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Experimental study on different properties of cenosphere based concrete using calcium lactate

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Abstract

The effective utilization of secondary products obtained from coal ash is a major focus of researchers, addressing the global issue of ash dumping on the ground. Cenospheres are a novel material, inherently possessing significant physical and chemical properties that pave the way for numerous future technological advancements in construction. In present work cement is replaced by cenosphere with 2.5%, 5%, 7.5% and 10% to examine physical and mechanical properties of concrete. Because of the fineness of the cenosphere, concrete exhibits little gain in strength, but subsequently because of the lower quantity of calcium contained in the cenosphere, it loses strength substantially. For greater improvement in mechanical properties, calcium lactate of 0.010 mol/lit and 0.015 mol/lit is added in concrete mix along with cement replaced by cenosphere. The obtained result shows that, there is a 4.69% and a 4.80% drop in density when cenosphere is used to replace 10% of cement. Additionally, it results in increases in compressive strength of 4.09% and 8.40%, flexural strength of 2.86% and 6.34%, and tensile strength of 4.02% and 9.77%.

Keywords: *Cenosphere; Calcium Lactate; Microstructural Analysis; Plastic And Dry Density; Compressive Strength; Flexural Strength; Split Tensile Strength*

Introduction

Concrete is the most extensively used building material and has contributed a significant amount to contemporary civil infrastructure over the past century. Concrete is a mixture of versatile materials which make it strong and durable[1]. Cenosphere, as a cementitious material, represents a novel technological advancement that forms the foundation for concrete development[2]. Cenospheres are derived from coal-fired power stations, it may also known as fly ash cenospheres (FAC). Cenospheres are valued in the construction industry for their lightweight, low-density, high compressive strength, and thermal insulation properties. Their chemical composition, primarily silica, contributes to their durability and resistance to chemical reactions. Their physical attributes, such the dispersion of their particle sizes [3]–[10], specific surface area[11], [12], shell thickness[13], diameter[13]–[15], colour[14], [16], particle bulk density [17], [18], specific gravity[19], [20] and water absorption [16], [20] may affects workability, strength and overall performance of concrete. These chemicals and physical properties make cenospheres a valuable additive for improving the performance of construction materials like concrete and composites. The average particle density of the cenospheres utilised in the concrete is about 850 kg/m^3. Table.1 shows the particle size distribution of the cenospheres, with the majority of the particles falling between 63 and 150 µm in size.

Table 1: Particle size distribution (wt.%) of cenosphere

Sieve	500 µm	250 µm	150 µm	106 µm	63 µm	< 63 µm
Cenosphere Content	Nil	Nil	0-5%	5-30%	60-95%	0-20%

Cenosphere is versatile material utilized in construction industry for lightweight concrete[8], [21], energy saving building design[12], ceramic construction [17], internal curing agent[15], [22]–[24] and manufacturing composite materials[23], [25], [26]. The qualities of both freshly poured and hardened cenosphere concrete will be discussed, and any differentiations observed will be compared to more conventional concretes. It aims to provide a deeper

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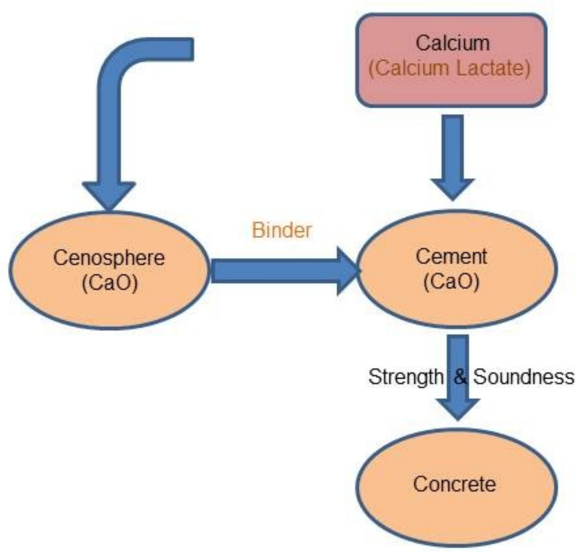
comprehension of the possible benefits and drawbacks of cenosphere concrete. This concrete investigates the ideal cenosphere component to take into account when designing concrete mixes.

Table 2: Chemical Structures (wt%) of cenosphere materials

Description	CaO	Fe_2O_3	MgO	SO_4	K_2O	SiO_2	Na_2O	MnO	Al_2O_3	TiO_2
Cenosphere	00	1.9	0.4	0.2	0.9	53.9	00	0.1	42.6	00

Concrete uses the cenosphere as a binding agent in place of some of the cement. The chemical composition of cenospheres shows high combined SiO_2 and Al_2O_3 content of 96.5% but low CaO content equal to 0% as shown in Table 2. The use of fly ash cenosphere is highly helpful for lowering density and bettering concrete's performance; utilising hazardous trash to alleviate environmental issues, and lowering the utilization of cement and hence lower the carbon footprint of the manufacture of concrete while only slightly reducing compressive strength. Utilizing industrial waste, cenosphere is employed in mixes up to about 10% by volume of total cement materials, calcium with 0.010 and 0.015 mol/lit gives concrete density under 2550 kg/m^3, Owever, they share many of the same mechanical characteristics as regular concrete.

