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Original Article

Effect of Lateritic Aggregate and Steel Fiber on Fresh and Mechanical Properties of Concrete

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Abstract *- This paper investigates the concrete's ability to function sustainably when laterite is used as a substitute for coarse aggregate at intervals of 25% from 0 to 100%. The construction sector uses natural resources extensively to build infrastructure. As a result, some natural resources, such as granite aggregates and river sand, are on the edge of extinction. One such natural resource that is currently depleting and needs urgent research attention is river sand. In this study, laterite and M-sand were used as substitutes for natural coarse aggregate and fine aggregate in fiber concrete containing 2% hook-end steel fibres. The introduction of laterite aggregate was shown to reduce the workability of fresh steel fibre-reinforced lateritic concrete linearly. The compressive strength of steel fiber-reinforced concrete exhibited an increase when laterite aggregate was replaced at its optimal level. In comparison to the control concrete, the concrete mixture incorporating 25% laterite aggregate exhibited a 17.77%, and 18.74% increase in compressive strength on days 7, and 28, respectively. The flexural and tensile strengths of fibre-reinforced concrete containing laterite aggregate exhibited a comparable trend of enhancement. Curing for 28 days resulted in a concrete mixture containing 2% hook-end steel fiber, 25% laterite aggregate, and M-sand had 12.21%, and 12.77% greater split tensile and flexural strength than the control concrete. The strength values exhibited enhancement up to a 50% substitution with laterite, but after that point, they started to decline. The study's findings demonstrate that laterite can partly substitute granite aggregates and enhance the strength of fibre-reinforced concrete.*

Keywords *- Fresh properties, Laterite aggregate, Manufactured sand, Mechanical characteristics, Steel fiber.*

1. Introduction

Concrete is widely acknowledged as the predominant construction material on a global scale. Concrete is widely regarded as the preferred construction material due to its numerous beneficial characteristics. This research article highlights the remarkable attributes of a material, including its exceptional strength, long-lasting nature, cost-effectiveness, environmentally friendly properties, and flexibility. Even though concrete has been used for millennia, the material is still afflicted with different strength and durability issues. Furthermore, because of the high consumption of natural materials, which leads to depletion, the use of concrete has been determined to be responsible for several environmental difficulties [1].

Currently, it is commonly accepted that standard concrete is made from river sand and crushed granite aggregate. Aggregates make up roughly 60-80% of the concrete's volume and have a significant impact on its economics, mix proportions, and characteristics [2]. Therefore, any attempt to lower the cost of aggregate would directly affect the cost of building, particularly housing [3]. Global consumption of concrete is estimated to consume 8-12 billion tons of traditional aggregates annually [4]. This demand motivates researchers to utilize mining and quarrying wastes [5, 6], agricultural practices [7, 8], and industrial wastes [9, 10] from various industries as coarse aggregates in concrete production.

Since the nineteenth century, masonry structures in India have been constructed using laterite, a prevalent construction material in tropical and subtropical locations, several of which are included as UNESCO World Heritage Sites. Laterite (sometimes referred to as red soil) is clay rich in ferrous and alumina oxides that can increase the hardness of concrete. Laterite is widespread in areas with high temperatures and high rainfall, such as Southeast Asia, Australia, India, and Africa [11].

The term was initially coined by Francis Buchanan, an English surgeon, in 1807 during his travels along the western coast of Southern India. Laterite is distributed over granite in vast quantities without any evidence of stratification and is also replete with voids filled with deep red to pale yellow ochre. In comparison to other tropical countries with periodic wet seasons, India has distinctive lateral soil forms. It covers around 248,000 square kilometres of land in India.

In the Deccan region of India, including parts of Assam, Madhya Pradesh, Karnataka, Kerala, and the Eastern Ghat regions of Maharashtra, Orissa, and Malabar [12]. Laterites are particularly well-established and have a wide variety of physical properties, ranging from soil to stone material, depending on the extent of concretionary enhancement [13].

