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ENHANCING THE PERFORMANCE OF CINDER-BASED LIGHTWEIGHT CONCRETE THROUGH CARBON FIBER AND NANO $CaCO_3$ ADDITIONS: A SUSTAINABLE SOLUTION FOR CONSTRUCTION AND WASTE MANAGEMENT

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Abstract

The present work studies the viability of using industrial waste such as cinder to develop lightweight aggregate concrete. The lightweight concrete using cinder aggregate as a substitute material in producing concrete for an alternative to conventional coarse aggregate aids in conserving natural resources. This research explores the feasibility of using 100% replacement of cinder as a fine aggregate in concrete to meet the strength requirements for various applications in sustainable construction. The characteristics like mechanical and physical properties including gradation, specific gravity, aggregate strength, water absorption, shape and texture tests, play crucial roles in determining concrete mechanical strength and microstructural properties. The properties of cinder lightweight aggregate is generally influenced by the loading and exposure conditions. The experimental program focused on assessing the mechanical characteristics of cinder lightweight aggregate concrete incorporating cement of OPC 53 grade, Nano CaCO3 and carbon fiber in volume proportions with the variation from 0.4%, 0.6%, 0.8%, 1%, and 1.2%. The conducted experimental investigations on the carbon fiber reinforced cinder based lightweight concrete included compressive strength test on cube specimen, split tensile test on cylinder specimen, flexural strength test on prism specimen. This study evaluated the mechanical and microstructural properties of concrete by utilizing the 100% cinder as a coarse aggregate with the variation of 0% to 5% of Nano Calcium Carbonate (Nano $CaCO_3$). Mineralogical and microstructural characteristics have been performed through X- ray Diffraction (XRD) and Scanning Electron Microscopy (SEM) for optimum mix combination of the concrete. The Results indicated that concrete with benefitted strength could be achieved through the complete replacement of lightweight coarse aggregate (Cinder) with Natural Coarse Aggregate (NCA), supplemented with 2% Nano $CaCO_3$ and 1% Carbon fibers.

Keywords: Lightweight Aggregate (LWA), Cinder Aggregate, Nano CaCO3 and Carbon Fibers, Lightweight Concrete, X-ray Diffraction (XRD), Scanning Electron Microscopy (SEM).

1. INTRODUCTION

One of the building materials widely utilized all over the world is concrete. As a result of advancements in the building industry, material substitution, and technical advancements, concrete's qualities are changing. In order to support sustainable urbanization expansion and infrastructure advancements. K Sadhana et.al [1] encourage the researchers to look for lightweight concrete with higher strength and durability for sustainable urbanization growth and infrastructural developments. Meena R et.al [2] invented Lightweight concrete (LWC), which is utilized in several fields of construction. This study has several immensely important applications, like curtain walls, shell roofs, folded plates frames, bridges, offshore oil platforms, and floors, and precast. Compared to regular concrete, the strength of LWC is 25 to 35% higher. With the rapid development of tall buildings, large-scale long-span concrete structures, the increased strength and toughness can be explored by using LWC, which is needed for better structural performance. Khalil, W.I., et al [3] found an increasing trend in the usage of natural volcanic materials, including pumice and ash. They can contribute to reduced construction costs when utilized in construction.

The modern use of lightweight aggregate (LWA) in concrete helps to reduce the load transmitted to the foundations by lightening the weight of various structural members. Nellore Bindu Sai [4] studies how the structural integrity is increased by the different fibrous materials in LWC. This fiber-reinforced concrete contains Steel, glass, synthetic, and natural fibers that are uniformly distributed and randomly oriented. The behavior of fiber reinforced concrete is influenced by concrete mix, type of fiber used, and the fibers distribution, orientation, and density. Concrete has a property of resistance against compressive loads, but is weak in resisting tensile loads which causes the cracks. Carbon fibers were mostly used as a substitute for secondary reinforcement in industrial floor slabs and prefabricated concrete elements. The use of Carbon fiber-reinforced concrete (CFRC) has significantly increased in recent years in the construction industry in pavements, roads, foundation slabs, tunnel segments, and concrete cellars as an effective alternative to conventional reinforcement. Mingli Cao [5] has studied that in recent years, due to the accelerated development of concrete technology, concrete is now the most extensively used structural material in building. However, manufacturing Portland cement results in the production of carbon dioxide (CO2), which intensifies the greenhouse effect.

The environmental problems caused by cement production are therefore attracting an increasing amount of attention from researchers. The most effective technique for lowering the carbon emissions of cement is to reduce the production and usage of cement. Alternative cementing materials or mineral admixtures such as calcium carbonate and silica fume have been utilized as partial substitution for cement, and these materials reduce CO2 emissions. Micro-calcium carbonate and Nano-calcium carbonate are common mineral admixtures, and they have the advantages of a relatively reasonable cost, high efficiency, and availability from a wide range of sources. The studies shown that Micro-calcium carbonate and Nano-calcium carbonate have a substantial impact on the microstructure and concrete's mechanical characteristics. Camiletti et.al [6]. Examined that Calcium carbonate has shown an ability to accelerate the hydration process of Portland cement. CaCO3 usually has no chlorides and can readily be found, for instance, in chalk and marble, or produced artificially by combining calcium and carbon dioxide. Yanjin Liu [7] the present review focused on the function of carbon nanomaterial's in properties of reinforcement in concrete and mechanical properties like a high tensile

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strength. Md Azree Othuman Mydin [8] have shown significant interest in the incorporation of Nanoscale components into concrete, primarily driven by the unique properties exhibited by these Nano elements. A nanoparticle comprises numerous atoms arranged in a cluster ranging from 10 nm to 100 nm in size. The brittle characteristics of foamed concrete (FC) it can be efficiently mitigated by incorporating nanoparticles, thereby improving its overall properties.

The experimental investigation goal is to analyze the effects of incorporating calcium carbonate nanoparticles (CCNPs) into FC on its durability and mechanical characteristics. The results suggested that incorporating CCNPs into FC enhanced its mechanical and durability properties, with the most optimal improvement observed at the CCNPs addition of 4%. Compared to the control specimen, it was observed that specimens containing 4% CCNPs demonstrated remarkably higher capacities in the flexural, splitting tensile, and compressive tests, with the increases of 66%, 52%, and 59%, respectively.

Dejian Shen et.al.[9] analyzed the Nano-calcium carbonate (CaCO3) has been added to high strength concrete (HSC) to reduce cement usage, control greenhouse gas emissions, increase durability, and control excessive shrinkage of HSC. Many investigations on the mechanical properties and shrinkage of HSC containing nano-CaCO3 have conducted. However, the early-age cracking failure behavior of that considering temperature, shrinkage, restrained stress, and tensile creep simultaneously was rarely investigated. Temperature stress test machine, which could measure these factors simultaneously, was used to examine the impact of nano-CaCO3 contents (0%, 1%, 2%, and 3% by weight of cement powder) on the early-age cracking failure behavior of HSC in the present investigation. Mechanical properties of HSC containing nano-CaCO3 were tested.

