Comparative Analysis of Steel Fibre Reinforced & Coir Fibre Reinforced Concrete with Conventional Concrete

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Abstract — Fibres have been used to improve concrete, which is often brittle and weak in stress. The use of asbestos to strengthen pottery, horse hair in plaster, and straw in mud bricks were the first materials used in this process. Conversely, continuous reinforcement is used to maintain reinforced concrete, but it requires a great deal of skill and accuracy. On the other hand, discrete fibre placement in plain or reinforced concrete appears to be more promising. In order to increase the compressive strength of concrete, this study investigates the possibilities of using steel and coir fibre as an efficient and sustainable reinforcement material. The development of fibre-reinforced concrete (FRC) in the early 1960s demonstrated that concrete might be transformed into uniform, isotropic materials. FRC's strength and ductility are increased by the randomly distributed fibres, which stop cracks from forming and spreading once concrete does. If the right amount and distribution of steel fibre in the concrete matrix are guaranteed, the steel wires in tires can be used effectively in concrete. On the other hand, adding coir fibre to the concrete structure improves its tensile and flexural qualities. Additionally, coir fibre is typically found in nature and is environmentally friendly. Bond failure between the fibre and matrix or material failure are the two primary failure modes for fibre reinforced composites. In order to assess the strength and durability characteristics of hardened concrete, we examined the performance of various fibres utilized at varying percentages by weight of cement. According to earlier research, adding fibres to such concrete barely changed its compressive strength, but also seemed to impair its flexural and tensile strength, which eventually affected the concrete's qualities. The uses of fiber-reinforced concrete are also covered in this paper, along with the numerous efficient ways it may be used to increase strength and improve crack resistance. In order to assess the strength characteristics of hardened concrete, we examine the performance of steel and coir fibers at various percentages, ranging from 5%, 10%, and 15% by weight of cement. Different concrete grades, such as M20, M25, and M30, are taken into account in the study for accurate evaluation.

Keywords: Fibre Reinforced Concrete, Steel Fibre, Coir Fibre, Workability, Durability, Strength Properties, Cost Optimisation

I. INTRODUCTION

According to certain academics, concrete is frequently utilized alongside water in the construction sector. Concrete is a quasi-ductile material that is weak under tension and has little resistance to crack formation. For skyscrapers and large-span buildings to satisfy the demands of the construction industry, high-performance concrete is necessary. Using fibres to increase the concrete's tensile strength before cracking and its ductility after cracking is one method of reducing brittleness and increasing its tension capacity. Fibre reduces temperature and shrinkage cracking and enhances impact and fatigue strength.

Concrete is a brittle, composite material used in many engineering projects, such as walls, reservoirs, dams, pavements, tunnels, bridges, and foundations. A lot of research has been done to improve the properties of concrete for increased applicability because of these many uses. One of the numerous attempts to enhance concrete's performance was the inclusion of steel. In order to withstand applied tensile and shear loads, these conventional reinforcements are steel reinforcing bars placed at specific points inside the structure. On the other hand, steel fibre integration in the concrete mixture is frequently erratic and uneven. They play a major part in lowering the frequency of cracks brought on by changes in temperature and relative humidity in concrete mixtures when the fibres are uniformly distributed. The cementitious compositions' mechanical qualities are enhanced by the addition of fibres, whether synthetic, natural, or steel. Fibre has a significant positive impact on ductility, toughness, and resilience to dynamic stress, even though its function may not always involve an increase in strength. Fibre-reinforced concrete is not a replacement for conventional steel reinforcing bars because steel bars and fibres have different purposes, although both enhance concrete performance. Short, irregular steel fibres are mixed into the concrete matrix to create steel fibre-reinforced concrete (SFRC). The main ingredients of SFRC are water, aggregates, cement, and steel fibres. SFRC may also include admixtures and pozzolana, depending on the intended usage. Researchers face knowledge gaps that could prevent new academic and research collaborations as they continue to study the SFRC in response to growing worries about the fragile nature of concrete. Therefore, it is essential to design and implement a system that enables scholars to obtain important information from the most reliable sources.

Natural fibres are organic fibres derived from plants and animals. Because of their abundance, adaptability, and desirable qualities, humans have been using them for thousands of years for a variety of purposes. Plants such as sisal, coir, and jute, as well as animal sources like wool and silk, are used to make fibres. Natural fibres have a number of beneficial qualities and can be used in a variety of ways. They are eco-friendly substitutes for synthetic fibres since they are biodegradable and renewable. They are comfortable to wear in textiles and apparel because of their superior breathability, moisture absorption, and thermal insulation qualities. Plant fibres are widely utilized as reinforcement materials in composites, including building materials like concrete and polymers, in addition to their textile applications. which give composites their strength, rigidity, and resistance to impact, improving their engineering qualities.

II. FIBRE REINFORCED CONCRETE

A composite material called fibre-reinforced concrete is created by combining cement, aggregates, water, and evenly distributed fibres. By acting as crack arrestors, the fibres increase the concrete's strength, ductility, and longevity. Fibres are evenly distributed throughout the mixture of this type of concrete to enhance its structural qualities. By acting as crack arrestors, these fibres improve concrete's ductility, toughness, and post-cracking strength. The fibrous material, which can be composed of steel, glass, synthetic materials, natural fibres, or a mix of these, improves the structural integrity of FRC. The following discusses the characteristics of fibre-reinforced concrete and how it is used:

A. Properties of Fibre Reinforced Concrete -

- Increased tensile & flexural strength
- Reduced shrinkage & crack formation
- Improved impact & abrasion resistance
- Enhanced ductility and energy absorption capacity
- Better durability under cyclic loading and thermal variations

B. Applications of Fibre Reinforced Concrete -

- Industrial floors & pavements (resists wear and cracking).
- Airport runways & highways (high fatigue resistance).
- Tunnel linings & shotcrete (improved ductility).
- Precast products (pipes, panels, manhole covers).
- Seismic and blast-resistant structures.
- Marine and hydraulic structures (durability against water ingress).

