FLEXURAL BEHAVIOUR OF RCC BEAMS PARTIALLY RELACED WITH CENOSPHERE AND SILICAFUME

Anukarthika B[1], Sivagama Sundari R[2], Christian Johnson S[3], Kumaran G[4] , Manikumari N[5]

[1]Research Scholar, Department of Civil and Structural Engineering, Annamalai University, Tamilnadu, India.
[2]Department of Civil and Structural Engineering, Annamalai University, Tamilnadu, India.
[3]Department of Civil Engineering, Erode Sengunthar Engineering College, State, Tamilnadu, India.
[4]Department of Civil and Structural Engineering, Annamalai University, Tamilnadu, India.
[5]Department of Civil Engineering, Annamalai University, Tamilnadu, India.

ABSTRACT

The extensive use of cement raises carbon dioxide (CO_2) emissions, which contributes to the greenhouse effect. Therefore, utilizing various cementitious materials as alternate to cement is recommended by researchers as an option to reduce emissions of carbon dioxide. This study investigates the impact of partially replaced concrete with cenosphere and silica fume on mechanical properties and flexural characteristics using a comprehensive experimental and numerical approach. After experimenting with different cenosphere and silica fume ratios, the ideal mix proportion was determined based on the compressive strength and the workability of fresh concrete. Substituting 4% cenosphere and 4% silica fume into concrete yields good results. Beams measuring 3200 mm x 150 mm x 250 mm had been cast and allowed to cure over 28 days with the ideal mix proportion. The behaviour of the beams was evaluated, and the results were discussed.

Keywords: Cenosphere, Flexural Behaviour, Greenhouse effect, Silicafume, Mechanical properties

1. INTRODUCTION:

Infrastructure is becoming more and more necessary as the population grows. As a result, massive cement manufacture is needed, which is bad for the environment. At the same time, a significant amount of waste products like fly ash, silica fume, metakaolin, etc., is in danger of being released into the air or disposed of in the ground, all of which are detrimental to the environment and human health. In order to accommodate both worst-case scenarios, these waste materials are now combined with cement to replace a suitable volume of cement. A spherical shape cenosphere develops the flow ability to distribute the composite matrix filler material uniformly. Compared to the other materials classified as fillers, they are 75% lighter.

It is applicable to both wet and dry slurry systems. Thermoplastics, latex, polyesters, plastisols, epoxies, phenolic resins, and urethanes can all be used with these hollow spheres. Their mechanical qualities are also better. As an alternate material, silica fume (SF), calcined kaolin, made by calcination can be used in its place. Because SF is an end product of the kaolin mineral, that has extensive, known reserves in India, it can be manufactured in large quantities there. SF is currently three to four times more expensive on the national market than cement. This study aims to evaluate the functionality of Silica Fume and Cenosphere as a partial replacement for cement in concrete. The primary attribute researched in this study is the behavior of beams constructed using M20 and M40 concrete mixes with partially replaced by cenosphere and silica fume added at different percentages by the quantity of cement. The article presents an intensive experimental investigation of concrete's compressive strength and flexural behavior partially replaced by cenosphere and silica fume.

2. LITERATURE REVIEW

Extensive research has been conducted on the benefits of using pozzolanic materials to create and improve concrete properties. A few questions about the mechanical and physical characteristics of metal and polymer composites enhanced by fly ash cenosphere were noted.

According to Chandrasekhar and Urmila Devi (2023), the concrete that was reformed with 20% silica fume and 4% cenosphere increased the compressive strength by 5% over the course of 28 days for M30 grade concrete when compared to ordinary concrete. The combination has a compressive strength of 38.43 N/mm^2. Concrete's low early age compressive strength is improved by the addition of silica fume and cenosphere. When Sampathkumaran P *et al.,* worked on fly ash cenosphere reinforced polymer composites, they discovered that the HDPE (high-density polyethylene) and LDPE (low-density polyethylene) polymer composites had better mechanical and physical qualities.

