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A Comprehensive Study on Electrically Conductive Concrete Enhanced by Steel Nail as Reinforcing Material

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Abstract : Using fibrous components to enhance its structural strength and functionality, fiber-reinforced concrete stands out as a distinctive type of concrete.This fibrous material is irregularly dispersed within the concrete matrix. These fibers are typically made from steel, glass, synthetic polymer or may have natural origin like basalt or cellulose. Type, dimensions of the fiber can be adjusted depending upon the requirement of the structural use. In this experimental investigation, steel nails are used as the fiber type. Steel nails are common fasteners used in the construction and woodworking. They are typically made of steel, a strong and durable metal, available in different sizes and shapes, each designed for specific tasks. To examine its impact on the mechanical characteristics and electrical conductivity, steel nails were incorporated. Introducing electrical conductivity into concrete is an innovative type of concrete. The steel nails were incorporated in different fraction to concrete to assess the optimal dosage for effective results. There are many applications for this new combination, such as de-icing runways and bridges, cathodic protection, radiant heating, and electromagnetic shielding. This experimental investigation includes conventional mechanical testing and specialized conductive tests. Also the effected of current over surface temperature was monitored. The study's findings show promise and warrant further exploration to introduce these novel types of concrete in applications involving conductive media in construction.

Keywords — Compressive Strength, Electrical Conductivity, Fiber Reinforced Concrete, Flexural Strength, Resistivity, Split Tensile Strength, Steel Nail, Workability.

I. Introduction

Fiber-reinforced concrete (FRC) is a type of concrete that incorporates fibrous materials to enhance its structural integrity, durability, and other mechanical properties[1]. The addition of fibers in concrete helps control cracking, improve toughness, and increase resistance to various types of stresses. Steel fibers are commonly used as a reinforcement material in concrete to enhance its mechanical properties[2]. These fibers are typically made from various types of steel and are added to the concrete mix during the batching process. The incorporation of steel fibers in concrete offers several advantages and can improve the performance of the material in various applications. The properties of steel fiber in reinforced concrete are influenced by several key factors. The type of steel, whether it be hooked-end, crimped, straight, or deformed, significantly affects bonding characteristics. Additionally, the geometry and dimensions of the steel fibers, including shape, length, and diameter, play a crucial role in determining their interaction with the concrete matrix. The volume fraction of steel fibers, aspect ratio (length to diameter ratio), and surface treatments such as galvanization or chemical coatings are all important considerations affecting the mechanical properties and performance of steel fiber-reinforced concrete (SFRC). The concrete mix design, encompassing factors like cement type, aggregate, water-cement ratio, and admixtures, further contributes to the overall behavior of SFRC. Curing conditions, loading scenarios, and environmental exposure, including exposure to chemicals and moisture, also impact the long-term durability and corrosion resistance of the material. In this experimental investigation Steel nails are being utilized as a substitute for conventional steel fibers in reinforced concrete. Steel nails, designed for fastening materials together and woodworking. Nail is a small, discreet material made of different shapes and sizes. The potential future directions of steel nail use in concrete composites for structural applications are examined in this

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paper. Steel nail imbibed concrete, will have variation in properties. These characteristics include variations in electrical conductivity and heating rates in addition to fundamental mechanical characteristics.

Electrical concrete, generally refers to the concrete possessing electrical properties[5]. The type of concrete is recent innovative material under smart concrete innovations, having several potential applications. The innovative solutions by the inclusion of these technologies offer notable applications viz Self-Heating Surfaces, Electromagnetic Shielding, Structural Health monitoring, and Reinforcement Cathodic Protection leading to smart infrastructure. The purpose will address for the development of specialized flooring and payments along with providing a conductive pathway for electrical currents where reliable electrical grounding is essential for safety and performance. In order to create a continuous network of current flow, steel nails — the conductive material was utilized in this experiment program. Concrete and steel nails are combined in the proper proportion. The dosage should be such that it maintains the appropriate mechanical properties of the concrete while promoting electrical conductivity. During harsh cold environmental conditions, human beings prefer indoor environmental, enabling them with thermal comfort. The material utilized during the construct phase of building, influences the energy requirements[6] . Additionally, efforts have been made to improve the thermal properties of concrete through the incorporation of phase change materials [3]. Thermal conductivity of the building material lowers the building's energy needs and consumption [7]. This study mainly focuses on the optimization of Steel Nail content in the Steel nail Reinforced Concrete, by optimizing the steel nail content in M30 grade of concrete. The mechanical strength was investigated with the various fractions of steel nails 0%, 2.5%, 5%, 7.5%, 10%, 12.5% and 15%. With the optimized percentage of steel nails the associated electric and thermal properties were investigated. The results showed that the optimum dosage of 15% steel nail content was possible. The material produced with the incorporation of steel nails showed low electrical resistivity, permitting enough electrical current to flow through it in order to raise the concrete's surface temperature noticeably. An attempt to enhance its thermal qualities, can help to control interior temperature and lower energy usage in buildings[4].