Following are the advantages and disadvantages of Fibre Reinforced Concrete -

C. Advantages

- Reduces crack formation (both plastic & drying shrinkage).
- Improves ductility and toughness.
- Better fatigue resistance → useful in pavements, runways, industrial floors.
- Increases service life of structures.
- Reduces maintenance costs.

D. Disadvantages

- Difficult to mix and place uniformly (risk of fibre balling).
- Workability reduces with fibre addition.
- Cost increases depending on fibre type (steel & carbon are expensive).
- Requires special design considerations (IS 456 & IS 10262 don't provide direct mix design methods for FRC).

III. TYPES OF FIBRES USED

Steel Fibres – Boost fatigue resistance, impact resistance, and flexural strength. Compared to rebar reinforced concrete, steel fibre-reinforced concrete is typically less expensive and simpler to employ. Although it takes a lot of work, rebar reinforced concrete is stronger because steel bars are inserted into the liquid cement. Thin steel wires are mixed with cement to create steel fibre reinforced concrete. This increases the concrete's structural strength, lessens cracking, and helps shield it from extreme cold. Aggregation of steel fibre with rebar or another form of fibre is common.

Properties of Concrete Improved by Steel Fibres

The incorporation of steel fibres significantly enhances several properties of concrete, including:

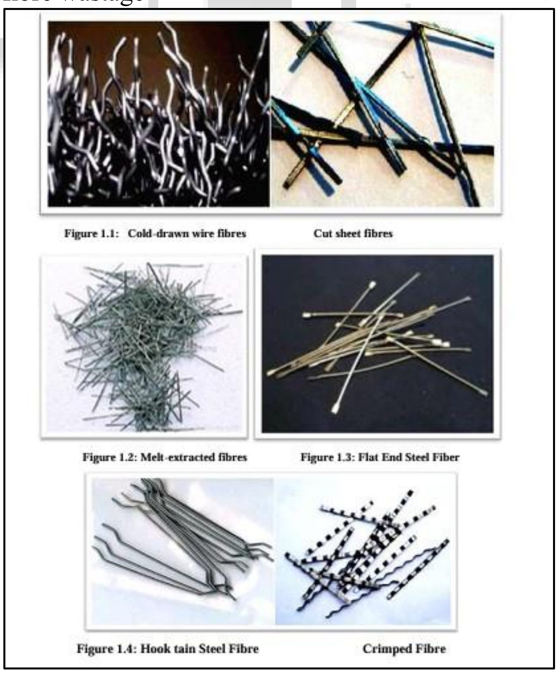
- Flexural Strength: Up to threefold increase compared to conventional concrete.
- Fatigue Resistance: About one and a half times greater fatigue strength.
- Impact Resistance: Enhanced resistance to damage from heavy impacts.
- Permeability: Reduced porosity.
- Abrasion Resistance: Improved resistance against abrasion and spalling.
- Shrinkage: Mitigation of shrinkage cracks.
- Corrosion: Limited impact of corrosion on the material.

A. Advantages:

- Increased durability, flexural and fatigue strength, and resistance to abrasion, spalling, and impact.
- Potential productivity improvements and cost savings
- Crack-free stress accommodation throughout the concrete
- Economical design alternative

B. Disadvantages:

- Aesthetically poor appearance if slabs are damaged
- Diminished cost savings in certain structural elements
- Strict control of concrete wastage required to minimize fibre wastage



Different Types of Steel Fibre used in Steel Fibre Reinforced Concrete

1) Glass Fibres (GFRC) – Improve surface finish, decrease shrinkage cracking, and increase tensile strength. Similar to fiberglass insulation, glass fibre-reinforced concrete uses fiberglass to reinforce the concrete. In addition to strengthening the concrete, the glass fibre also serves to

protect it. Additionally, glass fibre prevents the concrete from breaking over time as a result of thermal or mechanical stress. Furthermore, unlike steel fibre reinforcement, glass fibre does not block radio signals.

Glass Fibre used In Fibre Reinforced Concrete

2) Synthetic Fibres Plastic and nylon fibres are used in synthetic fibre-reinforced concrete to increase the concrete's strength. Furthermore, compared to other fibres, synthetic fibres offer a variety of advantages. They assist the cement pump work better by preventing it from sticking in the pipes, even though they are not as strong as steel. The synthetic fibres assist prevent cracking because they don't expand in hot weather or contract in cold weather. Lastly, synthetic fibres prevent concrete from leaking in the event of a fire or damage.
   - Polypropylene, nylon, polyester → control plastic shrinkage cracks.
   - Carbon fibres → improve strength but costly.

Synthetic Fibre used In Fibre Reinforced Concrete

3) Natural Fibres – To enhance the qualities of concrete, natural fibers derived from plants or animals are utilized as reinforcement. They are inexpensive, sustainable, and environmentally beneficial substitutes for steel or synthetic fibers. Natural fibers, such coconut fiber, have been employed in fiber-reinforced concrete. Although these fibers increase the strength of the concrete, excessive use of them might weaken it. Furthermore, rot may persist in the concrete if the natural fibers are already breaking down when they are added. FRC often uses a variety of natural fiber kinds, including
   - Coir (coconut fibre) – good tensile strength, widely available in India.
   - Jute fibre – economical, biodegradable, enhances toughness.
   - Sisal fibre – high tensile strength, good durability.
   - Bamboo fibre – very strong and sustainable.
   - Hemp, flax, straw fibres – used in rural and low-cost construction.
4) Coir Fibre - Between latitudes 20° N and 20° S, coconut agriculture is expanding throughout tropical and subtropical regions. Most Asian nations, including Thailand, Indonesia, India, and Malaysia, as well as those with tropical climates like Hawaii and the Fiji Islands, exhibit it. Coconuts are mostly grown on sands and clays found around the shore. The height of a coconut tree can reach 30 meters. Coir fiber, which is derived from a coconut's outer shell, is categorized as a natural fiber. Coir, Cocos nucifera, and Arecaceae (Palm) are the colloquial names, scientific names, and plant families of coconut fiber, respectively. Coconut fiber comes in two varieties:
   - Brown fibre extracted from matured coconuts and
   - White fibres extracted from immature coconuts.