The addition of nano-CaCO3 to HSC improved the mechanical properties, and reduced the tensile creep as well as autogenous shrinkage of that at early age. A simplified stress-strain failure criterion was proposed. Xiaoyan Liu [10] in the study effect of nano-CaCO3 (NC) on properties of cement paste was studied. Experimental results showed that NC had no effect on water requirement of normal consistency of cement. However, with the increase of NC content, the flow ability decreased and the setting time of fresh cement paste was shortened. The early hydration of cement was activated by NC.

The strength and the early age shrinkage of cement paste were also studied. Mechanical experiments showed that the compressive and flexural strength of hardened concrete increased with the addition of NC at the age of 7d and 28d, and the optimal content of NC was 1%. The early strength at (12h) shrinkage property of cement paste containing 1% NC was the most prominent which could decrease the shrinkage strain.

To address the above authors' concerns about CO2 emissions, this study examines how to incorporate nano-calcium carbonate into LWC can improve its performance in the mechanical properties. This study investigates the carbon fiber-reinforced LWC elements using cinder as a full substitute for natural coarse aggregate.

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2. NANO $CaCO_3$ SUBSTITUTION PROPORTION

To ascertain the ideal proportion of the Nano CaCO3 substitution for achieving optimum strength, we are examining six percentage variations, ranging from 0 to 5%, with increments of 1%. Detailed Substitution of Nano CaCo3 in Conventional M25 grade concrete and compressive strength values are tabulated in Table 1. The mix design is formulated to determine the optimum compressive strength in six variant mixes with Nano CaCO3 substitution. These mixes are considering with 100% natural coarse aggregate and manufactured sand (Natural fine aggregate) without light weight cinder aggregate and the substitution of Nano CaCo3 with addition of Carbon fiber in Conventional M25 grade concrete and its values of compressive strength is illustrated in Table 2. The outcome at the 28day age for the CM3 and CMF1.0% mix reveals the highest compressive strength of 35.68 MPa achieved with a 2% inclusion of the Nano $CaCo_3$ which is tabulated in Table 1 and 36.89 MPa achieved with a 2% inclusion of the Nano $CaCo_3$with 1% of Carbon fiber are presented in Table 2. Upon interpreting these findings, the decision has been made to include 2% of the $NaCO_3$ and 1% Carbon fibre in subsequent design mix studies to fulfill the outlined research objectives.

Table 1: Substitution of Nano CaCo3 in Conventional M25 grade concrete and its Compressive Strength.

Designation	Cement in kg/m³	Nano $CaCO_3$ in %	Manufactured sand %	Natural Coarse Aggregate in %	Combinations	Compressive strength @ 7days in MPa	Compressive strength @ 28days in MPa
CM1	350	0	100	100	100C+0%NCC	20.52	30.78
CM2	346.5	1	100	100	99C+1%NCC	22.68	33.98
CM3	343	2	100	100	98C+2%NCC	23.88	35.68
CM4	339.5	3	100	100	97C+3%NCC	23.61	35.50
CM5	336	4	100	100	96C+4%NCC	22.19	34.89
CM6	332.5	5	100	100	95C+5%NCC	21.66	32.64

Table 2: Substitution of Nano CaCo3 with addition of Carbon fiber in Conventional M25 grade concrete and its Compressive Strength

Designation	Cement in kg/m³	Nano $CaCO_3$ in %	Carbon Fibers %	Manufactured sand %	Natural Coarse Aggregate %	Combinations	Compressive strength @ 7days in MPa	Compressive strength @ 28days in MPa
CMF0.4%	343	2	0.4	100	100	100C+2%NCC+ 0.4%CF	19.32	29.78
CMF0.6%	343	2	0.6	100	100	100C+2%NCC+ 0.6%CF	22.24	33.21
CMF0.8%	343	2	0.8	100	100	100C+2%NCC+ 0.8%CF	25.76	36.49
CMF1.0%	343	2	1.0	100	100	100C+2%NCC+ 1.0%CF	29.67	36.89
CMF1.2%	343	2	1.2	100	100	100C+2%NCC+ 1.2%CF	27.67	34.42

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3. MECHANICAL PROPERTIES

Concrete's mechanical properties are encompassing a range of characteristics that reflect how material behaves under different loading scenarios. Compressive Strength, split tensile strength and flexural strength are important mechanical characteristics of concrete

3.1 Compressive Strength

One most important characteristics of concrete is compressive strength that measures its ability to withstand axial loads or forces applied along its axis. It is one of the most significant parameters used to measure the performance of the concrete in various structural applications. In the present study, cubes measuring 150 mm x 150 mm x 150 mm underwent compressive strength testing at intervals of 7, 14 and 28 days. Eighteen (CMF1-CMF18) different mix combinations are analyzed with mix which have Nano CaCO3 substitution from 1% to 5% with the addition of Carbon fiber from 0.8% to 1.2% in Conventional M25 grade concrete. Another eighteen mix combinations (LWF1-LWF18) with the same substitution percentages of Nano CaCo3 and carbon fiber by considering the cinder light weight aggregate in concrete with M25 grade has been compared with the Conventional M25 grade concrete.

Nano $CaCO_3$ have been used in the mix as cementations material to get the good compressive strength for the LWC. The progression in compressive strength for both combination mixes (CMF and LWF) at the age of 7, 14 and 28 days are presented in Table 3 and Table 4.

Table 3: Conventional M25 grade Carbon fiber reinforced Nano CaCo3 concrete and its Compressive Strength

Designation	Cement in kg/m3	Nano CaCO3 in %	Carbon Fibers%	Manufactured sand %	Natural Coarse Aggregate %	Combinations	Compressive strength		
							@7days in MPa	@14days in MPa	@28days in MPa
CMF1	350	0	0.8	100	100	100C+0%NCC+0.8%CF	20.98	27.72	34.64
CMF2	346.5	1	0.8	100	100	99C+1%NCC+0.8%CF	25.76	29.99	36.22
CMF3	343	2	0.8	100	100	98C+2%NCC+0.8%CF	21.58	28.98	36.49
CMF4	339.5	3	0.8	100	100	97C+3%NCC+0.8%CF	23.11	26.25	35.31
CMF5	336	4	0.8	100	100	96C+4%NCC+0.8%CF	18.69	26.03	32.53
CMF6	332.5	5	0.8	100	100	95C+5%NCC+0.8%CF	31.13	28.21	35.27
CMF7	350	0	1	100	100	100C+0%NCC+1%CF	29.67	29.00	36.89
CMF8	346.5	1	1	100	100	99C+1%NCC+1%CF	35.89	27.11	34.13
CMF9	343	2	1	100	100	98C+2%NCC+1%CF	23.11	24.25	36.89
CMF10	339.5	3	1	100	100	97C+3%NCC+1%CF	20.13	23.62	35.4
CMF11	336	4	1	100	100	96C+4%NCC+1%CF	21.36	25.52	34.9
CMF12	332.5	5	1	100	100	95C+5%NCC+1%CF	27.67	27.36	34.2
CMF13	350	0	1.2	100	100	100C+0%NCC+1.2%CF	24.89	25.86	34.32
CMF14	346.5	1	1.2	100	100	99C+1%NCC+1.2%CF	23.11	24.96	33.2
CMF15	343	2	1.2	100	100	98C+2%NCC+1.2%CF	20.13	24.10	34.42
CMF16	339.5	3	1.2	100	100	97C+3%NCC+1.2%CF	20.98	27.72	34.04
CMF17	336	4	1.2	100	100	96C+4%NCC+1.2%CF	25.76	29.99	33.49
CMF18	332.5	5	1.2	100	100	95C+5%NCC+1.2%CF	21.58	28.98	33.22