According to research done by Divya VC et al., composites containing “high density polyethylene”, “cenosphere”, and “multi-wall carbon nanotubes (MWCNT)” demonstrated superior mechanical qualities compared to composites lacking cenosphere and MWCNT. It has been discovered that the composite with 0.5 weight percent of MWCNT has a greater impact strength and that the composite with 0.1 to 0.2 weight percent of MWCNT has good flexural and tensile properties. Uma Reddy (2024) used different amounts of silica fume (5, 10, and 15% by aggregate volume). A universal testing machine was used to cast, cure, and test the cubes and beams. The results demonstrated that adding up to 15% silica fume increased both the compressive and flexural strengths. The maximum strength at bending was 4.448 MPa at 7 days and 6.72 MPa at 28 days. Toutanji et al. investigated the influence of silica fume on the compressive strength of mortars at various water-to-cement ratios. Their findings revealed that substituting silica fume for some of the cement improved the interaction between the cement paste and the aggregate, increasing the mortar's compressive strength. When preparing concrete, Hanumesh et al. substituted silica fume for 5%, 10%, 15%, and 20% of the cement. They discovered that the concrete's compressive strength peaked at 10% replacement and tended to decline at higher percentages. The ideal splitting tensile strength for 28-day cured concrete was achieved at replacement levels ranging from 5-10%, with no significant increase in strength after replacing more than 15%. According to Bhanja et al., who investigated the impact of SF by substituting 5%, 10%, 15%, 20%, and 25% instead cement on tensile strength of concrete. Fly ash is also substituted with solid waste silica fume in addition to cement. The workability was reduced and the various properties of the cured concrete were markedly boosted as fly ash was incorporated with silica fume according to Memon et al. Das et al. discovered that the geopolymeric concrete exhibited the densest microstructure and the maximum compressive strength at 2% silica fume content. In the authors' previous study, the microstructure was densest and its durability was the highest when silica fume was used in place of 50% of fly ash. Dilip Kumar Singha Roy and Amitava Sil attempted investigating the strength characteristics of concrete made with the partial substitution of cement with SF. The study found that replacing 10% of cement using silica fume results in higher compressive strength (19.6% and 16.82%) for cube and cylinder, as well as increased split tensile and flexural strength (38.58% and 21.13%) for SF concrete.

3. MATERIALS (CURRENT STUDY)

This study involves the materials such as cement (OPC), Cenosphere (Ce), Silicafume (SF), Coarse aggregate, Fine aggregate to produce test samples.Fig.1 shows details about the materials utilized in the current study.

Cenosphere

Silica Fume

Cement

Coarse Aggregate **M-Sand**

Fig.1. Materials involved in the present study

This study used OPC 53 grade, which conforms to “IS 8112:1989”. River sand ranging in size from 4.75 mm to 150 microns and passed through a 4.75mm IS sieve is used as fine aggregate as per IS 383:1970. The coarse aggregate of 20mm and down were considered Cenosphere is derived from Mettur coal power plants in the form of hollow spherical particles. Micro silica is a highly effective pozzolanic material particle due to its extreme fineness and silica content. The addition of silica fume also reduces the permeability of concrete to chloride ions, protecting the concrete's reinforcing steel from corrosion, particularly in chloride-rich environments such as coastal regions.

4. MIX DESIGN

According to IS 10262-2009, the mix proportion has been designed. As per the requirement and the limitations, the percentage dosage of super plasticizer is added up. The mix proportion was determined through several trial mixes. In this experimental study, concrete grades of M20 and M40 have been used and Table 1. presents the properties of materials.

Table 1. Properties of Materials

S.No	Materials	Properties	
		Specific gravity	Fineness modulus
1	**Cement**	3.5	-
2	**Cenosphere**	2.4	-
3	**Silica fume**	2.2	-
4	**Coarse Agg**	2.8	7.08
5	**Fine Agg**	2.6	2.56

According to the design, the dry form of cement, cenosphere and silica fume were calculated in correct proportions (Table 2) and mixed for 2 minutes. After that, proportioned water is added and super plasticizer is then added to improve workability. Finally, the mixture was poured into a mould (Cubes, Cylinders) in three layers and tampered after laying each layer. The mould was removed and samples were water cured for twenty eight days.

