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Experimental Investigation of Lightweight Wall Panel Using Cenosphere Incorporated with Ground Granulated Blast Furnace Slag

V. Raguraman [a,*], S. Deepasree [a]

[a] Department of Civil Engineering, Sri Shakthi Institute of Engineering and Technology, Coimbatore-641062, Tamil Nadu, India.

* Corresponding Author: vraguramancivil@siet.ac.in

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Abstract: The secondary form of waste is the major outcome of the various industries. Likewise, Cenosphere and Ground Granulateds Blast Furnace Slag (GGBS) are the waste material obtained from thermal power plants and the steel industry. This waste requires a large land area for disposal. In such cases, these can be used in the construction field. This paper investigated the lightweight wall panel made with cenosphere and GGBS as a replacement for cementitious material. Cenosphere was replaced at 5%, 10%, 15%, 20%, 25% and 30% respectively by weight of cement and GGBS was at 15% constant replacement of cement. The properties of wall panels such as compressive strength, flexural strength, and water absorption have been studied. The flexural behavior was carried out by inhibition of fiber into the matrix. The samples were tested at 7, 14, and 28 days respectively. The SEM analysis of the cenosphere has been carried out. The results infer an increase in the percentage of cenosphere does not impart strength to the mix. Therefore, 15% of constant replacement of GGBS to the mass of cement stabilize the strength which was lost due to the addition of the cenosphere. On an overall view, it was recommended that the strength loss of mixture due to the addition of the cenosphere can be alleviated by GGBS and nevertheless a secure value of strength can be gained.

Keywords: Cenosphere, Ground Granulated Blast furnace slag, lightweight wall panel, mechanical properties, fiber, water absorption.

1. Introduction

Lightweight structures have made considerable attention in society as well as from researchers. The use of lightweight structures results in lower self-weight, reduced area of cross-section, and also economic conditions. A decrease in self-weight results in a smaller cross-section of the member. It helps in easy fabrication, transportation, installation in the case of precast structures and also reduces the cost. Generally, lightweight concrete is made by incorporating lightweight aggregates such as shale [1–3], clay [4] and expanded perlite [5–8], pumice. Lightweight fillers affect the strength parameter by associating some issues such as lower mechanical strength, brittle behavior, increased air voids, permeability, and emission of CO2. Lightweight structures offer durability to chemical and frost attacks and have a lesser permeability [9]. Lightweight structures provide high resistance to fire and improve thermal installation [10]. Expanded perlite is utilized as a filler material in creating a lightweight concrete with a compressive and flexural strength values in a range of 2.8-11.98 N/mm2 and 0.7-3.5 N/mm2 [6]. Expanded glass was also used as a filler material with a compressive strength of 28-30 N/mm2 [11]. Fly-ash cenosphere as a lightweight material in the construction field not only reduces the disposal of the waste but also enhances the hardened properties due to its similar range of chemical composition [12,13] used Polyethylene terephthalate (PET) as a lightweight aggregate which results in reduced volumetric weight but hardened properties resemble the normal concrete. Generally, lightweight concrete is categorized under class II which renders the concrete with a lower weight. [14] used recycled plastic aggregate as a filler material results in a reduction of chloride penetration up to 13%. Compressive strength was also reduced and suggested non-structural buildings. The lightweight fillers for lightweight structures depends on the availability, storage and composition of material. Masonry walls are commonly used in construction field with quiet deficiencies when subjected to uncertain loadings [15-17] improved the masonry wall without a steel reinforcement. The reinforced walls having a higher self-weight compared to unreinforced. [18–21] used ferro cement wall panel which results in crack resistance, improved mechanical strength, ductility, and energy absorption. [22,23] used expanded polystyrene beads as a filler in making a sandwich panel which reduced the compressive and flexural strength due to the increased percentage of expanded polystyrene. Cenosphere is a hollow spherical particle obtained from coal-burning power plants. Nearly 700 million tons of ash were produced from thermal power plants in China in 2015, which is double the time greater production than in 2005 [24]. Cenosphere is a residual waste, where the size is relatively greater than fly-ash of size (10-400 μm) [25]. In the present scenario, lightweight panels are extensively used in the structural field. Cenosphere is obtained from fly-ash, where its concentration varies from 0.02 to 4.90 by a percentage of weight. But, mostly it limits between 0.3 to 1.5 by a percentage of weight [26–28]. The cenosphere is a by-product of fly ash that comes under class F fly ash. The cenosphere is spherical in shape and grey in color. [29] stated that nearly 70% of the cenosphere has a size of range 45 to 150 μm. The spherical shape has classified into two types such as single ring-like structure and network-like structure. A higher percentage of the cenosphere comes under a single structure. The pH of the cenosphere is neutral in solution. The thermal conductivity of the cenosphere is lower compared to cement. The fly-ash cenosphere is spherical particles with a smooth textured surface [30]. The size of the cenosphere (i.e) size in microns depends on the grade of the cenosphere. The sizes such as 1-100 µm [30], 1-300 µm [31], 1-400 µm [32–34], 1-600 µm [35]. [35] stated that a high percentage of the cenosphere has a size range of 20 to 300µm. As the grade decreases, the fineness of the material increases. The density of the cenosphere is around 300-800 kg/m3. [36] used