White fibers are finer, smoother, but weaker than brown fibers, which are thick, strong, and very resistant to abrasion. Three types of coconut fibers are sold commercially: decorticated (mixed fibers), mattress (relatively short fibers), and bristle (long fibers). Depending on the needs, these various fiber kinds serve a variety of purposes; brown fibers are primarily utilized in engineering.

C. *Advantages:*

- Concrete reinforced with coir fibers is more resilient to impact, abrasion, and spalling and has a high flexural and fatigue strength.
- Reducing section thickness and doing away with traditional reinforcing can sometimes result in notable increases in production. Together with lower material volumes, quicker construction, and lower labor costs, coir fibers can result in significant cost reductions.
- The uneven dispersion of coir fibers in concrete guarantees that tension is accommodated throughout the material without cracking. As a result, tiny cracks are stopped before they become larger and affect the concrete's functionality.
- Coir fibers offer a far more cost-effective design option.

D. *Disadvantages:*

- Slabs that are damaged expose aggregate and fibers, which will appear unsightly while preserving structural integrity.
- Although fibers can replace reinforcement in all structural components, including primary reinforcement, there will come a time when the cost-saving and design-economies of the fiber alternative are reduced within each component.
- To keep concrete waste to a minimum, strict control measures must be observed. Fibers are squandered when concrete is wasted.

Coir Extracted from Coconut Husk

IV. OBJECTIVES OF THE STUDY

- To evaluate how fibers, affect concrete's mechanical properties (compressive, tensile, and flexural strength).
- To investigate the effects of various fiber kinds on the workability and setting properties of concrete.
- To assess the durability performance of fiber-reinforced concrete.
- To look at the economic and environmental benefits of using fibers in concrete since it reduces cement consumption and CO_2 emissions.
- To determine the ideal fiber content for concrete.

V. METHODOLOGY –

Mix proportion details for the study

MIX	CEMENTIOUS MATERIALS		
	CEMENT PPC (43 GRADE)	STEEL FIBRE	COIR FIBRE
M1	100%	-	-
M2	95%	5%	-
M3	90%	10%	-
M4	85%	15%	-
M5	95%	-	5%
M6	90%	-	10%
M7	85%	-	15%
M8	80%	10%	10%

Dimensional Values of Steel Fibre –

PROPERTIES OF STEEL FIBRE	VALUES
LENGTH IN MM	50
SHAPE	CIRCULAR
SIZE / DIA. IN MM	1.6
ASPECT RATIO (L/D)	31.5

Steel Fibres Extracted from Binding Wire

Dimensional Values of Coir Fibre –

PROPERTIES OF STEEL FIBRE	VALUES
LENGTH IN MM	110
SIZE IN MM	0.2
SPECIFIC GRAVITY	0.68

Extraction Of Coir Fibre from Matured Coconut Husk

Tests On Cement

CEMENT PPC (43 GRADE)	Steel Fibre	Coir Fibre	NORMAL CONSISTENCY IN %	INITIAL SETTING TIME IN MIN	FINAL SETTING TIME IN MIN	Compressive Strength at 28 Days
100%	-	-	35	35	600	45.6
95%	5%	-	33	32	500	45.9
90%	10%	-	32	30	470	46.4
85%	15%	-	30	25	465	46.8
95%	-	5%	38	38	560	44.8
90%	-	10%	40	42	550	43.6
85%	-	15%	41	45	550	43.3
80%	10%	10%	36	33	480	45.5

Physical Properties of M Sand

S.No	Properties	Test Conducted as per IS 2386	Result of M sand
1	Water Absorption	Using Pycnometer	1.55%
2	Specific Gravity		2.36
3	Apparent Specific Gravity		2.4
4	Bulk Density	Using Cylindrical Measure of Capacity 3 L, Inside Dia – 15 cm & Inside Height – 17 cm	1.836
5	Fineness Modulus	Sieve Analysis	2.67

Physical Properties of Coarse Aggregates

S. No	Properties	Natural Aggregates	Standards
1	Water Absorption (%)	0.27	<2% (MoRTH 2013)
2	Specific Gravity	2.6	2.6-2.8 (IS:2386 Part III)
3	Bulk Density (Loose) (kg/m^3)	1498	(IS:2386 Part III)
4	Bulk Density (Compacted) (kg/m^3)	1711	
5	Fineness Modulus	7.04	(IS:2386 Part III)
6	Impact Value (%)	17.3	<30% (IS:2386 Part IV)
7	Crushing Value (N/mm^2)	22.06	<30N/mm^2 (IS:2386 Part IV)

