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Enhanced Mechanical and Durability Performance of M30 Concrete with Fly Ash (FA) and Neem Leaf Ash (NLA) as Sustainable Cement Replacements

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ABSTRACT: The cement and concrete business generate a lot of CO₂ largely because manufacturing cement entails heating limestone (CaCO₃) to roughly 1450 °C in a kiln. This method releases a lot of CO₂ both from the chemical reaction (calcination: CaCO₃ → CaO + CO₂) and from burning fossil fuels to provide that heat. Typically, for every ton of cement created, around 0.9 tons of CO₂ are released, so cement making accounts for almost 8% of world CO₂ emissions. The sector is looking more and more to substitute cementitious materials (SCMs) such fly ash, slag, calcined clay, and agro based waste. These materials, which are one of the most efficient and generally accessible solutions to minimise the carbon footprint of cement and concrete, partly replace clinker in cement and concrete and immediately cut the volume of CO₂-intensive clinker required while keeping or even boosting performance. This research studies if employing Fly Ash (FA) and Neem Leaf Ash (NLA), which are both industrial and agricultural waste products, can partially substitute cement in M30 grade concrete to make green and ecologically friendly construction materials.

The quantity of fly ash, a well-known pozzolanic component, in each combination maintained 15% by weight of cement in order to use this industrial waste properly. Neem Leaf Ash, a unique agro-waste additional cementitious ingredient, was introduced in varied amounts of 0%, 2.5%, 5%, 7.5%, 10% & 12.5% by weight of cement in 2.5% increments. The level of total cement replacement (fly ash + NLA) was kept within tolerable boundaries.

To evaluate their mechanical behaviour, concrete specimens were tested at 7, 14, and 28 days. Among other durability tests, sulphate attack resistance was examined for long-term performance utilising hybrid mixtures including 0% FA + 0% NLA, 15% FA + 2.5% NLA, 15% FA + 5% NLA, 15% FA + 7.5% NLA, 15% FA + 10% NLA, and 15% FA + 12.5% NLA.

KEYWORDS: M30 concrete, Fly Ash (FA), Neem Leaf Ash (NLA), Agricultural and Industrial waste, Mechanical & Durability studies, Cement.

I. INTRODUCTION

1.1 THE EVOLUTION OF SUBSTITUTE MATERIALS FOR PROXIES IN CONCRETE: A HISTORICAL PERSPECTIVE:

The journey of finding substitutes for traditional materials used in making concrete shows a constant change pushed by the need for sustainability, stronger structures, and more efficient building methods. Every new discovery brings new materials and ideas that help shape how we build with concrete, leading to major changes in construction. During this shift, new and creative options keep showing up because of the strong push to meet environmental goals, improve the performance of materials, and use more eco-friendly versions of concrete in big projects like buildings and infrastructure. Concrete has always been a key part of human architecture because of its strength, solid structure, and ability to be shaped in many ways. But as technology and society have developed, smart researchers and engineers have started looking beyond the usual materials like sand, gravel, and regular cement to make concrete greener, longer-lasting, and easier to use.

This ongoing effort has led to a wave of new inventions, offering better and more creative solutions to replace traditional building components. This change is driven by a complex need to support the environment, reduce harmful effects, and keep building projects affordable. For example, making regular cement creates about 8% of the world’s CO2 emissions, uses up important minerals that can’t be reused, and creates a lot of industrial waste. Leaders in the industry can help by reducing waste, cutting down on energy-heavy processes, and improving the quality of the final product.

Using materials like recycled paper sludge, calcined clay, or fly ash from coal plants as replacements can make concrete stronger, longer-lasting, and easier to work with. These materials not only use waste from other industries but also support a circular economy, turning the old "take-make-dispose" system into a sustainable loop that helps save resources, cut down on new material use, and save money by reducing the need to buy and dispose of materials. In the end, these developments help builders deal with the challenges of limited resources and changing climate conditions, while opening up new ways to improve cities and create strong, lasting infrastructure. This makes building methods not just more environmentally friendly, but also more resilient in the face of today’s global changes.