[14], illustrated that the main cementitious component utilized was Portland Composite Cement (PCC) to create two forms of SCC combinations. The first uses granite aggregate, while the second uses lateritic aggregates as coarse aggregate. The study concludes that the two SCC mixture types, slump flow and T500, had the same form at their fresh stage, were appropriately dispersed by weight in all directions, and met ENERFAC criteria for SCC blends. Both SCC combinations had almost identical compressive-strain stress relationships and similar peak strain values at 90 days of age. Physical properties, including compressive, elasticity, and tensile strength, revealed that SCC made from lateritic aggregates was marginally higher than SCC made from granite aggregate. Cubes were cast as mixes with different percentages (0–50%) of laterite aggregates and were studied by [15].

The samples underwent a process of immersion in water for 28 days and then were examined for compressive strength, acid resistance, and water absorption. The incorporation of 50% laterite aggregates led to a decrease in the water absorption capacity of the concrete. Like this, the incorporation of 20% of lateritic aggregates produces concrete with strong resistance to chloride ion ingression, water absorption and acid attack. As a result, it is concluded that the concrete with the desired strength may be achieved by using 20-30 percent of lateritic aggregates as a partial substitute for granite aggregates.

[16] analyzes the structural qualities of concrete constructed with laterite rock as coarse aggregates. The results identified an optimal w/c proportion of 0.55; The strength achieved is 22.88N/mm^2 for the mixture 1:1.5:3. The laterite concrete's flexural and splitting test results ranged from 6 to 21 percent of its compressive strength. Lateritic concrete has a static modulus elasticity of 22.72 N/mm^2.

[17] shows that concrete mixtures were cast in the laboratory and evaluated for fresh and mechanical properties. In the concrete, the fine aggregate replacement levels ranged from 0% to 10%, 20% to 25%, and 30%. At the same time, 25% of the granite aggregate was substituted with lateritic aggregate. Concrete with a 20% substitution of natural sand for quarry dust and a 25% substitution of granite aggregate for laterite stone offers flexural, greater compressive, and split tensile strength.

The research undertaken by [18] investigates the cyclic behaviour of reinforced concrete beams that have been strengthened with steel fibres added to the concrete mixture. Seven full-scale samples with identical geometries are examined in a slow-cyclic four-point bending test. Six samples with steel fibre volume fractions of 1, 2, and 4% were built in twin models, with one acting as a control sample with no steel fibres or 0% v_f.

A comprehensive study was carried out to determine the effects of steel fibres on the cyclic behaviour, which also examined ultimate resistance, degradation of loading, unloading stiffness ductility, dissipation, energy absorption, and equivalent viscous damping. In general, the cyclic behaviour of reinforced concrete beams is enhanced when steel fibres are added to a specific threshold (v_f = 2%) and increase maximum strength and ultimate displacement.

Research shows that using additives such as fly ash and hook-end steel fibre [19] is an efficient method of increasing the durability and strength of recycled concrete. For this study, three distinct dosages of steel fibre, namely 0%, 0.5%, and 1%. Additionally, the cement component was substituted with fly ash at three different levels: 0%, 15%, and 30%. The results of multiple durability and mechanical tests were employed to evaluate the mixtures.

The results revealed that integrating steel fibre reinforcement into fly ash-based recycled concrete considerably enhances mechanical behaviour and suggests that concrete could be improved greatly. Based on the findings from the strength tests, it was observed that the combination of 15% fly ash and 1% steel fibre resulted in a synergistic impact. This combination led to a significant increase in flexural strength by 73-78%, splitting-tensile strength by 39-50%, and compressive strength by 13-23%.

The outcomes of previous studies suggest that the substitution of laterite aggregate in place of granite aggregate has a significant effect on the strength properties of concrete. The incorporation of both laterite aggregate and steel fibres in concrete has not been extensively investigated in previous studies. The present investigation is centred on examining the fresh and mechanical properties of environmentally sustainable concrete, which is produced by incorporating laterite scraps as coarse aggregates and partially substituting granite aggregate in construction applications.