Fig. 1 Flow diagram of cenosphere concrete mix.



2 Material and Compositions

In accordance with Indian Standard (IS) 12269, the experimental work is done on concrete specimens made of fly ash cenosphere and ordinary Portland cement (OPC) as the binder ingredient. Cenosphere-based low-density concrete achieves good workability of concrete mix. According to the FAC grading, the majority of the particles are between 63 to 150 µm in size. Additionally, the SEM examination also supports the hollow spherical shape and size variation of the FAC, which ranges from 63 to 150 µm as shown in Fig. 2.

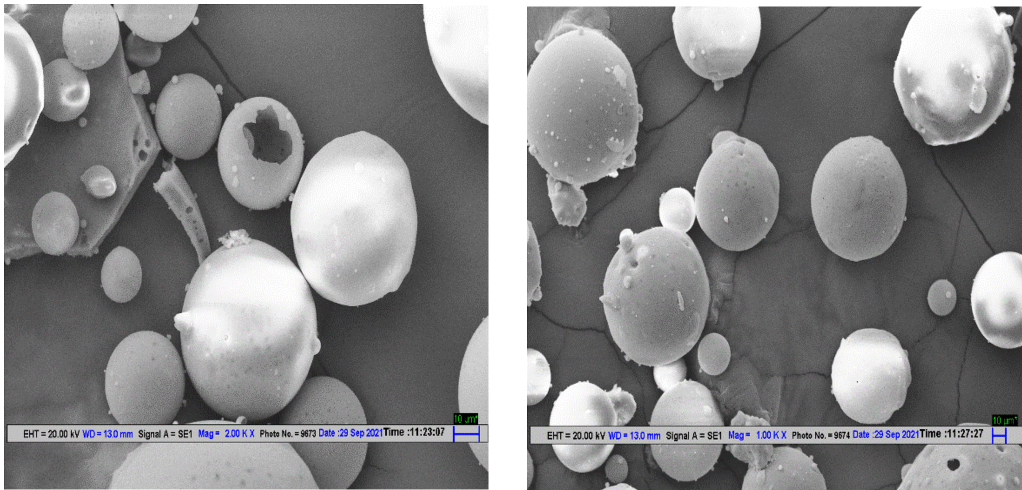


Fig. 2 SEM image of cenosphere

A versatile mineral called calcium lactate is utilized to meet the need for calcium required by cenosphere and bacteria in concrete at different stages of development. The calcium lactate has a chemical compound of ($C_6H_{10}CaO_65H_2O$) with a molar weight of 308.31 g/lit. Calcium lactate's physicochemical compositions are shown in Tables 3 and 4. The calcium lactate that is included in the mix design is added in hydrated form and is precisely soluble in the water together with the other ingredients of concrete. Calcium lactate molar weight quantity is utilised as 0.01(CL0.010) and 0.015(CL0.015) mol/lit shown in Table 6.

Table 3 Physical properties of calcium lactate

Property	Result
Appearance	White powder
Solubility	Water, Methanol, Ethanol
Odour	Peculiar smell

Table 4 Chemical composition of calcium lactate

Property	Result
Chemical formula	$C_6H_{10}CaO_65H_2O$
Molar weight	308.31 g/lit
Assay	98 %
pH	6.8
Phosphate	0.002 %
Potassium	0.005 %
Water	30 %

The concrete mixtures are made in the lab using a pan mixer. According to IS's recommendations, the physical characteristics of coarse and fine aggregate (CA and FA) are examined shows in Table 5. The potable water is utilised as instructed by IS 456.

Table 5 Specifications of the aggregate

Type of Aggregate	Property	Test Result	Indian Standard recommendation
Fine aggregate	Fineness modulus	2.60	Zone III (2.78-1.71)
	Water absorption (%)	1.69	0.3 to 2.5%
	Specific gravity	2.59	2.3 to 2.7
	Size (mm)	< 4.75	< 4.75
Coarse aggregate	Fineness modulus	6.8	6 to 6.9
	Water absorption (%)	1.41	Not more than 2%
	Specific gravity	2.66	2.6 to 2.9
	Size (mm)	20-6	>4.75

3 Mix Proportion

In the cement-based system, pozzolanic reactions might benefit from the presence of amorphous silica and a tiny amount of lime. Due to the dehydroxylation and decarbonization processes in the cement hydration, cement paste incorporated of FAC composites exhibits weight loss. still, it will give better mechanical properties even at lower density levels [2].