1.2 WHAT IS NEAM LEAF ASH (NLA)?

Neem Leaf Ash, or NLA, is a finely milled powder derived from the foliage of the neem tree, scientifically known as *Azadirachta indica*. NLA is a pozzolanic substance utilized in sustainable construction materials. It interacts with calcium hydroxide in the presence of water, forming compounds that enhance the strength and durability of concrete. This enhances the durability of concrete and diminishes the necessity for frequent cement usage

1.3 WHAT IS FLY ASH?

Fly ash is an extremely fine powder that is formed when coal or other fuels containing a lot of carbon are burned in power plants. Fly ash is also called fly cinder sometimes. Fly ash can have varying compositions and characteristics depending on the type of fuel consumed and how it is burnt. This substance is often used in construction, particularly as a supplementary ingredient that reinforces and extends the life of concrete. Using fly ash decreases the amount of limestone-derived cement needed to make ecologically friendly construction materials, hence boosting their sustainability

1.4 PROCESS OF CONVERTING OF NEAM LEAF INTO ASH:

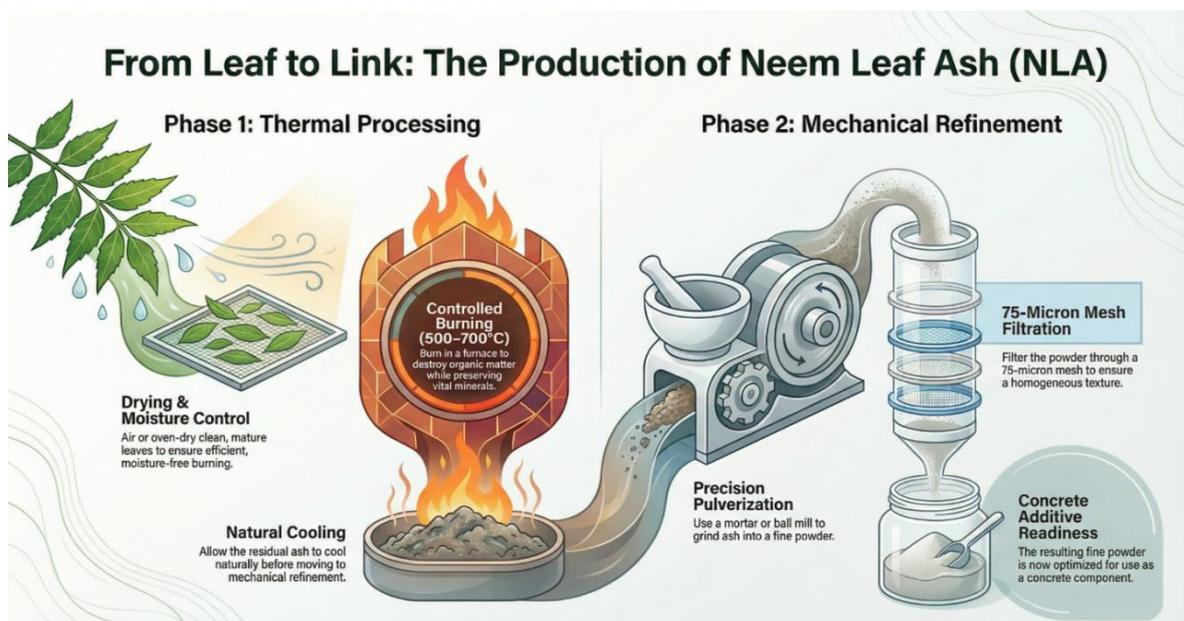


Fig 1: Steps involved in making Neam Leaf Ash (NLA)

