

EFFICACY OF NANO SUPPLEMENTARY CEMENTITIOUS MATERIALS ON MECHANICAL PROPERTIES OF LOW DENSITY FOAMED CONCRETE

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Abstract

Low density foamed concrete (LDFC) serves as an effective construction material with structural and thermal characteristics. This study reports results of experimental investigations on mechanical properties of LDFC including, thermal conductivity and drying shrinkage. Three different densities ± 800 , ± 1000 and $\pm 1300 \text{ kg/m}^3$, were made with two cementitious additives like Nano-GGBS and Nano-RHA in LDFC matrix in the form of SCM. The aim of this study is to investigate the effects of various percentages of SCM on compressive strength, split tensile strength, flexural strength, thermal conductivity and drying shrinkage up to 28 days on LDFC specimens. The experimental outcomes consistently represents that the 28 days mechanical strengths, thermal conductivity and drying shrinkage increased with increasing percentage of Nano-GGBS and Nano-RHA. The 10% replacement of SCM of both the materials shows good agreement on the performance of LDFC. The split-tensile strength and flexural strength attains in the range of 19-21% and 33-46% related with 28 days compressive strength. The thermal insulation and drying shrinkage of LDFC specimens reduced with the increased density. The purpose of this research to assess the efficacy of Nano-GGBS and Nano-RHA as a SCM considering aspects of economical and sustainable concrete in LDFC matrix. It is observed that, with increase in SCM percentages, the shrinkage strain increases with testing age. The drying shrinkage of LDFC specimens reduces with density. Overall, the 10% addition of Nano-GGBS and Nano-RHA as filler in LDFC production minimizes the load on consumption of natural resources, CO₂ emissions and achieves economy

Keywords: Supplementary cementitious materials (SCM), Low density foamed concrete (LDFC), Mechanical properties, Thermal conductivity, Drying shrinkage

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Introduction

LDFC is widely studied due to its lightweight properties, economic implications and for the higher availability of its constituting ingredients: cement, water, preformed foam and, in some cases, fine sand and other additions like silica fume and/or fly ash (Kearsley and Wainwright 2001; Babu *et al.*, 2003; Ramamurthy *et al.*, 2009). LDFC is a special form of concrete matrix in which stable aqueous foam is utilized as a key ingredient without consisting coarse aggregate (Jose *et al.*, 2020). LDFC can be casted for any density in the range of 300-1800 kg/m³. LDFC possesses various admirable characteristics like superior thermal insulation, acoustic insulation, spreadability and easy production. LDFC is a matrix considering target density lower than 1950 kg/m³ with strength in compression limited up to 17 N/mm². LDFC can be 20-30 % lighter than conventional concrete having strength in compression up to 60 N/mm² (Li 2011). LDFC has lower mechanical characteristics as compared with conventional concrete matrix; it can be utilized as load bearing or partition walls in low-rise residential structures. Before its usage in construction industry as a load bearing material, it is mandatory to obtain specific information about mechanical characteristics of LDFC [Mydin and Wang 2012]. Cement is the crucial ingredient in the production of concrete, which emits CO₂ in the existing environment causes pollution (Khan *et al.*, 2012, Aprianti *et al.*, 2015). The CO₂ emission is calculated as nearly 1 tonne of CO₂ produced per tonne cement production and globally CO₂ emissions in the range of 5-7% (Antiohos *et al.*, 2013; Aprianti *et al.*, 2015; Prasittisopin and Trejo 2015) majorly contributes to global warming. The by products from industry, naturally occurring pozzolanic, by products from agriculture etc. constitutes pozzolanicity in the form of residual solid wastes is defined as SCM (Papadakis and Tsimas 2002; Zunino and Lopez 2016). Utilization of industrial wastes or secondary materials has encouraged the cement and concrete industries for more beneficial product generation. Re-cycling of waste materials has great potential in the concrete industry (Lokesh *et al.*, 2022). Many researchers suggested that, the utilization of the different SCM's like fly ash (FA), waste paper sludge (WPS), ground granulated blast furnace slag (GGBFS), palm oil fuel ash (POFA), rice husk ash (RHA), silica fume (SF), and metakaolin (MK) in the preparation of mortar and normal concrete (Tambe and Nemade 2020). Rice husk (RH) is agricultural residual waste, after milling of paddy the external cover of rice kernel is obtained. The paddy of rice/tonne produces

