast samples were subjected to compression testing to determine their compressive strength. For the purpose of determining compressive strength, GPC samples were put through compression testing equipment that had a capacity of 2,000 kN. According to is: 5816-1999, cylinder splitting tensile apparatus is used for testing. Cylindrical concrete specimens measuring 150 mm by 300 mm were cast and tested for split tensile strength. The curing time for control geopolymer and lightweight geopolymer concrete samples were 7 and 28 days. A compression testing equipment with a 2000 kN capacity was used to gauge the split tensile strength of the cylindrical samples. The split tensile strength of all the arrived geopolymer concrete mixes was examined.

According to ASTM C 642, the acid resistance of 100 mm x 100 mm x 100 mm specimens mentioned in Table 5 was evaluated. The cast specimens underwent a 28-day curing process before spending 180 days at room temperature submerged in a 3% HCl solution. The concrete samples were removed from 2 pH HCl solution after 7, 28, 56, 90 and 180 days to assess weight and strength loss. Acid resistance was calculated using the differences in weight and strength loss of the concrete samples. About 90 samples in all were cast and sent to the tested for acid resistance. The test was conducted according to ASTM C 642-13 with a 100 x 100 x 100 mm specimen. To investigate the water absorption rates of GPC with cellulose, the required specimens were cast. After curing for 7 and 28 days, the geopolymer concrete specimens were dried in an oven at 100 °C for 24 hours. The weights of each cooled specimen were recorded as the beginning masses. The weight of each specimen after being submerged in water for 7 and 28 days was recorded.

RESULTS AND DISCUSSION

Each mix of geopolymer concrete used for the slump cone tests had a flyash replacement in the range of 1% to 5%. When compared to the control GPC (mix 1), the addition of MCC to the geopolymer concrete mixture improved the slump by about 5%. This improvement could be credited to MCC's ability to contribute plasticity internally. The fluidity of geopolymer concrete was increased by the addition of MCC, which also increased the material's ability to flow. In geopolymer concrete, the amount of microcrystalline filler mixtures ranged from 0 to 10.41 grams. The graphical representation of slump values for control geopolymer concrete and microcrystalline geopolymer concrete is shown in Figure 4.

For each mix, three cube specimens were cast, cured, and tested as part of this investigation. A group of 36 cube samples underwent a thorough examination when tested under compression. Figure 5 displays a graphical representation of compressive strength results. Comparing Mix1 geopolymer concrete specimens to MCC geopolymer concrete specimens, the compressive strength of Mix1 geopolymer concrete specimens was lower. A 3% replacement amount of MCC in fly ash sample increased the compressive strength of geopolymer concrete. The compressive strength of geopolymer concrete was increased by the inclusion of MCC. Addition of 3% of MCC GPC specimen achieved optimum compressive strength and it became 6% higher compressive strength compared to the control geopolymer concrete. The specimen 4% and 5% MCC GPC specimen strength decreased compared to 3% MCC GPC specimen. This was because 4% and 5% MCC GPC specimen absorbed more water content compared to 3% MCC GPC. Similarly compressive strength of 4% and 5% MCC GPC specimen decreased. Table 6 compares the results for compressive strength at intervals of 7 and 28 days. In the creation of MCC based geopolymer concrete, the size of air voids was significantly decreased by using 1 to 3% fly ash as a replacement for geopolymer concrete. The internal structure of the geopolymer concrete became denser as a result, increasing the geopolymer concrete's compressive strength.

Cylindrical specimens were employed in the split tensile strength test. Specimens made up of three cylinders were tested after 7 and 28 days of curing. A total of 36 cylinders were cast, put through a curing process, and then tested. The 7-day and 28-day strengths were measured using the universal testing apparatus. When compared to the specimens of

MCC geopolymer concrete, the split tensile strength of the specimens in Mix 1 was much lower. By replacing flyash with geopolymer concrete specimens in 3% of the mix, the split tensile strength of the geopolymer concrete was increased. Both the amount of MCC and the tensile strength of the geopolymer concrete increased with the addition of MCC. To reduce the existence of air spaces, MCC particles were added to geopolymer concrete in amounts ranging from 1 to 3%, which improved the split tensile strength. Specimens with 4 to 5% MCC absorbed more water. This resulted in a decline in mechanical performance. Figure 6 compares the split tensile strength throughout the 7-day and 28-day time frames.