cenosphere as an aggregate in making lightweight concrete. Cenosphere is used as a filler material in the construction field. Using a cenosphere, a lightweight concrete achieved a strength of 60 MPa [8]. [7] reported that finer particles enhance durability properties. The autogenous shrinkage can also be eliminated, by promoting the durability properties of concrete [37–39]. Ground Granulated Blast furnace slag (GGBS) also enhances the properties of cement. [40] GGBS can be used as an alternative to ordinary Portland cement. The properties of GGBS highly enhancing the corrosion resistance [40–43] and durability [44–46]. The particles of GGBS are finely in nature which inhibits the bond [47–51] and controls the permeability in concrete [52–55] studied the performance of RC beam using GGBS. When GGBS was added up to 40% of replacement to cement, there is slight decrease in compressive strength with time. Alternatively, there is a contrast in the strength development when GGBS added below 30%. Also, it controls the steel reinforcement from corrosion [56–59] higher the percentage of GGBS, higher the tensile strength. The outcome of this study reduces the consumption of cementitious material thereby contribution of CO_2 emission can be reduced. Lightweight structures are made by using secondary waste which meet the strength parameter similar to that of conventional. This study is the first attempt in making a lightweight wall panel using a secondary form of waste such as cenosphere and Ground Granulated Blast furnace slag.

Experimental Details

Materials used

The materials used in this study are cement, cenosphere, and GGBS.

Cement

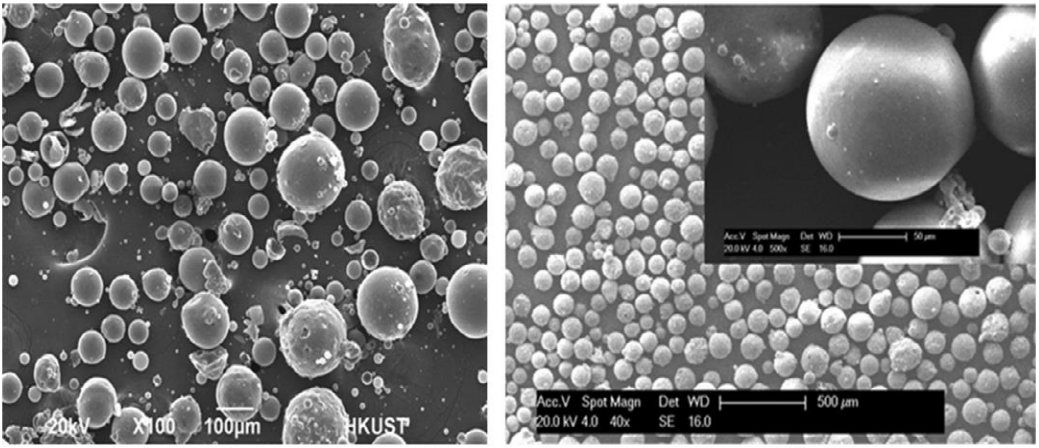
The ordinary Portland cement (OPC) is used conforming to the code IS 1226-1987. It is commonly made of limestone, shells, clay, and silica sand. The properties of OPC are tabulated in table 1.

Cenosphere

Cenosphere is obtained from fly-ash as a by-product. It is a hollow, inert material comprised largely of silica and alumina. It has been used as a filler material in lightweight construction. The SEM images of the cenosphere have been shown in figure 1. The porous structure in a cementitious material when added with the cenosphere can be viewed. The porosity occurs at 43%, whereas 70% of cenosphere in weight fraction with a water-binder ratio of 0.70 [33].