II. LITERATURE SURVEY

Many research have looked at the performance and environmental advantages of employing fly ash (FA) and neem leaf ash (NLA) as part replacements for Portland cement. When used normally at 15–30% replacement, FA, a well-known supplementary cementitious material, releases tiny reactive silica and alumina that react slowly with $\text{Ca}(\text{OH})_2$ to generate more C–S–H, therefore improving long-term strength, durability, and workability and lowering permeability and hydration heat. A locally available, inexpensive pozzolan rich in SiO_2 and Al_2O_3 , NLA is a bio-ash made from burnt neem leaves. It has showed potential at modest replacement levels (typically 5–15%) to optimise pore structure and increase durability while also cutting embodied CO_2 . FA and NLA used together or combined may cause synergistic effects. FA's gradual pozzolanic nature compliments NLA's reactivity, which leads in better compressive strength growth throughout time and enhanced chemical attack resistance. But, these ingredients may reduce early-age strength and necessitate a well-thought-out mix design and quality control (particle size, LOI, alkali concentration) to avoid issues like delayed setting or alkali-silica interaction. To ensure consistent performance and improved field adoption, new study recommends increasing replacement ratios, carrying out long-term durability testing (sulfate, chloride intrusion, carbonation), and standardizing biomass ash processing.

- M. Thomas, R. Walker *Materials* 2021 Vol. 14, Issue 15 Page Nos: pp. 4241 <https://doi.org/10.3390/ma14154241> Eco-efficient fly ash at 25% trims workability woes, short-term strengths steady at 30 MPa, long-term legacies in low-carbon lays. Review reveals 20-30% sweet spot for sustainable symphonies.
- Farooq, F. Ostrowski *Scientific Reports* 2025 Vol. 15 Page Nos: pp. 1-18 <https://doi.org/10.1038/s41598-025-88923-3> M-sand fly ash at 25% hits 40 MPa, ML models map mixes for precision pours. Spherical savings slow hydration for harmonious highs.
- T. Phani Madhavi, V. Sampathkumar *Sustainable Cities and Society* Year of Publication: 2023 Vol. 99 Page Nos: pp. 104910 <https://doi.org/10.1016/j.scs.2023.104910> Slag-fly ash 50-65% in mass marvels minimize maritime miles' malice, LCA lights 40% emission eases. Optimal blends balance burdens for bridge behemoths.
- K. C. Onyelow, M. E. Ede *Scientific Reports* 2025 Vol. 15 Page Nos: pp. 1-20 <https://doi.org/10.1038/s41598-025-92227-x> Activated fly ash + coconut fiber at 20% revives recycled realms to 50 MPa, 1.5% fiber finesse for fracture-free futures. Waste weave waltzes toward weathered wonders.
- Y. Shi, H. Jing *Materials* 2023 : Vol. 16, Issue 13 Page Nos: pp. 4567 <https://doi.org/10.3390/ma16134567> 80% fly ash in mortar micro-aggregates max compressive (35 MPa), superior to OPC via filler finesse. Permeability plummets for porous-proof pastes.
- M. Bouasria, F. Khadraoui *PLOS One* 2025 Vol. 20, Issue 2 Page Nos: pp. e0314277 <https://doi.org/10.1371/journal.pone.0314277> Fly ash-ceramic co-blend at 20% sulfate-survives dry-wet duels, +11% compressive vs. control, CWP curbs cracks. Response
- V. Sameer Kumar., Ahmed Vali, D., Venkata Prakash, M., & Chand Basha, S. (2023). (Vol. 10, Issue 2, pp. 1–2) The workability of the control specimen of SCC, as well as the SCC that included Alccofine and Fly Ash, was found to be within the limitations allowed by the Indian Code, according to the findings of a battery of tests. This verifies the mix design of the SCC. It seems that the addition of Alccofine and Fly Ash improves the workability of the SCC, since this tendency was also seen in other evaluation techniques. Using a compression testing equipment, we measured the concrete's average compressive strength at 7, 14, and 28 days. According to the results, as compared to regular concrete, the average compressive strength is much higher, reaching its peak at a 25% Alccofine replacement level. Additionally, the average split tensile strength was also tested at 7, 14, and 28 days, with the maximum value reported at a combination of 20% Fly Ash, 20% Alccofine, and 1% superplasticizer. Similarly, the average flexural strength at these intervals was measured, with the highest value again observed at the same mix proportions of 20% Fly Ash, 20% Alccofine, and 1% superplasticizer. <https://www.ijrar.org/papers/IJRAR23B1720.pdf>
- Mohd Allauddin , Vanam Sameer Kumar *International Research Journal of Modernization in Engineering Technology and Science* Volume:07/Issue:03/March-2025 Emphasizing the main ideas taken from the previous conversations and results, this article closes: Fly Ash (FA) and Recycled Paper Cinder (RPC) may effectively replace cement, retaining FA at a constant 10% while altering RPC in increments of 0%, 4%, 8%, 12%, 15%, and 20% in M30 Solid, the results show. Examining the compressive, ductile, and flexural properties reveals that 12%