Table 6 Mix proportion for 1m3 of cenosphere based concrete

Mix ID	Cement (Kg)	Cenosphere (Kg)	Water (Lit.)	Calcium Lactate (Gm)		Coarse aggregates (kg)	Fine aggregates (kg)
				0.010 Mol/L	0.015 Mol/L		
CN00-CL0.010	394.32	----	197.16	607.25	----	1114.40	712.67
CN2.5-CL0.010	384.46	9.86	197.16	607.25	----	1114.40	712.67
CN5-CL0.010	374.60	19.72	197.16	607.25	----	1114.40	712.67
CN7.5-CL0.010	364.75	29.57	197.16	607.25	----	1114.40	712.67
CN10-CL0.010	354.89	39.43	197.16	607.25	----	1114.40	712.67
CN00-CL0.015	394.32	----	197.16	----	910.88	1114.40	712.67
CN2.5-CL0.015	384.46	9.86	197.16	----	910.88	1114.40	712.67
CN5-CL0.015	374.60	19.72	197.16	----	910.88	1114.40	712.67
CN7.5-CL0.015	364.75	29.57	197.16	----	910.88	1114.40	712.67
CN10-CL0.015	354.89	39.43	197.16	----	910.88	1114.40	712.67

Calcium oxide is a dominant compound that is observed in the chemical analysis of FAC, to overcome that calcium lactate is precisely soluble in the water together with the other ingredients of concrete. To know the effect, the Concrete mix was categorized into two groups, the first specimen set with five combinations of FAC and cement percentages of replacements, those five combinations are Normal Concrete (CN), Concrete with FAC 2.5% (CN2.5), FAC 5% (CN5), FAC 7.5% (CN7.5), and FAC 10% (CN10).

The second specimen set with two combinations of FAC with different contents of calcium lactate, those two combinations are Concrete with FAC (0%,2.5%,5%,7.5% and 10%) with calcium lactate (0.010 mol/L) and FAC (0%,2.5%,5%,7.5% and 10%) with calcium lactate (0.015 mol/L). The criteria provided by IS- 456:2000 and IS-10262:2019 are used to determine the ratio of the concrete mix design for M25 and In Table 6, all proportions are described.

The water/cement ratio is a crucial parameter in concrete strength, and its influence becomes more intricate when incorporating cenosphere and calcium lactate. The water/cement ratio is carefully adjusted to maintain adequate workability while taking advantage of cenosphere. Calcium lactate, as an additive, use as an accelerator for concrete curing, potentially influencing the early strength development. Its use at a specific concentration (0.010 and 0.015 mol/liter) indicates a precise consideration for the concrete mix's chemical properties and the desired curing rate.

4 Experimentation

Concrete mixtures were divided into two groups; the first specimen set consisted of five concrete mixtures that were made by using FAC instead of OPC, in different combination of 0%, 2.5%, 5%, 7.5% and 10% each & second specimen set consist of two combinations of FAC with different contents of calcium lactate, those two combinations are Concrete with FAC (0%,2.5%,5%,7.5% and 10%) with calcium lactate (0.01 mol/L) and FAC (0%,2.5%,5%,7.5% and 10%) with calcium lactate (0.015 mol/L). The control mix was the concrete mix that did not contain FAC or calcium lactate.

Table 6 lists the precise mix proportions along with their names. As the two sets of mixes were prepared, in the first set FA and CA well mixed together to get uniformity then cement and FAC add as a binder in composition. Dry mixing time is increased by 5-7 minutes over the control concrete mix. Finally calculated the exact amount of water added to the dry mix to get homogeneous and workable concrete. In the second set dry mix was prepared in the same way as that of the first set, but before adding water to the mix, calcium lactate by weight is added to the water and uniformly diluted for 4-5 min afterward the water was added in the dry mix.

The obtained fresh mix was utilized right away to perform a slump cone test to determine its workability; the results are listed in Table 7. Utilizing the special qualities of cenospheres to promote flow and lessen friction within the mixture, cenosphere concrete with a slump range of 104-111mm exhibits high workability and is appropriate for a variety of building applications. According to IS 1199, the slump cone examination is carried out on new laid concrete; the W/C ratio is kept at 0.5 in each mix. Fresh concrete was then poured into the designated mould needed for the various tests. A table vibrating machine was used for achieving the compactness of poured concrete. After 24 h ± 1 h of air curing, specimens were taken out from the molds and placed for curing in water. The test specimens were taken out from the curing tank after receiving enough curing and allowed to dry at room temperature. At the ages of 7 and 28 days, the specimens are subjected to the standard test using the instructions outlined in IS 516.

Table 7 Properties of fresh concrete

Mix ID	Slump (mm)	Unit Weight (Kg/m^3)
CN00-CL0.01	113	2551
CN2.5-CL0.01	111	2535
CN5-CL0.01	109	2512
CN7.5-CL0.01	107	2443
CN10-CL0.01	105	2398
CN00-CL0.015	111	2565
CN2.5-CL0.015	108	2542
CN5-CL0.015	107	2508
CN7.5-CL0.015	105	2436
CN10-CL0.015	105	2406

5 Result and Discussion

5.1 Plastic and Dry Density

The density is a key index for evaluating the physical and mechanical properties of concrete. The density of material affects the consumption and utilization of the material in the mix, which directly affect the cost of the structure. The density of the concrete mix was measured for freshly laid concrete after 24 hours, for surface saturated concrete after

28 days, and for oven-dry concrete after 24 hours. Table 8 shows the impact of various circumstances noticed on the sample.