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Table 4: Cinder Light weight aggregate-based Nano CaCo3 Carbon fiber reinforced concrete M25 grade and its Compressive Strength

Designation	Cement in kg/m³	Nano $CaCO_3$ in %	Carbon Fibers %	Manufactured sand %	Cinder in %	Combinations	Compressive Strength in MPa		
							@7days	@14days	@ 28 days
LWF1	350	0	0.8	100	100	100C+0%NCC+0.8%CF	20.22	21.91	29.55
LWF2	346.5	1	0.8	100	100	99C+1%NCC+0.8%CF	19.28	20.97	32.62
LWF3	343	2	0.8	100	100	98C+2%NCC+0.8%CF	20.58	22.55	34.25
LWF4	339.5	3	0.8	100	100	97C+3%NCC+0.8%CF	23.18	26.88	34.08
LWF5	336	4	0.8	100	100	96C+4%NCC+0.8%CF	24.78	27.33	33.49
LWF6	332.5	5	0.8	100	100	95C+5%NCC+0.8%CF	19.04	23.25	31.33
LWF7	350	0	1	100	100	100C+0%NCC+1%CF	18.88	24.67	33.25
LWF8	346.5	1	1	100	100	99C+1%NCC+1%CF	23.18	26.69	34.07
LWF9	343	2	1	100	100	98C+2%NCC+1%CF	21.42	25.79	34.77
LWF10	339.5	3	1	100	100	97C+3%NCC+1%CF	20.80	23.36	33.90
LWF11	336	4	1	100	100	96C+4%NCC+1%CF	16.82	23.17	31.23
LWF12	332.5	5	1	100	100	95C+5%NCC+1%CF	28.02	25.11	33.86
LWF13	350	0	1.2	100	100	100C+0%NCC+1.2%CF	26.70	25.81	35.41
LWF14	346.5	1	1.2	100	100	99C+1%NCC+1.2%CF	32.30	24.13	31.80
LWF15	343	2	1.2	100	100	98C+2%NCC+1.2%CF	20.80	21.58	32.94
LWF16	339.5	3	1.2	100	100	97C+3%NCC+1.2%CF	18.12	21.02	31.45
LWF17	336	4	1.2	100	100	96C+4%NCC+1.2%CF	19.22	22.71	32.54
LWF18	332.5	5	1.2	100	100	95C+5%NCC+1.2%CF	24.90	24.35	32.83

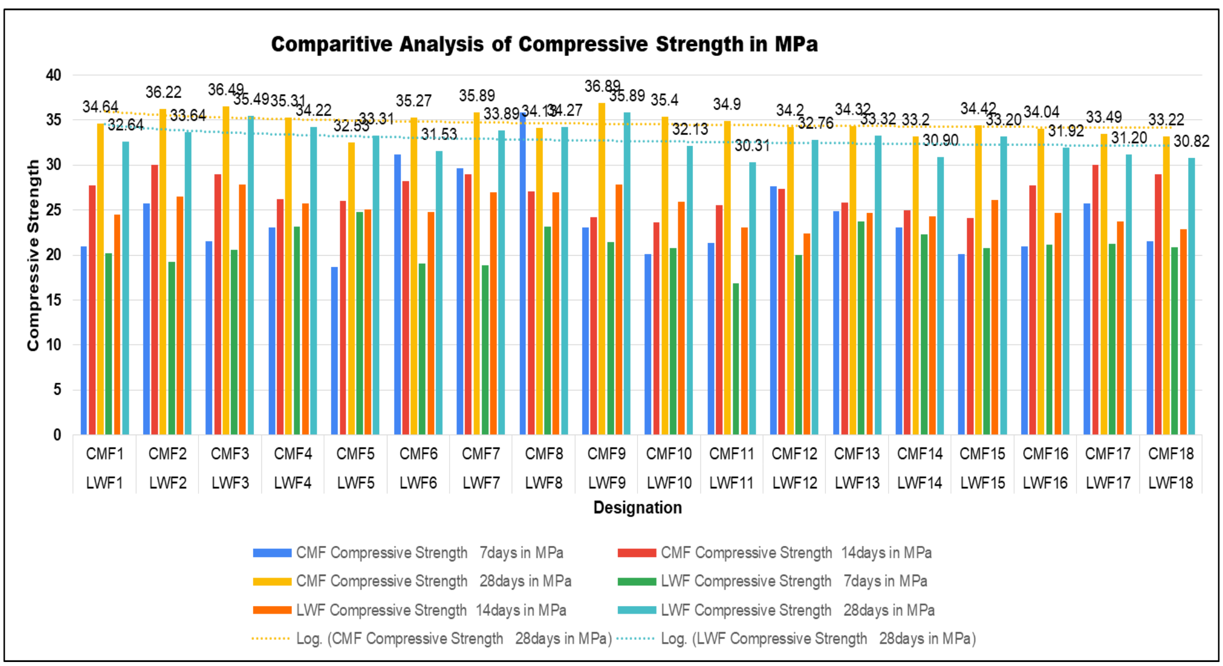

Figure 2: Comparative analysis of Compressive strength of M25 grade of CMF and LWF

The Compressive strength analysis from the results showing that the LWF9 combination mix with 2% Nano CaCO3 and the 1% of carbon fiber showing benefited strength for M25 grade concrete performing approximately equal with Conventional mix of M25 grade

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CMF9 concrete. Notably, LWF9 make evident a commendable strength of 34.77MPa at 28 days. So this study confirms that the Nano CaCO3 enhances the strength property in the concrete mix. This Nano $CaCO_3$ helps in improving the early and long-term strength, which qualifies them suitable for structural applications and also helps in weight reduction and strength optimization. Incorporation of Nano $CaCO_3$ can contribute to sustainable reduction in cement content while maintaining or improving strength characteristics.