Table 2. Mix Proportions of Conventional concrete

Materials	**M20**	**M40**
Cement(kg/m^3)	390	385
Fine Aggregate(kg/m^3)	714	835
Coarse Aggregate(kg/m^3)	1083	1090
Water(kg/m^3)	197	154
W/C	0.5	0.4
Superplasticiser(kg/m^3)	-	7

5. WORKABILITY AND COMPRESSIVE STRENGTH

Workability is an important property of a fresh concrete mix to arrive at the required strength properties. According to IS 1199:1959, on replacing cement partially with other materials the workability is to be checked. Thereby, the workability of concrete with various percentages of silica fume and cenosphere was tested prior to use, and the results are presented in Table 3. On adding up cenosphere, the workability gradually reduces and this may be due to the finer particles of both Cenosphere and Silica fume which causes a higher water consumption thereby reducing workability. Based on the compressive strength after 28 days, the optimal percentages of cenosphere and silica fume were secured. Fig.2 shows the variation of compressive strengths for different mix proportions.

Table 3. Experimental Obervations

Specimens	**Workability (slump, mm)**	**Comp Strength, N/mm^2**	**Specimens**	**Workability (slump, mm)**	**Comp Strength, N/mm^2**
M1C	102	**30.00**	**M2C**	90	**50.00**
M1Ce1%	102	30.20	M2Ce1%	90	52.00
M1Ce2%	101	30.50	M2Ce2%	90	53.20
M1Ce 3%	100	31.60	M2Ce 3%	88	54.60

M1Ce 4%	98	**33.00**	**M2Ce 4%**	85	**55.40**
M1Ce 5%	95	26.70	M2Ce 5%	85	53.60
M1Ce 6%	94	26.00	M2Ce 6%	84	52.00
M1Ce4%SF1%	94	33.60	M2Ce4%SF1%	84	55.40
M1Ce4%SF2%	94	34.00	M2Ce4%SF2%	84	56.20
M1Ce4%SF3%	94	34.80	M2Ce4%SF3%	84	58.60
M1Ce4%SF4%	94	**36.00**	**M2Ce4%SF4%**	84	**60.00**
M1Ce4%SF5%	90	33.00	M2Ce4%SF5%	80	58.40

Where M1 - M20; Ce - Cenoshere; SF- Silica Fume; M2 - M40

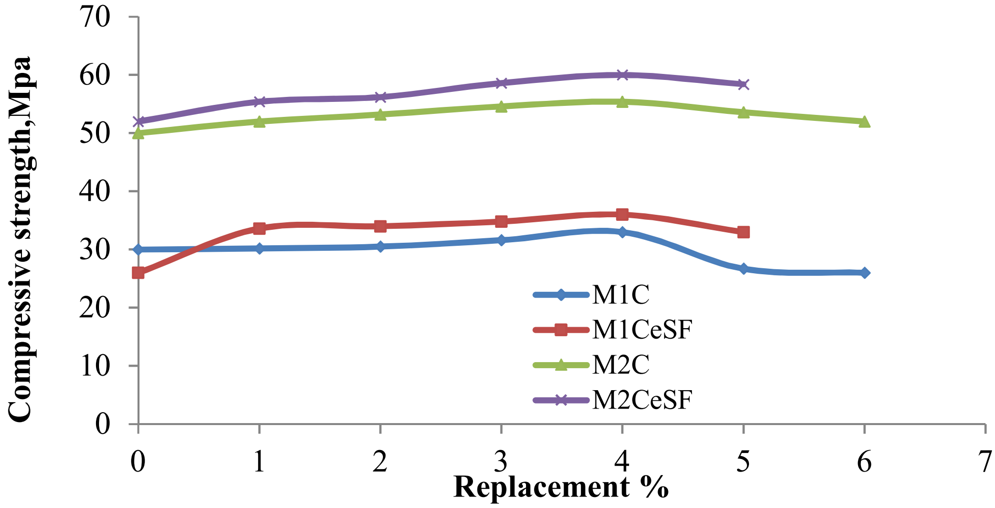

Fig. 2 Variation of compressive strengths for different mix proportions

On adding 1%, 2%, 3%, 4% of cenosphere, the compressive strength increases by 0.7%, 1.7%, 5.3% and 10% respectively. This clearly demonstrates that attainment of strength is owing to the pozzolanic influence of cenosphere. The pozzolanic capabilities of Cenospheres are because of the occurrence of nebulous silica in it which forms Calcium silicate hydrate with the calcium hydroxide generated from hydration mechanism. However, due to the glassy surface of cenospheres, it possess limited pozzolanic capability. On adding 5% and 6% of cenosphere the strength gets reduced by the intensification in the void content and permeability. Adding 1, 2, 3 and 4% of silica fume along with 4% cenosphere, increases concrete's compressive strength by 4, 6.4, 9.2, and 10.8%, respectively. The lesser addition of SF finds suitable and advantageous. SF beyond 4% reduces the slump value, and also the strength of concrete, due to a minimum quantity of calcium hydroxide. It has also, been demonstrated that the impact of SF and Cenosphere improves microstructure while decreasing free calcium hydroxide concentrations via a pozzolanic reaction.