The concrete's strength, mainly compressive strength, is its most significant characteristic. However, other characteristics, such as split-tensile and flexural strengths, are also considered. The investigation was conducted on M25-

grade concrete. The replacement percentage of coarse aggregate by laterite varies from 0% to 100% at a 25% interval. According to the literature assessment, 2% by weight of steel fibre was added to enhance the strength of concrete.

The feasibility of fibre-reinforced lateritic concrete, which is made from laterite and granite aggregates, was evaluated in accordance with Indian Standards. The slump test was performed to see the workability of concrete mixes. Also, the properties of hardened concrete were examined through the split-tensile, flexural, and compressive strength tests.

2. Materials and Methods

2.1. Characteristics of Cement

In the process of making concrete, 53-grade Ordinary Portland Cement (OPC) was used as a binding agent and assessed in accordance with IS code IS 12269, 2013 [20]. Concrete's physical characteristics were determined by laboratory testing, including its specific gravity of 3.15, soundness of 2.8 mm, and typical consistency of 31%. The findings indicate that cement has a greater calcium concentration (CaO-64.12%). Table 1 displays the chemical compositions of cement.

2.2. Characteristics of Fine Aggregate

The study sourced M-sand from a local distributor. The physical properties of M-sand were determined using the tests specified in IS 2386, 2016 (Part 3) [21]. The physical properties are presented in Table 2. It has an angular form, a rough surface roughness, a fineness modulus of 3.06, and a water absorption percentage of 1.98%. The percentage of fines passing through a 600-µm sieve for M-sand is estimated to be around 40%. The particle size distribution S-curve for M-sand is illustrated in Figure 2.

2.3. Characteristics of Coarse Aggregate

The present study utilizes crushed granite aggregates sourced from a local supplier. The study utilized a metamorphic granite rock as the coarse aggregate, which was graded into a 20 mm scale. It has a rounded form, a rough surface texture, a fineness modulus of 3.6, and a rate of water absorption of 0.92%. The physical properties of granite and laterite aggregate were determined according to IS 2386, 2016 (Part 4) [22]. The results are presented in Table 2.

The laterite aggregate used in this study was sourced from a quarry in Mangalore, Karnataka, India, as shown in Figure 1. Sieve analysis was carried out on mixtures of laterite and granite aggregate at 0, 25%, 50%, 75%, and 100%. The S-curve for granite and laterite aggregates is shown in Figure 2. The laterite aggregate exhibits a flaky and elongated shape, characterized by a rough surface texture. It possesses a fineness modulus of 3.1 and a water absorption rate of 2.56%. Furthermore, it is free from silt and organic impurities.