3.2 Split tensile strength

The split tensile strength test is performed on concrete to evaluate its tensile strength, which is a measure of the material resistance to tensile forces. In this investigation, split tensile strength is evaluated using 150mm * 300mm cylinders at various ages of 7, 14 and 28 days. This experimental investigation has been done to perform the split tensile strength test and obtained results are detailed in Table 5. tensile strength test of M25 grade Cinder Lightweight aggregate-based Nano $CaCO_3$ Carbon fiber reinforced concrete are graphically represented in Figure 3.

Table 5: Cinder Light weight aggregate-based Nano CaCo3 Carbon fiber reinforced M25 grade concrete and its Split tensile Strength

Designation	Cement in kg/m^3	Nano $CaCO_3$ in %	Carbon Fibers %	Manufactured sand %	Cinder in %	Combinations	Split Tensile Strength in MPa		
							@7 days	@14 Days	@ 28 days
LWF1	350	0	0.8	100	100	100C+0%NCC+0.8%CF	2.32	2.97	3.78
LWF2	346.5	1	0.8	100	100	99C+1%NCC+0.8%CF	2.47	3.08	4.11
LWF3	343	2	0.8	100	100	98C+2%NCC+0.8%CF	2.87	3.59	4.78
LWF4	339.5	3	0.8	100	100	97C+3%NCC+0.8%CF	2.82	3.53	4.70
LWF5	336	4	0.8	100	100	96C+4%NCC+0.8%CF	2.77	3.47	4.62
LWF6	332.5	5	0.8	100	100	95C+5%NCC+0.8%CF	2.71	3.38	4.51
LWF7	350	0	1	100	100	100C+0%NCC+1%CF	2.65	3.24	4.87
LWF8	346.5	1	1	100	100	99C+1%NCC+1%CF	3.01	3.76	5.01
LWF9	343	2	1	100	100	98C+2%NCC+1%CF	3.25	4.07	5.42
LWF10	339.5	3	1	100	100	97C+3%NCC+1%CF	2.91	3.63	4.85
LWF11	336	4	1	100	100	96C+4%NCC+1%CF	2.52	3.15	4.20
LWF12	332.5	5	1	100	100	95C+5%NCC+1%CF	2.35	2.94	3.92
LWF13	350	0	1.2	100	100	100C+0%NCC+1.2%CF	2.78	3.43	4.79
LWF14	346.5	1	1.2	100	100	99C+1%NCC+1.2%CF	2.99	3.74	4.98
LWF15	343	2	1.2	100	100	98C+2%NCC+1.2%CF	3.07	3.84	5.12
LWF16	339.5	3	1.2	100	100	97C+3%NCC+1.2%CF	2.79	3.49	4.65
LWF17	336	4	1.2	100	100	96C+4%NCC+1.2%CF	2.52	3.15	4.20
LWF18	332.5	5	1.2	100	100	95C+5%NCC+1.2%CF	2.39	3.58	3.98

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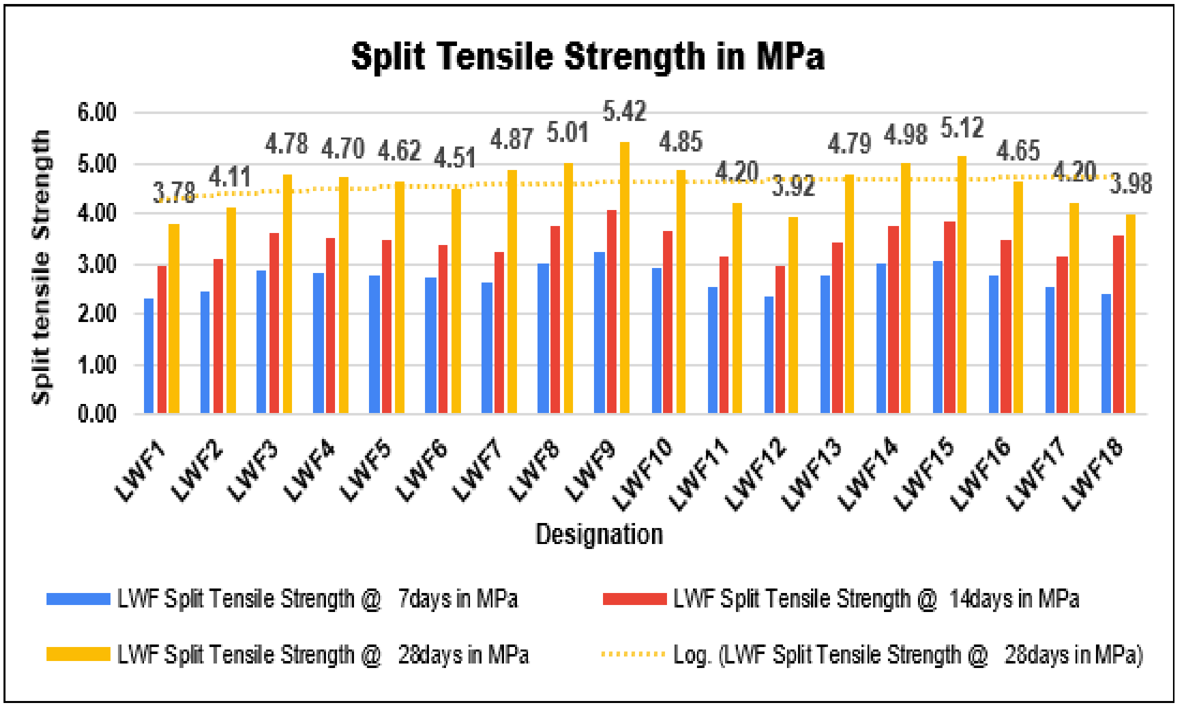

Figure 3: Split tensile strength of M25 grade of CMF and LWF

The Split tensile strength analysis from the results showing that the LWF9 combination mix with 2% Nano CaCO3 and the 1% of carbon fiber showing benefited strength for M25 grade concrete. So this study confirms that the Nano CaCO3 enhances the tensile strength property in the concrete mix with the Carbon fiber addition in the mix.

Notably, LWF 9 make evident a commendable strength of 5.42MPa at 28 days. The addition of 1% carbon fiber in the LWF9 combination mix improves tensile resistance, crack bridging contributing to enhanced structural integrity. These fibers help control micro-cracks, reducing their propagation by enhancing the strength resistivity.

3.3 Flexural strength test

The flexural strength test on prismatic specimens of 100mmx100mmx500mm is essential for a comprehensive assessment of concrete's mechanical properties, particularly its behavior under bending or flexural loads.

Third-point loading was employed on basic concrete prisms to ascertain the flexural strength for all trail mixes. The flexural strength test was conducted on all trial mix formulations at intervals of 7, 14 and 28 days, and the results have been tabulated in Table 6. The variation of flexural strength with respect to carbon fiber percentage is visually depicted in Figure 4.