Table 1 Properties of Cement, Cenosphere and GGBS

SI.no.	Constituent	Cement	Cenosphere	GGBS
1	SiO_2	21.06	69 – 72	34.90
2	Al_2O_3	5.15	25 – 28	14
3	K_2O	0.42	1.2 – 3.2	-
4	Fe_2O_3	2.8	1 – 2	0.60
5	TiO_2	0.18	0.8 – 1.3	-
6	MgO	1.46	1 – 2.5	6.00
7	Na_2O	0.32	0.2 – 0.6	0.46
8	Cao	64.17	0.1 – 0.5	39.80



(a) (b)

Figure.1 SEM images of cenosphere: (a) 100 µm [32,60]; (b) 500 µm [68]

This is due to the fact that spherical particle of the cenosphere leaves more air voids and also possess a lower iso-static strength. The pozzolanic reaction takes place in the cementitious material where the particles consume themselves thereby increasing the calcium-silicate-hydrate gel. The reaction of the cenosphere in a cementitious material composite is the reason for enhancing the greater strength with reduced unit weight. The interfacial property between the cenosphere and the cementitious matrix can be seen with the crack growth in figure 2(b). The shell of the cenosphere is not cracked, alternatively, it passes through the weaker zone of the particle. This infers that the cenosphere has a better bond with the cementitious material. Cenosphere has predominantly silica and alumina content (i.e) 45 to 80% of total ash is silicious and aluminous material [60]. Therefore, the cenosphere is also knowns as alumino-silicate [31,61–65]. The cenosphere depends on Fe_2O_3. Therefore, the lesser the Fe_2O_3 higher will be the cenosphere [61]. [66] discuss the phase minerals in the cenosphere. The minerals such as rutile, quartz, calcite, mullite, alumino-silicate. But quartz and mullite are the high percentages of minerals present in the cenosphere [31,62]. The cenosphere has roughly comparable properties of fly-ash since it is a by-product of fly-ash obtained from coal consumption [12]. The presence of silica results in high strength whereas alumina for quick setting property and also lowers the clinker temperature [67]. The chemical composition of the cenosphere has been tabulated in table 1.

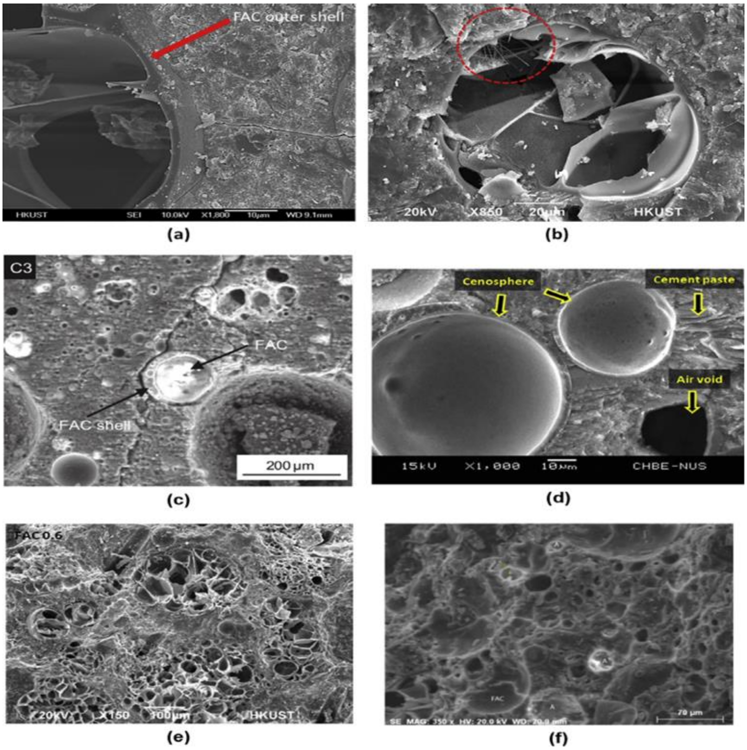


Figure. 2 SEM images of cenosphere : (a) [32] (b) [32] (c) [35] (d) [32,69] (e) [32] (f) [33]

Ground Granulated Blast furnace slag

Ground Granulated Blast furnace slag (GGBS) is a secondary form of waste obtained from the steel industry. It is a cementitious material and rich in calcium silicate hydrate. It advances the strength, durability, and appearance of concrete. The properties of GGBS are tabulated in table 1.