Design Mix Proportions - Table: Mix Proportions for M20 Grade Concrete

Cement	Water	FA	CA
394	197	608	1092
1	0.5	1.54	2.77

Table: Mix Proportions for M25 Grade Concrete

Cement	Water	FA	CA
420	197	585	1097
1	0.47	1.39	2.61

Table: Mix Proportions for M30 Grade Concrete

Cement	Water	FA	CA
448	197	575	1080
1	0.44	1.28	2.41

VI. RESULTS

Tests on Fresh Concrete - Workability Test

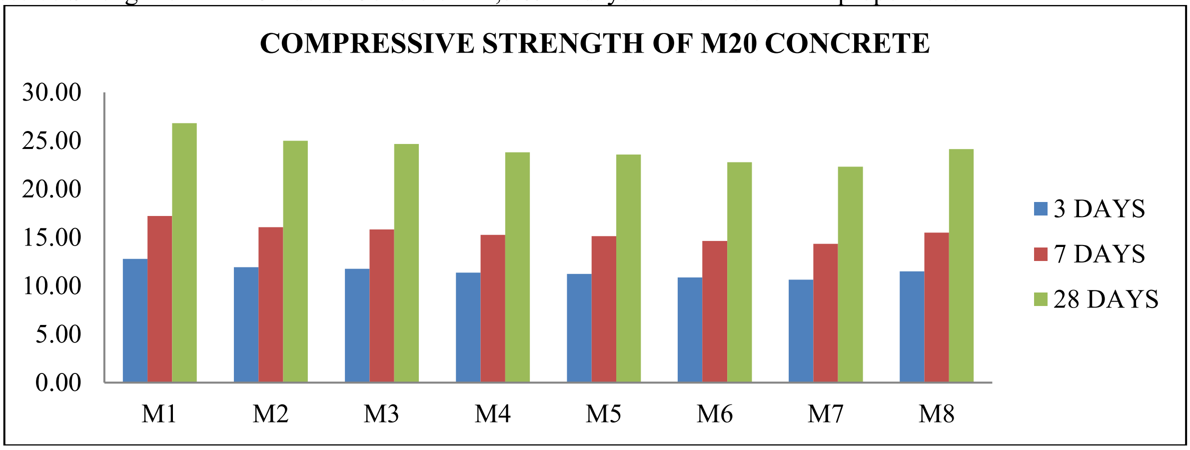
MIX PROPORTIONS	VALUE OF SLUMP IN MM FOR M20 GRADE OF CONCRETE	VALUE OF SLUMP IN MM FOR M25 GRADE OF CONCRETE	VALUE OF SLUMP IN MM FOR M30 GRADE OF CONCRETE
M1	110	95	85
M2	115	105	95
M3	125	115	110
M4	130	125	120
M5	100	90	85
M6	90	80	75
M7	85	75	70
M8	110	95	85

A. Tests on Hardened Concrete

Compressive Strength Test Results

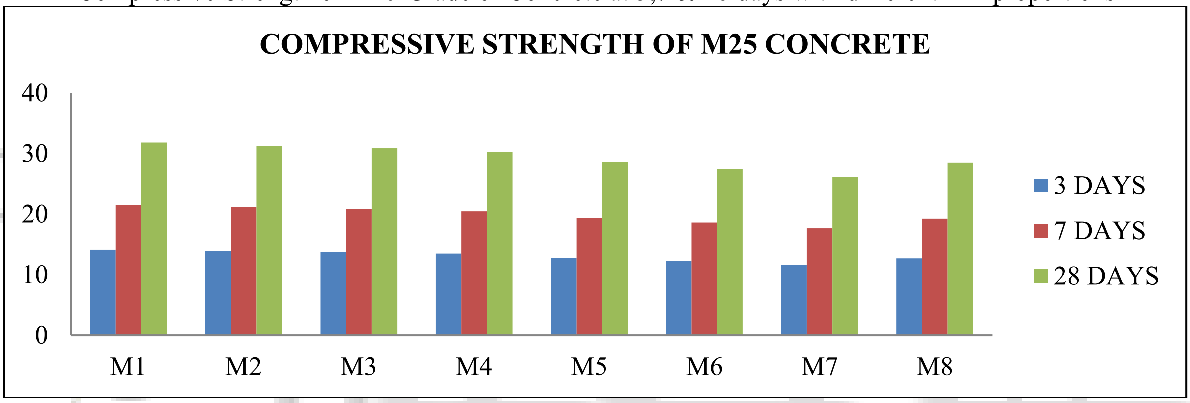
For M 20 Grade of Concrete

Compressive Strength of M20 Grade of Concrete at 3,7 & 28 days with different mix proportions



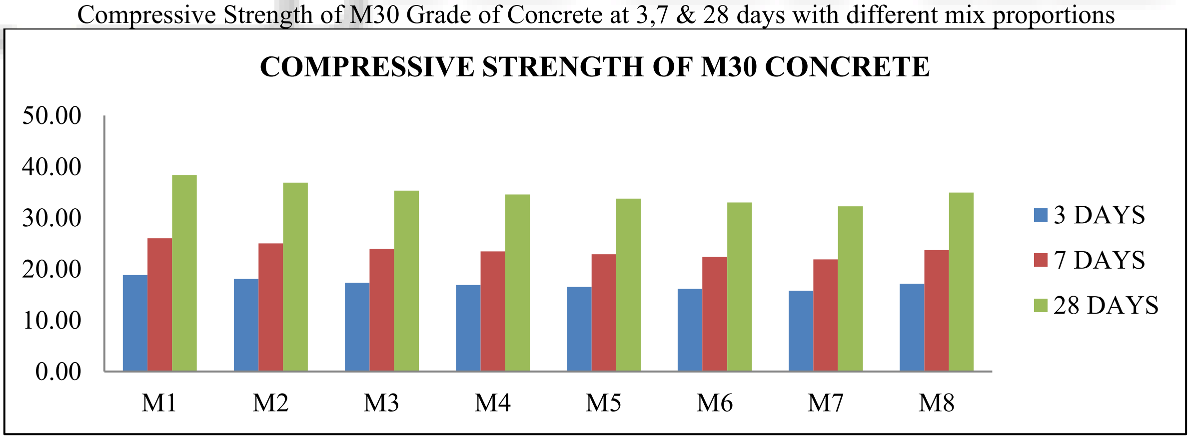
For M 25 Grade of Concrete

Compressive Strength of M25 Grade of Concrete at 3,7 & 28 days with different mix proportions