nearly 0.2 tonne of RH, composing about 20% total production of rice (Mahmud *et al.*, 2010; Thanh *et al.*, 2015). India is utmost in the production of rice and its yearly production of paddy estimated about 54.5 million tonnes in the year 2014 (Rice Market Monitor 2015), which generates nearly about 31 million tonnes of RH. The United States Department of Agriculture (USDA) evaluated that in 2019-20 the worldwide production of rice nearly about 499.31 million metric tons (World agricultural production, 2020). The single kg of rice produces nearly 0.28 kg of RH during milling activity. Thus, large quantity of RH waste is generated annually. The RHA comprises greater amount of silica content (Zain *et al.* 2011), pozzolanicity and fineness of the particle as compared with OPC. The maximum percentage of extremely amorphous silica in RHA reveals the increase in strength of RHA incorporated concrete matrix [Zunino and Lopez 2016]. The GGBS is a mineral admixture which has the chemical components equivalent to that of OPC. The iron and steel industries / tonne produce approximately 0.45-0.50 tonne of GGBS. The optimum usage of GGBS as a supplementary to the OPC is having major environmental concerns in the construction industry (Saranya *et al.*, 2017). The hydraulicity of GGBS contributes in concrete performance, depletion of natural resources and in the saving of energy (Suresh Kumar *et al.*, 2017). Nanotechnology widely developing area of exploration in the construction sector which represents excellent characteristics. The various nanomaterials and nanotechnologies can be utilized in the construction industry for structural concrete, real-time structural monitoring, coating, paintings and thermal insulations (N.T. Suryawanshi *et al.*, 2022). The advancements in concrete nanomaterials can be used in different fields of the construction industry. The constituents of the LDFC matrix affects on its long term strength and durability, etc. Nanomaterials usage has certain benefits due to the usage of hazardous material in construction; however, these also include health risks associated with it. So, advantages, disadvantages and availability of various nanomaterials are essential (C.B. Nayak *et al.*, 2021). The existing literature about mixture LDFC mix proportioning was found to be very little. Therefore, this research is directed to evaluate and develop the suitable mix proportion of all ingredients considering SCM percentage is very important to achieve superior characteristics in LDFC. Hence, this study is aimed to optimize all the constituents blended in the LDFC matrix. Also, the broad research work was carried out considering the major aspects of mechanical strengths, physical and chemical characteristics of Nano-GGBS and Nano-RHA as a SCM.

Materials Characterization

Ordinary Portland Cement (OPC)

The 53 grade OPC having sp. gravity of 3.15 confirming to IS 12269-2013 with trade name “Birla Super” was used.

Sand

River sand of IIIrd zone with size 2-4mm obtained from “Nira-river” considering modulus of fineness 3.2, sp. gravity 2.65 and capacity of absorption as 0.83%.

Foaming agent

Lightweight and free-flowing LDFC prepared by using EABASSOC foaming agent. The addition of foaming agents produces air-voids in the concrete matrix and governs the density of LDFC. The foaming agents significantly affects on the characteristics of LDFC in its fresh and the hardened state. LDFC can be placed easily and does not require compaction, vibration or levelling. Foaming agent quantity of 1 ml diluted in 50 ml volume of water and agitated with blade type mixer to produce foam.

Water

The water used in the LDFC production should be normal clean tap water. The entire water quantity and the w/c ratio are crucial in the preparation of desired quality matrix. Also, the foaming agent was diluted into water for producing the stable foam (Ikponmwosa *et al.*, 2017).

Supplementary Cementitious Materials (SCM) at Nano scale

The following Table 3 represents summary of binders/fillers used in production of LDFC. The SCMs were added in the form of Nano-GGBS and Nano-RHA with different proportions to replace the OPC. The SCMs were sieved to get appropriate size of particles with nearly 100% passing through 0.6mm sieve openings. The following Figure 1. shows grading curve for sand, unprocessed GGBS and RHA used in LDFC preparation. The particles of GGBS and RHA reached to nanoscale by using ball milling technique to achieve proper size. The addition of Nano-SCMs in LDFC improves the overall performance of matrix in terms mechanical strengths and rheology. The detailed characterization of Nano-GGBS and Nano-RHA are as follows;

Nano-Ground granulated blast furnace slag (Nano-GGBS)

Nano-GGBS is a mineral admixture obtained from steel manufacturing industries which has the

chemical components equivalent to OPC. Iron is extracted in the form of iron silicate usually called so as slag. Disposal of slag may create toxic health hazards. Table 1 and 2 represents chemical and physical compositions of Nano-GGBS and Nano-RHA as compared with OPC. The GGBS gives excellent binding characteristics when mixed with OPC (Ali and Shaikh 2014). It has same chemical properties as that of cement, but it is less reactive than OPC. Due to presence of alkalis in OPC, the particles of Nano-GGBS get activated and produce their own products of hydration. The formation of cement paste with fine pores is due to generated products of hydrates. The percentage of tri calcium aluminate (C_3A) is very less in GGBS and its addition in LDFC minimizes the overall composition of C_3A in the concrete matrix and improves the resistance against the sulphate attack (Siddique *et al.*, 2012).

Nano-Rice husk ash (Nano-RHA)

The Nano-RHA was utilized in this study is obtained from rice mills of Tamil Nadu, India. The Nano-RHA contains more percentage of silica and fineness as compared with OPC. The RHA effectively represents pozzolanic and binding properties due to maximum percentage of amorphous silica and fineness modulus (Siddika *et al.*, 2020). The oxides of iron (Fe), aluminium (Al), and sulphur (S) causes very less effects on hydration process, although the oxides of aluminium (Al) enhances the strength of LDFC matrix due to development of aluminosilicate products. The alkali contents present in the RHA adversely effects on the setting time and hydration process of the LDFC (Kashani *et al.*, 2019).