Fig. 1 Laterite aggregate

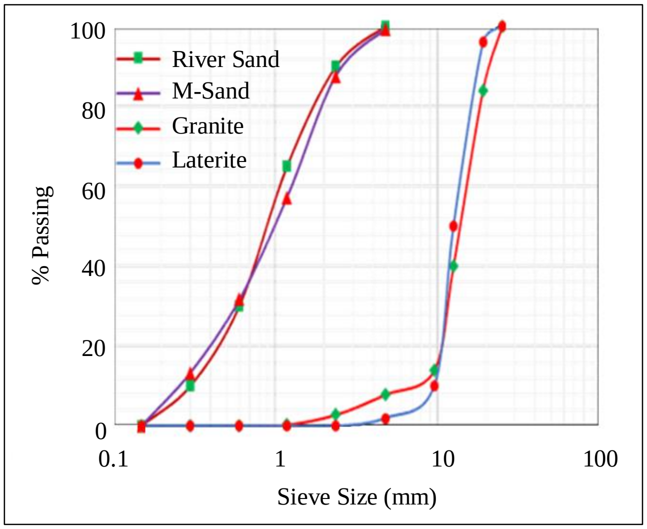


Fig. 2 Gradation curve

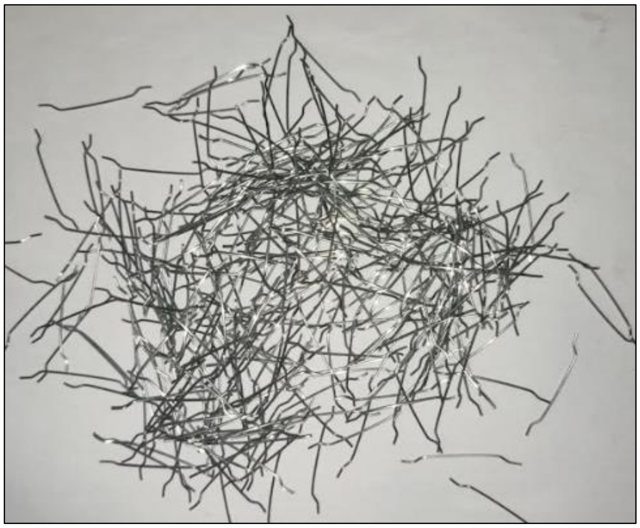


Fig. 3 Hook-end steel fiber

2.4. Characteristics of Steel Fiber

The concrete was reinforced using hook-end-shaped steel fibres, as depicted in Figure 3. The fibres measured 30 mm in length and 0.6 mm in diameter. These fibres were added to increase the concrete's tensile strength.

2.5. Characteristics of Admixture

The Aura-mix 500 is a unique blend consisting of a polycarboxylic ether polymer with extended lateral chains. The purpose of this superplasticizer is to meet the requirements for significant water reduction and long-lasting workability retention. The performance of the system is outstanding. FORSOC Chemicals, an Indian company, carries out the sourcing of Auramix 500.

2.6. Mix Design

The mix ratio approach used to obtain M25 grade concrete is based on Indian Standard IS 10262-2019 [23]. Table 3 shows the quantities of components necessary to make the specified composition. For the M25 grade, a w/c proportion of 0.5 was utilized. The study employed mixing identities L0-L100, where 'L' represents laterite and 0-100 represents the percentage of laterite aggregate substitution in the different mixtures, specifically set at 25%. This research is primarily concerned with the effect of steel fibres on lateritic concrete. In all the mixtures examined here, an addition of 2% steel fibre by weight of mould is used.

3. Experimental Program

The fresh properties are evaluated by conducting a slump test. The test is carried out in accordance with the methods outlined in the Indian Standard, IS 1199-1959. Utilizing a 2000 KN load capacity Compression Testing Machine (CTM), compression testing is performed on hardened concrete.

The sample is progressively loaded until it fails. By dividing the load at failure by the specimen cross-sectional area, we may determine the material's ultimate compressive strength. Test specimens for this study were concrete cubes measuring 150 x 150 x 150 mm, in accordance with IS 516-1959 [25].

Three sets of cubes are produced and water-cured for seven to twenty-eight days. The concrete cube's cross-sectional area is subjected to the ultimate load percentage to determine its average compression strength. Because direct tension testing is complex, the tensile strength of concrete is assessed via split-tensile and flexural tests. For flexural strength testing, concrete samples with dimensions of 100 x 100 x 500 mm prisms and 150 x 300 mm (diameter x height) cylinders are used. After seven and eighteen days of curing, these samples are evaluated. The tensile strength of concrete is measured by carrying out a test using a cylindrical specimen that has a longitudinal split along its vertical diameter.