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6. FLEXURAL INVESTIGATIONS

The experimental programme consisted of six reinforced concrete beams of size 3200 mm × 250 mm × 150 mm. The beams were reinforced with 8 mm diameter stirrups spaced at 200 mm c/c along the beam length, while 10 mm diameter bars were used as the main longitudinal reinforcement. A clear concrete cover of 20 mm was provided on all sides of the beams. Concrete mixing was carried out using a rotary mixer. The use of cenosphere as a partial replacement material in concrete has been reported to enhance mechanical performance, as observed by Prasad et al. (2025).

The beams were subjected to static loading and tested using a 50-tonne capacity loading frame. The support conditions were provided as hinge support at one end and roller support at the other end. Two-point loading was applied using spreader beams. To prevent local stress concentration, thick rubber/neoprene pads were placed beneath the spreader beams. Spirit levels were used to ensure proper alignment of the beam supports.

Static loads were applied gradually using a hydraulic jack of 250 kN capacity and monitored through proving rings or load cells. The load was applied in increments of 2 kN until failure, following the experimental methodology adopted by Prasad et al. (2025) for evaluating the mechanical behaviour of cenosphere-based concrete. Beam deflections and strains were measured using dial gauges, strain gauges, LVDTs, and Demec gauges. External electrical strain gauges were fixed at the top and bottom fibres of the beams. Dial gauges were positioned at the mid-span, one-third span locations, and at the supports for deflection and support correction measurements. Demec gauges were used to measure linear strains at the top, bottom, and centre fibres. For this purpose, brass pellets were pasted at known gauge lengths.

Vertical deflections were also monitored using LVDTs (0–100 mm range) placed at mid-span and one-third span points. All strain and displacement signals from the LVDTs and strain gauges were recorded using a data acquisition system, and the electrical signals were converted into strain values using appropriate software.Crack widths were periodically measured using a crack width microscope. Figure 3 shows the beam reinforcement details, and Figure 4 presents the experimental test setup.

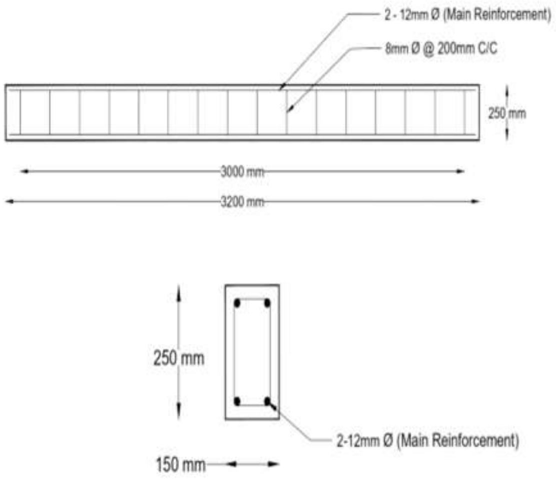

Fig.3 Beam Details

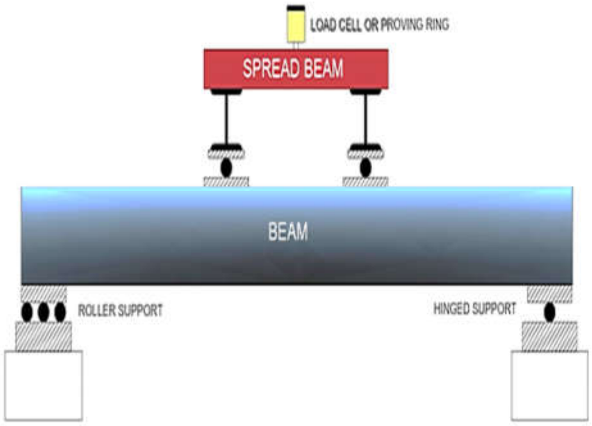

Fig.4 Experimental Test Setup

6. DISCUSSIONS OF RESULT

The parameters considered in this study contained First crack along with deflection, maximum load and deflection, crack width across different loading intervals. The calculated parameters are the first crack load and deflection, ultimate load and deflection, strain at the compression zone, and strain at the tension zone. Load: Deflection Behaviour Load-deflection curves have four regions of behavior. At initial load, concrete behaves linearly elastically. Bending stress increases due to the increasing load. Cracks in bending occurs early on in Static moment area. In the Tension zone, the Steel reinforcement carries most of the bending moment as soon as the Concrete starts cracking. All of the beams exhibited typical flexural failure. Table 4. shows the obtained parameters at different loading stages for control beams and partially replaced concrete beams.