II. MATERIAL

A. Cement

Cement is the main key ingredient in the concrete mix. Cement when mixed with aggregates and water starts to set and harden and binds the other materials together. In this experimental investigation, Ordinary Portland cement 43 Grade confirming to IS 8112 – 1989. The cement was physically test and results are tabulated in Table – 1, before utilization.

Table 1 : Physical properties of cement

S. No	Properties	Result
1	Fineness modulus	4.37 %
2	Consistency	30 %
3	Initial setting time	76 minutes
4	Final setting time	383 minutes

B. Fine Aggregate

River Sand locally available, procured from the lower course of Doodganga River near Chadoora belt of District Budgam JK. The particles used were with its maximum size 4.75 mm. While confirming the Sand Zone the sample was confirming zone II specification with respect to IS 2386 – 1963. The utilized sand was free from clay particles or any kind of debris. Further physical test conducted, reveled results as tabulated in Table 2.

Table 2 : Physical properties of fine aggregate

S. No	Properties	Result
1	Specific Gravity	2.59
2	Water Absorption	0.86 %
3	Zone	II

C. Coarse Aggregate

Coarse aggregate utilized were typically consisting of crushed angular stone with nominally 20mm size. The prime function of course aggregate is to provide strength and volume to the concrete. The aggregates used were readily available in the local crusher zone. Sample from batch was physical tested as per Indian Standard specifications are enlisted below.

Table 3: Physical properties of coarse aggregate

S. No	Properties	Result
1	Shape	Angular
2	Nominal Size	20 mm
3	Specific Gravity	2.64
4	Water Absorption	1.17 %
5	Crushing Value	21.63

D. Water

Uncontaminated water, supplied through the drinking water supply line was utilized for the production of concrete. The sample investigated for pH was showing pH value of 7.2. However, it's essential to ensure that the storage container used for holding water for mixing is free from any contaminants, including oil or other harmful impurities.

E. Steel Nails

Steel nails are a type of fastener that are hard-wearing and can be used for a variety of purposes. The purpose of their addition in concrete, is to enhance the mechanical strength along with other engineering properties. In this experimental steel wire nails of length 23 mm and dia 1.0 mm were used.

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II MIX PROPORTIONS & SAMPLING

The reference mix of M30 was prepared according to the IS Mix design code of practice IS Code 10262-2009. The each fraction of material to be utilized was calculated at a fixed water-to-cement ratio of 0.45. The amount of materials calculated per meter cube of concrete is given below, in table 4.

Table 4: MIX PROPORTION FOR REFERENCE CONCRETE

	Water	Cement	Fine Aggregate	Coarse Aggregate
Material for 1m^3	180.792	401.76	660.93	1099.17
Ratio	0.45	1	1.53	2.55

The experimental modification with the reference concrete was the addition of steel nails into the concrete mix. The addition was done by the total weight of the concrete mix material excluding water fraction. The different mix which were casted with different addition level of steel nails ranging between 2.5% to 15%. The fraction of addition of steel nails to the respective mix are tabulated in Table 5 below.