Mix proportioning

A total of 7 samples were made including the control mix. A mix consist of cement, cenosphere and GGBS with different proportions of cenosphere such as 5%, 10%, 15%, 20%, 25%, 30% respectively with constant 15% of GGBS. Table 2 shows the mixed proportioning of mortar. A mortar cube of size 70.6 × 70.6 × 70.6 mm^3 and a panel of size 459.13 × 304.79 × 76.2 mm^3 was cast and cured under room temperature.

Table 2 Mix proportion of mortar at 15% constant replacement of GGBS to a mass of cement

Mix	% of cenosphere	Cement(gm)	Cenosphere (gm)	Sand (gm)
M1	0	1010	-	3255
M2	5	838.3	50.5	3255
M3	10	787.8	101	3255
M4	15	737.3	151.5	3255
M5	20	686.8	202	3255
M6	25	636.3	252.5	3255
M7	30	583.8	303	3255

Results and Discussion

Compressive Strength of Mortar by Using Cenosphere

The cenosphere having a low density with high compressive strength compared to normal concrete. Contradictory, [68] concluded that the addition of the cenosphere may decrease the strength so that it can be stabilized by the addition of silica fume. The property of nano-silica is to improve the interfacial transition zone in concrete, thereby obtaining an early-age strength and attains a high compressive strength [69-72] stated that a slight decrease in strength of the mortar even at low density and low thermal conductivity of the cenosphere. 65] stated that strength loss in mortar can be strengthened by improving the interfacial property by using the cenosphere. The compressive strength of mortar cube specimen of size 70.6 × 70.6 × 70.6 mm3 has been taken and tested at 7 days, 14 days, and 28 days respectively as shown in figure 3.

(A) (B)

Figure 3. Mortar cubes

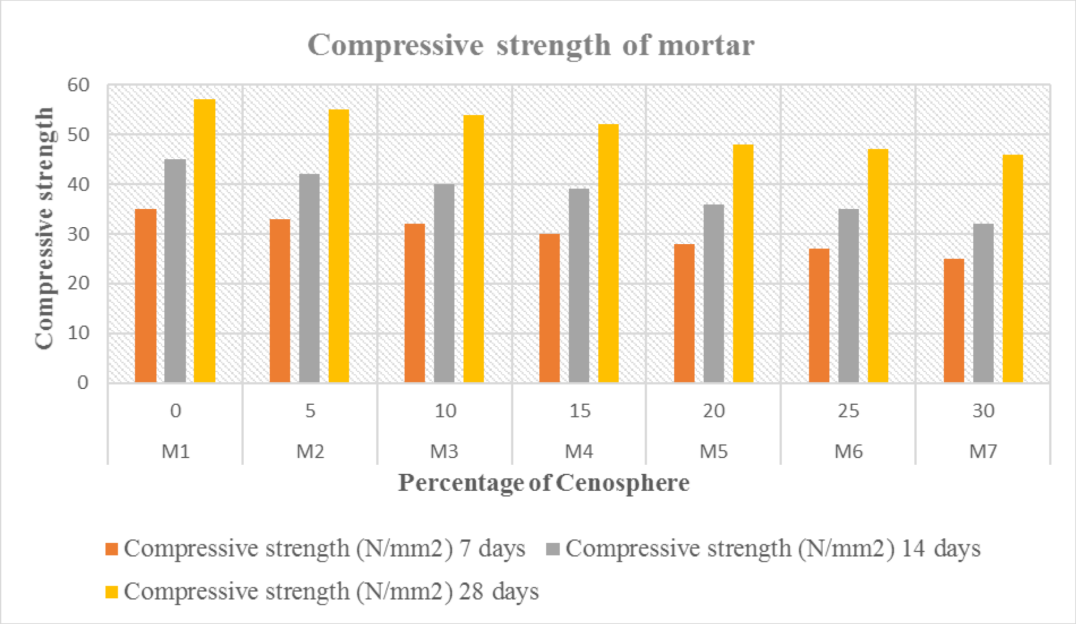


Figure 4. Compressive strength of mortar

Table 3. Compressive strength of mortar by using Cenosphere

SI.no	Mix	% of Cenosphere	Area (mm^2)	Compressive strength (N/mm^2)		
				7 days	14 days	28 days
1	M1	0	4984.36	35	45	57
2	M2	5	4984.36	33	42	55
3	M3	10	4984.36	32	40	54
4	M4	15	4984.36	30	39	52
5	M5	20	4984.36	28	36	48
6	M6	25	4984.36	27	35	47
7	M7	30	4984.36	25	32	46