Table 6. Fresh and Hardened Geopolymer Concrete Test Results

Mix	Coconut Husk MCC	Slump	Compressive Strength (N/mm^2)		Split Tensile Strength (N/mm^2)	
			7 days	28 days	7 days	28 days
Mix 1	0%	78.4	27.62	42.52	2.62	4.03
Mix 2	1%	79.1	28.46	43.79	2.68	4.15
Mix 3	2%	80.4	29.29	45.06	2.78	4.27
Mix 4	3%	81.1	29.47	45.33	2.79	4.29
Mix 5	4%	82.1	28.74	44.21	2.72	4.19
Mix 6	5%	82.6	28.19	43.36	2.67	4.11

The water absorption test was done by following the standards of ASTM C 642-82. The experiment was conducted using cubic specimens of 10 × 10 × 10 cm. To determine the quantity of water absorbed via full immersion, the initial mass of each specimen was measured. The specimens were then totally immersed in water for seven and twenty-eight days, during which time the wet and dry masses of the specimens were noted. Three samples from each combination were chosen for testing, and subsequent data analysis after 28 days of ambient curing. Figure 7 displays the water absorption test findings graphically. After 28 days, the water absorption of MCC showed a decrease of 35% to 45% relative to the control GPC when 3% of the flyash specimen was replaced. Additionally, none of the mixes 1 through 3 had any holes, and all the pores were securely packed with geopolymer gel. Table 7 displays the results of water absorption. The 3% MCC GPC specimen 45% less water absorption recorded compared to control geopolymer concrete. 4% to 5% MCC GPC specimens holding some excess water internally cause increase water absorption.

Cubic specimens were employed for the acid resistance test. The specimens after 28 days of ambient curing. After that, three cubic samples from each mix and day were examined while weighing the cubic specimens. A total of 90 cube specimens are created, put through the curing process, and then tested to determine their performance. In this research, the benefits in terms of weight loss and increased strength were investigated across time periods of 7, 28, 56, 90, and 180 days. The first combination, which is known as the control mixture, was created without the addition of MCC. 90 cubes in all were immersed in a 2 pH HCl acid solution for a range of times including 7, 28, 56, 90, and 180 days. The acid resistance test is carried out in a typical lab setting, often at room temperature or ambient conditions. Additionally, to maintain consistency within the acidic solution, the acid solution was often agitated. Every 30 days, the acidic solution was changed out, as scheduled. The samples were submerged for a certain amount of time, removed, and then their dry weights were then calculated. Additionally, assessments of strength and weight loss were calculated. The results of the tests are listed in Table 7.

Though the 3% microcrystalline mixed geopolymer concrete samples showed a 6% weight loss, it was very much less compared to other mixes.

Figure 8 shows a visual illustration of the weight loss brought on by acid attacks. The research discovered that acid assault reduced the strength of control geopolymer concrete by 17%. However, a reduced loss of strength was seen when 3% of MCC was added to the geopolymer concrete. Additionally, the 3% MCC mixed geopolymer concrete showed a 10% reduction in compressive strength. When 4 to 5% of MCC specimens were present, both weight loss and strength decline were accelerated. This may be attributable to MCC's greater propensity to absorb water, which caused sulphate attack to fragment the species into smaller particles. The samples of geopolymer concrete with 1% to 3% MCC had compact microstructures, where the geopolymer MCC paste filled every vacant area in the aggregate. The contrast of the strength loss brought on by acid attack is displayed in Figure 9. The experimental result shows that control geopolymer concrete and 5% MCC GPC had large voids and were porous, but 3% MCC blended geopolymer concrete was very dense compared to the CGPC and 5% MCC GPC. The mechanical performance of control geopolymer concrete and 5% MCC GPC was less compared to the 3% MCC blended geopolymer concrete. 3% MCC blended geopolymer concrete achieved optium mechnical performace. The effective filler percentage was 3% by the weight of flyash.