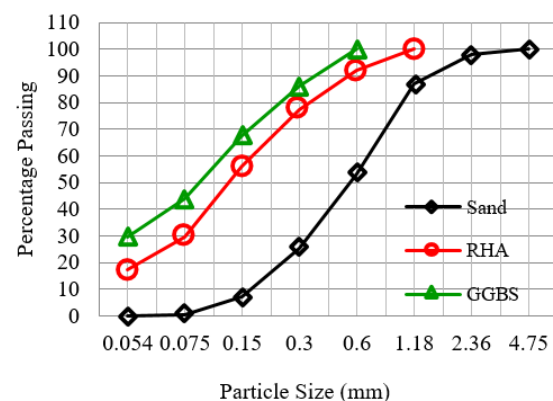


Figure 1. Grading curve of Sand, unprocessed GGBS and RHA

Table 1. Chemical properties of Nano-GGBS & Nano-RHA in comparison with OPC

Oxides	OPC	Nano-GGBS	Nano-RHA
SiO ₂	19.71	33.46	82.6
Al ₂ O ₃	5.2	15.17	2.32
Fe ₂ O ₃	3.73		
CaO	62.91	25.02	17.07
MgO	2.54	7.97	0.52
SO ₃	2.72	0.85	0.11
K ₂ O	0.9	1.28	0.13
Na ₂ O	± 0.25	± 1.32	± 0.16

Table 2. Physical characteristics

Characteristics	OPC	Nano-GGBS	Nano-RHA
Colour	Grey	White	Greyish
Shape	Spherical	Spherical	Irregular
Specific gravity	3.14	2.7	2.33
Bulk density [kg/m ³]	1440	1040–1090	180–200
Appearance	Powder form	Powder form	Powder form

Table 3. Summary of binders/fillers used in FC

6.5	Additives C:B Ratio Density kg/m ³	Parameters studied	References
Cement	FA-class F 1 : 3 -	Shrinkage, Porosity, Compressive and Flexural Strength	[N. Narayanan et al. 2000]
	FA-class F 1 : 1 650,1000, 1150	Shrinkage, Compressive strength	[E.K. Nambiar et al. 2006]
	FA 1 : 1.5 1000–1200 1300–1500	Shrinkage, Porosity, Compressive strength	[K. Gelim 2011]
	FA + SF 1 : 1.5 1 : 2.5 1280–1870	Compressive and Flexural Strength	[A.A. Hilal et al. 2015]
	BFS Replacement 30–70 % 1300	Compressive and Flexural Strength	[H. Awang et al. 2014]
	GHB 2.4 wt% 400	SEM, XRD, Compressive strength, Thermal conductivity	[Chi Hu et al. 2016]
	POFA OPC 10 to 20% 1300	Toughness, Compressive and Split- tensile strength	[Tambe et al. 2021]
	POFA Sand 10 to 20% 1000	Compressive and Flexural Strength	[S.K. Lim et al. 2013]
Aggregate/ Filler	CB 0-100% with 25% interval 750–550	Porosity, Compressive strength	[A.A. Aliabdo et al. 2014]
	Laterite Sand 0-15% with 5% interval 800–1800	Compressive strength	[Y.H. Khaw 2010]

Annotation: FC: Foamed concrete, FA: Fly ash, SF: Silica fume, BFS: Blast furnace slag, GHB: Glazed Hollow Beads, POFA: Palm oil fuel ash, CB: Clay bricks

According to (Suresh Kumar *et al.*, 2017) using XRD test results of OPC-53 grade, Nano-GGBS and Nano-RHA particles size can be obtained by using Debye - Scherer equation shown in Table 4. The following Figure 2a, b, c represents the SEM images of materials used in the LDFC preparation. Based on the shown figures the particle size is calculated using Origin software.

Where $\lambda=1.78 \text{ \AA}$, β = full width at Half maximum intensity (FWHM) of the peak in radians, Θ = angle, K is constant, i.e.0.9

$$\text{Particle size in nm, (D)} = \frac{K\lambda}{\beta \cos \theta} \quad (1)$$

$$\beta = \frac{\pi}{180} \times \text{FWHM} \quad (2)$$

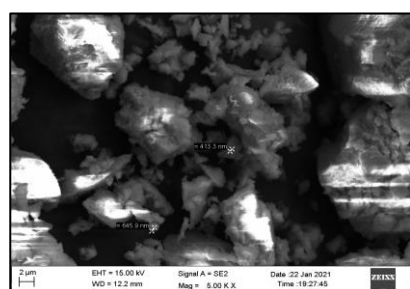
Table 4. Calculation of particle size from XRD plots

Material	2 θ	FWHM	K	λ	Particle Size (nm)
OPC-53	37.5	0.5	0.9	0.178	20.24
Nano-GGBS	36	8	0.9	0.178	1.26
Nano-RHA	25	0.5	0.9	0.178	18.75