Table 4. Beam Test Results

Beam Designation	First crack		Service state		Yield State		Ultimate state	
	P (kN)	δ(mm)	P (kN)	δ(mm)	P (kN)	δ(mm)	P (kN)	δ (mm)
M1C	12	2.14	25.47	11	29.72	13.5	45	20.8
M1Ce	13	2.15	25.6	10.4	29.83	13	46	20.3
M1CeSF	13.5	2.14	25.65	10	29.92	12.6	47.5	20
M2C	16	2.15	25.92	8	30.24	10.8	50	18.3
M2Ce	16.5	2.15	25.98	7.5	30.31	10.2	53.5	17.8

M2CeSF	17	2.15	26.04	7	30.38	9.6	54.2	17.3

All the beams are designed as under reinforced beams showing flexural type of failure. From the experimental results, it is observed that the M1ce,M1CeSf beams exhibit an increase of 8.3% and 12.5% for first crack load, 0.8% and 1%, for service load, for yield load 0.3% and 0.74%, for ultimate load 2.2% and 5.6% concerning Control beam(CC). The ultimate deflection rate seems to be that M1ce,M1CeSf beams exhibit a decrease of 2.4% and 3.8% concerning Control beam(CC).In the same way, M2Ce, M2CeSf beams exhibit an increase of 3.1% and 6.25% for first crack load, 0.23% and 0.46%, for service load, as well as yield load and 7% and 8.4%, for maximum load respectively than CC. The rate of ultimate deflection of M2Ce, M2CeSf beams exhibit a decrease of 2.7% and 5.5% concerning Control beam(CC). **Hence it has been observed that the cenosphere and Silica Fume has good pozzolanic nature.** Fig. 5 and 6 shows the Load versus deflection of M20 and M40 beams respectively.