Table 1. Chemical composition of cement

Minerals Composition (%)	SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	MgO	SO_3	Na_2O
Cement	20.65	5.94	4.13	64.12	0.54	1.48	1.75	0.24

Table 2. Physical properties of fine and coarse aggregate

Sl. No.	Physical Properties	M-Sand	Granite	Laterite
1	Shape	Angular	Rounded	Flaky and Elongated
2	Texture	Rough	Rough	Rough
3	Fineness Modulus	3.06	3.6	3.1
4	Bulk Density (kg/m^3)	1752	1668	1931
5	Specific Gravity	2.54	2.63	2.56
6	Water Absorption	1.98%	0.92%	1.048%
7	Silt and Organic Impurities	Absent	Absent	Absent
8	Elongation Index	-	6.3	7.6
9	Flakiness Index	-	6.2	8.1
10	Aggregate Impact Value (%)	-	26.6	29.3
11	Aggregate Crushing Value (%)	-	29.7	31.3
12	Ten Percent Fines (%)	-	8.7	10.3
13	Moisture Content (%)	-	0.47	0.53

Table 3. Mix ratio of concrete

Mix	Steel Fibre (%)	W/C Ratio	Cement (kg/m^3)	M-Sand (kg/m^3)	Granite Aggregate (kg/m^3)	Laterite Aggregate (kg/m^3)	Water (kg/m^3)
L_0	2	0.5	310	620	1240	-	155
L_{25}	2	0.5	310	620	930	310	155
L_{50}	2	0.5	310	620	620	620	155
L_{75}	2	0.5	310	620	310	930	155
L_{100}	2	0.5	310	620	-	1240	155

Table 4. Fresh and mechanical strength properties

Mix	Slump (mm)	Compressive Strength (MPa)		Split-Tensile Strength (MPa)	Flexural Strength (MPa)
		7 Days	28 Days	28 Days	28 Days
L_0	90	19.92	29.24	2.62	3.21
L_{25}	75	23.46	34.72	2.94	3.62
L_{50}	55	19.46	28.78	2.78	3.48
L_{75}	30	18.24	26.68	2.51	2.96
L_{100}	15	14.98	21.84	2.45	2.74

4. Results and Discussion

4.1. Slump Test

Table 4 displays the values of fresh and mechanical strength properties. Figure 4 displays the concrete slump parameters, which represent its workability. The fresh concrete with laterite and granite aggregates as coarse aggregate had slump values of 90 to 15 mm, respectively. Slump tests revealed that the workability of freshly reinforced lateritic concrete with fibre reinforcement had slump values that were lower than those of the control concrete. With an increase in the proportion of laterite and steel fibres, the slump value falls. This outcome suggests that when laterite aggregates are added, the workability of the concrete decreases. As a result, to make the mixtures workable, additional water is required. Due to these aggregates' greater rate of water absorption and more significant porosity than granite counterparts, the laterite concrete mix's workability is most likely lowered. M-sand has comparable characteristics. Table 3 lists the tests that look at workability parameters with the designated limits.

4.2. Compressive Strength

Figure 5 illustrates the outcomes of a compression strength test conducted on lateritic concrete reinforced with steel fibres. It has been shown that the substitution of laterite with granite aggregate at a proportion of 25% results in an improvement in compressive strength. However, when the amount of replacement rises further, the strength decreases. Concrete mixes containing 2% steel fiber, 25% laterite aggregate, and M-sand obtained 17.77% and 18.74% greater compressive strength than the control mixture at 7 and 28 days, respectively.

Lateritic concrete has a more significant compressive strength percentage increase compared to control mixtures. It is premised on the concept that extending the curing period will speed up hydration and increase compressive strength. The rough surface of the laterite aggregate and M-sand was the main reason for this strength improvement when optimal replacement (25%) of laterite was added.

The use of steel fibre at a concentration of 2% has been seen to enhance the compressive strength of concrete. In contrast, laterite has a rich clay content and greater additions of laterite (more than 50%) have higher fineness values, which can increase air entrapment owing to void development, which results in a strength drop.