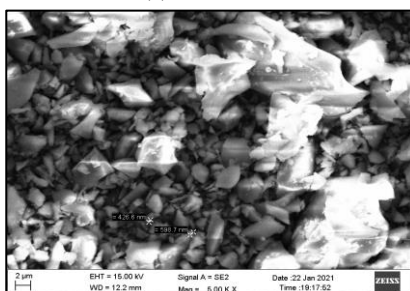
Proportioning and preparation of LDFC

The design mix proportion adopted in this research was (C:S:W)-(1:1.125:0.5). Foaming agent quantity of 1 ml diluted in 50 ml volume of water and agitated with blade type mixer to produce foam. The LDFC was prepared using Pre-foaming method, which involves separate preparation of base mix and stable foam and then thoroughly blending foam into the base mix Figure 3. The selection of controlled parameters is a crucial phase in the design of experiments (DOE) (Kate *et al.*, 2021). The DOE was carried out to minimize the number of trials and provides detailed information of all factors responsible for optimization. Three different target casting densities were considered in this study ± 800 , ± 1000 and $\pm 1300 \text{ kg/m}^3$. The following Table 5 represents the design mixes with parameters considered using DOE. Total 15 trials for each trial, 9 specimens (3 cubes, 3 cylinders and 3 beams) were cast of size 150 mm $\times$ 150 mm $\times$ 150 mm for cube, 100 mm in diameter and 200 mm in height for cylinder and 100 mm $\times$ 100 mm $\times$ 500 mm for beam

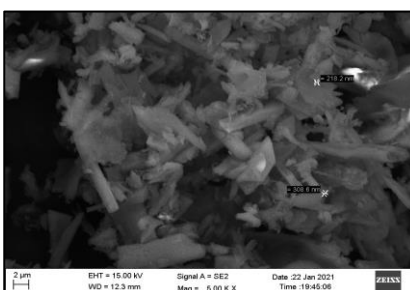
and subjected to mechanical strength tests under three various curing time at $\pm 28^\circ\text{C}$ temperature. Also, the LDFC panels of size $300\text{ mm} \times 300\text{ mm} \times 100\text{ mm}$ were used to perform steady-state thermal conductivity and $100\text{ mm} \times 100\text{ mm} \times 250\text{ mm}$ size of beam specimens were casted to study drying shrinkage of LDFC.



(a) OPC 53 Grade



(b) Nano-GBS



(c) OPC 53 Grade

Figure 2. SEM images of materials used in LDFC preparation

Table 5. Design mixes with parameters

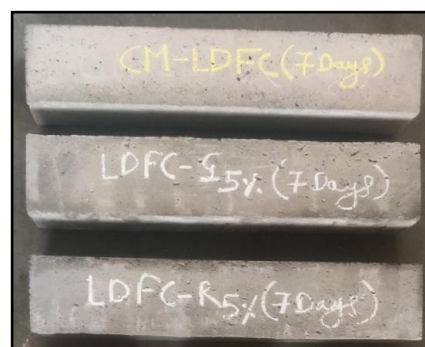
Design Mix	LDFC-CM	LDFC-G5%	LDFC-G10%	LDFC-R5%	LDFC-R10%
GGBS/RHA Loading %	0	5	10	5	10
Target Density (kg/m^3)	± 800	± 800	± 800	± 800	± 800
Curing Time (Days)	14	14	14	14	14
Avg. Particle size (nm)	-	1.26		18.75	



(a)



(b)



(c)

Figure 3. a) Foam and dry base mix (C-FA), b) Mixing of Foam into base mix and LDFC mix preparation, c) Casted LDFC Beam specimens

Experimental Programme

SEM/EDS Analysis

The SEM/EDX analysis was carried out using Bruker Sigma-IV (Zeiss) instrument with an intensive resolution and X-ray (energy dispersive) spectrometry was to get SEM graph and analysis of chemical composition for OPC-53 grade, GGBS and RHA samples.

XRD Analysis

The purpose of XRD analysis is to identify crystalline phase of the sample using XRD diffractogram by finding the peak position and matching it to the mineral database (Abdullah Al-Shwaiter et al., 2021). The XRD analysis was carried out using Bruker XRD Advanced D8.0 instrument with an intensive resolution X-ray spectrometry to get particle size of OPC-53 grade, GGBS and RHA samples.

Tests setups for strengths

The compressive and splitting tensile strength testing was carried out on digital CTM of 3000 kN capacity with $\pm 2\%$ accuracy. The flexural testing on beam specimens was employed using UTM of 5000 kN capacity.

Compressive strength

The crucial feature of LDFC matrix is compressive strength which estimates the intensity of applied load carried by the matrix before failure (Tambe and Nemade 2021). The average of 3 cubic specimens was used to calculate the strength in compression for LDFC at 28 days according to IS 516-1959. The testing was carried out on digital CTM having capacity range up to 3000 KN with $\pm 2\%$ accuracy with a 0.5 KN/s loading rate. The Eq. (3) shown below represents the compressive strength of LDFC;

$$CS = \frac{P}{A} \quad (3)$$

Where, CS = compressive strength (N/mm²), P = maximum applied load (N), A = cross-sectional area (mm²).