Table 8 Unit weight of concrete (Kg/m^3)

Days	Control Mix	Cenosphere (10%)	Cenosphere (10%) + Calcium Lactate (0.010)	Cenosphere (10%) + Calcium Lactate (0.015)
1 (Fresh Mix)	2598	2449	2398	2406
28 (SSD)	2612	2507	2479	2457
28 (ODS)	2547	2406	2380	2356

The use of FAC and calcium lactate in the mix shows little variation in density. FAC is hollow in nature due to which concrete loses density when the proportion of FAC rises. The addition of calcium lactate in the mix shows linear changes in the density of concrete. From the obtained result it is observed that at FAC 10% replacement of cement shows a 4.62% reduction in density, simultaneously when calcium lactate of 0.010 mol/lit and 0.015 mol/lit is added to the mix it shows 4.69% and 4.80% reduction in density. The obtained result shows density at various percentages of FAC shown in Fig. 3.

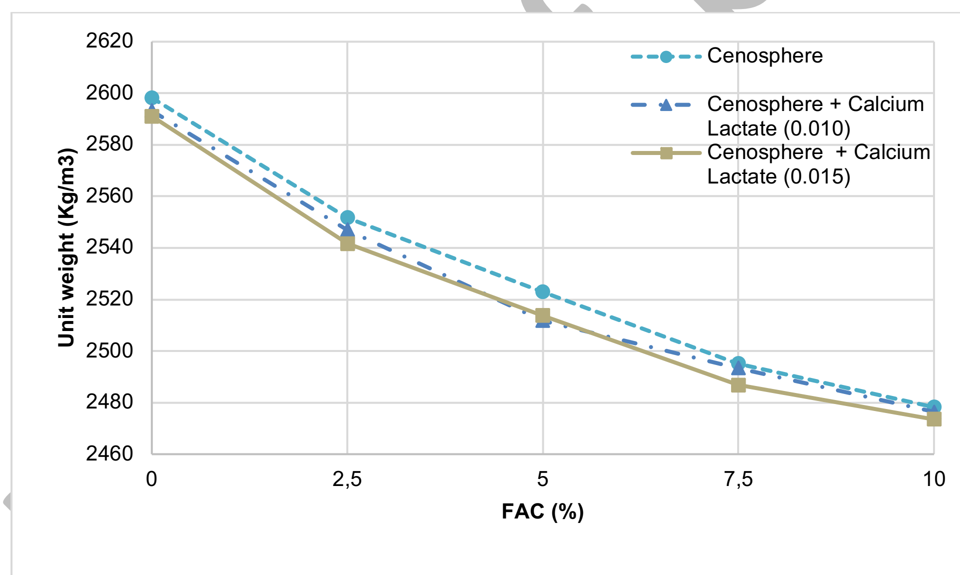


Fig.3 Unit weight (Kg/m3) Vs FAC (%)

5.2 Compressive Strength

Testing a 150 x 150 x 150mm cast cube on a compression testing equipment yields information about concrete's compressive strength. Concrete mixes were categorized into two groups to check the effect of FAC replacement with cement and adding of dissolved Calcium lactate on the compressive strength of concrete. Employing IS 10262, the concrete mix was built for M25 grade, and then FAC is added to the mix as a partial substitution of 2.5%, 5%, 7.5%, and 10% for OPC. According to the results, FAC 2.5% replacement provides stronger strength when compared to regular concrete because of cenosphere fineness. But it exhibits a loss of strength when the proportion of FAC rises, this may happen because of its hollow shape and less amount of calcium elements present in FAC. The variation of compressive strength at various percentages of FAC shows in Fig. 4.

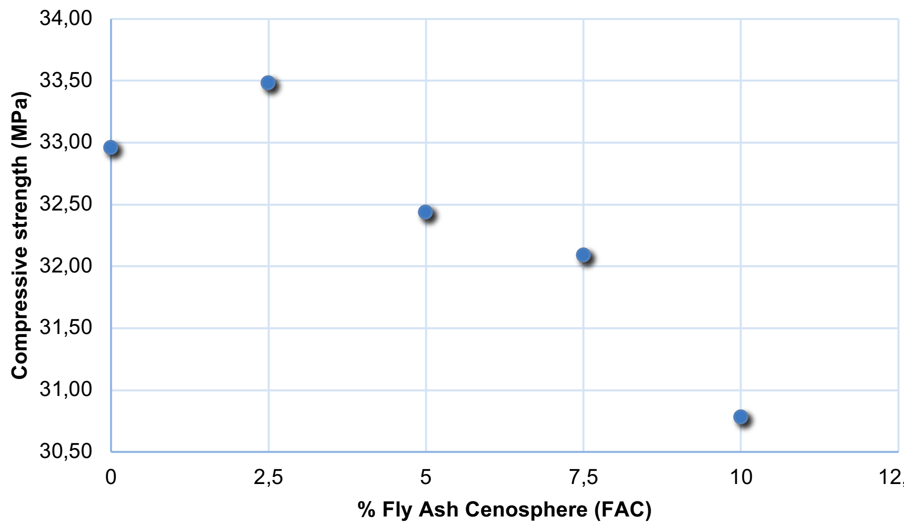


Fig. 4 Compressive strength of FAC concrete at 28 days

Further to this two concentrations of calcium lactate were added to the mixture of 0.010 mol/lit and 0.015 mol/lit. For a uniform mixture of calcium lactate in the mix, calcium lactate was dissolved in water and afterward, it was added to the concrete mix. The obtained result shows compressive strength improvement after the inclusion of CL. The variation of compressive strength at various percentages of FAC shows in Fig. 5.