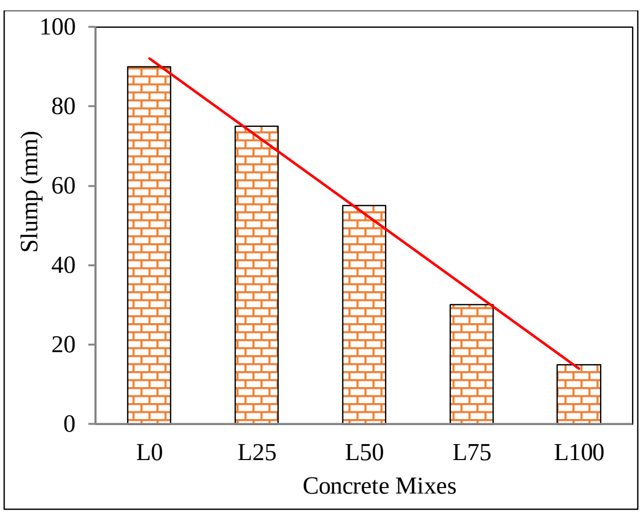


Fig. 4 Slump test

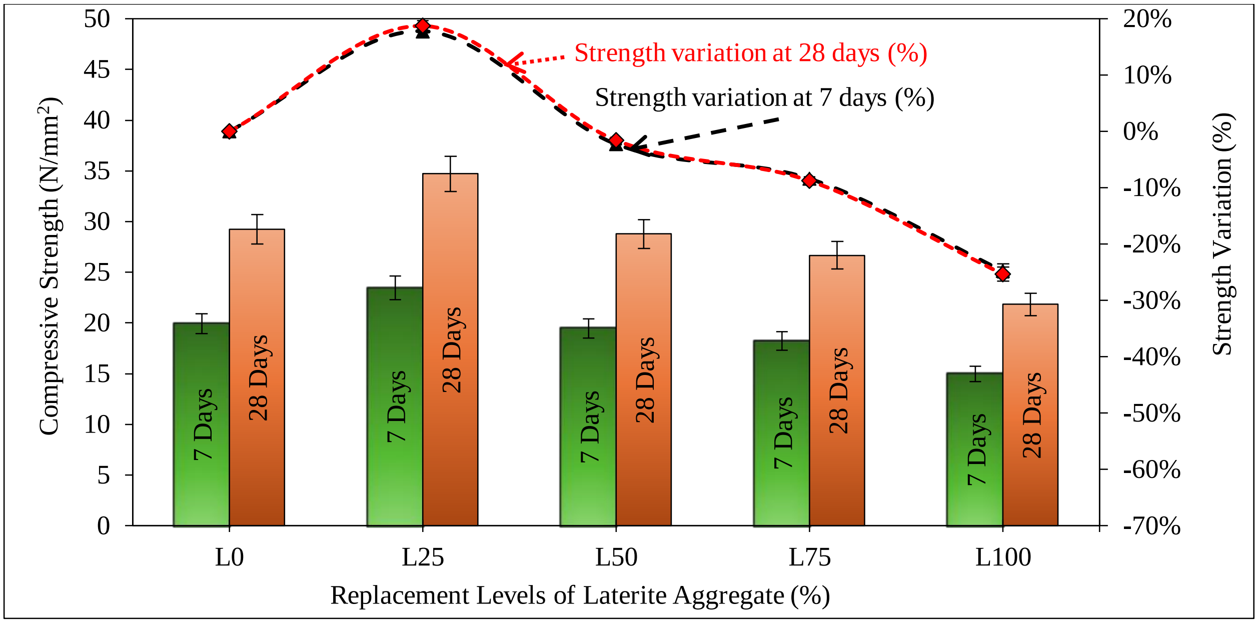


Fig. 5 Compressive strength for 7, and 28 days

4.3. Split-Tensile and Flexural Strength

As a result of the limitations of direct tension testing, flexural and split-tensile strength measurements are utilized to evaluate the tensile strength of concrete. Figure 6 depicts the flexural and split-tensile strengths of the concrete mixtures. With increasing curing time, the values of flexural and tensile strengths rise as well, similar to the results seen for compressive strength.