Splitting tensile strength

The splitting tension strength is a crucial characteristic of LDFC, due to applied loading and various internal as well as external effects causes tensile cracking into the concrete matrix (Tambe and Nemade 2021). The average of cylindrical samples with size 100 mm in diameter and 200 mm in length in triplicate utilized to evaluate the split-tensile strength of LDFC in accordance with IS 5816-1999. The Eq. (4) represents the splitting tension strength of LDFC;

$$STS = \frac{2P}{\mu DL} \quad (4)$$

Where, STS = split-tension strength (N/mm²), P = maximum applied load (N), L = length of cylindrical specimen (mm), and D = dia. of cylindrical specimen (mm).

Flexural strength

The beam specimens of size 100 mm $\times$ 100 mm $\times$ 500 mm were used to estimate the flexural strength of the LDFC in accordance with ASTM C 78 standards. The average of the triplicate prisms utilized to evaluate the flexural strength of LDFC beam under one-point loading condition. The Eq. (5) represents the flexural strength of LDFC;

$$FS = \frac{PL}{bd^2} \quad (5)$$

Where, FS = flexural strength (N/mm²), P = maximum applied load (N), L = span of beam (mm), b = width of beam (mm), and d = depth of beam (mm).

Thermal conductivity

The thermal conductivity of material significantly depends on its conductance, cross-sectional area and thickness having capability to conduct heat (Awoyera et al., 2019). In accordance with BS EN 12664, the LDFC panels of size 300 mm $\times$ 300 mm $\times$ 100 mm were used to perform steady-state thermal conductivity. The LDFC samples were kept in oven at temperature $\pm 105^\circ\text{C}$ for 24 hours to eliminate existing moisture. A hot plate subjected to 50°C temperature was placed on the top of the sample while 30°C temperature plate at bottom. The heat transfer mechanism was recorded using using Campbell scientific CR 3000 instrument nearly up to 15 hours. The following Eq. (6) represents thermal conductivity;

$$K = \frac{Q \times L}{A \times \Delta T} \quad (6)$$

Where, K= thermal conductivity in W/mK, Q= Amount of heat transferred through LDFC in Watts, L= distance between isothermal planes in m, A= Surface area in m², ΔT = difference in temperature in Kelvin

Drying shrinkage

There is paucity about the behavior of the drying shrinkage of LDFC containing cement. The reduction in the volume of LDFC with time is defined as shrinkage (Kate and Thakare, 2017). Several researchers concluded that, the contents of cement adversely affects on the performance of LDFC considering drying shrinkage. But, the performance of LDFC improved with partial substitutions of OPC with SCM like, GGBS, RHA, flyash and silica fume etc. due to slower hydration. In this research, the 100 mm $\times$ 100 mm $\times$ 250 mm size of beam specimens were casted. The changes in the LDFC beam samples due to moisture reduction

was measured by using length comparator apparatus according to IS 4031-1988 specifications. The following Eq. (7) represents the shrinkage strain;

