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Influence of eco-friendly lightweight aggregates in mechanical and durability properties of geopolymer concrete

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ABSTRACT

This research is to replace natural coarse aggregate as 20%, 40%, 60%, 80%, and 100% respectively, by weight in an M20 grade geopolymer concrete. The geopolymer concrete with different mixes is subjected to fresh, hardened, and durability tests. Utilization of thermal ash aggregates increased the slump and compressive strength of geopolymer concrete by about 15% and 9% respectively. Whereas the slump and compressive strength of geopolymer concrete decreased by about 30% and 38% respectively by using 100% Lightweight Expanded Clay Aggregate (LECA). Density reduction in geopolymer concrete was found by using both thermal ash aggregate and lightweight expanded clay aggregate for about 9% and 28% respectively. Thermal ash aggregate decreased the density of geopolymer concrete up to 1850 kg/m^3 and improved the strength up to 24.50 N/mm^2, on the other side using lightweight expanded clay aggregate, the density of geopolymer concrete drastically decreased up to 1250 kg/m^3 with a huge decrease in strength up to 14 N/mm^2. Other mechanical test results showed similar variations with respect to the compression test results. To ensure the durability of lightweight geopolymer concrete for mixes of GPC, TM5, and LM2 conducted tests like acid resistance, sulphate resistance, salt resistance, water absorption, accelerated corrosion, and sorptivity test.

Keywords: Geopolymer concrete; green concrete; thermal ash aggregate; lightweight expanded clay aggregate, durability.

1. INTRODUCTION

As a result of the scarcity of raw materials necessary for cement manufacturing, an increase in price and a lack of cement in the market happened. This seriously affects the building sector in completing the projects at a low cost. Cement also consumes a lot of energy during its production process [1]. Since fossil fuels are burned to meet the energy needs of these industries, a lot of pollution is emitted into the environment. Pollutants that are produced during the calcination process cannot be avoided [2]. According to estimates, about 5-6% of total carbon dioxide emissions to the atmosphere are brought by the production of cement. Cement kiln exhaust gases may include nitrogen oxides (NOx), carbon dioxide and trace quantities of dust, chlorides, fluorides, sulphur dioxide, carbon monoxide and even small amounts of organic compounds and heavy metals. This seriously affects the oxygen content in the atmosphere. Pollutants are bad for people's health and change the quality of the air. It also affects both the natural green environment and the ecosystem [3]. Cement manufacturing also causes many problems like a decrease in agricultural yields, acid rain, global warming, and ozone layer depletion. Cement concrete uses a lot of water and labor for its curing process. It is essential to have an alternate binder for Portland cement to avoid the mentioned problems.

Fly ash (FA) is a resource that has significance within the context of sustainable development due to its use in the alkali-activation process, which offers the advantage of minimal energy consumption and thus reduces the emission of environmentally harmful CO_2 [4]. The incorporation of fly ash (FA) in the alkali-activation process, known as geopolymerization, serves to diminish the reliance on natural raw materials while simultaneously meeting the intricate requirements of the construction sector in terms of material properties and quality.

Using geopolymer as a binder in concrete reduces the environmental pollution and drawbacks caused during cement production [5]. An inorganic aluminum-hydroxide polymer known as a geopolymer is created by primarily using silicon (Si) and aluminium (AI) byproducts such as fly ash or silicon and aluminium materials with a geological origin. To describe the mineral polymers that come from geochemistry, the term "geopolymer" was introduced. An amorphous polymeric Si-O-AI-O bond is produced as a result of a chemical reaction

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occurring in Si-AI minerals under extremely alkaline circumstances. This claim demonstrated that GeoPolymer Concrete (GPC) is green concrete since it does not adversely affect the environment. Flyash, Ground Granulated Blast Furnace Slag (GGBS), metakaolin, silica fume and rice husk ash are some of the admixtures used in geopolymer concrete [6–9]. Flyash and GGBS are combinedly and used in many types of research and obtained good strength. Flyash as an aluminosilicate material obtained strength only at hot air curing. Researches shown increase in flyash based geopolymer strength with the increase in curing temperature. On the other hand, GGBS in ambient & hot curing and flyash in hot curing have attained good results. To achieve good strength by using flyash even at ambient temperature, GGBS can be incorporated into the mix [10, 11]. The calcium content in GGBS when incorporate with the flyash based GPC, the actual setting time was reduced along with an increase in strength. Subash et.al developed a mix design for geopolymer concrete with 50% of flyash and 50% GGBS as powder materials.

On the other hand, while designing big infrastructures like high-raised buildings and bridges, the weight of the concrete plays an important role in calculating the dead load. Making lightweight concrete may reduce the dead load drastically. Introducing low-density concrete can minimize the self-weight and steel requirement in RCC members [12]. Developing lightweight concrete has various ways like using foaming agents, lightweight aggregates, etc. Foaming agents and lightweight natural aggregates are too costly and many researches are there. To conserve the environment, avoid pollution and to save cost, lightweight manufactured aggregates are alternatives to natural aggregates for concrete [13, 14]. Thermal Ash Aggregate (TAA), an artificial aggregate, resists external loads better due to its uniform shape and size. This uniform-shaped artificially made aggregate is also used to reduce the pollution occurred by flyash dumped in thermal power plants. Using these flyash aggregates, it is feasible to produce high-strength concrete with excellent carbonation resistance. Lightweight Expanded Clay Aggregate (LECA) manufactured in a rotary kiln which consists of a long, large-diameter steel cylinder drastically reduces the density of cement concrete. The LECA can be used to make very lightweight structural elements. LECA is very easy to use and transport when compared to other aggregates since the density is too low. Attempts are made in past research by replacing up to 30% of coarse aggregate with LECA. No works are there using 100% LECA in geopolymer concrete as coarse aggregate. Lack of research is there using artificial lightweight coarse aggregates such as TAA and LECA in geopolymer concrete. Also, no clear discussion is available for comparing GPC with these two artificial aggregates. This research concentrates on comparing the mechanical and durability properties of GPC made of TAA and LECA as coarse aggregates. In an M20 grade GPC, experiments are carried out by replacing natural coarse aggregate (NCA) with TAA and LECA at 20%, 40%, 60%, 80% and 100% by its weight. The density study for the arrived mixes was also found for the obtained GPC mixes. Tests on the durability of the selected Light Weight Geo-Polymer Concrete (LWGPC) mixes with each lightweight aggregate were conducted.

2. MATERIALS USED

To know the impact of both lightweight artificial aggregates on the performance of GPC, the basic materials to make GPC is used. Flyash, GGBS, sodium hydroxide and sodium silicate are the materials used to make geopolymer binder. GGBS and flyash are used as powders. Both the powders are the byproduct of thermal power plant and the steel industry. The powders namely flyash and GGBS are 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. Natural granite stone, thermal ash aggregate and light expanded clay aggregate are the coarse aggregate used in this research. Zone II river sand is used with a specific gravity value of 2.65. River sand is taken from Pazhayar river, Kanyakumari district, India. Broken natural coarse

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 aggregates.

MATERIAL	FLY ASH	GGBS	RIVER SAND	LECA	TAA
Specific Gravity	2.35	3.2	2.65	1.85	2.10
Moisture content %	nil	nil	nil	nil	nil

Figure 1: Thermal ash aggregate (TAA).

Figure 2: Lightweight expanded clay aggregate (LECA).

aggregate was purchased from a nearby quarry in south India. The fineness of natural coarse aggregate is found to be 6.1 for the size ranges from 10 to 20 mm. The size of thermal ash aggregate and LECA falls between 10 to 20 mm. The fineness of TAA and LECA was found to be 5.9 and 6.3 respectively. The bulk density of TAA and LECA is 840 kg/m^3 and 320 kg/m^3, whereas for natural aggregate it is 1480 kg/m^3. The physical properties of the materials used in this research are given in Table 2. The TAA and LECA used in this research are shown in Figures 1 and 2. Alkaline liquids, namely sodium silicate and sodium hydroxide, were used to produce GPC. Pellets purchased from the chemical shop were diluted in water to get 10M 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.