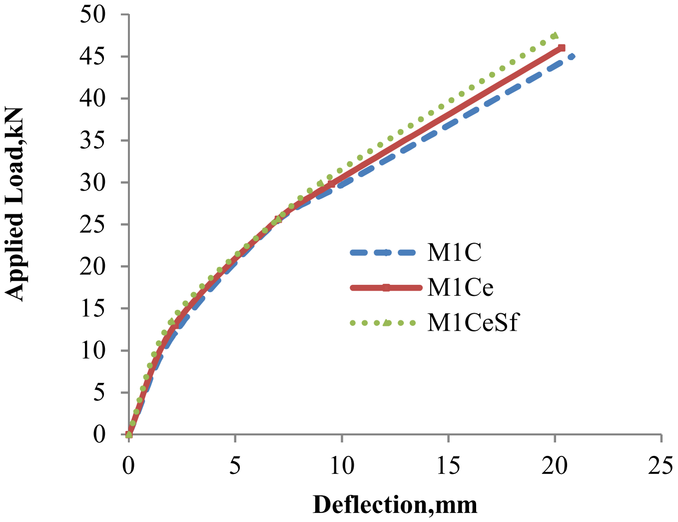

Fig.5 Load versus deflection of M20 grade beams

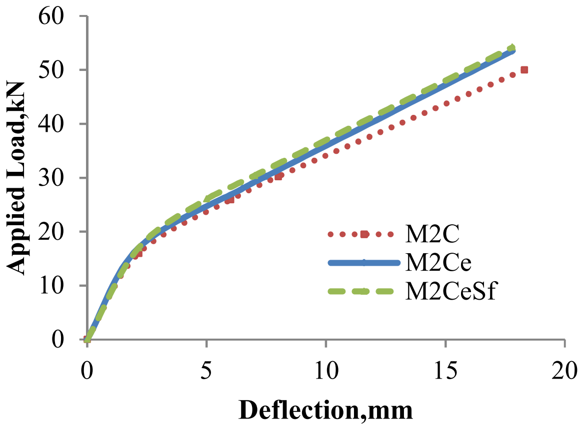

Fig.6 Load versus deflection of M40 grade beams

8. STRAIN DISTRIBUTION

Strain adjacent to the compression side of beams M1Ce and M1CeSf beams are 13.3% and 21% lesser than that of M1C. Strain adjacent to the tension side of M1Ce and M1CeSf beams are 5.3% and 14.3% lesser than that of M1C. Strain at the compression side of M2Ce and M2CeSf beams are 3% and 30% lesser than that of M2C. Strain adjacent to the tension side of M2Ce and M2CeSf beams are 10.7% and 45.5% lesser than that of M2C. Fig. 7 and 8 shows the strain plot of M20 and M40 beams. Table 5. Shows the Strain values of Tested beams.

Table 5 . Strain Values of tested beams

Sl. No	Beam designation	No.of flexural cracks	Ultimate Strain	
			Compression side (ε_{cu})	Tension side (ε_s)
1	**M1C**	13	0.0034	0.0040
2	**M1Ce**	12	0.0030	0.0038
3	**M1CeSF**	12	0.0028	0.0035
4	**M2C**	12	0.0030	0.0030
5	**M2Ce**	10	0.0028	0.0029
6	**M2CeSF**	10	0.0023	0.0025

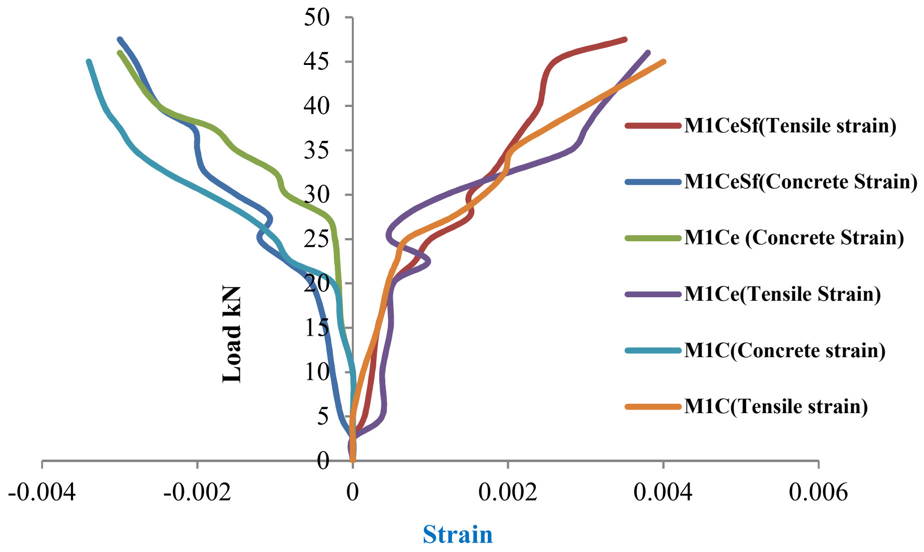

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Fig.7 Load versus Strain of M20 Grade beams