$$\text{Shrinkage strain} = \frac{\Delta L}{L} \quad (7)$$

Where, ΔL = change in length in mm, L = original length in mm

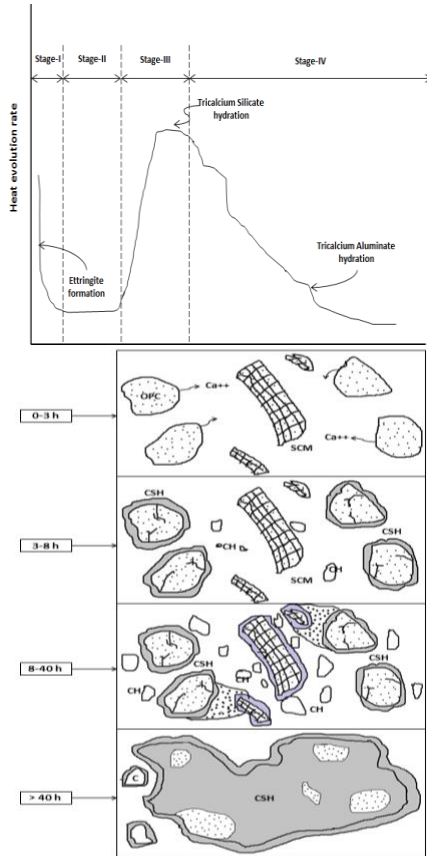


Figure 4. Rate of hydration with SCM

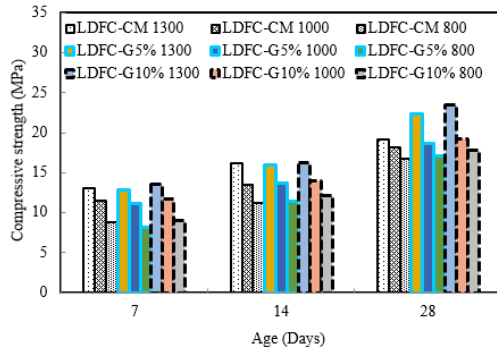


Figure 5. Effect of age on achievement of compressive strength with Nano-GGBS

Results and discussion

Behavior of LDFC integrated with SCM at Nano scale

The action of SCM initiates when it is blended with cement and water, and thereafter, changes the setting time and hydration rate. Generally, the OPC takes 300 min for final setting, while the OPC blended with 10% of Nano-GGBS and Nano-RHA requires 273 min and 259 min respectively. Due to the accelerated rate of hydration and hardening of the cement paste, the final setting time of LDFC gets reduced. The following Figure 4 represents the stage wise hydration of cement paste integrated with SCM. The initiation of the products of calcium hydrates (CH) are equivalent in both the SCM-integrated cement and OPC which continues up to 3-8 h. When the SCM particle initiates reaction with the CH, extremely increases heat generation (Van *et al.*, 2014) due to the development of calcium silicate hydrates (CSH) (Feng *et al.*, 2004). The complete hydration of SCM based samples occurs with optimum CH products and silica dissolution from the SCM. Though, the key products in the hydration of the SCM-integrated cement are CSH, ettringite, calcium tri sulfo-aluminate hydrate (Nguyen, 2011). Initially, the increasing percentage of SCM attains pozzolanicity; but, beyond the optimal quantity of cement replacement, the extent of formation of CaO and CH starts decreasing.

Compressive strength

The attainment in the compressive strength of LDFC matrix increases with target casting density. Also, Figs 5 and 6 shows that, the strength in compression increases with increase in replacement percentage of SCM, due to fineness and contents of Nano-GGBS and Nano-RHA up to 10% replacement for the cement. According to the obtained results, the strength of compression at 28 days increases with addition of Nano-GGBS and Nano-RHA in LDFC as a replacement to cement by 2%, 10.2%, 7.22% and 1.25%, 2.80%, 3.68% with different densities ± 800 , ± 1000 and $\pm 1300 \text{ kg/m}^3$ respectively. The attainment of the strength is due to the reaction of the calcium hydroxide Ca(OH)_2 produced from hydration of cement with the amorphous silica present in the Nano-GGBS and Nano-RHA integrated LDFC samples. Also, the strength of mixes in compression containing Nano-GGBS and Nano-RHA has improved gradually in comparison with LDFC-CM due to higher surface area and reactivity of nanoparticles leading to acceleration of CSH gel production process.

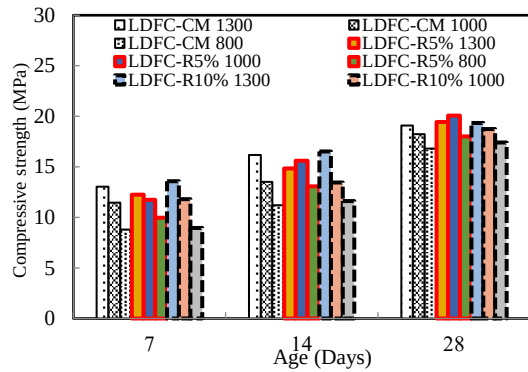


Figure 6. Effect of age on achievement of compressive strength with Nano-RHA

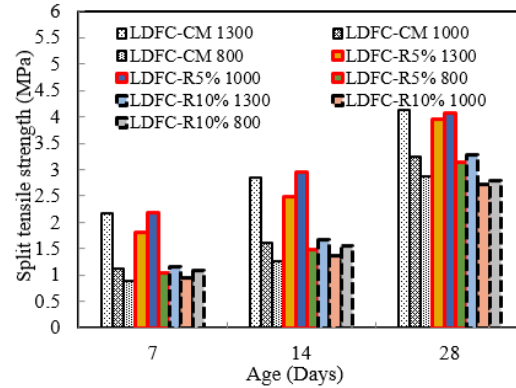


Figure 8. Effect of age on achievement of split-tensile strength with Nano-RHA

Split-tensile strength

The enhancement in the split-tension strength of LDFC matrix increases with target casting density. The oxide contents and fineness of Nano-GGBS and Nano-RHA attains the strength of the LDFC in tension. Also, Figure 7 and 8 shows that, the strength in tension increases with increases in replacement percentage of SCM Nano-GGBS and Nano-RHA up to 10% for the cement. Based on the obtained results, the 28 days splitting tensile strength significantly improves with the addition of Nano-GGBS and Nano-RHA in LDFC as a replacement to cement by 8.25%, 2.87%, 16.67% and 9.37%, 9.87%, 7.29% with different densities ± 800 , ± 1000 and ± 1300 kg/m³ respectively. The enhancement of strength in tension of LDFC samples is due to formation of CSH which improves its bonding behavior, thus carries additional load to split the cylindrical samples. The 28 days splitting tensile strength is in between 19-21% related with compressive strength as shown in Figure 11.