RPC and 10% FA replacement yields the optimum strength. After 28 days, the greatest compressive strength recorded is 38.69 MPa. 3.09 MPa is the highest tensile strength reached after 28 days.

➤ After 28 days, the flexural strength maximum reported is 6.19 MPa. Including recovered waste RPC, this concrete is regarded as green concrete. <https://doi.org/10.56726/IRJMETS69930>

➤ Shaik Imran, Vanam Sameer Kumar IJPREMS Vol. 05, Issue 04, April 2025, pp : 177-185 Based on the foregoing considerations and developments, this essay can be concluded by concentrating on the following points: The result clearly shows that the substitution of FC & GHA both are replaced in place of cement by maintaining FC as constant with 10% and GHA with ascending follows from 0%, 3%, 6%, 9%, 12% & 15% in M35 Solid. Based on results as considered the compressive quality, ductile quality & flexural quality attained maximum strength at percentage of replacing 9%GHA+10%FC. The maximum Compressive strength quality gained for 28 days is 43.55 MPa. The maximum Tensile strength quality gained for 28 days is 4.59 MPa. The maximum Compressive strength quality gained for 28 days is 8.41 MPa. It can be referred as green concrete due to the replacement of agro based waste GHA. <https://www.doi.org/10.58257/IJPREMS39569>

➤ V.SAMEER KUMAR Journal of Engineering Sciences Vol 16 Issue 04,2025 The value of slump cone value decreases with increase in the percentage of drug waste Powder and bottom ash from 0%Drug waste power+0%Bottom ash to 6%drug waste powder+10% bottom ash in M30 grade concrete. The values of compaction factor increase with increase in the percentage of biomedical waste powder and bottom ash in M30 grade concrete. The maximum value of compressive strength was observed at 3%Drug waste power+10%Bottom ash for 3days, 7days, 28days curing period The maximum value of split tensile strength was observed at 3% Drug waste power+10% Bottom ash for 7days and 28days curing period in M30 Grade Concrete. DOI:10.15433.JES.2025.V16I4.43P.507.

III. METHODOLOGY

The Methodology summarizes the replacements for cement mentioned in this paper:

- Examining the usage of Fly Ash (FA) at a constant ratio of 15% with Neam Leaf Ash (NLA) in levels varying from 2.5% to 12.5% with const interval of 2.5 % increment.
- Assessing the compressive strength of cubes measuring 150 x 150 x 150 mm.
- Analyzing the tensile strength of cylinders with a diameter of 150 mm and a height of 300 mm.
- Evaluating the bending strength of beams sized 500 x 100 x 100 mm.
- Finding the test results on Sulphate attack resistance on concrete for 28 days with respect to % weight loss and % Strength loss.