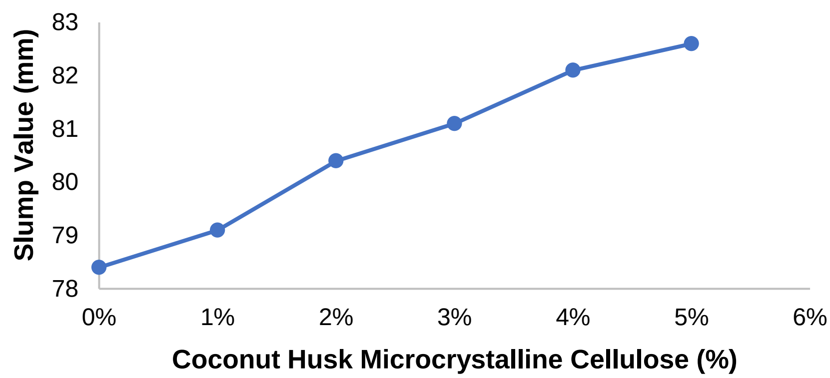

Fig. 4. Slump of geopolymer concrete with cellulose

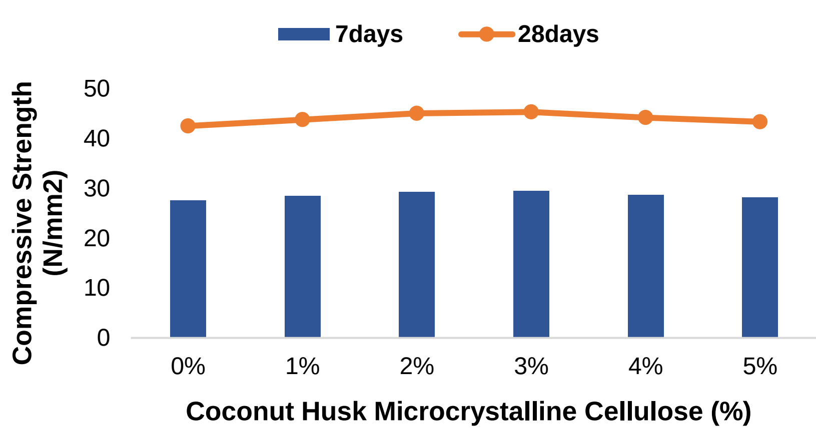

Fig. 5. 7-days and 28-days geopolymer concrete compressive strength with cellulose

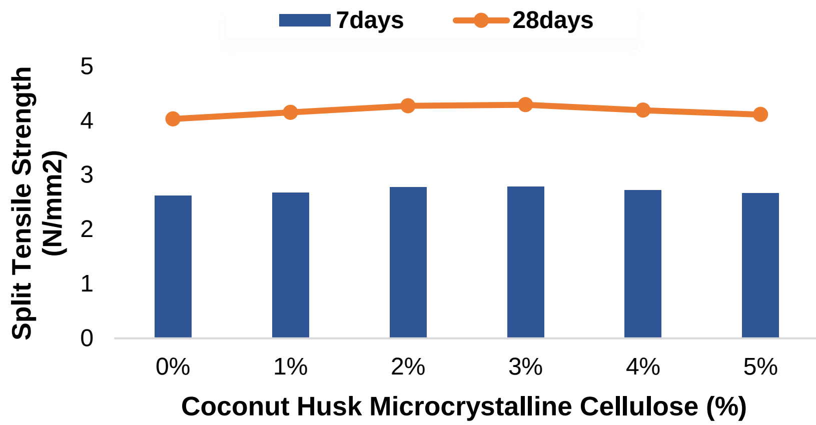

Fig. 6. 7-days and 28-days geopolymer concrete split tensile strength with cellulose