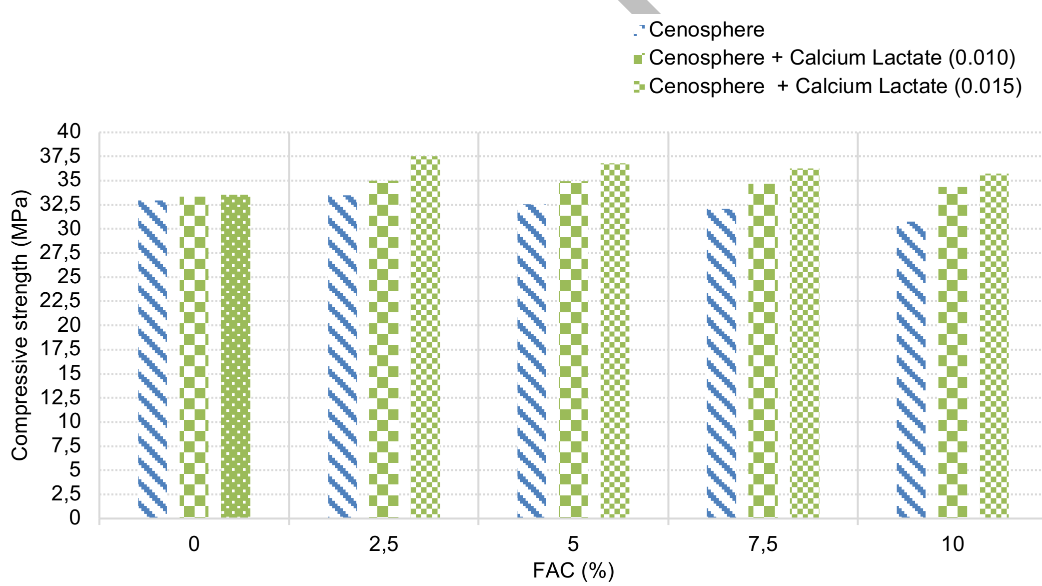


Fig. 5 Compressive strength of concrete (Mpa) Vs FAC (%) at 28 days

The obtained normal strength of concrete is 32.96N/mm2. Addition of FAC 2.5%, 5%, 7.5% and 10% shows linearly decrease in strength, 10% FAC replacement with cement shows strength 30.78 N/mm2 which is 6.61% decrease in strength, after addition of calcium lactate with 0.010 mol/lit & 0.015 mol/lit shows strength 34.31 N/mm2 and 35.73 N/mm2 which is 4.09% & 8.40% higher strength than normal concrete.

Failure pattern

A concrete cube was tested on a compression testing equipment with a steadily increasing force, the concrete cube was placed between upper and bottom plate of loading frame afterward hydraulic pressure was applied on the cube which observed from dial gauge of the control panel. The dial gauge shows incremental readings up to the failure of the concrete cube. The failure sample of a cube was taken away from the loading frame and the failure pattern was observed as shown in Fig. 6, the matrix shows all ingredients mixed well at the time of mixing and compacted properly. The surface shows no tension zone was observed on the concrete cube. Fine and coarse aggregate shows proper bond with other materials of the matrix, it was also observed that aggregate failure or break in the central portion of a cube, this means all the material used in mix perform well within the limits.

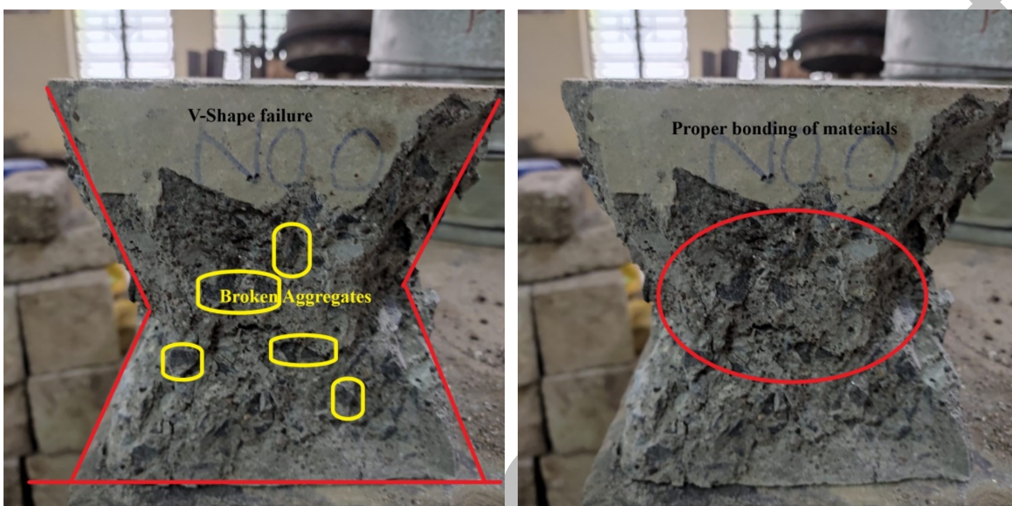


Fig. 6 Failure pattern of compression member

5.3 Flexural Strength

To examine the flexural properties of FAC, two points load test was conducted on a beam specimen of size 100 x 100 x 500mm. After completion of the curing period, the beam specimen sample was thoroughly checked for defects then demarcation was done on the beam, 50mm cover was left from both ends of the beam and the remaining span was equally divided into 3 spans of each length of 133mm. The universal testing machine of force capacity 250 KN was used for the application of uniform loading at the rate of 0.15mm/min. the beam specimen was kept on the loading frame and two points were applied to a specimen, applied load and deflection of the beam were measured on screen. The flexural strength of the beam was calculated by using the following relation.