IV. EXPERIMENTAL RESULTS

TABLE NO 1: MIX PROPORTION OF M30

Grade	M30
Proportion	1:1.65:2.26
W/C ratio	0.42
Cement	417.77
Fine Aggregate	728.44
Coarse Aggregate	947.25
Water	193.81

TABLE NO 2 TEST RESULTS OF COMPRESSIVE STRENGTH AT 7 DAYS, 14 DAYS & 28 DAYS:

Mix % Replacement	7 days in Mpa	14 days in Mpa	28 days in Mpa
0%NLA+0%FA	25.81	30.88	36.23
2.5%NLA+15%FA	26.22	31.27	37.61
5%NLA+15%FA	26.61	31.56	37.98

7.5%NLA+15%FA	27.08	32.02	38.69
10%NLA+15%FA	23.35	26.21	32.53
12.5%NLA+15%FA	21.28	22.84	28.28

TABLE NO 3 TEST RESULTS OF SPLIT TENSILE STRENGTH AT 7 DAYS, 14 DAYS & 28 DAYS:

Mix % Replacement	7 days in Mpa	14 days in Mpa	28 days in Mpa
0%NLA+0%FA	1.27	1.71	2.08
2.5%NLA+15%FA	1.53	1.98	2.55
5%NLA+15%FA	1.82	2.33	2.85
7.5%NLA+15%FA	2.03	2.64	3.09
10%NLA+15%FA	1.21	1.49	1.85
12.5%NLA+15%FA	0.97	1.17	1.39

TABLE NO 4 TEST RESULTS OF FLEXURAL STRENGTH AT 7 DAYS, 14 DAYS & 28 DAYS:

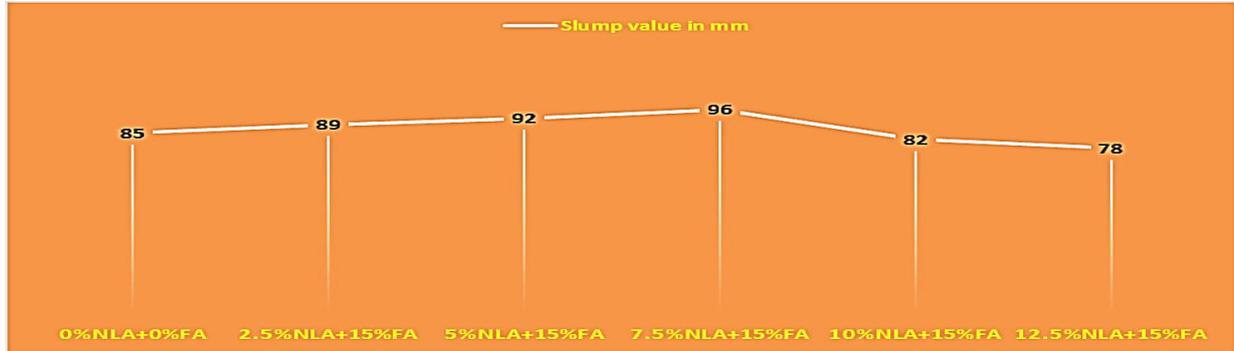
Mix % Replacement	7 days in Mpa	14 days in Mpa	28 days in Mpa
0%NLA+0%FA	3.17	4.71	5.25
2.5%NLA+15%FA	3.42	5.06	5.57
5%NLA+15%FA	3.68	5.39	5.88
7.5%NLA+15%FA	3.95	5.61	6.19
10%NLA+15%FA	2.98	3.81	4.78
12.5%NLA+15%FA	2.48	3.33	4.41

TABLE NO 5 TEST RESULTS OF % WEIGHT LOSS FOR 28 DAYS:

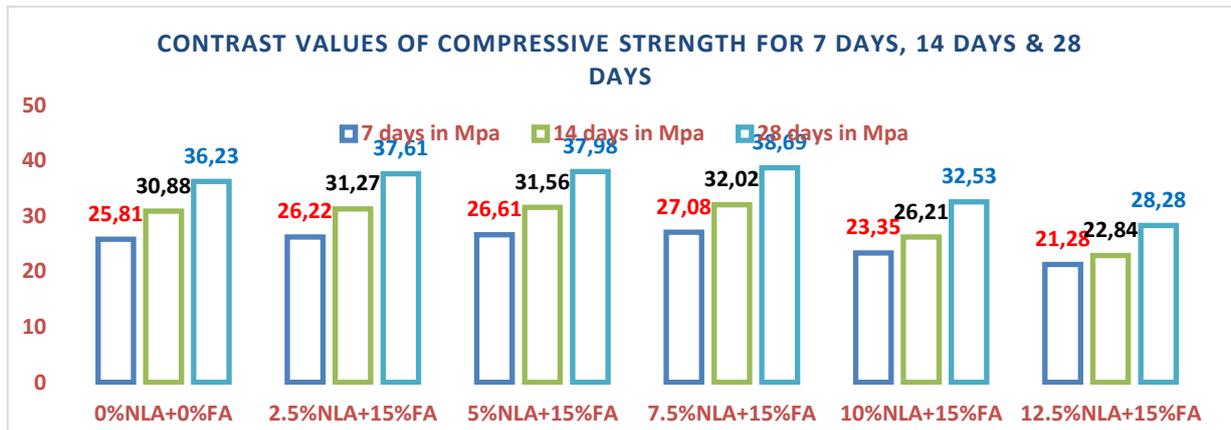
Mix % Replacement	Weight Before (g)	Weight after 28 days in Na ₂ SO ₄ (g)	% Weight Loss
0%NLA + 0%FA	8122	8013	1.34
2.5%NLA + 15%FA	8123	8046	0.94
5%NLA + 15%FA	8116	8049	0.82
7.5%NLA + 15%FA	8126	8072	0.66
10%NLA + 15%FA	8106	7992	1.4
12.5%NLA + 15%FA	8057	7906	1.87

TABLE NO 6 TEST RESULTS OF % STRENGTH LOSS FOR 28 DAYS:

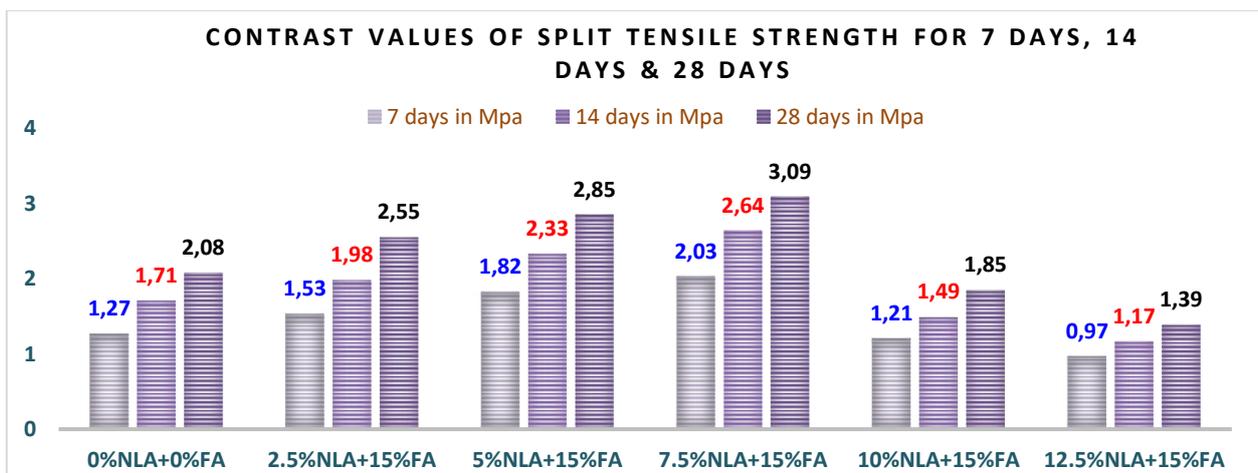
Mix % Replacement	Strength Before (MPa)	Strength after 28 days in Na ₂ SO ₄ (MPa)	% Strength Loss
0%NLA + 0%FA	36.23	35.07	3.2
2.5%NLA + 15%FA	37.61	36.52	2.89
5%NLA + 15%FA	37.98	37.08	2.36
7.5%NLA + 15%FA	38.69	37.84	2.19
10%NLA + 15%FA	32.53	31.43	3.38
12.5%NLA + 15%FA	28.28	26.98	4.59