The L25 mix (which contained 25% laterite) produced higher results, as expected. For 28 days of split-tensile and flexural strength tests, an estimated strength improvement of 12.21% and 12.77% compared to control concrete (L_0) is achieved. The strength values increased until 50% of the material was replaced by laterite, at which point they began to decline. The primary cause of the increased splitting tensile strength of concrete is the inclusion of 2% steel fibre.

Additionally, the control mix's aggregate-paste bonding is improved by the rough surface of laterite aggregate and M-sand, and the crushed laterite aggregate and M-sand have a more significant impact on flexural strength than on compressive strength, which accounts for the significantly higher flexural strength.

4.4. Microstructural Studies

The Scanning Electron Microscopy (SEM) analysis of the M25 grade concrete mixture with an optimal mix containing 25% laterite aggregate is presented in Figures 7(a) and 7(b). The Interfacial Transition Zone (ITZ) between cement paste and aggregates, along with the strength of coarse aggregates, significantly influences the mechanical properties.

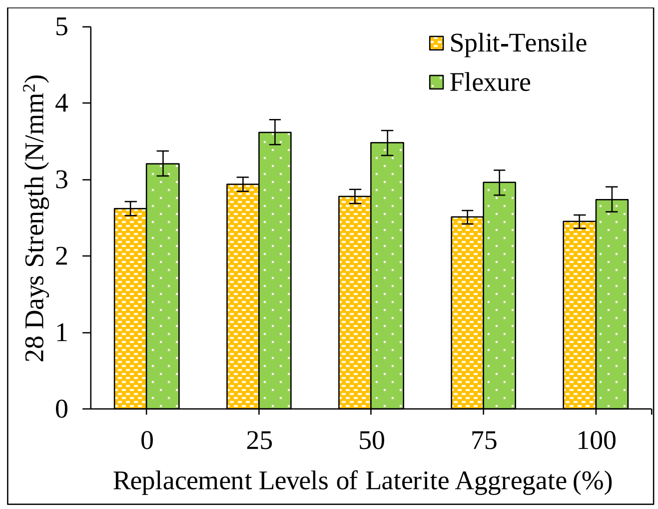
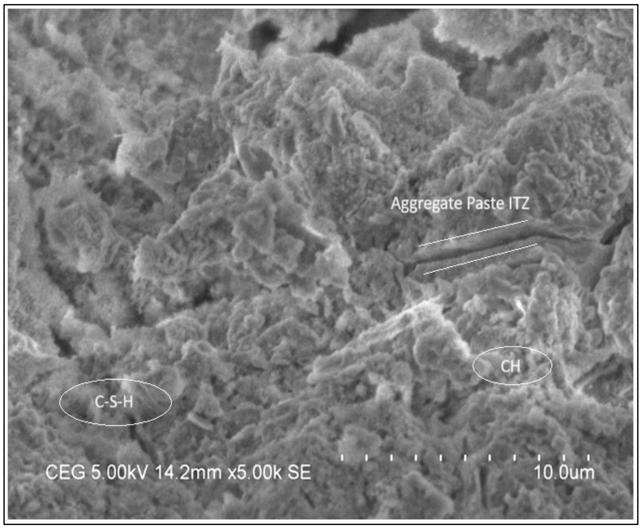
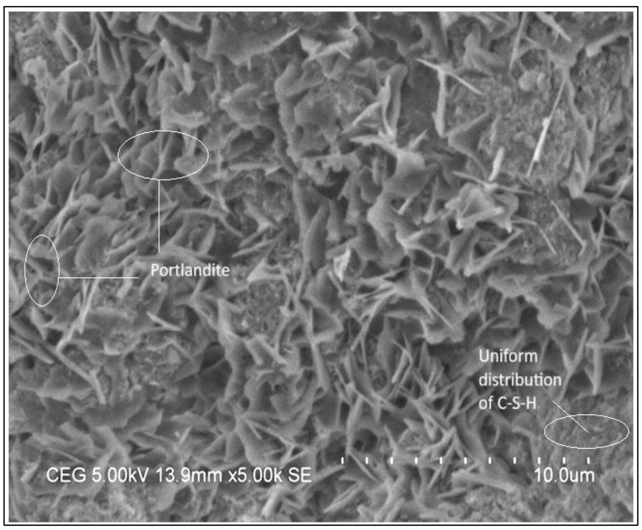