Flexural strength

The flexural strength of LDFC matrix enhances with increase in target casting density. Also, Figure 9 and 10 shows, the strength in bending improves with rise in replacement percentage of SCM's Nano-GGBS and Nano-RHA up to 10% for the cement. According to the obtained results, 28 days flexural strength increases with addition of Nano-GGBS and Nano-RHA in LDFC as a replacement to cement by 2.87%, 3.62%, 3.82% and 5.03%, 2.29%, 7.42% with different densities ± 800 , ± 1000 and ± 1300 kg/m³ respectively. The obtained results represented that, due to silica content in Nano-GGBS and Nano-RHA initiated a formation of additional CSH which results in the densification of LDFC's microstructure. The flexural strength is in between 33-46% related to the strength in compression for 28 days as shown in Figure 11.

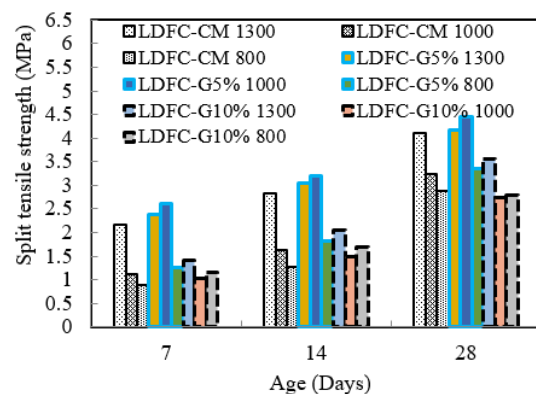


Figure 7. Effect of age on achievement of split-tensile strength with Nano-GGBS

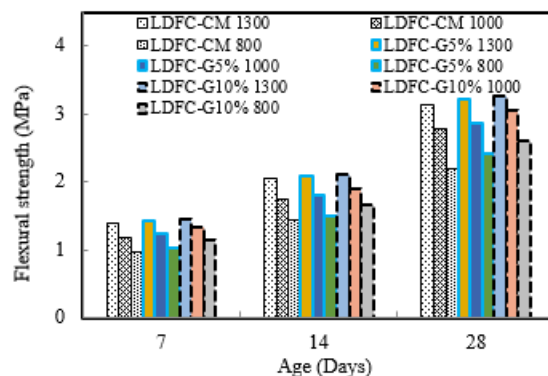


Figure 9. Effect of age on achievement of flexural strength with Nano-GGBS

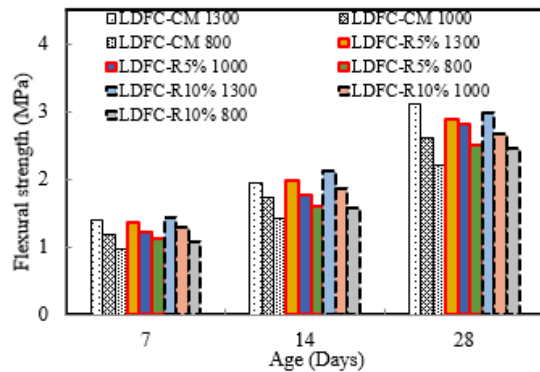


Figure 10. Effect of age on achievement of flexural strength with Nano-RHA

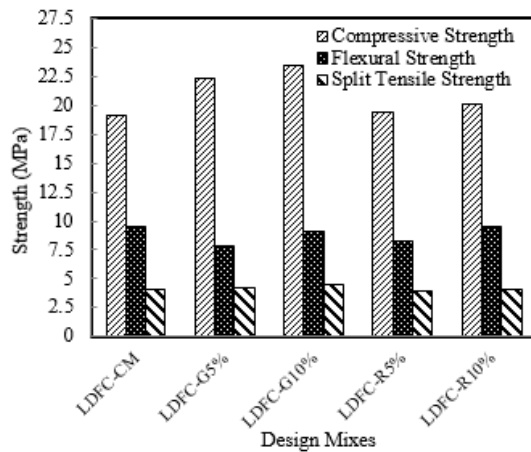


Figure 11. Relationship between compression, split-tension and flexural strength with design mixes at 28 days

Thermal conductivity

The following Figure 12 depicts the effects of SCM on thermal conductivity of LDFC tested specimens at 28 days. The LDFC incorporated with SCM attains higher thermal conductivity than LDFC-CM. The densification of microstructure in LDFC samples was due to pozzolanic behavior of SCM by amorphous silica present in Nano-GGBS and Nano-RHA. Also, $\text{Ca}(\text{OH})_2$ attains the strengths and improves thermal conductivity. Based on the obtained results, the thermal conductivity behaves evenly with casting density and insulation properties reduce with increase in density.

Drying shrinkage

The following Figure 13, 14 and 15 represents the behavior of drying shrinkage with respect to testing age of LDFC specimens with three different densities. Due to addition of SCM with lower

specific gravity than OPC, the hydration reaction occurs slowly to attain 28 days target strengths. It is observed that, with increase in SCM percentages, the shrinkage strain increases with testing age. The drying shrinkage of LDFC specimens reduces with density.