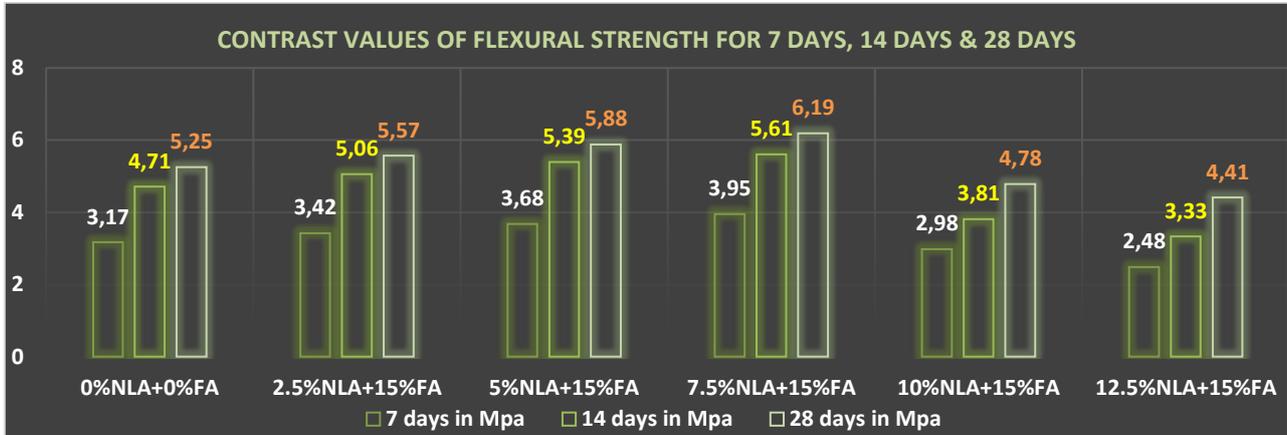
GRAPH NO 1 SLUMP CONE VALUES



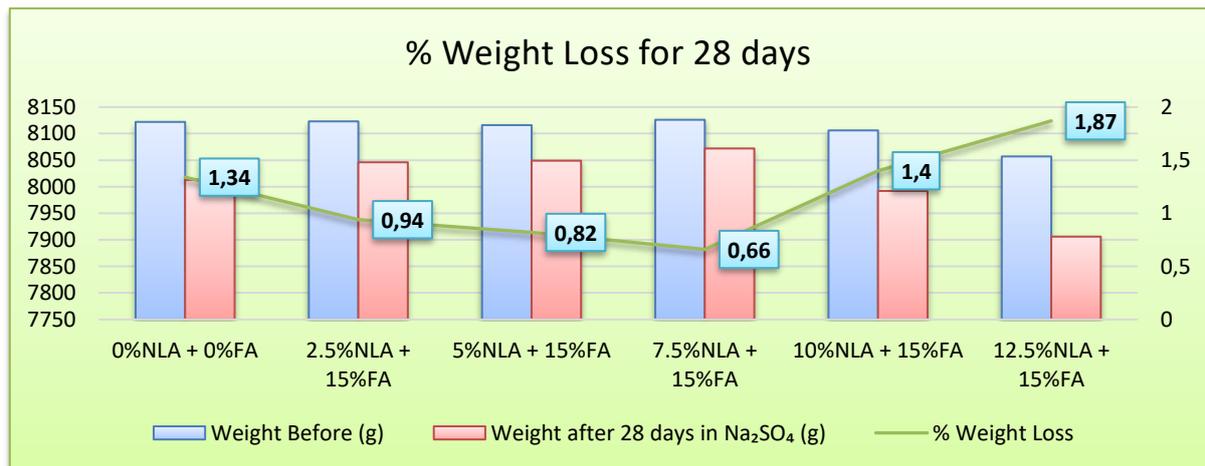
GRAPH NO 2 CONTRAST VALUES OF COMPRESSIVE STRENGTH FOR 7 DAYS, 14 DAYS & 28 DAYS