Table 5: Mix Proportion For Different Mix

Mix	Cement	Steel Nails		Fine Aggregate	Coarse Aggregate	Water
	kg	%	kg	kg	kg	Kg
REF	401.76	0	-	660.93	1099.17	180.79
SN1C	401.76	2.5	54.05	660.93	1099.17	180.79
SN2C	401.76	5	108.09	660.93	1099.17	180.79
SN3C	401.76	7.5	162.14	660.93	1099.17	180.79
SN4C	401.76	10	216.19	660.93	1099.17	180.79
SN5C	401.76	12.5	270.23	660.93	1099.17	180.79
SN6C	401.76	15	324.28	660.93	1099.17	180.79

After the mix for each mix was prepared, the fraction of concrete was investigated for workability by conducting the slump text. Remaining fraction of concrete was filled in the moulds – cube mould, cylinder mould prism-beam and slab mould respectively for the preparation of samples to verify the mechanical strength, resistivity and associated temperature parameters. For each mix 19 samples – 9 cubes, 6 cylinders, 3 beams and 1 slab were prepared, in total 133 samples were prepared for this investigation. The sampling procedure followed included filling the moulds by the fresh concrete in 3 successive layers followed by vibrations over vibrating table and finishing the top surface. After 24 hours the concrete samples were removed from the mould and placed in the water curing tank upto to respective ages of testing.

III. EXPERIMENTAL PROCEDURE

A. Workability

The workability of concrete was assessed through the slump test, corresponding to IS 1199-1959, "Methods of Sampling and Analysis of Concrete." The standard procedure for conducting the slump test, for evaluating the consistency and workability of fresh concrete. The test involves using a slump cone and a tamping rod, where the concrete mix is placed in the cone, compacted in layers, and the cone is lifted vertically to measure the change in height, known as the slump. The resulting slump value offers insights into the workability of the concrete mix, with a higher slump indicating greater workability.

Figure 1: Workability Check – Slump Value

B. Compressive Strength

The compressive strength of concrete is determined through the cube test, as per IS 516:1959 - "Method of Tests for Strength of Concrete". Typically a cube of 150 mm size, are cast and cured in water at 27 ± 2°C for either 7, 14 or 28 days. Subsequently, the cubes undergo testing for compressive strength using a compression testing machine, with a loading rate of around 35 MPa/min. The calculation involves dividing the maximum load applied to the cube by its cross-sectional area, and the results are reported in Megapascals (MPa).

Figure 2: Compression Test

C. Split Tensile Strength

The split tensile strength of concrete is assessed through a test on cylindrical specimens, corresponding to IS 5816:1999, "Method of Test Splitting Tensile Strength of Concrete". The procedure for conducting the split tensile strength test, involves providing cylindrical specimens to a

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diametrical compressive load until failure. The split tensile strength is then calculated using the applied load and the dimensions of the specimen, with results reported in Megapascals (MPa).

Figure 3: Split Tensile Test

D. Flexural Strength

The flexural strength of concrete is determined through a test on prismatic beam specimens, as per is IS 516:1959, "Method of Tests for Strength of Concrete". Prismatic beam specimens are subjected to a bending load until failure. The flexural strength is then calculated based on the maximum applied load and the dimensions of the specimen, with results reported in Megapascals (MPa).

Figure 4: Flexural Test

E. Conductivity Test

The absence of a standardized reference for this particular test, has leads to establish a setup, where the current, voltage values along with the specimen dimensions were chosen, and the conductivity values were calculated empirically. Slabs measuring 70x30x10 cm (one for each mix) were cast, with two connecting embedded metallic strips on opposite sides within each slab. The experimental setup involved connecting the main AC power supply to a transformer. An ammeter was incorporated in series, followed by a light bulb to determine the minimum voltage required to induce sufficient current for bulb illumination. The wiring was connected to one of the embedded metallic strip, and another wire was linked to the opposite strip, completing the circuit back to the transformer. Voltage and current reading was recorded after the experimental setup to evaluate the material properties. Electrical conductivity, for each mix is calculated :

Equation for resistance as per equation:

$$R = \frac{V}{I}$$

where V is the voltage in volts, I is the current in amperes

and R is the resistance in ohms.