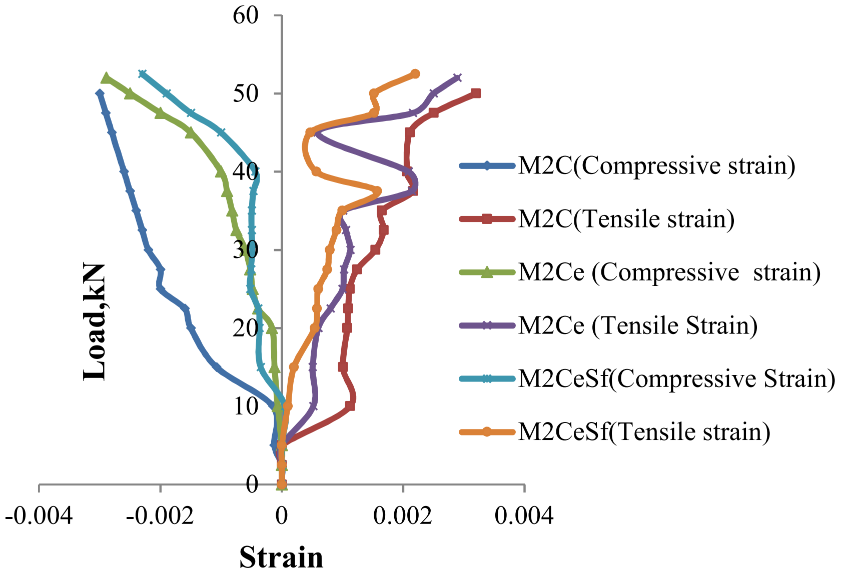

Fig.8 Load versus Strain of M40 Grade beams

9. CRACKING BEHAVIOUR

All the tested beams failed by flexure. None of the specimens failed suddenly. Figure 9 shows the crack pattern of beams. It can be concluded that the decrease in deflection is directly proportional to silica fume and Cenospere replacement. All the beams showed flexural cracks in the static moment area. Usually, reinforcement ratios greatly influence the crack width of flexural members.

(a) Crack pattern of M20 beam **(b) Crack pattern of M40 beam**

Fig.9 Crack Patterns of Beams

10. CONCLUSION

The discharge of discarded materials which creates pollution to environment have been taken into consideration to recreate as cementitious materials and to utilise it for construction purpose. Silica fume (SF), an artificial pozzolan and cenosphere, a waste from coal mining, are selected as cement replacement in the current work. From the investigational interpretations, following points have been noted.

1. The compressive strength of concrete increase to 0.6%, 1.7%, 5.3% and 10% with 1%, 2%, 3%, 4% addition of cenosphere respectively and by adding 5% and 6% the strength gets reduced by 11 % and 13.3%.

2. Similarly by adding 1%, 2%, 3%, 4% silicafume in concrete replaced through 4% cenosphere, the compressive strength has been enhanced to 1.8%, 3%, 5.5% and 9% respectively and then gets reduced by adding 5% SF.

3. Regarding the flexural investigations, the ultimate load of M1Ce and M1CeSf beams are 2.0% and 5.6% greater than M1C beams. Similarly, the ultimate load of M2Ce and M2CeSf beams are 7.0% and 8.4% greater than M1C beams.

4. The ultimate deflection of M1Ce and M1CeSf beams are 8.0% and 15.0% lesser than M1C beams. Similarly, the ultimate deflection of M2Ce and M2CeSf beams are 3.8% and 10.2% lesser than M1C beams.

As a whole it has been concluded that the impact of using Light Weight Cenosphere and Silica Fume as a partial replacement works well and satisfactorily. It is observed that, upto 4% of Cenosphere and Silica Fume replacement, the strength is found to be increased but beyond this point the strength is decreased due to increased voids and capillary channels. The enhancement in Strength and reduction in deflection is attributed to the Pozzalanic properties of Cenosphere and Silica Fume. Cenosphere and Silica Fume interact with Ca(OH)2 to form additional calcium silicate Hydrate gel (C-S-H). This gel is dense and monolithic, which adds structural integrity to the composite. (C-S-H) Gel helps to seal the micropores.

REFERENCES

1. Dilip Kumar Singha Roy, Amitava Sil (2012). "Effect of Partial Replacement of Cement by Silica Fume on Hardened Concrete", International Journal of Emerging Technology and Advanced Engineering 2(8):472-475.
2. JA Prasad, P Lingeshkumar, R Felixnikeshraj, SR Devi (2025). "An Experimental Investigation on Mechanical Properties of Cenosphere Based Concrete", Procedia Structural Integrity Volume 70: 690-697
3. Fareed Ahmed Memon, Muhd Fadhil Nuruddin & Nasir Shafiq (2013), "Effect of silica fume on the fresh and hardened properties of fly ash-based self-compacting geopolymer concrete", International Journal of Minerals, Metallurgy, and Materials, Volume 20, pages 205–213, 2013.
4. Hanumesh B, B K Varun, Harish B A (2015), "The Mechanical Properties of Concrete Incorporating Silica Fume as Partial Replacement of Cement", International Journal of Emerging Technology and Advanced Engineering, Volume 5, Issue 9, September 2015.
5. Houssam A. Toutanji, Tahar El-Korchi (1995), "The influence of silica fume on the compressive strength of cement paste and mortar", Cement and Concrete Research Volume 25, Issue 7, October 1995, Pages 1591-1602.
6. I.A. Sharaky, F.A. Megahed, M.H. Seleem, A.M. Badawy (2019), "The influence of silica fume, nano silica and mixing method on the strength and durability of concrete", SN Appl. Sci., 1 (2019), pp. 575-584.
7. M.V. Deepthi, Madan Sharma, R.R.N. Sailaja, P. Anantha, P. Sampathkumaran, S. Se etharamu (2010). "Mechanical and thermal characteristics of high density polyethylene–fly ash Cenospheres composites", Materials & Design, Volume 31, Issue 4, April 2010, Pages 2051-2060.