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Table 6: Cinder Light weight aggregate-based Nano CaCO3 Carbon fiber reinforced M25 grade concrete and its Flexural Strength

Designation	Cement in kg/m^3	Nano $CaCO_3$ in %	Carbon Fibers %	Manufactured sand %	Cinder in %	Combinations	Flexural Strength in MPa		
							@7 days	@14 days	@ 28 days
LWF1	350	0	0.8	100	100	100C+0%NCC+0.8%CF	2.98	3.23	4.32
LWF2	346.5	1	0.8	100	100	99C+1%NCC+0.8%CF	3.21	3.69	4.53
LWF3	343	2	0.8	100	100	98C+2%NCC+0.8%CF	3.55	3.83	4.71
LWF4	339.5	3	0.8	100	100	97C+3%NCC+0.8%CF	3.25	3.77	4.63
LWF5	336	4	0.8	100	100	96C+4%NCC+0.8%CF	3.37	3.59	4.58
LWF6	332.5	5	0.8	100	100	95C+5%NCC+0.8%CF	3.03	3.57	4.39
LWF7	350	0	1	100	100	100C+0%NCC+1%CF	3.78	3.54	4.86
LWF8	346.5	1	1	100	100	99C+1%NCC+1%CF	3.91	3.72	5.14
LWF9	343	2	1	100	100	98C+2%NCC+1%CF	3.81	3.77	5.32
LWF10	339.5	3	1	100	100	97C+3%NCC+1%CF	4.19	3.64	5.17
LWF11	336	4	1	100	100	96C+4%NCC+1%CF	3.37	3.45	5.08
LWF12	332.5	5	1	100	100	95C+5%NCC+1%CF	3.14	3.40	4.99
LWF13	350	0	1.2	100	100	100C+0%NCC+1.2%CF	3.02	3.47	4.67
LWF14	346.5	1	1.2	100	100	99C+1%NCC+1.2%CF	3.24	3.54	4.99
LWF15	343	2	1.2	100	100	98C+2%NCC+1.2%CF	3.68	3.66	5.06
LWF16	339.5	3	1.2	100	100	97C+3%NCC+1.2%CF	4.19	3.56	4.89
LWF17	336	4	1.2	100	100	96C+4%NCC+1.2%CF	3.37	3.50	4.62
LWF18	332.5	5	1.2	100	100	95C+5%NCC+1.2%CF	3.14	3.44	4.75

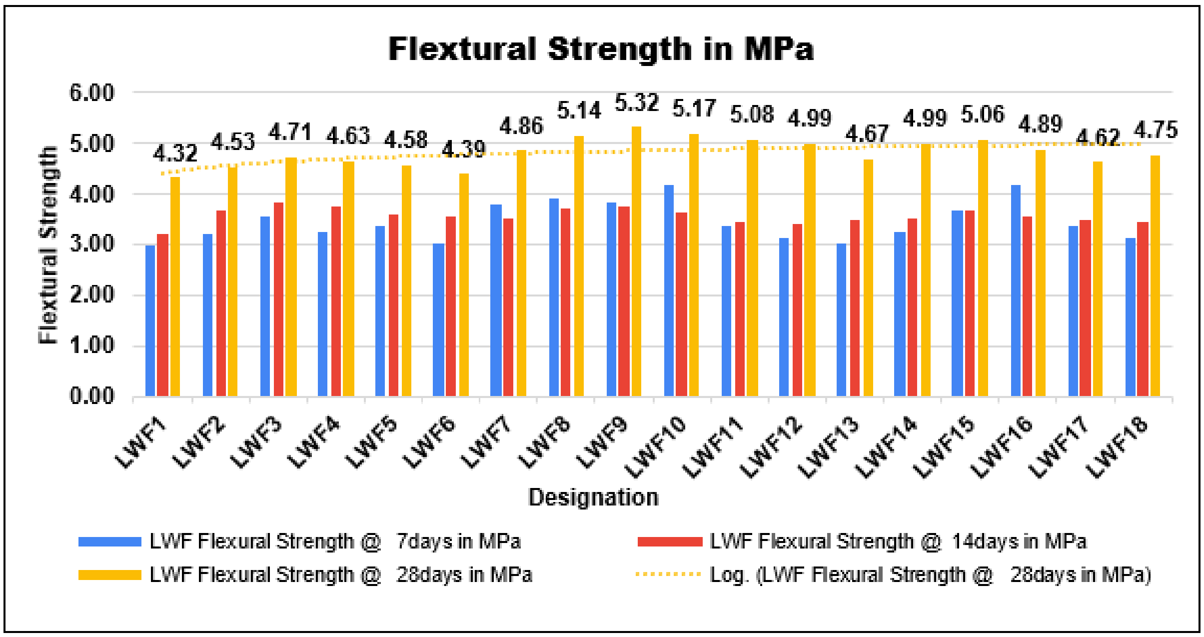

Figure 4: Flexural strength of M25 grade of CMF and LWF

The Flexural strength analysis from the results showing that the LWF9 combination mix with 2% Nano CaCO3 and the 1% of carbon fiber showing benefited strength for M25 grade concrete. So this study confirms that the Nano CaCO3 enhances the strength

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property in the concrete mix by exhibiting a flexural strength of 5.32 MPa at 28 days. This demonstrates that Nano $CaCO_3$ enhances the mix strength and bonding properties, while carbon fibers contribute to crack control and load redistribution. This effect results in higher flexural strength, improved toughness, and making the concrete more appropriate for structural applications such as slabs, beams, and pavements where bending resistance is critical.

4. MICROSTRUCTURAL CHARACTERISTICS

Additional experimental investigations were conducted, morphological tests on light weight aggregate cinder and Carbon fiber and three samples proportions for a comprehensive analysis of microstructural characteristics, such as SEM (Scanning Electron Microscopy).Within this research, the study will involve the analysis of particle morphology, agglomeration, clustering characteristics, and the interfacial transition zone between light weight aggregate cinder and cement in Light Weight Concrete . This analysis, conducted through SEM & EDAX technique, is anticipated to impact the strength parameters and durability performance of the material.