The cenosphere has been replaced as cementitious material at 5%, 10%, 15%, 20%, 25%, and 30% respectively by the weight of cement. The test results are discussed in table 3 and figure 4. The test outcome at 7days strength indicates that the strength of mixture M1, M2, M3, M4, M5, M6, and M7 decreases by 5.69%, 8.6%, 14.12%, 19.9%, 21.86and 27.5% in contrast with M1. The test outcome at 14days strength indicates that the strength of mixture M1, M2, M3, M4, M5, M6 and M7 decreases by 6.7%, 11.1%, 13.3%, 19.2%, 21.15%, and 28.9% in contrast with M1. The test outcomes at 28days strength indicates that the strength of mix M1, M2, M3, M4, M5, M6 and M7 decreases by 3.5%, 5.3%, 8.8%, 15.85%, 17.5%, and 19.8% in contrast with M1. From the outcomes, it infers that addition of cenosphere decreases the compressive strength of mortar.

Compressive Strength of Mortar At 15% Constant Replacement of GGBS

The compressive strength of mortar cubes has been tested as shown in figure 3.3 at 7 days, 14 days, and 28 days respectively. The cenosphere has been replaced as cementitious material at 5%, 10%, 15%, 20%, 25%, and 30% respectively by weight of cement in addition to 15% constant replacement of GGBS. The test outcomes are discussed in table 4 and figure 6. The test results at 7days strength show that the strength of mixture M1, M2, M3, M4, M5, M6, and M7 increases by 2.85%, 11.42%, 14.28%, 20%, 28.57%, and 31.42% in contrast with M1.

(A) (B)

Figure 5. UTM machine under loading

Table 4 Compressive strength of mortar at constant 15% replacement of GGBS with Cenosphere

SI.no	Mix	% of Cenosphere	Area (mm2)	Compressive strength (N/mm^2)		
				7 days	14 days	28 days
1	M1	0	4984.36	35	45	57
2	M2	5	4984.36	48	46	59
3	M3	10	4984.36	39	48	59
4	M4	15	4984.36	40	51	61
5	M5	20	4984.36	42	53	62
6	M6	25	4984.36	45	54	63
7	M7	30	4984.36	46	56	65