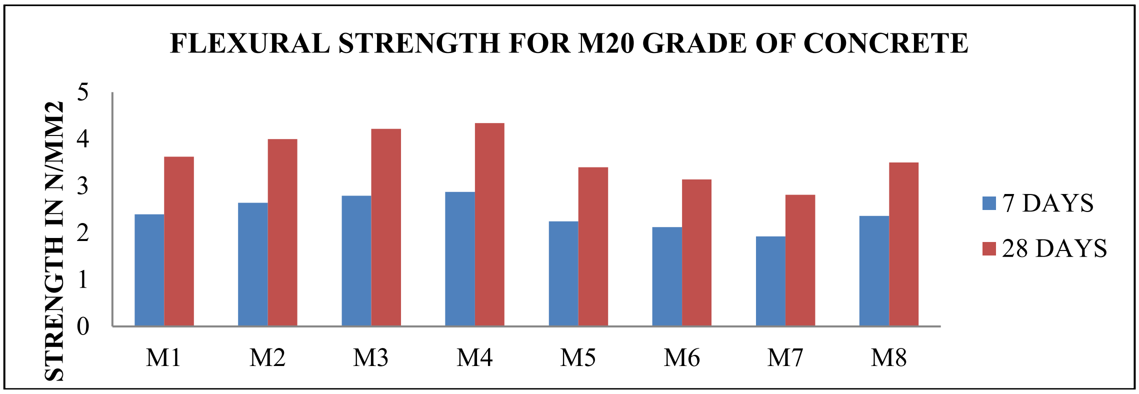
For M 30 Grade of Concrete

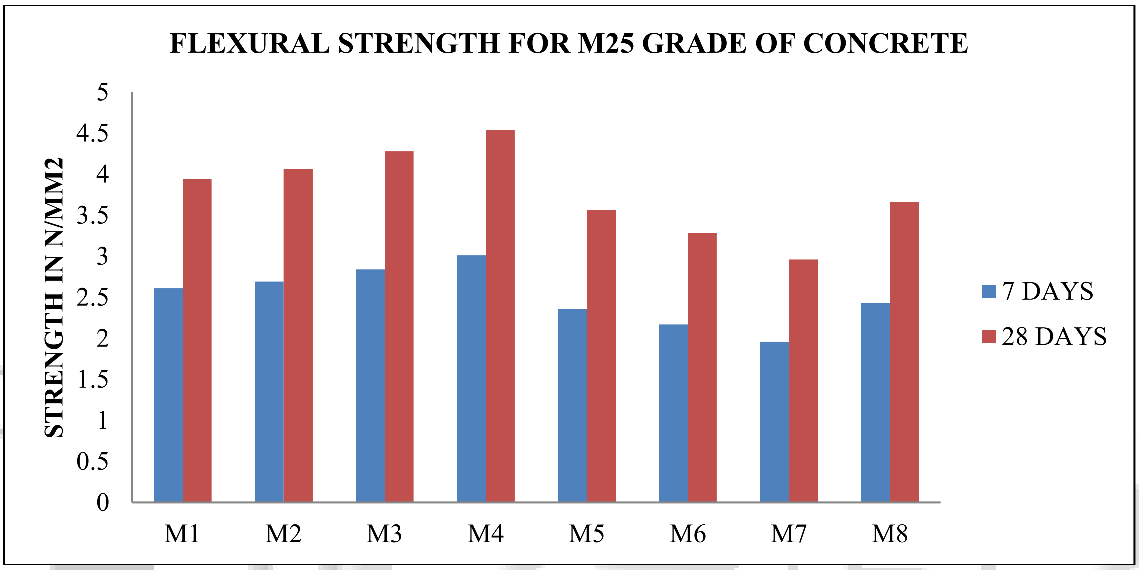
Compressive Strength of M30 Grade of Concrete at 3,7 & 28 days with different mix proportions

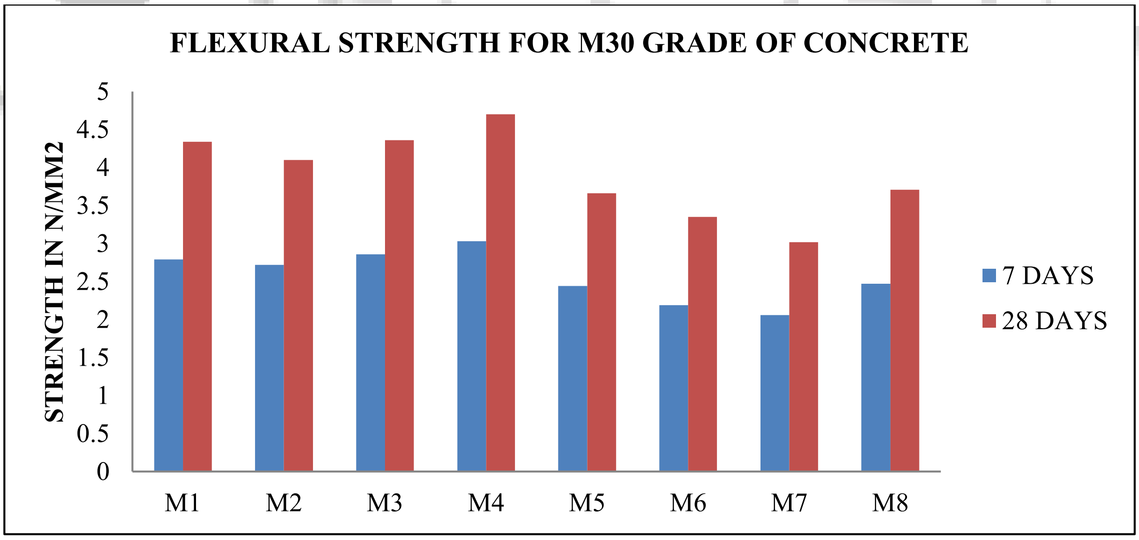


B. Flexural Strength Test Results –

Beams of size 10cm*10cm*50cm are casted for determining flexural strength. Test on beams are performed at the age of 28 days of the specimen. Placement of specimen in machine is done as per IS: 516-1959 in the clause no 8.3.1 page no 17. Load is applied at increasing rate of 108KN/min.