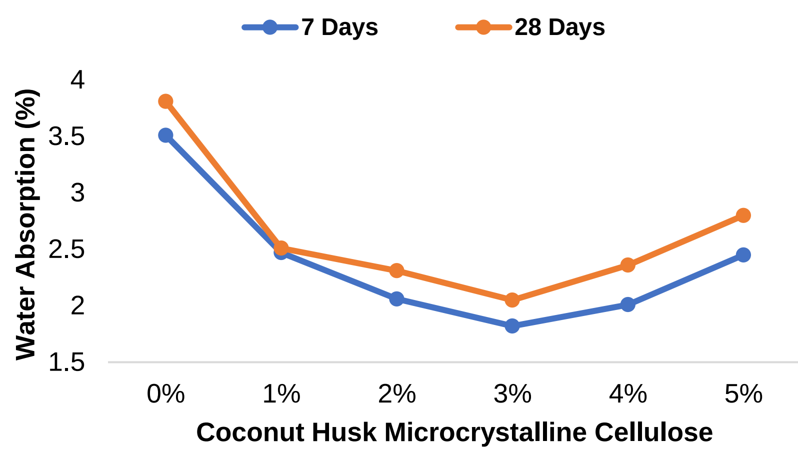

Fig. 7. Water absorption percentage

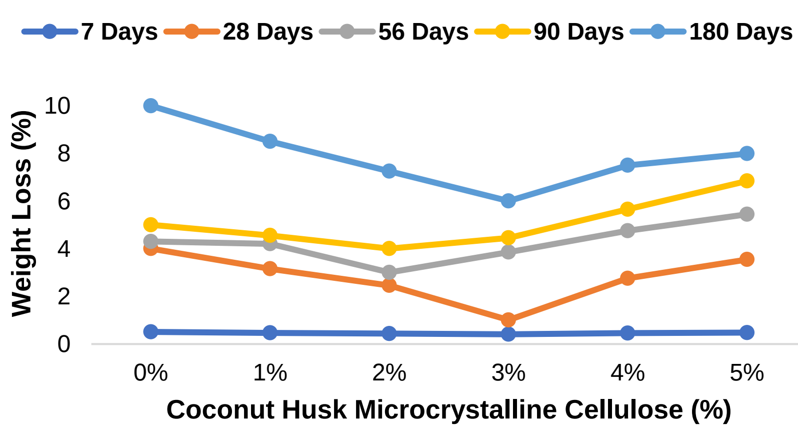

Fig. 8. Acid attack on geopolymer concrete weight loss percentage

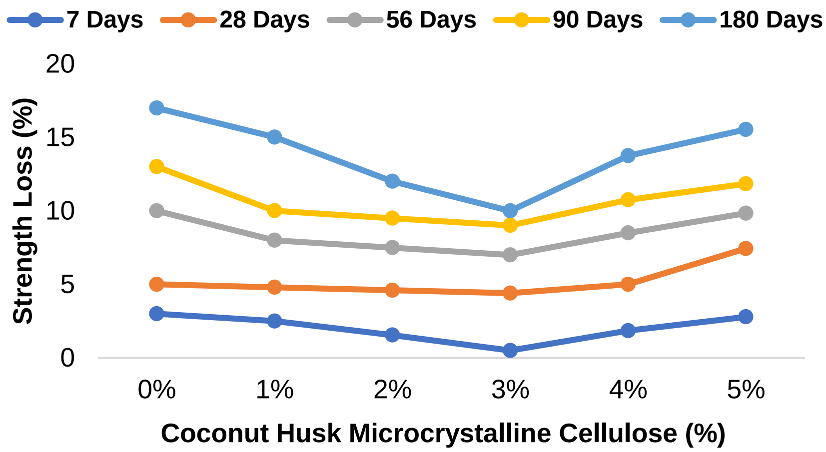

Fig. 9. Acid attack on geopolymer concrete strength loss percentage

Table 7. Resistance of Geopolymer Concrete with Cellulose towards Water Absorption and Acid Attack

Mix	Coconut Husk Micro crystalline Cellulose	Percentage Water Absorption (%)		Acid Resistance Test									
				Weight Loss (%)					Strength Loss (%)				
		7 D	28 D	7 D	28 D	57 D	90 D	180 D	7 D	28 D	56 D	90 D	180 D
Mix 1	0%	3.51	3.81	0.51	4.01	4.31	5.01	10.01	3.01	5.01	10.01	13.01	17.01
Mix 2	1%	2.47	2.51	0.47	3.16	4.21	4.56	8.51	2.51	4.81	8.01	10.02	15.03
Mix 3	2%	2.06	2.31	0.44	2.46	3.01	4.01	7.26	1.56	4.61	7.51	9.51	12.02
Mix 4	3%	1.82	2.05	0.41	1.01	3.86	4.46	6.01	0.51	4.41	7.01	9.02	10.01
Mix 5	4%	2.01	2.36	0.46	2.76	4.76	5.66	7.51	1.86	5.01	8.51	10.76	13.76
Mix 6	5%	2.45	2.80	0.48	3.55	5.45	6.85	8.00	2.80	7.45	9.85	11.85	15.55

Note: D - Days

CONCLUSIONS

The characteristics of fresh-stage geopolymer concrete, harden-stage geopolymer concrete, and durability features are all examined in this research. After then, the results are displayed. The results show that the presence of microcrystalline cellulose (MCC) significantly have good interaction with the chemical and physical properties of geopolymer concrete. Below are the results of this research. To enhance the fresh concrete qualities of geopolymer concrete, the substitution of fly ash with coconut husk MCC was implemented.

1. This substitution resulted in an improvement in the workability of the geopolymer concrete. The observed trend indicated that with a rise in MCC content, there was a corresponding increase in the slump value by 5%. During this research, a moderate level of workability was attained.
2. The compressive strength and split tensile strength parameters were determined for the optimal specimen of geopolymer concrete with 3% coconut husk MCC and was

found to get 6% higher when compared to control specimen. The MCC led to a reduction in the quantity of air spaces, resulting in an improvement in mechanical performance.

3. The water absorption of MCC specimens at concentrations of 4% and 5% was shown to be significantly higher compared to specimens with concentrations ranging from 1% to 3%. This increase in water absorption may be attributed to the cellulose inside the specimens absorbing a certain quantity of water.

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