4.1 Microstructural Characteristics of Light weight Coarse Cinder

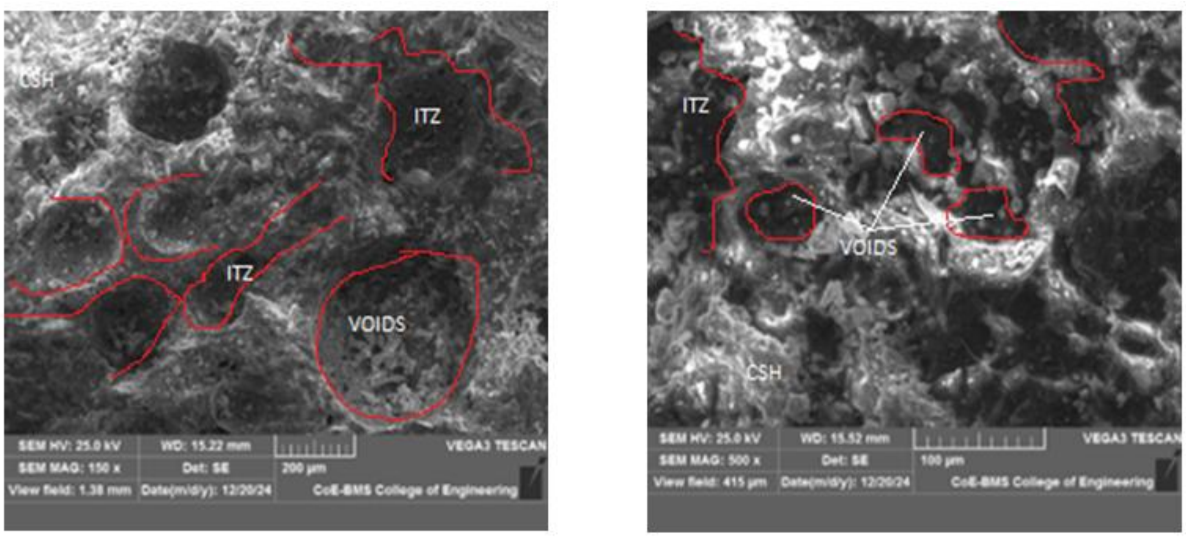

Figure 5: Scanning electron microscopy of the Cinder

The microstructural characteristics of coal combustion cinder as showed in figure 5 was derive from SEM analysis. Its illustrations that the large, irregularly shaped voids and pore characteristic of cinder materials. Voids are formed due to the combustion process, which creates a highly porous structure. The cinder surface is rough and jagged, providing excellent mechanical interlocking potential when used as aggregate in concrete. Smaller particles and debris visible within and around the pores suggest the presence of fine ash or residual combustion products. The high porosity of cinder reduces its bulk density, making it an ideal aggregate for lightweight concrete.

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4.2 Carbon fibers

Scanning electron microscope was used to study the morphology of the sample is as shown in Figure 7. The fiber use in this investigation is 5 mm long, 9 µm in diameter, and has a smooth surface texture with sporadic imperfections. with occasional irregularities. This high carbon content provides strength, stiffness, and lightweight properties by enhancing the mechanical properties and it indicates good carbon purity, essential for high-performance fibers in the concrete mix

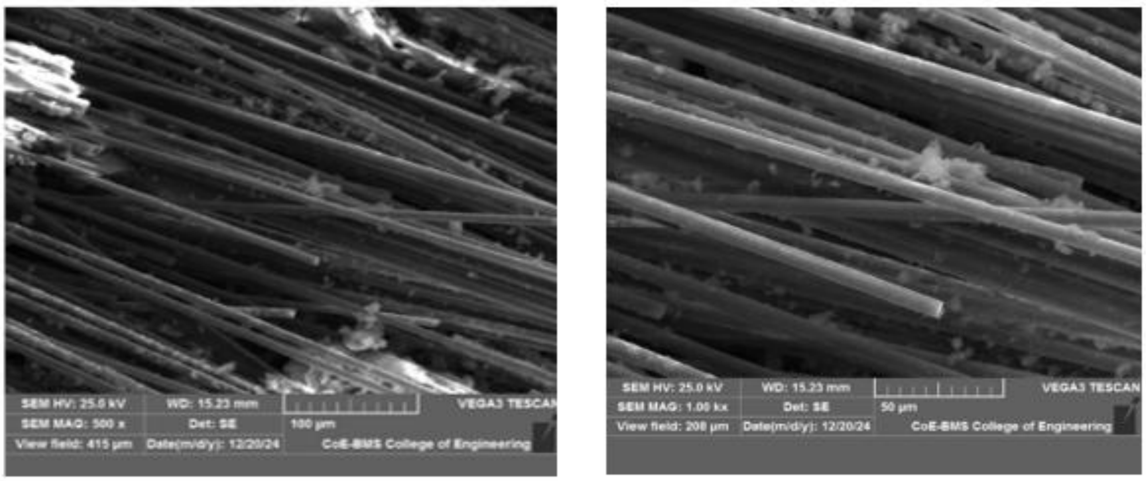

Figure 7: Scanning electron microscopy of the Carbon fiber

4.3 With 2% of Nano Calcium Carbonate

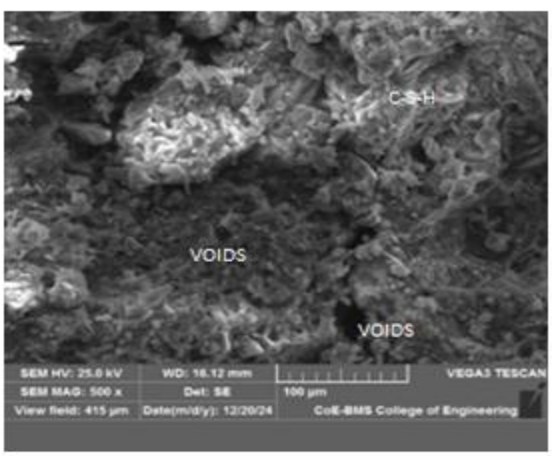

Figure 9: CM3 (98C+2%NCC+0%CF) @ 7days

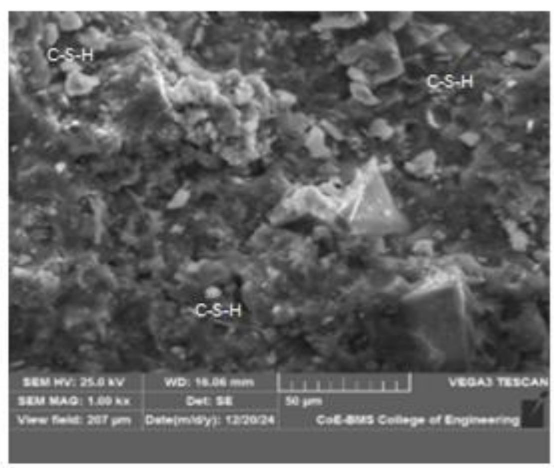

Figure 10: CM3 (98C+2%NCC+0%CF) @ 28 days

The Figure 9 and Figure 10 shows a microstructural characteristic of the conventional concrete with 2% nano calcium carbonate. High amorphous content reflects a dominant C-S-H gel phase with decent bonding with well formation of C-S-H gel at the age of 28

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days as compared with 7day age, this confirms that reduce in the voids and the concrete as dense structure as shown in figure 10.