3. EXPERIMENTAL METHODS

The design of the mix for the geopolymer concrete was determined for the M20 grade. Since the density of aggregates may vary quite a bit, the weight of the natural aggregate that must be replaced is calculated based on volume. After that, the concrete that has been mixed is put through the slump test as well as many other tests on hardened concrete, such as the compression, split tensile, flexural, modulus of elasticity, and density tests [15]. A battery of durability tests, including water absorption, sorptivity, salt resistance, acid resistance, and resistance to sulphates and acids, were carried out on both the control geopolymer specimens and the lightweight geopolymer concrete specimens. After the allotted amount of time and in a variety of conditions, the test samples' resistance to wear and tear was measured and analyzed.

Table 3: Mix proportion of lightweight geopolymer concrete (kg/m³).

SL. NO.	MIX ID	FLYASH	GGBS	SODIUM SILICATE	SODIUM HYDROXIDE	FINE AGGREGATE	COARSE AGGREGATE	THERMAL ASH AGGREGATE	LECA
1	GPC	200	200	142.86	57.14	630	1170	0	0
2	TM1	200	200	142.86	57.14	630	936	234	0
3	TM2	200	200	142.86	57.14	630	702	468	0
4	TM3	200	200	142.86	57.14	630	468	702	0
5	TM4	200	200	142.86	57.14	630	234	936	0
6	TM5	200	200	142.86	57.14	630	0	1170	0
7	LM1	200	200	142.86	57.14	630	936	0	234
8	LM2	200	200	142.86	57.14	630	702	0	468
9	LM3	200	200	142.86	57.14	630	468	0	702
10	LM4	200	200	142.86	57.14	630	234	0	936
11	LM5	200	200	142.86	57.14	630	0	0	1170

3.1. Mix design

In earlier days flyash based geopolymer concrete are designed by undergoing many trial and error methods, due to the unavailability of standard mix design for geopolymer concrete. Researchers provided many mix design procedures for flyash based GPC, GGBS based GPC, metakaolin based GPC, five admixtures-based GPC in recent days. M20 grade of geopolymer concrete was designed by referring to these articles and by having some trails with slight modifications. The mix proportion of the geopolymer concrete per cubic meter is given in Table 3. Table 3 also provides the replacement level of the coarse aggregate with TAA and LECA. Thermal ash aggregate and LECA are replaced for coarse aggregate at 20%, 40%, 60%, 80% and 100% respectively. The powder materials are mixed along with the aggregates first, later the alkaline liquids were introduced. 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.

3.2. Slump cone test

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.

3.3. Compressive strength test

Compressive Testing Machine was used so that we could carry out the testing. 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 receives the appropriate compaction as a result of the filling of three levels. After a day has passed, the cast samples are 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 that the temperature of the room is between 25 and 30 degrees Celsius, and it falls somewhere in that range. After 7, 14, 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.

3.4. Split tensile strength test

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, 14 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.

3.5. Flexural strength test

Control geopolymer concrete and lightweight geopolymer concrete prisms of 100 mm by 100 mm by 500 mm were cast and the flexural strength was evaluated per IS: 516-1959. A total of 33 samples were cast and at 28 days, flexural strength tests were performed in Flexural Testing Machine. The control and geopolymer concrete samples were subjected to two-point loads utilizing a universal testing machine with a 1000 kN capacity.

3.6. Modulus of elasticity test

Samples of control geopolymer concrete and lightweight geopolymer concrete were put through a test to determine their modulus of elasticity using a compressometer. This test followed the technique outlined in the standard known as IS: 516-1959. Following a curing period of 28 days, cylindrical concrete specimens with dimensions of 150 millimeters by 300 millimeters were made and put through tests to determine their modulus of elasticity. In all, 33 samples were evaluated with the use of compression testing equipment with a capacity of 2000 kN. The results of the tests were used in the production of the stress-strain curve, and the modulus of elasticity was determined.

3.7. Density of concrete

The study mainly focuses on using lightweight aggregates in concrete. So, it is essential to find the density of the concrete casted using all the mixes. The weight of the cube specimens is used to calculate the density per cubic meter of concrete. The control geopolymer mix was compared with the geopolymer mixes with TAA and LECA as fine aggregates.

3.8. Acid resistance test

According to ASTM C 642, the acid resistance of 100 mm × 100 mm × 100 mm control 8 GPC and 8 LWGPC specimens 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.

3.9. Sulphate resistance test

By ASTM C 1012, the sulphate resistance test was performed on the control 8 GPC and 8 LWGPC to evaluate the concrete samples' resistance to sulphate attack. 100 mm × 100 mm × 100 mm of material was cast and it was then allowed to cure for 28 days. Cast specimens were submerged in a 5% solution of magnesium sulphate for 180 days at room temperature. Concrete samples were removed from the sulphate solution at intervals of 7, 28, 56, 90 and 180 days and the weight and strength losses brought on by sulphate treatment were then determined. To determine the geopolymer concrete's sulphate resistance, the weight and strength loss of lightweight geopolymer concrete were compared to the control geopolymer concrete. A total of 90 specimens were cast and put through a sulphate resistance test.

3.10. Salt resistance test

A specimen measuring 100 × 100 × 100 mm were cast and cured for 28 days to examine the salt resistance of the control GPC and LWGPC. The casted specimens were submerged in 3.5% NaCl solution for 180 days at room temperature. Concrete samples were removed from the salt solution after 7, 28, 56, 90 and 180 days and the weights of control and geopolymer concrete were measured. Concrete's weight and strength loss percentage variation and salt resistance were computed using the test results. A total of 90 samples were cast and tested for salt resistance.

3.11. Accelerated corrosion test

For the control GPC and LWGPC, an accelerated corrosion test was conducted. 16 mm diameter reinforcement has been inserted into concrete samples that are 100 mm in diameter and 200 mm in depth. In a 5% NaCl solution, the bottom two-thirds of concrete examples were submerged. The stainless-steel material served as the anode while the reinforcement served as the cathode. To speed up the corrosion in the cathode, a 12V DC supply was continuously provided to the stainless-steel material and reinforcement. Copper-to-copper sulphate electrodes coupled to volt meters were used to calculate the potential difference between the steel and the concrete. Based on the test findings, an estimation of the corrosion activity in control and geopolymer concrete was made. There were six specimens cast and tested for the accelerated corrosion test.

3.12. Water absorption test

The test was conducted according to ASTM C 642-13 with a 100 × 100 × 100 mm specimen. To investigate the water absorption rates of CGPC and LWGPC, a total of six specimens were cast. After curing for 7 and 28 days, the control geopolymer concrete specimens (CGPC) and lightweight geopolymer concrete specimens were dried in an oven at 100^{O}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 for the CGPC and LWGPC specimens. This is the CGPC and LWGPC's final mass. The proportional change in mass of CGPC and LWGPC indicates how much water each compound absorbed.

3.13. Sorptivity test

A sorptivity test was performed using cylindrical specimen samples of 12 with a 100 mm diameter and a 50 mm depth per ASTM C1585-13. On the circumferential surface of the cylindrical specimen, non-absorbing epoxy resin was used to seal the control GPC and LWGPC samples. 3 mm epoxy-coated specimens were submerged in water. The amount of water that was measured to be absorbed by capillary action in the concrete specimen's pores and the specimen's sorptivity was calculated. There were 6 total specimens cast, each of which was examined for sorptivity.