8. Mallikarjuna Rao, G., & Gunneswara Rao, T. D. (2018). “A quantitative method of approach in designing the mix proportions of fly ash and Silica fume-based geopolymer concrete”, Australian Journal of Civil Engineering, 16(1), 53-63.
9. Prof. Vishal S. Ghutke, Prof. Pranita S.Bhandari (2014). “Influence of silica fume on concrete IOSR Journal of Mechanical and Civil Engineering”, (IOSR-JMCE) e-ISSN: 2278-1684, p-ISSN: 2320-334X.
10. R Duval A, E.H Kadri A (1998). “Influence of Silica Fume on the Workability and the Compressive Strength of High-Performance Concretes”, Cement and Concrete Research, Volume 28, Issue 4, April 1998, Pages 533-547.
11. S Chandrasekhar, K Urmila Devi (2023). “An Experimental Investigation to determine the Cement Concrete Strength with Silica Fume and Cenosphere”, IJSART - Volume 9 Issue 10 – october 2023.
12. S. Bhanja, B. Sengupta (2002), “Investigations on the compressive strength of silica fume concrete using statistical methods”, Cement and Concrete Research, Volume 32, Issue 9, September 2002, Pages 1391-1394.
13. S.K. Das, S.M. Mustakim, A. Adesina, J. Mishra, T.S. Alomayri, H.S. Assaedi, C.R. Kaze (2020). “Fresh, strength and microstructure properties of geopolymer concrete incorporating lime and silica fume as replacement of fly ash”, J. Build. Eng., 32 (2020), Article 101780.
14. Sampathkumaran P, Kishore, Subramanyam Seetharamu, V.V. Pattanashetti, M.Shekhar Kumar, H.B. Niranjan (2015). “Fly ash cenospheres as reinforcement in different polymer composites – a comparative study of physical and mechanical properties”, Indian Journal of Engineering and Materials Sciences 22(3):354-362.
15. Tak, Sudhansu, Priyanshu Gupta, Alok Kumar, A. Sofi, and Chin Mei Yun (2023). "Effect of using silica fume as a partial replacement of cement in concrete", Materials Today: Proceedings (2023).
16. Uddin, M. A., Bashir, M. T., Khan, A. M., Alsharari, F., Farid, F., & Alrowais, R. (2024). "Effect of Silica Fume on Compressive Strength and Water Absorption of the Portland Cement–Silica Fume Blended Mortar", Arabian Journal for Science and Engineering, 49(4), 4803-4811.
17. Uma Reddy, Swaminathan P, Ch. Vijendar Reddy, Sorabh Lakhanpal, Lalit Kumar Tyagi, Muntadar Muhsen and Irfan Khan (2024). “Use of silica fume as a replacement of cement in the concrete”, E3S Web of Conferences 529, 01036 (2024), ICSMEE'24.

18. V.C. Divya, M. Ameen Khan, B. Nageshwar Rao, R.R.N. Sailaja (2015). "High density polyethylene/cenosphere composites reinforced with multi-walled carbon nanotubes: Mechanical, thermal and fire retardancy studies", Materials & Design (1980-2015) Volume 65, January 2015, Pages 377-386.
19. Verma Ajay, Chandak Rajeev and Yadav R.K. (2012). "Effect of Micro Silica on The Strength of Concrete with Ordinary Portland cement", Research Journal of Engineering Sciences ISSN 2278 – 9472 Vol. 1(3), 1-4, Sept. (2012).
20. Vikas Srivastava, Rakesh Kumar, V. C. Agarwal and P. K. Mehta (2014). "Effect of Silica Fume on Workability and Compressive Strength of OPC Concrete", J. Environ. Nanotechnol. Volume 3, No.3 pp. 32-35.
21. Yogendran, Y., Langan, B. W., Haque M. N. and Ward, M. A (1987). "Silica Fume in High Strength Concrete", ACI Materials Journal, 84(2), 124-129 (1987).