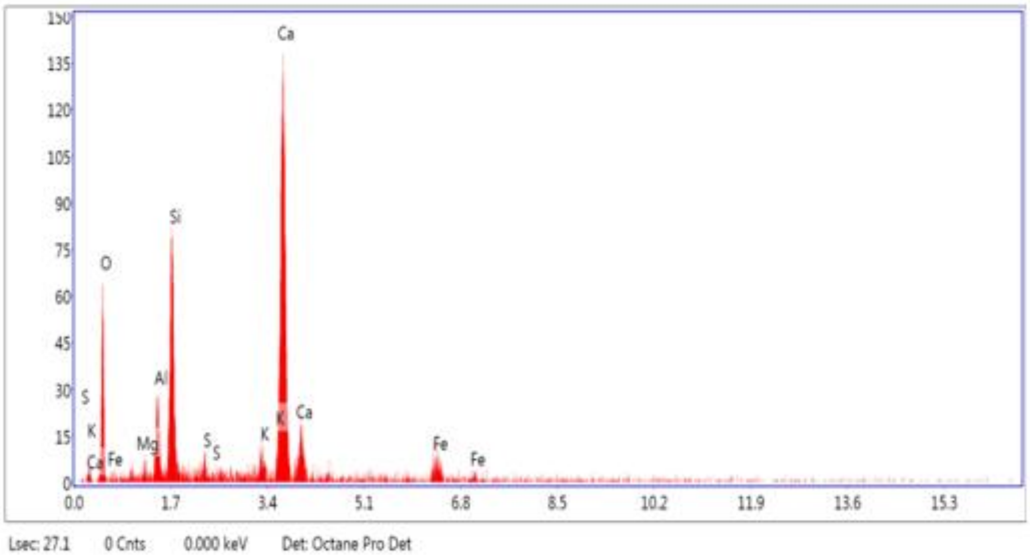
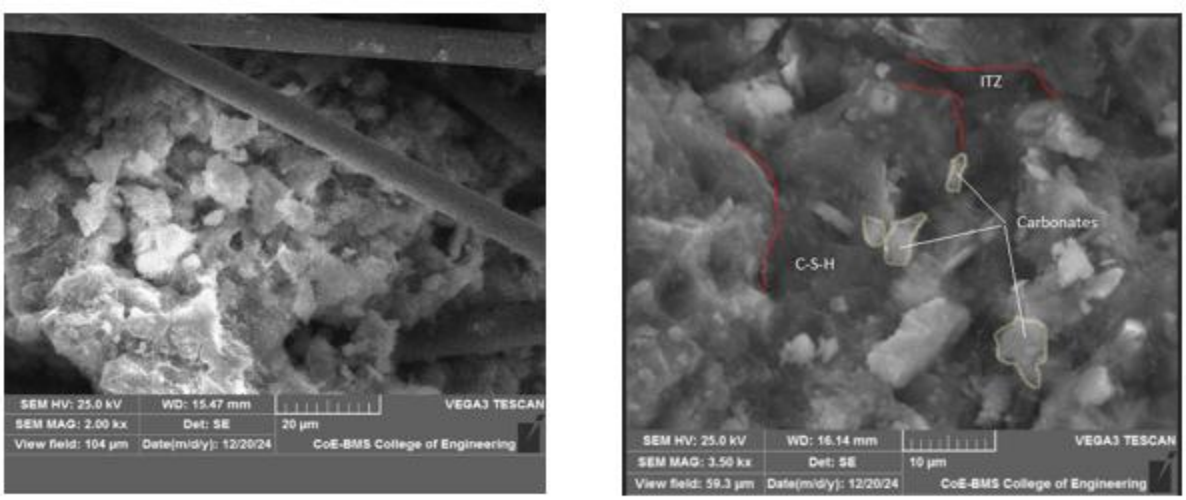


Figure 11: XRD analysis of CM (98C+2%NCC+0%CF)

Figure 11 displays the EDAX analysis and illustrates that the presence of sharp peaks and it indicates a crystalline nature of the sample with high calcite peaks. It confirm that good hydration in the mix.

No graphite peaks expected because of absence of Carbon Fiber.

4.3 With 2% of Nano Calcium Carbonate and 1% of carbon fibre of Light weight cinder aggregate



7days **28 days**

Figure 12: LWF9(98C+2%NCC+1%CF)

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The mineralogical study by SEM analysis shows in figure 12, indicating the crystalline nature of the sample. A well-formed hydration product can be seen from C-S-H formation in the form of calcium silicate in the compound. Good formation of Interfacial transition zones (ITZ) is performed for 28 days conforming that the well binding property with the concrete components. Carbonate products can be seen whereas additional Nano calcium carbonate products are formed confirms that additional carbonates will help in make the compound as dense structure by decreasing the voids.

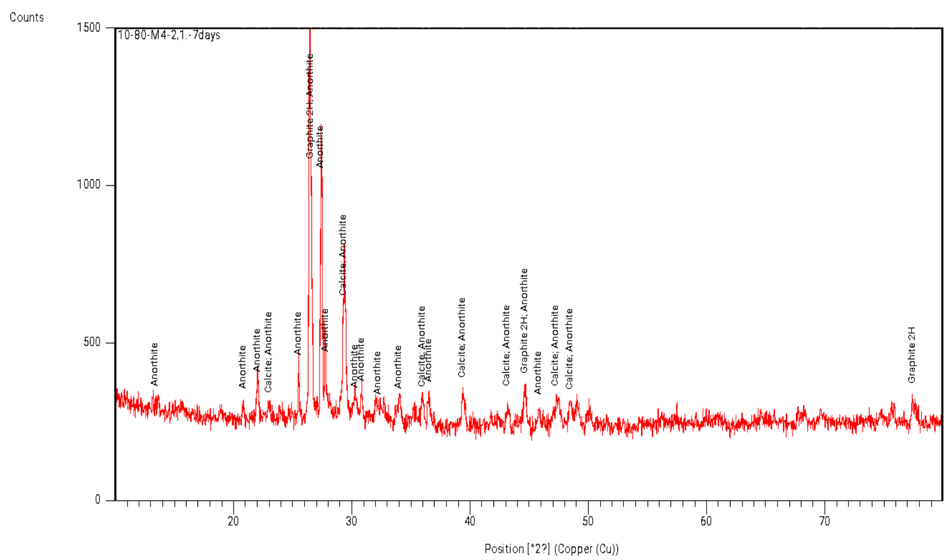

Figure 13: XRD of LWF9 (98C+2%NCC+1%CF)

The XRD analysis shown in figure 13 has been plotted with intensity (counts) plotted against 2-theta (position) values. The occurrence of sharp peaks indicates a crystalline nature of the sample.

Phase Identification:

1. Based on the prominent peaks and their positions, the sample is composed of Anorthite. This confirms that calcium-rich feldspar minerals with a chemical composition of $CaAl_2Si_2O_8$.
2. Some weaker peaks that belong to other phases like Calcite and Graphite. However, their presence is less certain due to the lower intensity of their peaks.