4. RESULTS AND DISCUSSION

In this research, fresh, hardened concrete tests and durability tests were carried out and the results obtained are discussed clearly. The results of conventional geopolymer concrete, TAA based LWGPC and LECA based LWGPC are compared and discussed. The mixes TM5, LM2 are considered to conduct durability tests, since these two mixes fall under the lightweight category with maximum strength.

4.1. Slump of LWGPC

The slump of LWGPC with TAA and LECA is shown in Figure 3. The thermal ash aggregate based lightweight geopolymer concrete mix TM5 showed a 15% increase in a slump when compared with the control GPC mix. On the other hand, Lightweight expanded clay aggregate based lightweight geopolymer concrete mix LM5 showed a 30%decrease in workability when compared with GPC. An increase in workability was found with the increase in TAA and a decrease in workability was found with the increase in LECA as coarse aggregate. LECA has an approximately round shape or potato shape with more voids. Due to the voids present in the aggregate, the workability of geopolymer concrete decreases with increasing percentage of LECA [16], this reflects in this work also. The TAA density is higher than LECA, which shows a higher crushing value and less permeable, this influences the geopolymer concrete in getting good workability. The surface of TAA is found to get bind easily to the geopolymer binder when compared with the LECA. This may prevent the flow of concrete. The workability of concrete may vary by the aggregate's shape and texture [17]. It was observed the uniformity in slump flow when TAA is used, which clearly shows the better adhesive property within the materials. Whereas the small segregation of aggregates was visible when LECA is used.

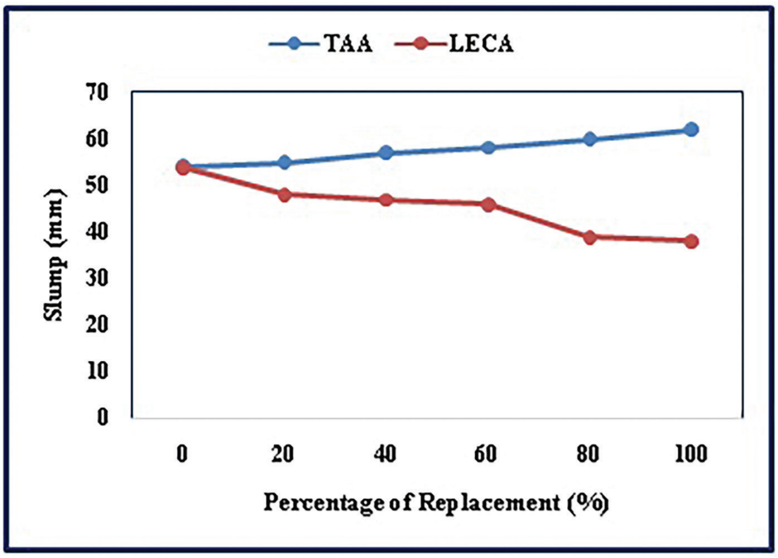

Figure 3: Slump of TAA & LECA based LWGPC.

4.2. Compressive strength of LWGPC

The compressive strength of LWGPC mixtures at the age of 7, 14 and 28 days is shown in Figure 4 and Table 4. The thermal ash aggregate based lightweight geopolymer concrete mix TM5 showed a 9% increase in compressive strength compared with control GPC. In every replacement level, the strength was found to get increase. LECA based lightweight geopolymer concrete mix LM5 showed a 38% decrease in compressive strength when compared with the control mix at 28 days. The crushing value and water absorption of aggregates alter the strength of concrete. TAA has a good crushing value when compared to LECA. This surely affects the strength of concretes embedded with TAA and LECA. An increase in water absorption of aggregates happens due to more porous aggregates [18]. LECA contains more porous compared to the TAA may lead to decrease in compressive strength [19].

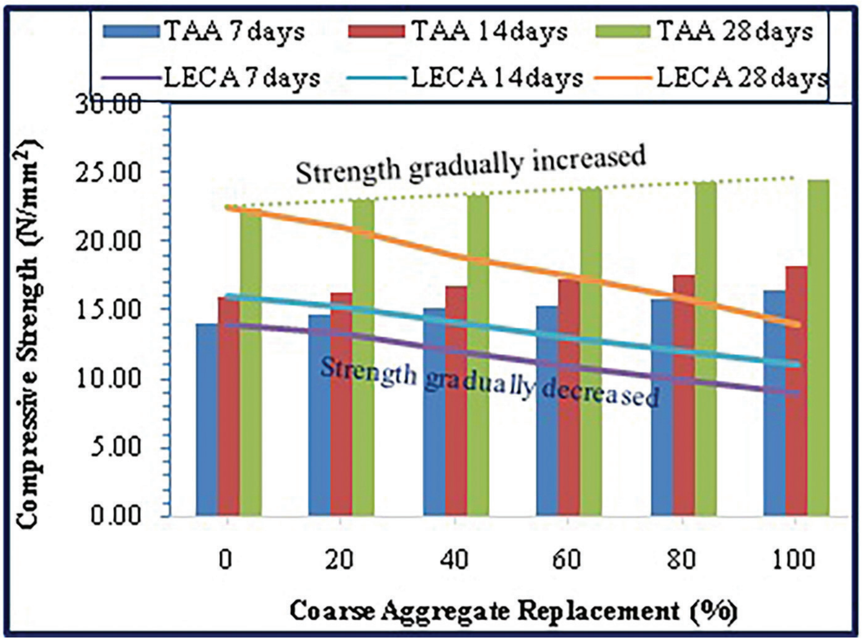

Figure 4: Compressive strength of TAA & LECA based LWGPC.

Table 4: Test results of lightweight geopolymer concrete.

SL. NO	MIX ID	SLUMP (mm)	AVG DENSITY (kg/cu.m)	COMPRESSIVE STRENGTH (N/mm^2)			SPLIT TENSILE STRENGTH (N/mm^2)			FLEXURA STRENGTH (N/mm^2)	MODULUS OF ELASTICITY (Gpa)
				DAYS							
				7	14	28	7	14	28	28	28
1	GPC	54	2470	14.00	16.00	22.50	1.50	1.80	2.20	3.10	19.20
2	TM1	55	2350	14.60	16.30	23.00	1.60	1.90	2.30	3.20	19.60
3	TM2	57	2200	15.20	16.70	23.40	1.65	1.90	2.30	3.60	19.97
4	TM3	58	2050	15.40	17.20	23.80	1.65	2.00	2.40	3.80	20.22
5	TM4	60	1930	15.80	17.60	24.30	1.70	2.05	2.45	3.90	20.74
6	TM5	62	1850	16.40	18.20	24.50	1.70	2.10	2.50	3.95	20.96
7	LM1	48	2100	13.40	15.20	21.10	1.40	1.70	2.10	2.80	18.87
8	LM2	47	1960	12.00	14.00	19.00	1.30	1.60	1.90	2.65	17.45
9	LM3	46	1790	11.00	13.00	17.50	1.20	1.40	1.70	2.50	16.52
10	LM4	39	1460	10.00	12.00	16.00	1.10	1.30	1.60	2.35	14.53
11	LM5	38	1250	9.00	11.00	14.00	1.05	1.20	1.40	2.20	13.84

The impact and crushing strength of TAA are more than LECA. The LECA has a high-water absorption capacity [20] when compared to conventional aggregates. The reasons stated may be matched to the results obtained in this work. That is an increase in compressive strength with the addition of TAA and a decrease in strength with LECA addition on behalf of natural aggregates.

4.3. Split tensile strength of LWGPC

The split tensile strength of LWGPC mixtures at the age of 7, 14 and 28 days is shown in Figure 5 and Table 4. The split tensile strength of GPC with 100%. TAA increased up to 14% when compared to the control mix. Whereas the GPC specimens with 100% LECA reduced the strength by about 36%. The current factor of aggregates affects the strength of concrete. Due to low crushing value, the specimens made of LECA failed soon. A clear vertical failure occurred in all the samples was identified. This ensures the development of tension along the transverse direction in all LWGPC specimens. After failure it has come to know, the TAA has more bond with the geopolymer binders and this is not found in failed GPC specimens made of LECA. Some LECA aggregates separately spall out of concrete after failure, this ensures that LECA has low adhesive capacity when compared to TAA.