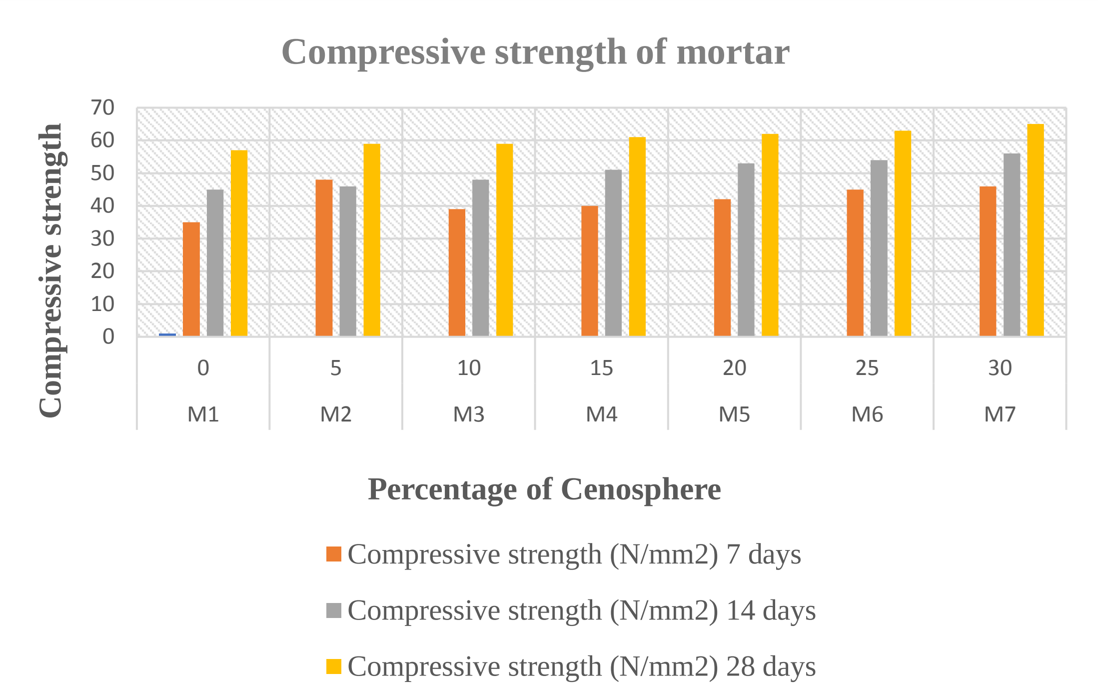


Figure 6. Compressive strength of mortar (15% of GGBS)

The test results at 14days strength show that the strength of mixture M1, M2, M3, M4, M5, M6, and M7 increases by 2.22%, 6.66%, 13.33%, 17.77%, 20%, and 26.66% in contrast with M1. The test results at 28days strength show that the strength of mixture M1, M2, M3, M4, M5, M6, and M7 increases by 1.75%, 3.5%, 7.01%, 8.77%, 10.52%, and 14.03% in contrast with M1. From the test results, it infers that as discussed in table 3, the replacement of cement by cenosphere without adding any other admixture weakens the mortar. To overcome such effects, constant replacement of GGBS at 15% improves and stabilizes the strength of mortar.

Flexural Strength of Mortar

Generally, lightweight structures are brittle. Cenosphere has been incorporated into cementitious material with fiber such as polyethylene fiber [73], steel fiber [74], and polypropylene fiber. In this study, fiberglass mesh has been used. The flexural behavior of mortar was tested at 7 days, 14 days, and 28 days respectively. The cenosphere has been replaced at various percentages such as 5%, 10%, 15%, 20%, 25%, and 30% respectively by the weight of cement. The test results are discussed in table 5 and figure 7. The test outcomes at 7 days strength indicate that the strength of mixture M1, M2, M3, M4, M5, M6, and M7 increases by 17.24%, 20.68%, 31.03%, 34.48%, 34.48%, and 34.48% in contrast with M1. The test outcomes at 14days strength indicate that the strength of mixture M1, M2, M3, M4, M5,M6, and M7 increases by 9.75%, 17.07%, 26.82%, 34.14%, 36.58%, and 36.58% in contrast with M1.