$$MR = \frac{PL}{bd^2} \tag{1}$$

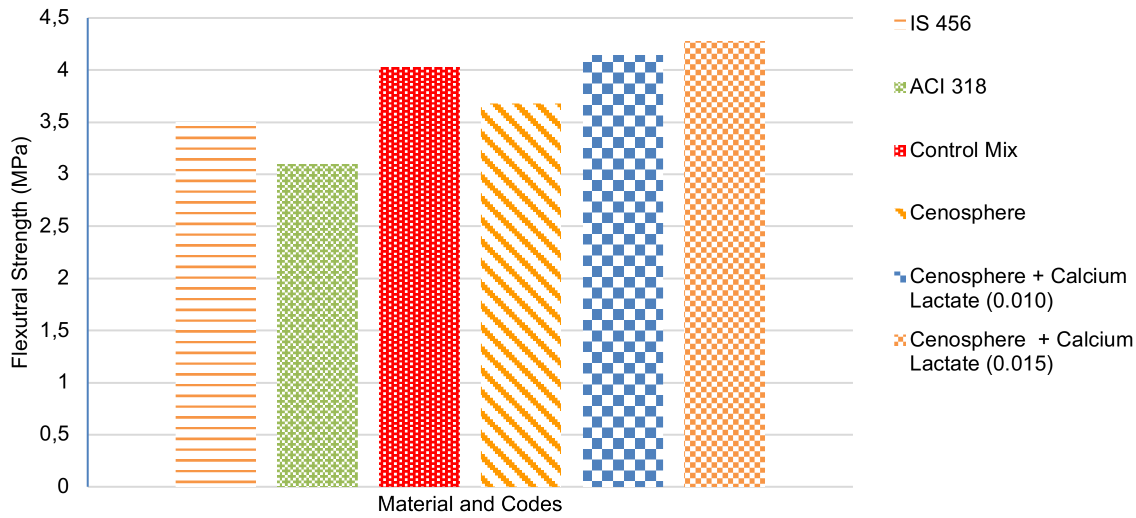


Fig. 7 Flexutral strength (MPa) Vs Materials and Codes for replacement of cement by cenosphere (10%)

Fig. 7 shows the flexural strength comparison between different materials and codes. The obtained result of FAC and calcium lactate compared with IS and ACI code indicate satisfactory application of calcium lactate along with FAC. FAC added in the mix with 2.5%, 5%, 7.5% and 10% replacement with cement exhibits a loss of strength when the proportion of FAC rises, whereas when calcium lactate is added in the mix with 0.010 mol/lit and 0.015 mol/lit shows increasing in strength. The variation of flexural strength with FAC (%) shown in Fig. 8.

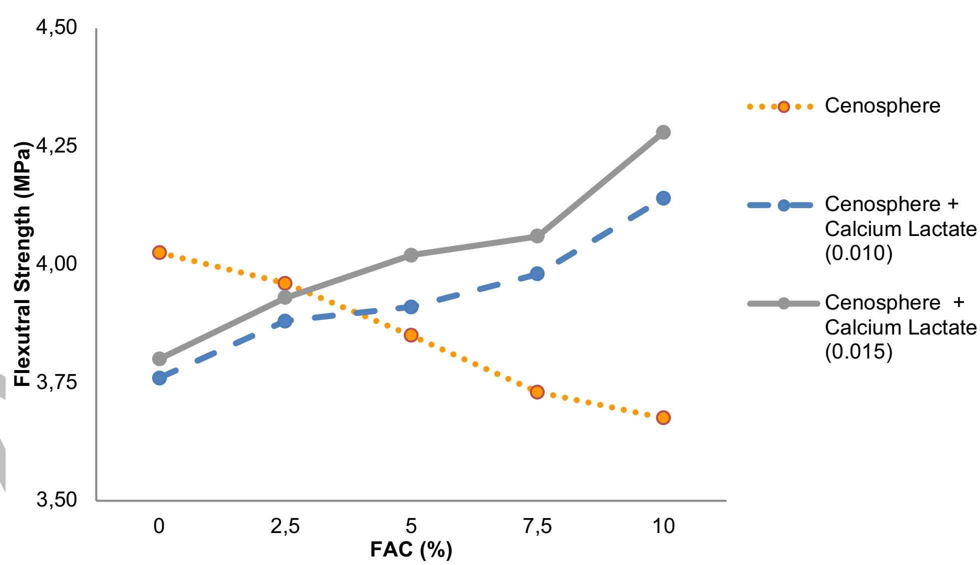
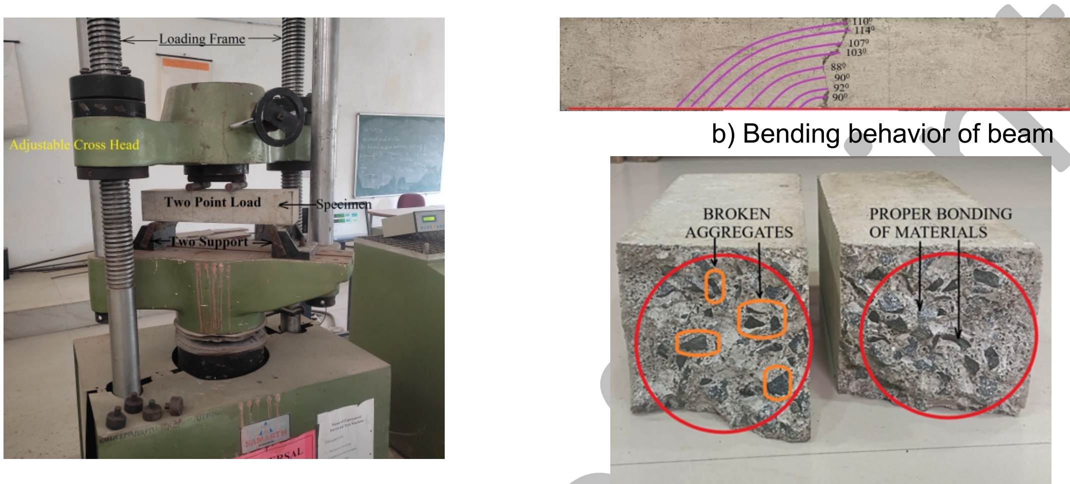