4.4. Flexural strength of LWGPC

The flexural strength of concrete increases only if the bond of all the concrete materials is good. The flexural strength of mix TM5 was found to be higher than the control GPC can be seen in Figure 6. This ensures a good bond of TAA with geopolymer binders. The surface roughness of the TAA makes the geopolymer binders bind strongly. But due to the surface smoothness in LECA, the bond was not as good like TAA based GPC. Utilizing 100% of LECA in GPC, nearly 29% of flexural strength was reduced.

4.5. Modulus of elasticity of LWGPC

The modulus of elasticity of control GPC and LWGPC mixtures at the age of 28 days is shown in Figure 7 and Table 4. The TAA based lightweight geopolymer concrete mix TM5 showed a 9% increase in modulus of elasticity compared with CGPC. LECA based lightweight geopolymer concrete mix LM5 showed a 28% decrease in modulus of elasticity when compared with CGPC at 28 days. With respect to the addition of TAA, which has low density when compared to natural aggregate, the increase in elastic property was found in geopolymer concrete. But the same is not resembled in using low dense LECA as coarse aggregate. The elastic property of GPC got reduced by using the LECA as coarse aggregate. This excellent property in TAA is unfair to other aggregates used in the construction industry.

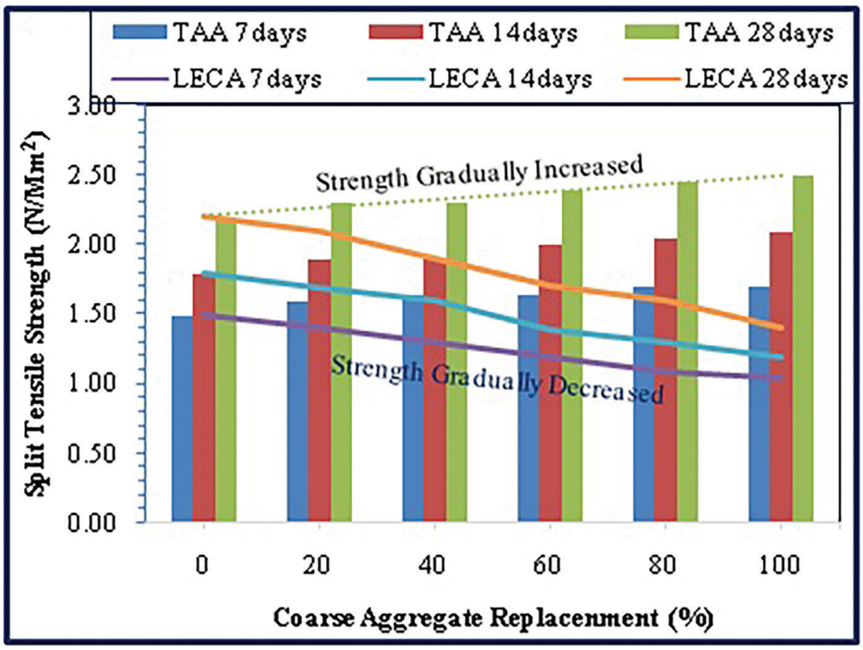

Figure 5: Split tensile strength of TAA & LECA based LWGPC.

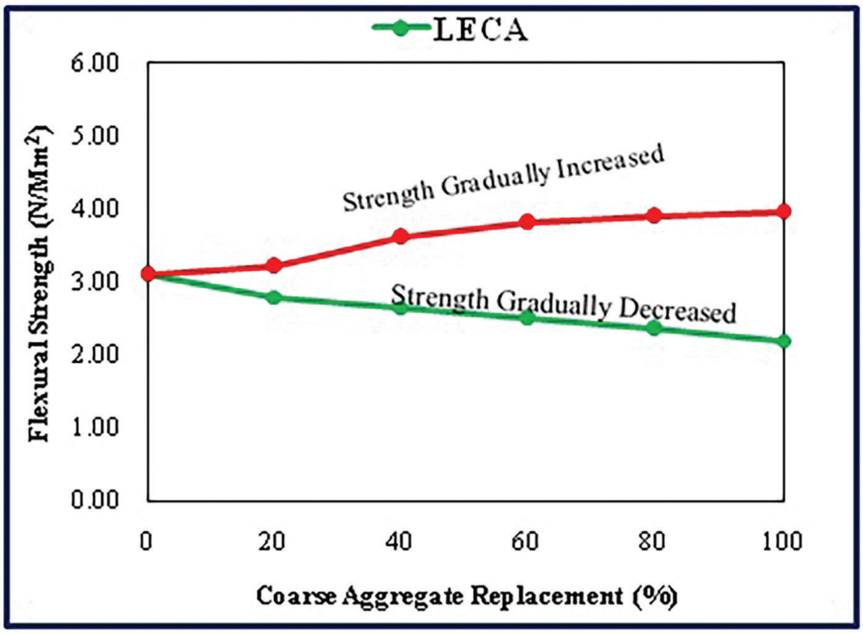

Figure 6: Flexural strength of TAA & LECA based LWGPC.

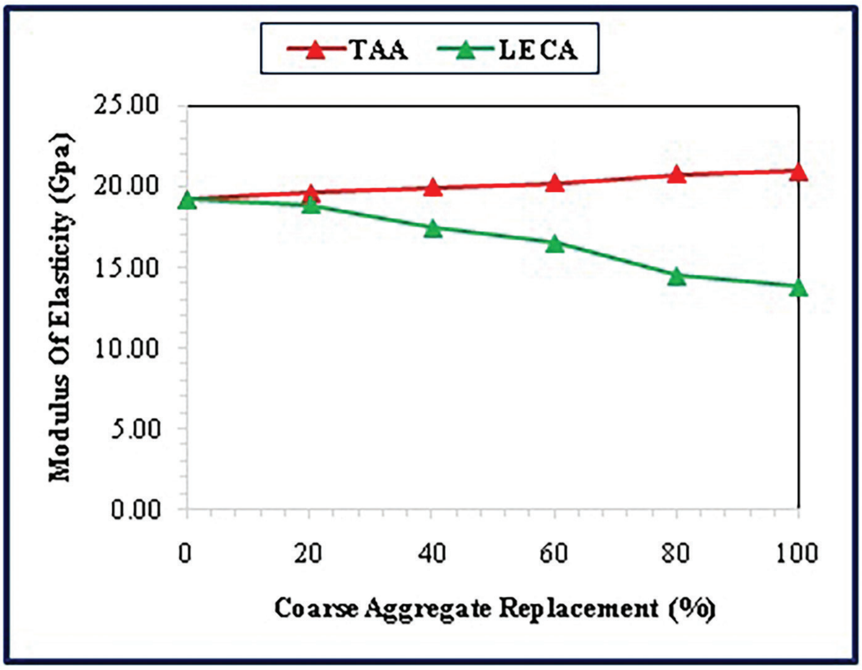

Figure 7: Elasticity of TAA & LECA based LWGPC.

4.6. Density of LWGPC

The Density of control GPC and LWGPC made of TAA and LECA are shown in Figure 8. The density of TAA is higher than LECA. The same density reduction was identified in the density of concrete. About 9%of density was reduced with the addition of TAA replacing 100% of natural coarse aggregate. On the other hand, 28% of density was reduced for GPC by using 100% of LECA as coarse aggregate. The density of concrete was found to fall within lightweight concrete with 80% and 100% of TAA and with 40%, 60%, 80% and 100% of LECA. This can be easily known in the Figure 8.