5. CONCLUSIONS

The imperative challenge arises from the depletion of natural aggregates and raw materials in contemporary construction, leading to a critical issue of construction and waste within aging concrete structures. Addressing this concern involves minimizing the reliance on natural aggregates and embracing the reuse of construction and steel industry waste like

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cinder in the concrete industry. This study establishes the viability of substituting natural coarse aggregate (NCA) with light weight Coarse aggregate cinder (LWCA) ranging from 0% to 100%, along with the complete replacement of natural fine aggregate (MS) with light weight Course aggregate cinder, to formulate To augment the strength of mixtures, a substitute Nano $CaCO_3$ has been incorporated. The compressive strength of Trial LWF9 exhibits a strength of 34.77MPa at 28 days, classifying it as M25 grade. concrete. The utilization of light weight Course aggregate in M25 grade concrete, particularly in LWF9 , demonstrates notable progress in strength achievement, credited to the application of the Nano $CaCO_3$. Trial LWF9 displays commendable strength of 5.42MPa and 5.32 MPa in both split tensile and flexural strength tests. Based on these findings, the incorporation of the Nano CaCO3 can be considered as a substitute in Lightweight aggregate concrete which will enhance the mechanical strength properties as mentioned below,

1. Compressive strength of the 98 % Cement and 100 % of Cinder coarse aggregate (NCA) and 2% Nano Calcium carbonate with 1% carbon fiber found 36.89 MPa.

2. Split tensile strength of the 98 % Cement and 100 % of Cinder coarse aggregate (NCA) and 2% Nano Calcium carbonate with 1% carbon fiber found 5.42 MPa.

3. Flexural strength of the 98 % Cement and 100 % of Cinder coarse aggregate (NCA) and 2% Nano Calcium carbonate with 1% carbon fiber found 5.32 MPa.

SEM analysis illustrates a robust bond between cement and Cinder aggregates with Nano Calcium carbonate with carbon fiber micro reinforcement by creating a well-developed interfacial transition zone characterized by certain clustering morphology and reduced porosity. This signifies the favorable binding properties of Nano calcium carbonate with cement, fostering dense characteristics and maintaining compactness within the mix.

References

1) K Sadhana, K Suguna, P N Raghunath (2024). Material Performance Evaluation of Cinder Based Light Weight Concrete with Micro-reinforcement, Indian Journal of Science and Technology **https://doi.org/10.17485/IJST/v17i9.84**

2) Meena R, Sharma S, Sharma A, Ku M. Study on lightweight concrete- review. Int J Eng Technol (IJERT). 2020;09(07):786-7. DOI: 10.17577/IJERTV9IS070348

3) Khalil, W.I., H.K. Ahmed, and Z.M.Hussein, (2015). Properties of artificial and sustainable lightweight aggregate. Berlin Germany Sep 14-15. Vol. 17, Isuue 9(PartIV), pp. 633-637.

4) Nellore Bindu Sai1, Dr. B. Madhusudana Reddy. A Study on the Hardened Properties of M25 Grade Concrete Using Carbon Fibers and Its Evaluation by NDT. International Journal of Scientific Research in Science and Technology Print ISSN: 2395-6011 | Online ISSN: 2395-602X (**www.ijsrst.com**) Doi: **https://doi.org/10.32628/IJSRST52310317**

5) Mingli Cao, Xiaoling Yuan, Xing Ming and Chaopeng Xie(2022) , Effect of High Temperature on Compressive Strength and Microstructure of Cement Paste Modified by Micro- and Nano-calcium Carbonate Particles.

6) Camiletti, Soliman and Nehdi (2013) Effect of nano-calcium carbonate on early-age properties of ultra-high-performance concrete. Magazine of Concrete Research, 2013, 65(5), 297–307 **http://dx.doi.org/10.1680/macr.12.00015**

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DOI: 10.5281/zenodo.15573112

7) Yanjin Liu, Xi Zhong, Hamid. et al. (2023) Role carbon nanomaterials in reinforcement of concrete and cement; A new perspective in civil engineering Alexandria Engineering Journal. Volume 72, 1 June 2023, Pages 649-656. https://doi.org/10.1016/j.aej.2023.04.025

8) Md Azree Othuman Mydin a, P. Jagadesh b, Alireza Bahrami c,Anmar Dulaimi d,e, Yasin Onuralp €Ozkılıc¸ f, Mohd Mustafa Al Bakri Abdullah g,h Ramadhansyah Putra Jaya (2023). Use of calcium carbonate nanoparticles in production of nano-engineered foamed concrete. **https://doi.org/10.1016/j.jmrt.2023.08.106**

9) Dejian Shen, Jiacheng Kang, Haoze Shao, Ci Liu, Ming Li, Xusheng Chen (2023) “Cracking failure behavior of high strength concrete containing nano-CaCO3 at early age” Cement and Concrete Composites. **https://doi.org/10.1016/j.cemconcomp.2023.104996**

10) Xiaoyan Liu, Lei Chen (2013), Aihua Liu, Xinrui Wang Effect of Nano-$CaCO_3$ on Properties of Cement Paste. Energy Procedia 16 (2012) 991 – 996. **https://doi.org/10.1016/j.egypro.2012.01.158**

11) Yanjin Liu, Xi Zhong, HR Mohammadian (2023)” Role carbon nanomaterials in reinforcement of concrete and cement; A new perspective in civil engineering”, Alexandria Engineering Journal Volume 72, 1 June 2023, Pages 649-656. **https://doi.org/10.1016/j.aej.2023.04.025**

12) Gokhan Calis et al. (2021) “Evaluation and optimisation of foam concrete containing ground calcium carbonate and glass fibre” (experimental and modelling study), Case Studies in Construction Materials Volume 15, December 2021, e00625. **https://doi.org/10.1016/j.cscm.2021.e00625**

13) Wael Jasim Mohammed1, Nagham Tariq2, Zainab M. Hussein3 (2023) “Mechanical Properties of Sustainable Fiber-reinforced Lightweight Aggregate Concrete” Journal of Engineering and Sustainable Development.

14) Annapurna P Bennur, Chethan Kumar S(2022) “Light Weight Concrete Using Cinder – A Review“ International Advanced Research Journal in Science, Engineering and Technology, Vol. 9, Issue 4, April 2022. **10.9734/CJAST/2022/v41i3131811**.

15) C. Sahoo, S. Sahoo, Madhurima Das, S. Mishra (2022) “Lightweight Aggregate Concrete: Strength Analysis” Current Journal of Applied Science and Technology. 10.9734/CJAST/2022/v41i3131811.

16) J. M. Khatib et al. (2018)"Properties of Lightweight Aggregate Concrete with Cinder” Construction and Building Materials.