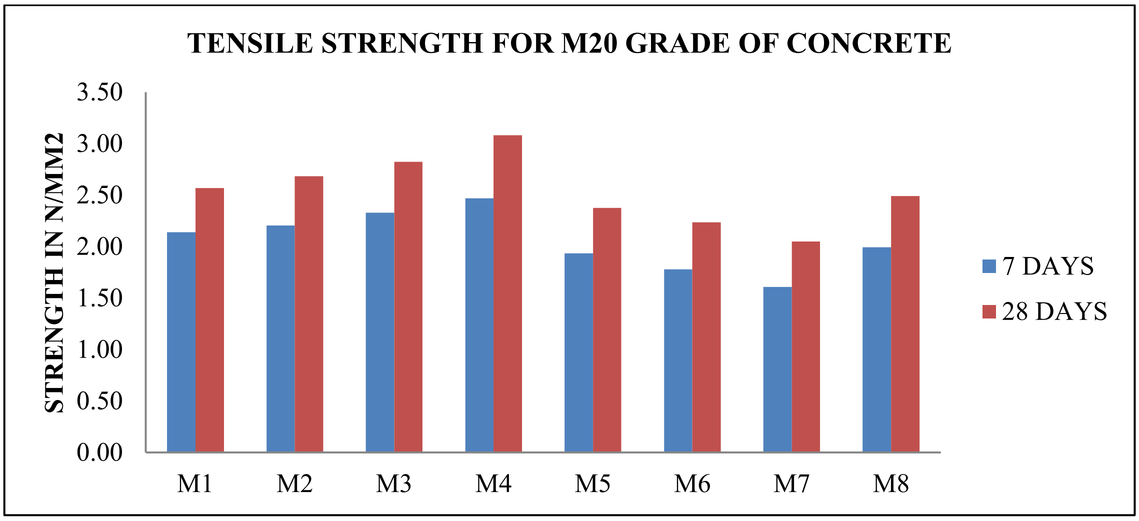


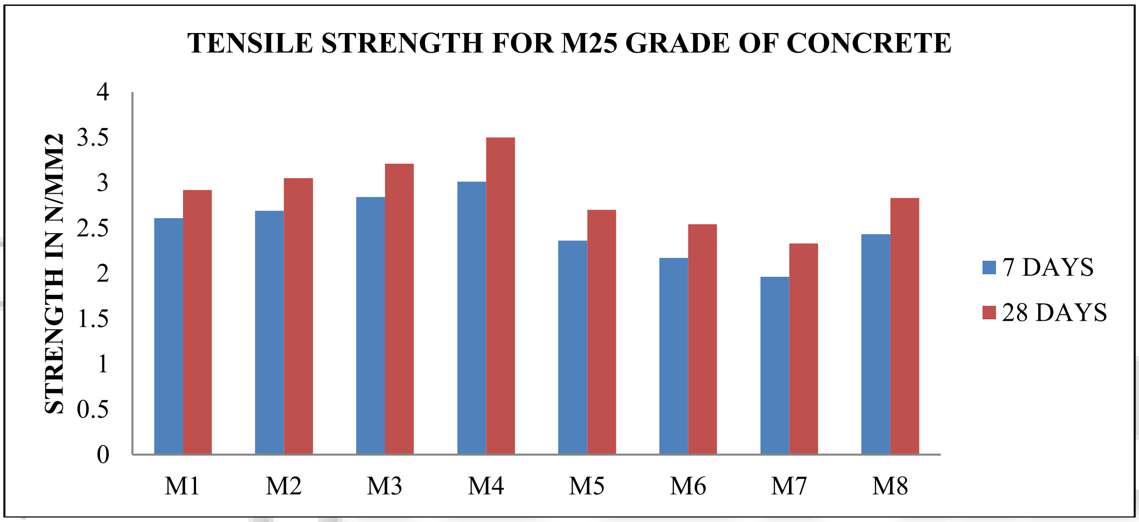


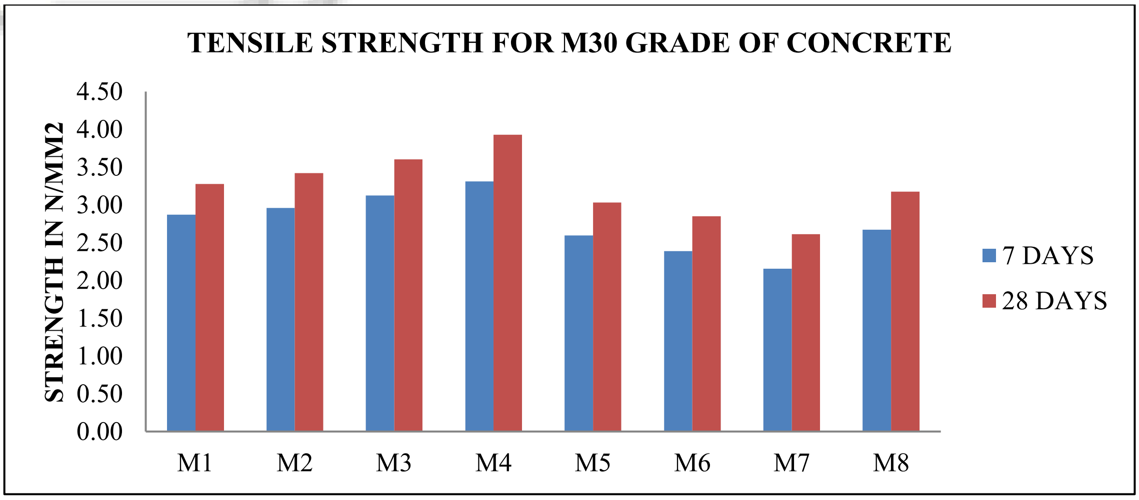


C. Tensile Strength Test Results –

Cylinders of size 15 cm diameter and 30 cm height are casted for determining Split Tensile Strength. Test on cylinders are performed at the age of 28 days of the specimen. Placement of specimen in machine is done as per IS: 516-1959.