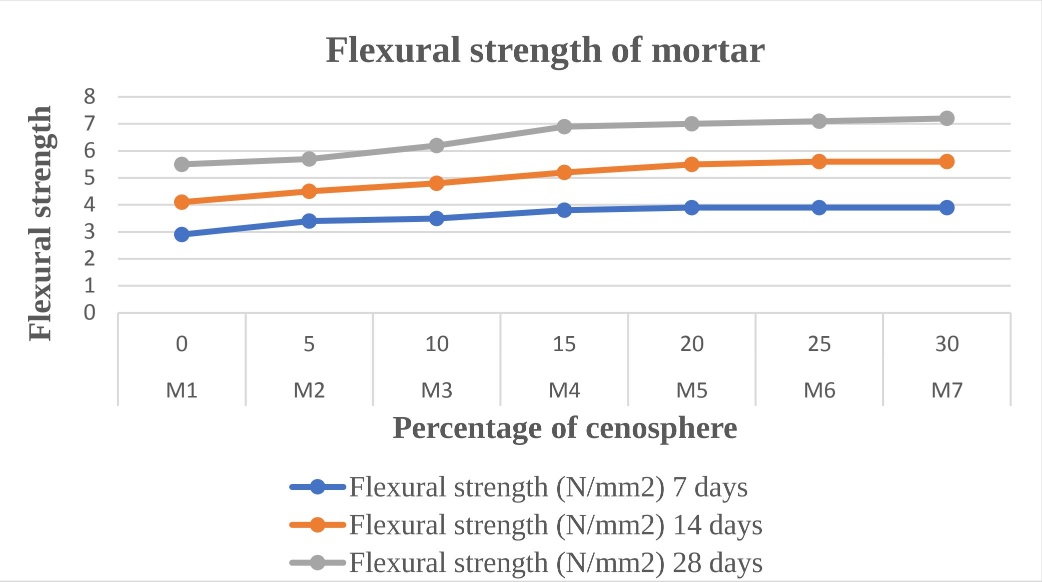


Figure 7. Flexural strength of mortar

Table 5. Flexural strength of mortar

SI.no	Mix	% of Cenosphere	Flexural strength (N/mm^2)		
			7 days	14 days	28 days
1	M1	0	2.9	4.1	5.5
2	M2	5	3.4	4.5	5.7
3	M3	10	3.5	4.8	6.2
4	M4	15	3.8	5.2	6.9
5	M5	20	3.9	5.5	7
6	M6	25	3.9	5.6	7.1
7	M7	30	3.9	5.6	7.2

The test outcomes at 28days strength indicate that the strength of mixture M1, M2, M3, M4, M5, M6, and M7 increases by 3.63%, 12.72%, 25.45%, 27.27%, 29.09%, and 30.9% in contrast with M1. From the test outcomes, it infers that mortar is good in compression however vulnerable to tension. Therefore, inhibition of fiber into the matrix improves flexural strength.

Water Absorption of panel

Water absorption of the panel has been tested and the values are discussed in table 6. The water absorption was found to be 1.65% which is categorized under vitrified. The vitrified is the one that is resistant to water and provides high durability.

$$\text{Water absorption} = \frac{M2-M1}{M1} \times 100$$

$$= \frac{4900-4820}{4820} \times 100$$

$$= 1.65\%$$

Table 6. Water absorption of panel

SI.no	M1	M2	Water absorption %
1	4820	4900	1.65

Wall panel

The wall panel of size 459.13 × 304.79 × 76.2 mm^3 has been made. The wall panel has been tested against the mechanical properties. The mold of the sample has shown in figure 8. Figure 9 shows the prototype of the wall panel.

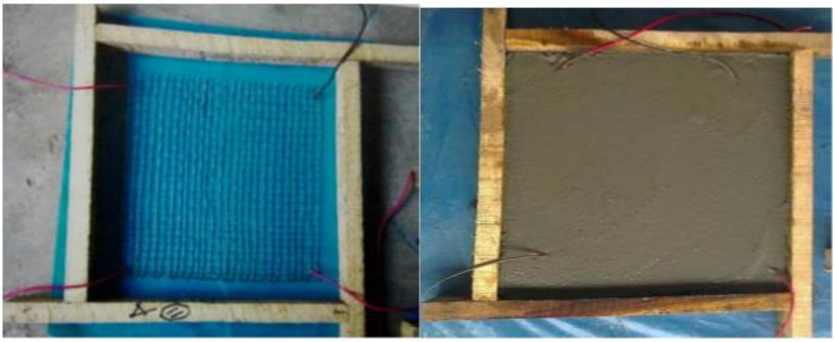


Figure 8. Preparation of sample

Figure 9. wall panel

Conclusion

This study has been carried out with the mortar cubes which can be produced with a blend of cenosphere and GGBS as a replacement for cement. The material properties have been analyzed. Cenosphere is a by-product of fly-ash which resembles the properties of fly-ash material. It has a hollow spherical particle. Generally, spherical particles aid strength to the mortar or concrete. In this research, the mechanical properties of the mortar have been tested. From the test results, the following conclusions are made

1. The cenosphere was replaced with cement. The compressive strength infers that an increase in the percentage of cenosphere decreases the strength compared to the conventional mix.
2. To stabilize the strength loss caused by the cenosphere and also to improve the strength, a constant 12% replacement of GGBS has to be made.
3. The cenosphere and GGBS were replaced to cement up to 30% and 12% respectively. According to a strength basis, the cenosphere improves the strength up to 30% of replacement. Beyond 30% of the cenosphere, decreases the strength.
4. Therefore, it is suggested to replace the cenosphere as a cementitious material up to 30% to the mass of cement.
5. Generally, the concrete is strong in compression however vulnerable in tension. To improve the tensile property, the fiber is placed in the mix to improve the flexural strength.
6. The water absorption test has been taken and the specimen was categorized under vitrified. Therefore, it possesses high durability and water resistance.
7. The test on mortar cubes discovered that strength loss of cement occurs due to the replacement of the cenosphere. However, the loss of strength can be stabilized by adding GGBS.

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