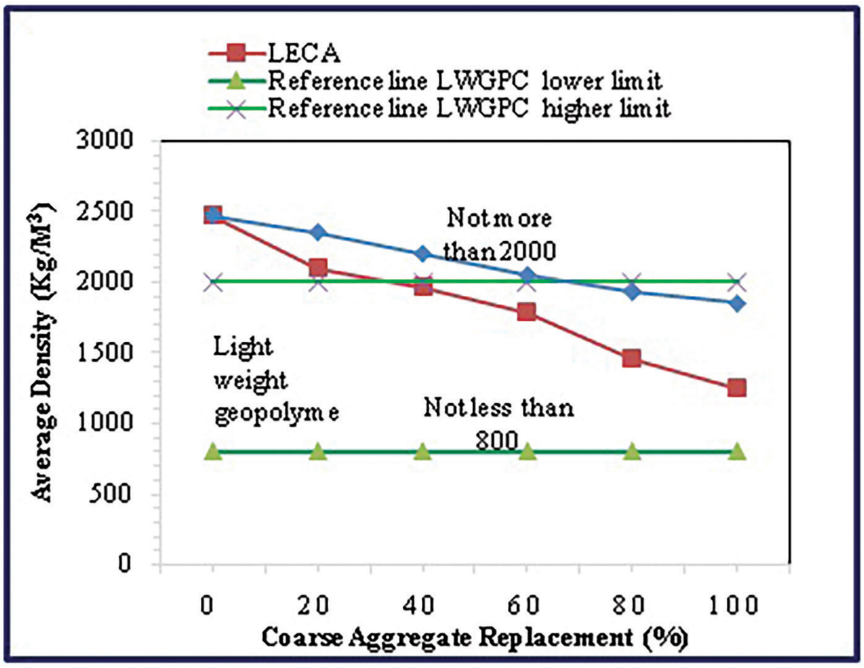

Figure 8: Density of TAA & LECA based LWGPC.

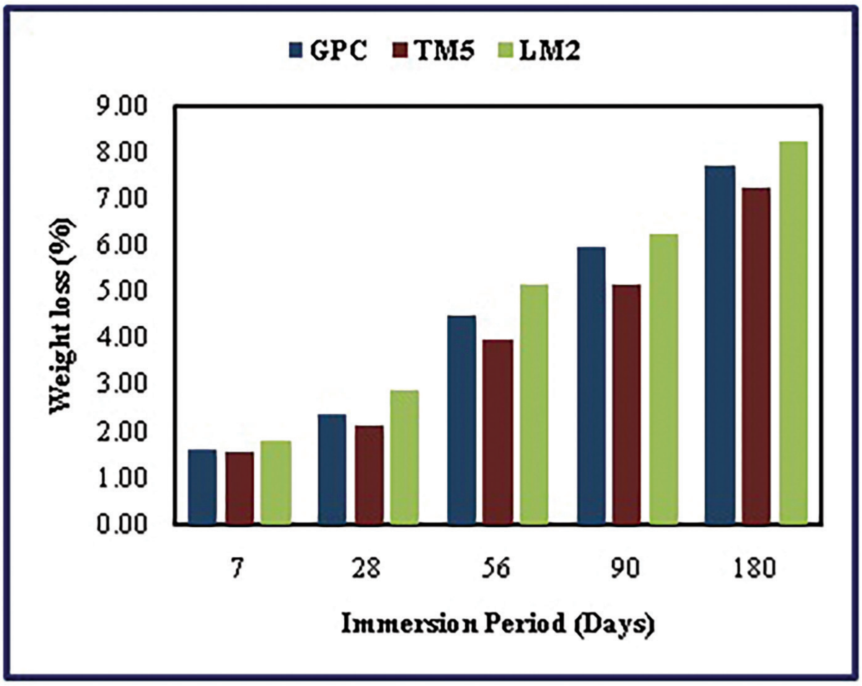

Figure 9: LWGPC weight loss due to acid attack.

4.7. Acid resistance of LWGPC

The strength and weight loss due to acid attack are shown in Figures 9 and 10. Figure 11 shows the specimens after immersed for 180 days in acid solution. About 25.28%, 24% and 26.65% of the strength loss was identified for the GPC, TM5 and LM2 specimens respectively. Similarly, 7.74%, 7.25% and 8.23%of the weight loss were identified for the GPC, TM5 and LM2 specimens respectively when compared with the specimens kept in open air curing. The percentage loss of strength and weight are less for TM5 made of TAA as coarse aggregate, secondly good resistance is found for control GPC. The specimens with LECA as coarse aggregate entirely

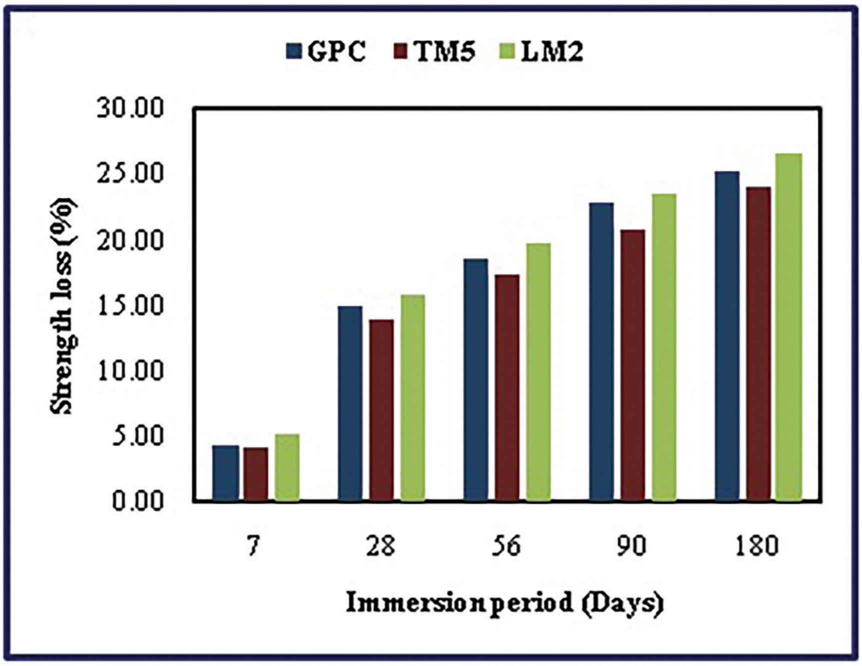

Figure 10: LWGPC strength loss due to acid attack.

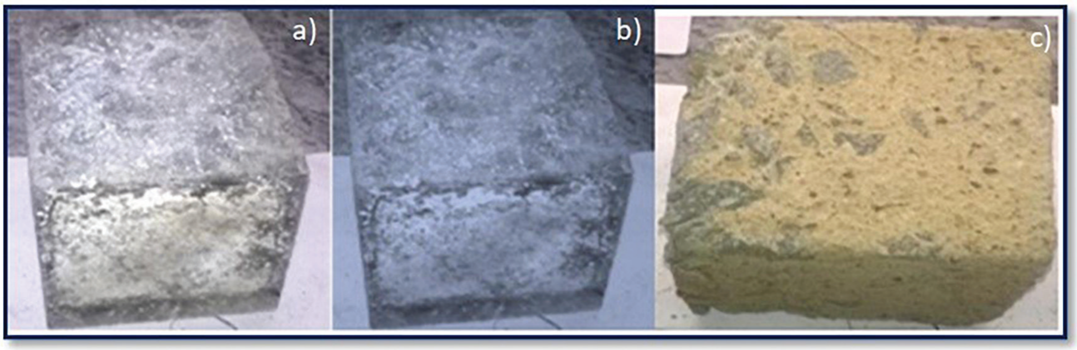

Figure 11: Visual appearances of TM5 (a), LM2 (b) and GPC (c) specimens after 180 days immersion in acid solution.

loosed more strength and weight when compared with the other two mixes. Due to the good bonding of TAA with geopolymer binder the resistance towards the chemicals will be very high. The resistance of geopolymer concrete toward the chemical environment is good. The same resistance was not identified in LECA based GPC specimens, because of high porosity and poor bonding with geopolymer binder.