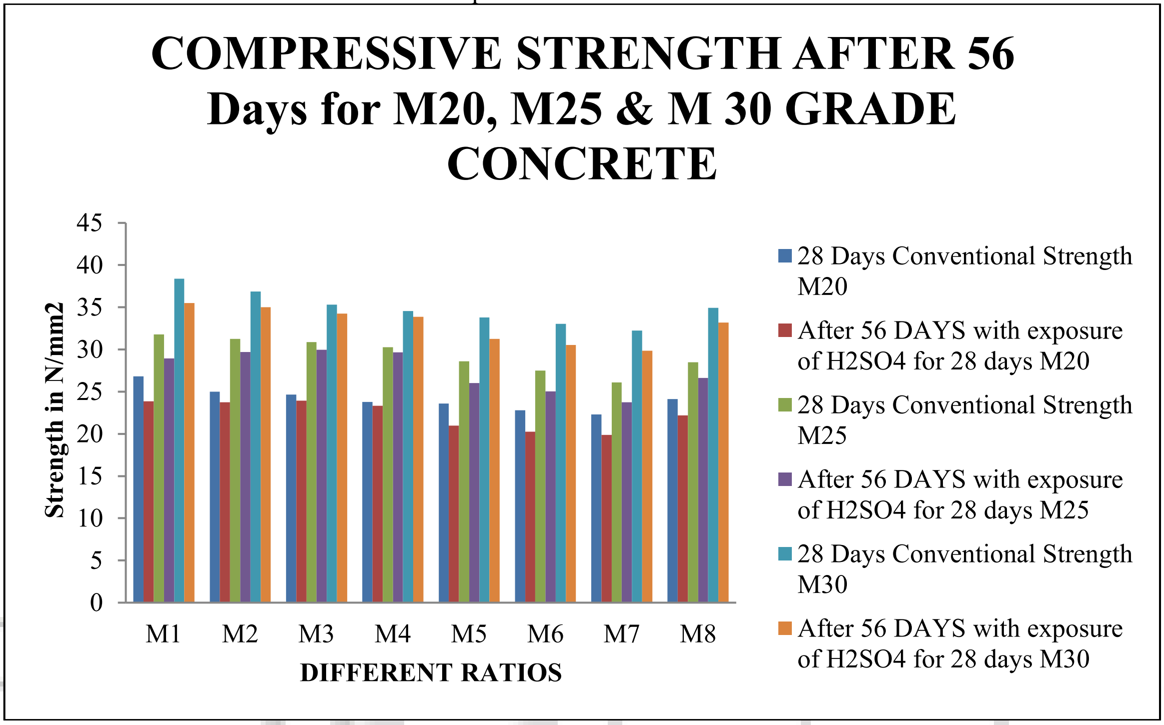
D. Durability Test -

The durability of concrete is the ability to resist weathering action, chemical attack, abrasion, or any process of deterioration. Durable concrete will retain its original form, quality, and serviceability when exposed to its environment. For the study of durability of concrete, the tests conducted were Acid resistance test (Sulphuric Acid attack), Alkalinity test (Sodium hydroxide attack) & Sea water attack test.

E. Sulphuric Acid Attack Test

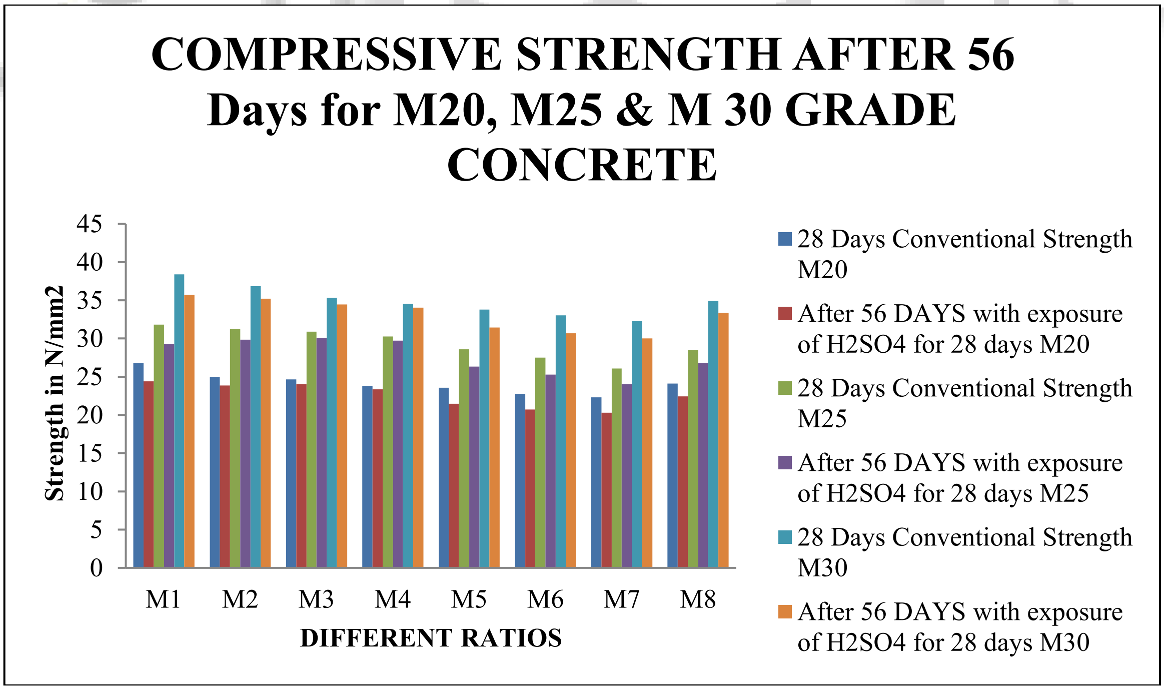
The compressive strength of specimens immersed in H_2SO_4 solution for 28 days after gaining its complete strength (strength after 28 days) were determined and compared with normal cured specimen at 28 days. Below table shows the percentage strength loss.