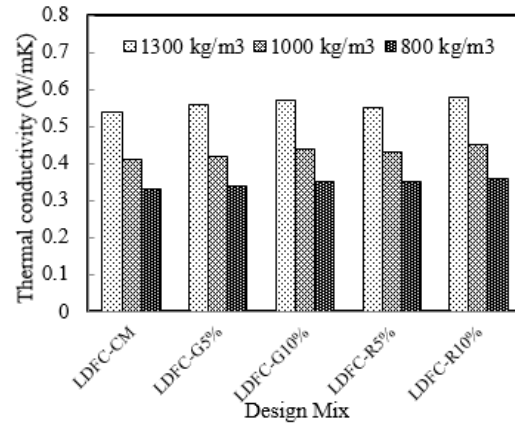


Figure 12. Relationship between design mixes and thermal conductivity at 28 days

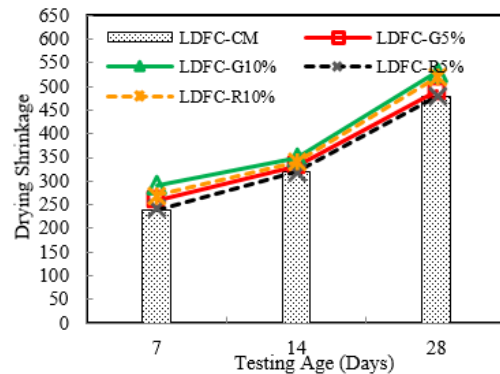


Figure 13. Effect of drying shrinkage with age for density=1300 kg/m³

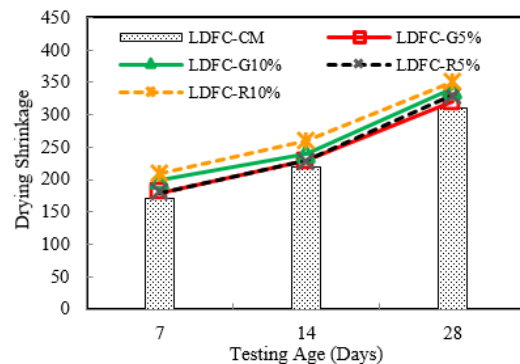


Figure 14. Effect of drying shrinkage with age for density=1000 kg/m³

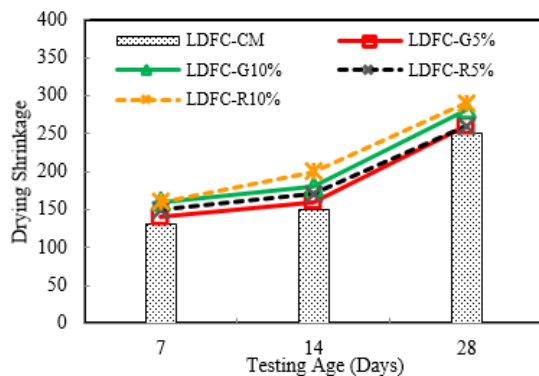


Figure 15. Effect of drying shrinkage with age for density=800 kg/m³

Conclusions

Based on the experimental results, the following conclusions were drawn ;

1. The compressive strength of LDFC matrix increases with increase in target casting density. The strength in compression at 28 days increases with addition of Nano-GGBS and Nano-RHA in LDFC as a replacement to cement by 2%, 10.2% ,7.22% and 1.25%, 2.80%, 3.68% with different densities ± 800 , ± 1000 and ± 1300 kg/m³ respectively.

2. The split-tension strength of LDFC matrix increases with increase in target casting density. The split-tensile strength at 28 days increases with addition of Nano-GGBS and Nano-RHA in LDFC as a replacement to cement by 8.25%, 2.87% ,16.67% and 9.37%, 9.87%, 7.29% with different densities ± 800 , ± 1000 and ± 1300 kg/m³ respectively. The split-tension strength was in between 19–21% related with 28 days compressive strength.

3. The flexural strength of LDFC matrix increases with increase in target casting density. The flexural strength at 28 days increases with addition of Nano-GGBS and Nano-RHA in LDFC as a replacement to cement by 2.87%, 3.62% ,3.82% and 5.03%, 2.29%, 7.42% with different densities ± 800 , ± 1000 and ± 1300 kg/m³ respectively. The one point loading flexural strength was in between 33-46% related with 28 days compressive strength.

4. The thermal conductivity behaves evenly with casting density and insulation properties reduce with increase in density.

5. It is observed that, with increase in SCM percentages, the shrinkage strain increases with testing age. The drying shrinkage of LDFC specimens reduces with density.

Overall, the 10% addition of Nano-GGBS and Nano-RHA as filler in LDFC production minimizes

the load on consumption of natural resources, CO₂ emissions and achieves economy. Therefore, it can be concluded that, incorporation of Nano-GGBS and Nano-RHA in LDFC matrix shows to be superior alternative for sustainable development.

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Conflict of interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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