Fig. 6 Split tensile and flexural strength for 28 days

The mechanical and physical properties of cement-based products are significantly influenced by the Interfacial Transition Zone (ITZ) despite its relatively low proportion in cured concrete. The microstructure of the aggregate-paste contact is dense, as depicted in Figure 7(a). The objective of this study is to investigate the potential of aggregates with rough surfaces to enhance the bonding in lateralized concrete by penetrating through the large surface pores of the concrete mixture. The hexagonal crystals observed in the laterized concrete mixture exhibit characteristics similar to those of portlandite, as depicted in Figure 7(b). The presence of portlandite is commonly observed in AFm phases, where iron, hydroxide, and carbonate ions substitute for aluminium within the structural framework.



(a)



(b)

Fig. 7 SEM images of optimal mix laterized concrete

5. Conclusion

- The physical characteristics of the M-sand and laterite aggregate employed in this investigation were discovered to be comparable to those of river sand and granite aggregate. Furthermore, the properties of laterite and M-sand meet the specified standards.
- The steel fibre-reinforced lateritic concrete mixture's workability is reduced because laterite is absorptive; adding it to the matrix reduces its workability. The addition of supplementary cementitious materials such as fly ash, rice husk, and silica fumes to the mixture, along with a superplasticizer, may improve its workability.
- Concrete's compressive strength is improved by laterite substitution by up to 25%, while more excellent additions reduce the strength. Compressive strength was raised by 17.77% and 18.75% after seven and twenty-eight days, respectively, as measured by the conventional mix. The formation of C-S-H gel in lateritic concrete is increased, which enhances strength properties and is primarily responsible for the enhancement of compressive strength with lateritic particles.
- The values of flexural and split-tensile strength likewise rise with curing time, similar to the results seen for compressive strength. The L25 mix (which contained 25% laterite) produced higher results, as expected. For split-tensile and flexural strength experiments conducted over 28 days, an estimated strength gain of 12.21% and 12.71% is attained compared to control concrete (L_0). The strength values increased until 50% laterite substitution, at which point they began to decline.
- The addition of steel fibre to concrete enhances ductility, fatigue life, and crack width under fatigue stress.

The study found that the cost of making lateritic concrete was significantly decreased by employing laterite aggregates, a common naturally occurring resource. Since lateritic concrete mixes consume much less energy, they also generate less harmful pollutants and other sorts of pollution. As a result, using lateritic aggregates as coarse aggregate in addition to M-sand lowers the cost of producing concrete as well as some of its adverse environmental effects, including greenhouse gas releases, pollution, the reduction of natural resources, and the loss of biodiversity.

5.1. Future Research

This research focuses on the characteristics of steel fiber-reinforced lateritic concrete for M-25 grade. Many things can be done, including studying the microstructure and thermal behaviour of lateralitic concrete for different grades of concrete. One drawback of utilizing laterite as the coarse aggregate in concrete is the decreased workability. Testing different mineral admixtures in lateritic concrete, such as micro-silica, nano-silica, rice husk ash, and GGBS, may provide a solution to this issue. Superplasticizers are also employed to make the concrete easier to work with. More research into the efficacy of laterite and fibre-based high-strength concrete is also possible.

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