Fig. 8 Flexutral strength (MPa) Vs FAC (%)

The 28 days flexural strength of normal concrete reaches up to 4.03 N/mm2, when FAC 10 % is added in replacement with cement it shows 3.68 N/mm2 which is a 8.70% reduction in strength, this might happened due to its shape, hollow nature, and its chemical compositions. When calcium lactate is added to the mix it shows 4.14 N/mm2 and 4.28 N/mm2 which is a 2.86% and 6.34% increase in strength.

Failure pattern

The beam specimen was placed in the loading frame of the universal testing machine, the arrangement of the loading frame make like; the beam specimen rest on two supports, and a two-point load was applied from the top. Due to the application of gradually applied load the sample beam specimen break from the central portion of the beam. The break sample was taken away from the loading frame and the failure pattern of the beam was observed carefully as shown in Fig. 9. The matrix of the broken sample shows a uniform and well mix of all ingredients with each other. The aggregate failure was observed in the concrete section; this shows proper bonding of aggregate with other materials.



a) Experimental Setup

b) Bending behavior of beam

c) Internal material behavior

Fig. 9 Failure pattern of flexural member

5.4 Split tensile strength

Split tensile strength gives tensile stress resistance capacity of the material, due to application of load tensile cracking get started in concrete which affects the performance of concrete. FAC is versatile material due to its chemical compositions; the combination of FAC with other minerals may show changes in its mechanical properties. To determine the tensile strength of concrete, the samples were prepared with different combinations of FAC and Calcium lactate. The tensile strength of concrete was ascertained using a Universal testing machine with a 250KN capability. The cylindrical sample of 150mm in diameter and 300mm in length were used in the test. The testing sample was prepared with FAC 10%, Calcium lactate at 0.01 mol/lit and 0.015 mol/lit. After 28 days of curing the sample were tested as per the guideline of IS 5816. For all the mixes and for each property under consideration, three samples were examined, and the average of these was given for the associated test.