4.8. Sulphate resistance of LWGPC

The strength and weight loss percentage due to sulphate attack is plotted in Figures 12, 13. Figure 14 shows the specimens after 180 days of immersion in sulphate solution. On the 180th day, the specimens are taken out of the sulphate solution and their weight is measured and then subjected to a compressive strength test. As a result of the weighing test, specimen GPC shows a 2.25% weight loss and specimenTM5 shows a 2.15% weight loss and specimenLM2 shows a 2.90% weight loss. As a result of the compressive strength test, specimen GPC shows a 21% strength loss and specimenTM5 shows a 20.25% strength loss and specimen LM2 shows a 22.15% strength loss. Specimen TM5 achieved better resistance to sulphate attack compare to the other two mixes. Also, TM5 and GPC have a dense structure and, all the aggregate pores are filled by geopolymer paste. LECA based specimen LM2 has a less dense structure and, presents more void in geopolymer concrete, this causes sulphate

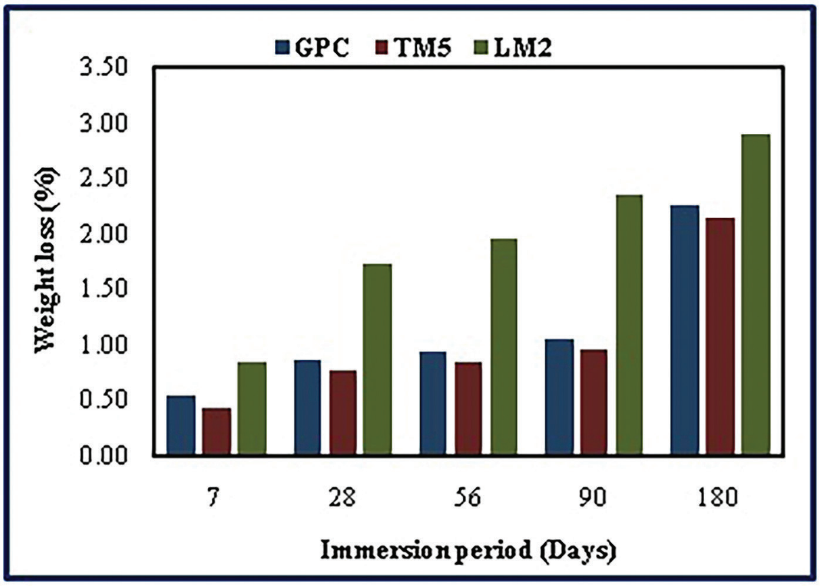

Figure 12: LWGPC weight loss due to sulphate attack.

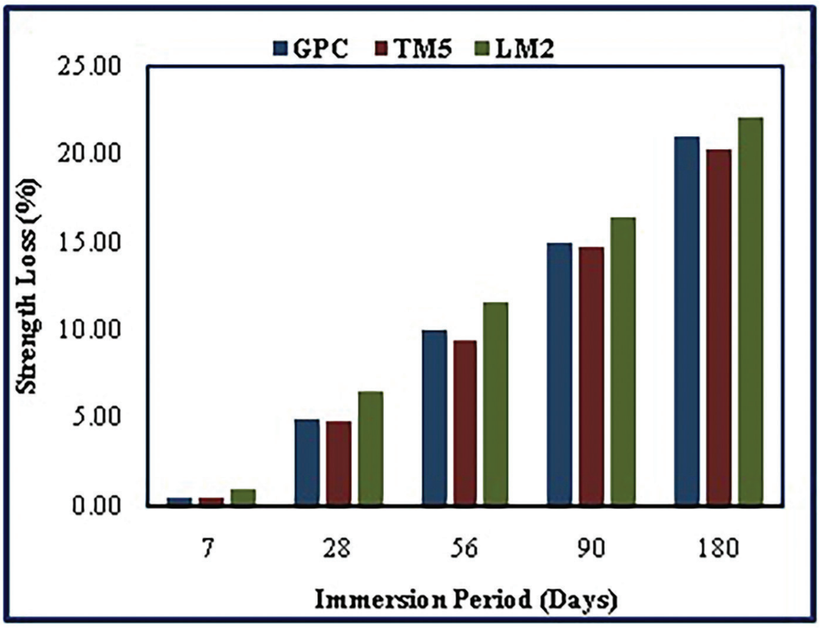

Figure 13: LWGPC strength loss due to sulphate attack.

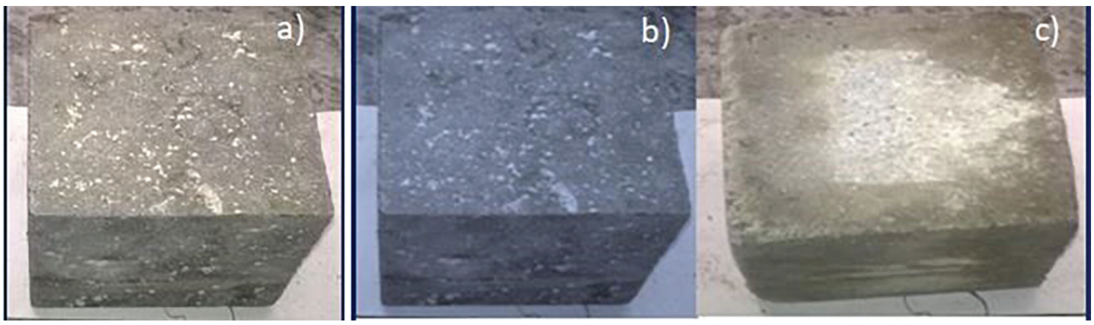

Figure 14: Visual appearances of TM5 (a), LM1 (b) and GPC (c) specimens after 180 days of immersion in sulphate solution.

resistance capacity reduced compared to specimen TM5 and GPC. Alkali-activated materials present in lightweight geopolymer concrete will resist the sulphate environment [21]. In general, GPCs resisted magnesium and sodium-based sulphate attacks better than other concrete types [22].

4.9. Salt resistance of LWGPC

Figure 15 shows the strength and weight loss percentage caused by salt attack. Figure 16 shows the specimens after 180 days of immersion in salt solution. The samples are removed from the salt solution on the 180th day and their weight is measured before a compressive strength test is performed on them. The results of the weighing test show that specimen GPC has lost 0.57% of its weight, specimen TM5 has lost 0.51% and specimen LM2 has lost 0.63%. The compressive strength test reveals that specimen GPC has lost 4.23% of its strength, specimen TM2 has lost 3.90% and specimen LM5 has lost 4.70%. The weight and strength of geopolymer concrete gradually decrease, which reflects that salt erosion will lead to the strength loss of geopolymer concrete, causing its internal damage, thus having adverse effects on it. The sample TM5, GPC has less internal damage compared to the sample LM5. TM5, GPC specimens tend to perform against internal damage, cracking, and crumbling. LECA present higher porosity compared to other aggregate so this cause occurs internal damage and concrete pill out from the position.