Sulphuric Acid Attack Test



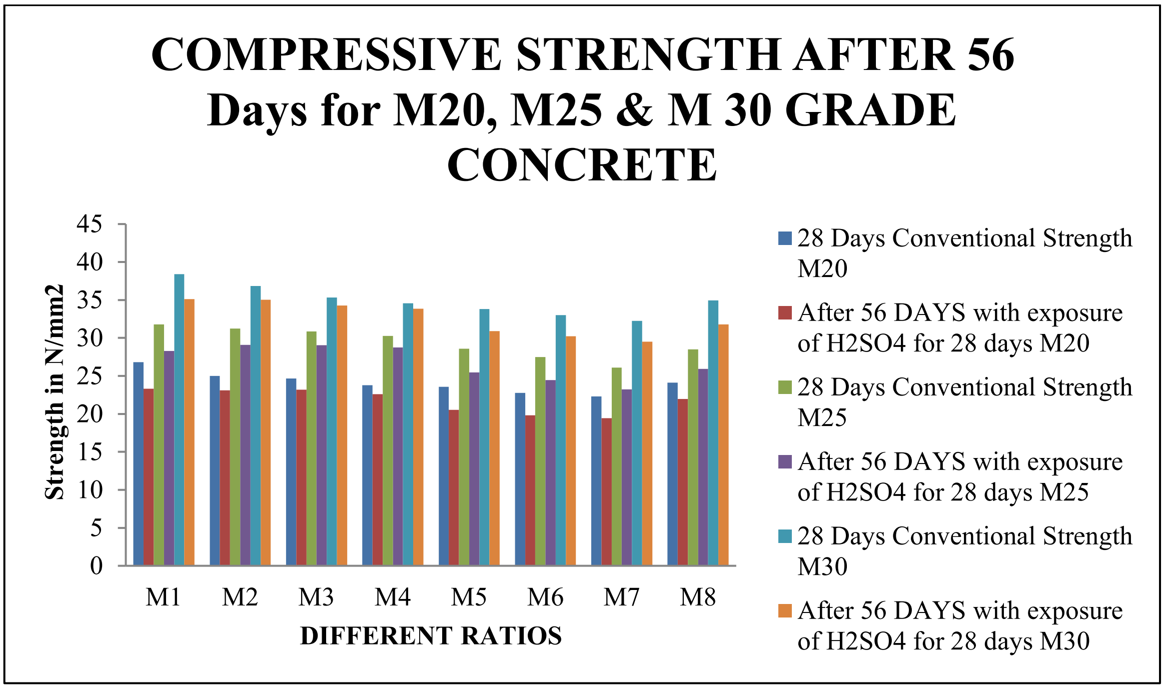
F. Alkalinity Test - Sodium Hydroxide Test

The compressive strength of specimens after NaoH exposure at 56 days (i.e. 28 days after gaining its strength) were determined and compared with normal cured specimen at 28 days. Below table shows the percentage strength loss in alkaline solution.



G. Sea Water Attack Test

The compressive strength of specimens after sea water exposure i.e. immersed in NaCl solution at 56 days (i.e. 28 days after gaining its strength) were determined and compared with normal cured specimen at 28 days. Below table shows the percentage strength loss in NaCl solution.



VII. CONCLUSION

It was crucial to remember that the amount of by-product significantly influenced the characteristics of the concrete. The following conclusions have been drawn from all of the studies:

– The addition of steel fibers to the traditional blend improved workability. For all concrete grades, the highest workability was achieved when 15% of the cement was substituted with steel fibers. The workability diminishes while employing coir fiber.
– Comparing the mix with steel fibers to the standard mix M1, the compressive strength dropped by up to 1%. Furthermore, compared to the traditional mix M1, the strength values have dropped by up to 5% when coir fiber is included, and by 3% when both are utilized in the M8 mix.
– As the number of steel fibers increased, so did the cylinder's splitting tensile strength. The highest amount attained for the mixture containing 15% steel fibers. When comparing coir addition mixes to conventional mixes, the percentage drop in splitting tensile strength can be as much as 10% lower than M1.
– It is discovered that beams with steel fibers have a higher flexural strength. When compared to a standard mix, the strength of the mix fraction including steel fibers increases by a significant 5%. The coir fiber blends once more exhibit extremely minimal degradation when compared to the M1 mix, which may be preferable.
– When compared to other mixtures, concrete that has 5% steel fiber replaced exhibits almost the same durability properties in acid and alkalinity. Following 56 days of exposure to a sulfuric acid solution, M2's compressive strength improved significantly—by as much as 8%—demonstrating that steel fibers can increase resilience to acidic environments.
– The percentage strength increase for mix proportions using steel fibres after 56 days of curing in NaOH solution was roughly 10%, however the value drops by 10-12% only when coir fibre is included in comparison to a typical mix.
– When steel fibres are added, seawater's endurance improves in comparison to a standard mix since the rate of degradation is roughly doubled when coir fibres are used.
– The cost of concrete goes up from 33% to 100% when steel fibres are used. Admixtures and additional cementitious materials can be used to provide cost-effective solutions. By replacing some of the cement with fly ash or GGBS and adding a tiny quantity of steel fibres, it is possible to create an economical solution for this grade of concrete while simultaneously lowering the amount of natural resources consumed in its production.

A. Recommendation

Concrete's strength, durability, and resistance to corrosion are all improved early on by steel fibres. By altering the ratio of different cementitious materials, much more can be accomplished. The ideal percentage for steel fibres is up to 5% replacement of cement, which yields good results. The cost of using steel fibres in place of cement over the ideal percentage appears to be higher than that of regular concrete. Compared to the price of 1 m3 of standard concrete for M25 grade, it is around 33% more expensive. Given that this mix is costlier than regular concrete and frequently used in large, massive structures that may need special mixing and have been shown to be cost-effective, research into the addition of additional cementitious material can provide insight into how well such concrete performs.

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