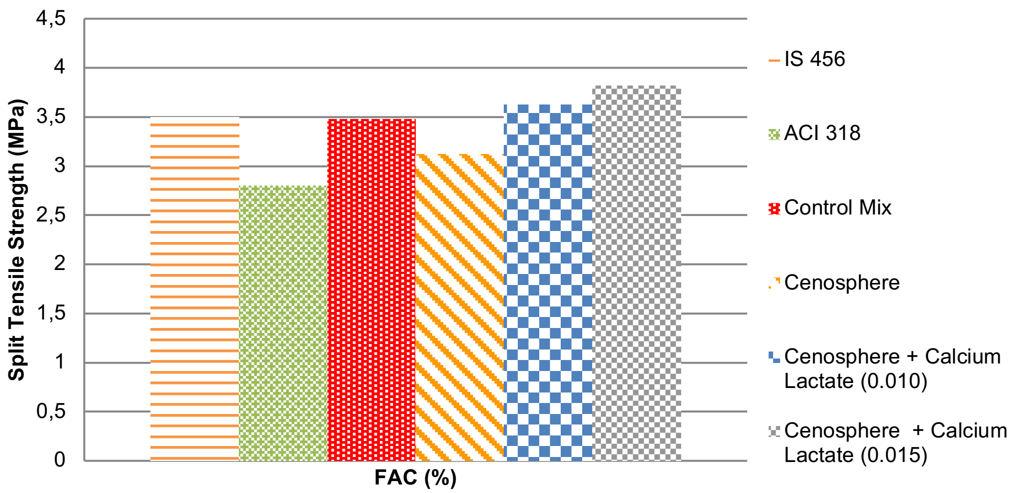
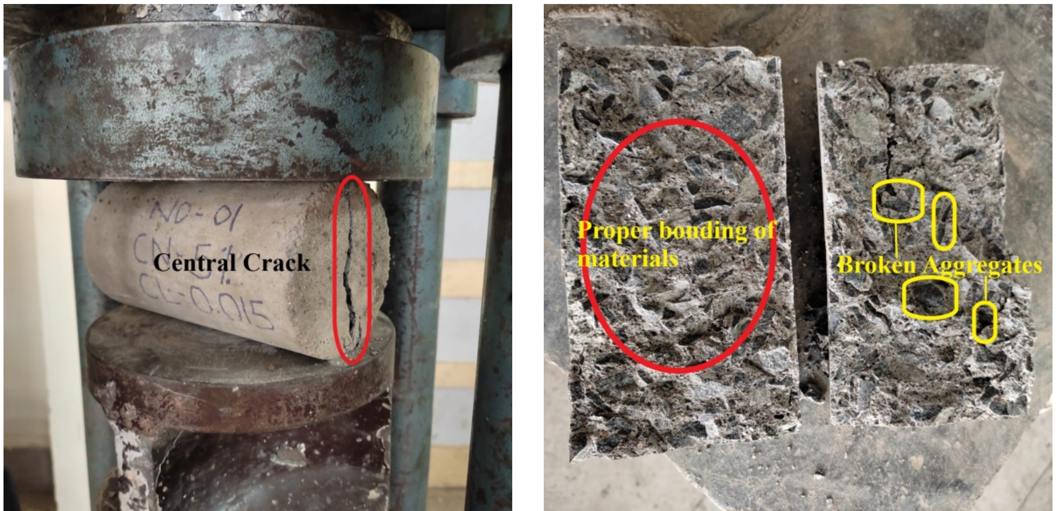


Fig. 10 Split Tensile Strength (MPa) Vs Materials and Codes for replacement of cement by Cenosphere (10%)

FAC with 10% replacement to cement gives less tensile strength than the result expected from IS code, whereas the addition of calcium lactate of 0.10 mg/lit in the mix increases, the tensile strength of 3.43% above IS code and 4.02% above control mix, similarly, the addition of calcium lactate of 0.15 mg/lit in the mix increases the tensile strength of 9.14% above IS code and 9.77% above control mix. The obtained result present in Fig. 10. FAC with 10% lowers the concrete's tensile strength this is caused by the FAC particle's lower strength and increased void content, however after addition of calcium lactate tensile strength get increases this may happen due to effectively bond between FAC particles. Calcium lactate was found to be effective in bonding between FAC particles.

Failure pattern

A cylindrical specimen was placed in the universal testing machine, a specimen was placed in such a way that load shall be applied on the longitudinal portion of a cylinder. The Upper and lower plate of loading fame make clean before placing of sample underneath, the cylinder specimen was kept exactly in the center of the plate. Gradually load was applied to the specimen, applied load fails the specimen and divide into two parts exactly from the center half of the specimen as shown in Fig. 11. The casted cylinder shows a uniform mix of all ingredients present in the mix. Fine and coarse aggregate make proper bonding with other materials in the matrix; it is also reflected in broken aggregate surfaces.



a) Crack Pattern on cylinder b) Internal material behavior

Fig. 11 Failure pattern of tension member

6 Conclusion

Cenosphere is waste material increasing its own volume day by day and simultaneously creating problems for the environment. The cenosphere has an advantageous physical property of being light in weight which makes economical and sustainable concrete for the construction industry. The main focus is given on studying the behavior of the cenosphere with other construction materials, its application, and its limitations. Chemical study of cenosphere shows absence of calcium mineral in its composition this affect mechanical property of concrete. The observation of experimentation, results, and discussion gives following conclusion;

1. The findings indicate that using cenosphere in place of cement results in a reduction in the weight and density of concrete, making it economical and sustainable.
2. Fly ash cenosphere adds incrementally (2.5, 5, 7.5 & 10%) replacing cement into the mix, showing a linear strength reduction due to the absence of calcium in cenosphere concrete.

3. Strength may be enhanced at specific percentages due to the cenosphere's involvement in pozzolanic processes and its extremely fine particles. Concrete strength increases little (1.51%) at FAC 2.5 percent.

4. FAC 10% replacement of cement shows a 4.62% reduction in density, simultaneously when calcium lactate of 0.010 mol/lit and 0.015 mol/lit is added to the mix it shows a 4.69% and 4.80% reduction in density after 28-days.

5. FAC 10% replacement of cement shows a 6.61% decrease in compressive strength, after addition of calcium lactate with 0.010 mol/lit & 0.015 mol/lit shows 4.09% & 8.40% higher compressive strength than normal concrete.

6. Flexural strength of typical concrete at 28 days is up to 4.03 N/mm2, when FAC 10 % added in replacement with cement it shows 8.70% reduction in strength, after addition of calcium lactate in the mix it shows 2.86% and 6.34% increase in strength.

7. FAC with 10% replacement to cement gives 10.34 % less tensile strength than the result expected from normal concrete, whereas the addition of calcium lactate gives a 4.02% and 9.77% increase in tensile strength.

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