4.10. Accelerated corrosion of LWGPC

During the accelerated corrosion test, the mix LM2 corrosion was initiated at 250hrs whereas, in mix TM5, GPC corrosion was initiated after 424 and 324hrs only. From the above, TM5 and GPC have 174hrs and 74hrs more

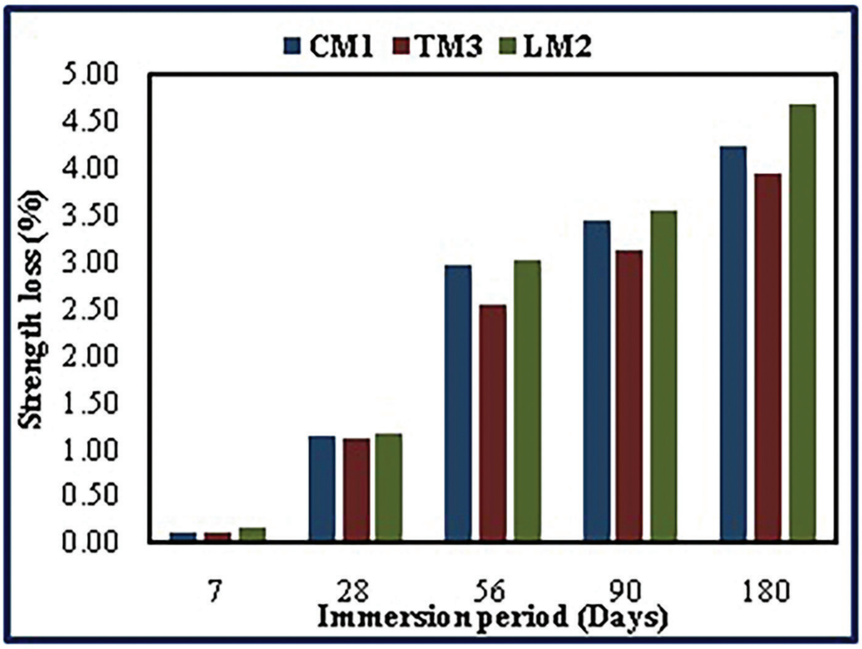

Figure 15: LWGPC strength loss due to salt attack.

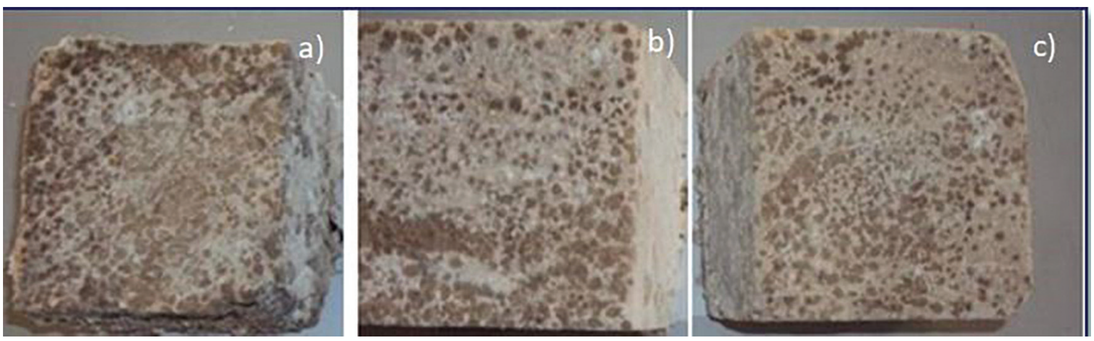

Figure 16: Visual appearances of TM5 (a), LM1 (b) and GPC (c) specimens after 180 days of immersion in salt solution.

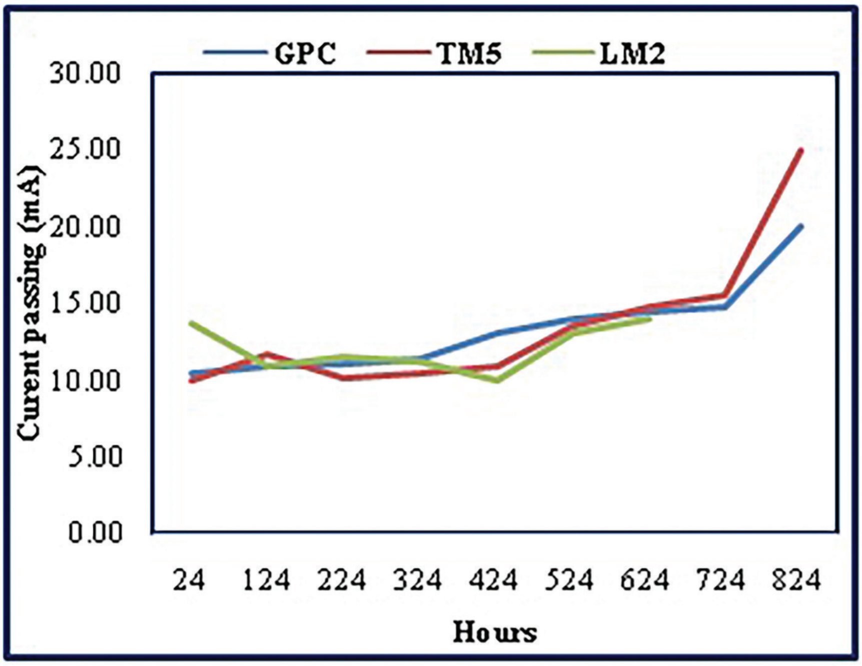

Figure 17: The relationship between the current passed and the duration of time.

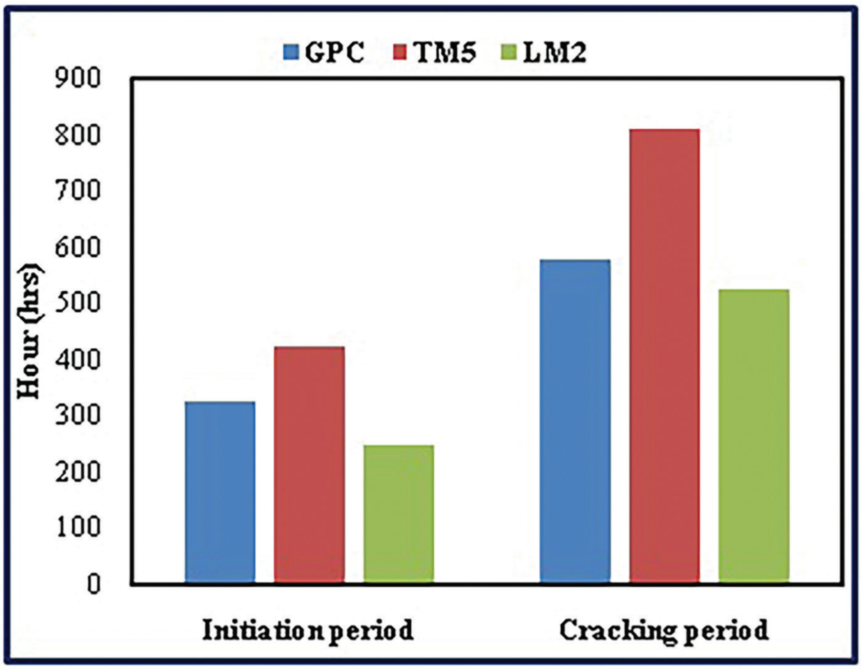

Figure 18: Corrosion period and cracking time of LWGPC.

life than LM2. In the same way, TM5, GPC cracking time was observed at 810hrs and 580hrs and it's higher than LM2 because TM5, GPC formed a protection layer against chloride ion penetration. In accordance with the evaluation of the steel's weight loss, the geopolymer made from fly ash has a lower corrosion rate than OPC concrete. This may be caused by sodium silicate in the pore system or by the geopolymer system's alkalis and chloride competing with one another [23]. TAA-based LWGPC density is higher than LECA-based LWGPC because LECA-based LWGPC presents more voids, porosity, and high-water absorption [24] compared to the TAA-based LWGPC. So, LECA specimens appeared high corrosion compared to the TAA specimen. The current vs duration relationship and the specimen's initial and cracking periods as shown in Figures 17 and 18.