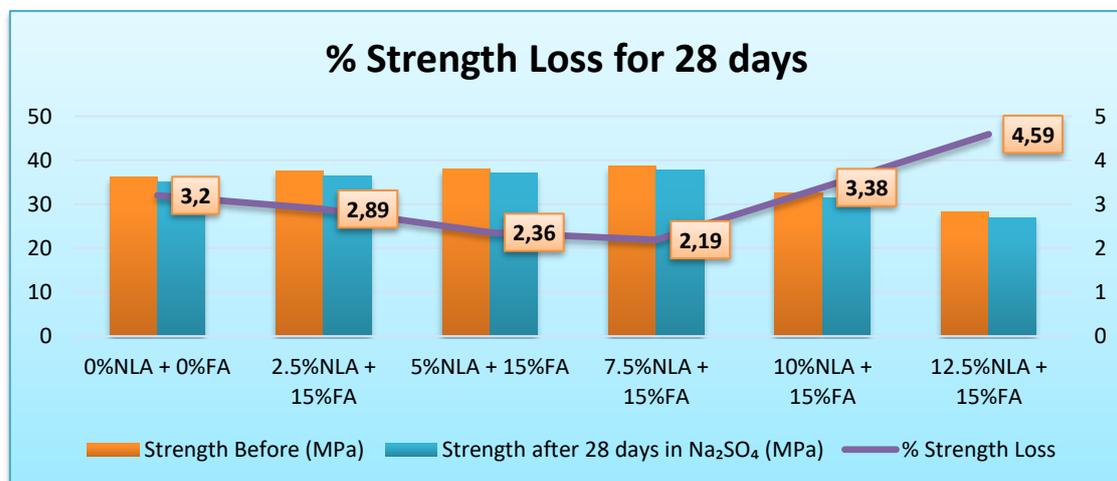
GRAPH NO 3 CONTRAST VALUES OF SPLIT TENSILE STRENGTH FOR 7 DAYS, 14 DAYS & 28 DAYS



GRAPH NO 4 CONTRAST VALUES OF FLEXURAL STRENGTH FOR 7 DAYS, 14 DAYS & 28 DAYS



GRAPH NO 5 DEVELOPMENT OF % WEIGHT LOSS AFTER 28 DAYS



GRAPH NO 6 DEVELOPMENT OF % STRENGTH LOSS AFTER 28 DAYS

V. CONCLUSION

Emphasising the main ideas taken from the previous conversations and results, this article closes:

- * Fly Ash (FA) and Neem Leaf Ash (NLA) may effectively replace cement, retaining FA at a constant 15% while altering NLA in increments of 0%, 2.5%, 5%, 7.5%, 10%, and 12.5% in M30 Solid, the results show.
- * Examining the compressive, ductile, and flexural properties reveals that 7.5% NLA and 15% FA replacement yields the optimum strength.
- * After 28 days, the greatest compressive strength recorded is 38.69 MPa.
- * 3.09 MPa is the highest tensile strength reached after 28 days.
- * After 28 days, the flexural strength maximum reported is 6.19 MPa.
- * The Durability test results of sulphate resistance attack show their % weight loss & % Strength loss as 0.66 & 2.19 for the mix replacement of 7.5% NLA + 15% FA has their best.
- * Including recovered waste NLA, this concrete is regarded as green concrete

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