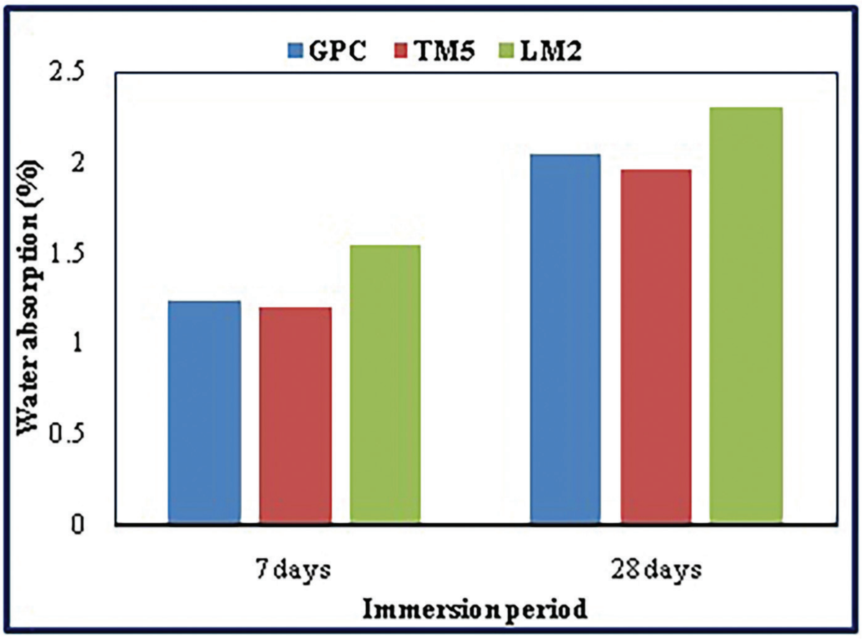

Figure 19: Water absorption of LWGPC.

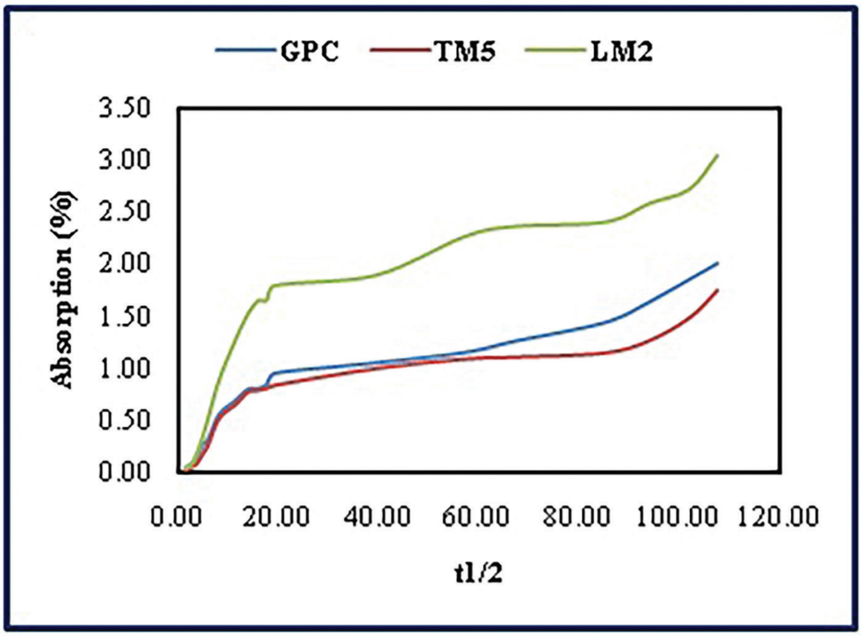

Figure 20: Sorptivity of LWGPC.

4.11. Water absorption of LWGPC

The water absorption of TM5, GPC results show 17% and 12%lesser water absorption obtained compared to the mix LM2 at 28 days and TM5, GPC has fewer pores and all the pores were perfectly packed with geopolymer gel. The LECA aggregate present more voids [25] or porous compared to the TAA. So, this reasons water absorption of LECA-based LWGPC is higher compares to the TAA-based LWGPC. Water absorption also depends on NaOH molarity and 8 to 12M NaOH used LWGPC reduce water absorption [22]. In this investigation, M10 NaOH molarity was used. In general, the much-reduced durability of LWAC compared to NWAC should not be identified with its significantly higher water absorption [26]. Graphical representation of water absorption percentage as shown in Figure 19.

4.12. Sorptivity of LWGPC

In the sorptivity test, the final absorption of TM5 and GPC specimens obtained2.01% and 1.74% and it is lesser compared to the LM2 specimen. LM2 specimen obtained final water absorption is 3.05%. Also, TM5 and GPC specimens have a dense microstructure and are less permeable than LM2. TM5 and GPC have less water absorption than LM2. In Figure 20, the absorption graph is shown. This prevents water and its hazardous agents from entering, which would otherwise cause concrete to deteriorate and reinforcement to corrode. In order to prevent major devastation from chloride or sulfate-containing water from entering concrete, sorptivity must be kept to a minimum [27].

5. CONCLUSION

- The study investigated the influence of lightweight aggregates on the properties of lightweight geopolymer concrete (LWGPC), focusing on workability, density, compressive strength, split tensile strength and flexural strength. Two types of aggregates were considered: TAA and LECA.
- In terms of workability, it was observed that TAA-based GPC (TM5) exhibited a 15% increase in workability compared to conventional GPC (CGPC) at 28 days. On the other hand, LECA-based GPC (LM5) showed a 30% increase in workability compared to CGPC. These findings highlight the impact of lightweight aggregates on the ease of concrete placement and compaction.
- Density is a crucial property in LWGPC. The bulk density of TAA was found to be higher than that of LECA. At 28 days, TM5 demonstrated a 9% decrease in density compared to CGPC, while LM5 showed a 28% decrease. The variation in density can be attributed to the lightweight nature of the aggregates and their distribution within the concrete matrix.
- Regarding mechanical properties, TM5 exhibited a 9% increase in compressive strength compared to CGPC at 28 days, whereas LM5 showed a 38% decrease. Similar trends were observed in split tensile and flexural strength, with TM5 displaying a 10% increase and LM5 showing a 20% decrease compared to CGPC. These results indicate that the high density of TAA-based GPC contributes to enhanced mechanical strength, while the low density of LECA-based GPC leads to reduced strength characteristics.
- The research looked at other elements that may have contributed to the observed disparities. It was discovered that LECA has a larger water absorption capacity than TAA, which may have an impact on the concrete's general characteristics. Low density of LWGPC is a consequence of closed pores in lightweight aggregates, but lower crushing strength in LECA may be a result of more fragmented particles.

In conclusion, the results show how much lightweight aggregates affect the workability, density, and mechanical characteristics of LWGPC. Due to its greater density, TAA-based GPC showed enhanced workability and higher compressive, split tensile and flexural strengths. On the other hand, GPC based on LECA showed improved workability but decreased density and mechanical strength. Understanding how various lightweight aggregates affect LWGPC might help in the creation of concrete mixes that are optimal for certain applications demanding strong, lightweight buildings.

6. FUTURE WORK

The current work extensively examined the tensile characteristics of lightweight geopolymer concrete using open-air curing techniques. The present study investigated the flexural behavior and durability qualities of lightweight geopolymer concrete when subjected to open-air curing conditions. Moreover, it is worth noting that there exists a possible scope for future research in the following domain.

- The assessment of the performance of the lightweight precast concrete (LWGPC) beam-column junction subjected to cyclic loads.
- The study of self-compacting lightweight concrete with ground palm kernel shell may be conducted in accordance with the recommendations provided by the European Federation for Specialist Construction Chemicals and Concrete Systems (EFNARC).
- The objective of this study is to examine the behavior of Lightweight Geopolymer Concrete (LWGPC) in relation to short columns and slabs.

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