Electrical resistivity, can thus be calculated using the equation:

$$\rho = \frac{V}{I}\left(\frac{wt}{l}\right)$$

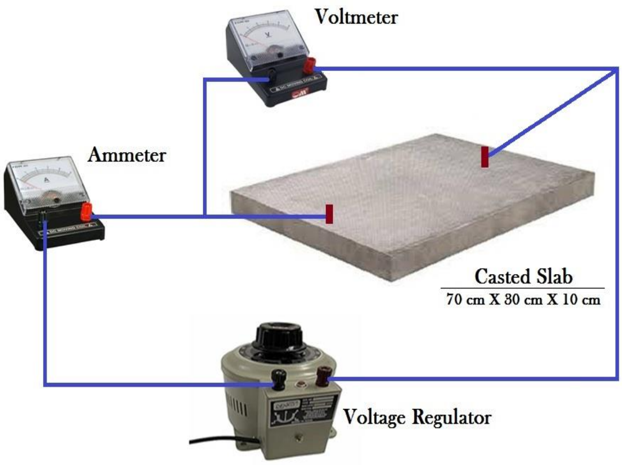
where V is the voltage in volts, I is the current in amperes and w, t, & l are the width, thickness, and length of the specimen respectively.

Electrical conductivity

$$\sigma = \frac{1}{\rho}$$

where σ is the electrical conductivity in 1/ohm-cm.

Figure 5: Conductivity Test Setup



F. Surface Temperature

Laser Infrared Thermometer Non-Contact Digital Temperature Gun, was utilized to measure the surface temperature. The temperature of the casted slab specimen was observed after passing the current for 15 minutes. The purpose of this observation was to observe the effect of passing current through conducting slabs with different fractions of steel nails.

Figure 6: Surface Temperature

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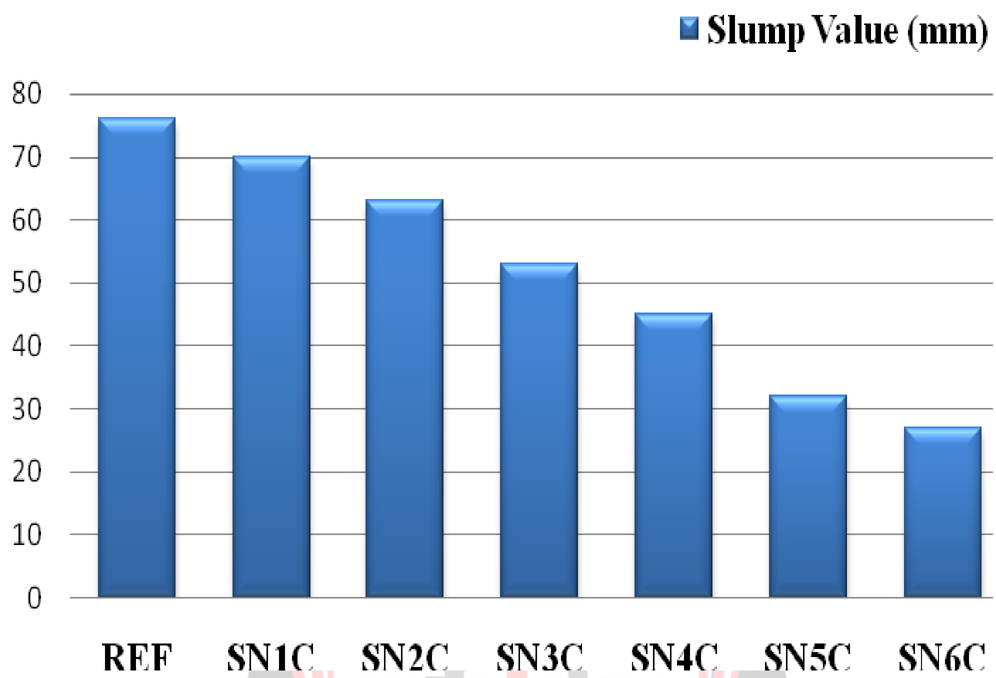
IV. RESULTS & DISCUSSION

A. Workability

The workability of concrete, measured by the slump value was influenced the addition of steel nails. The amount of steel nails added impact on the workability of the fresh concrete mix. In general with the increase in the steel nail content there was a decrease in the slump values, making concrete less fluid. The steel nails tend to interlock and create a more viscous mixture, creating a reduction in the flowability of the concrete, leading to a lower slump. The slump values obtained for various mix proportions have been represent in Figure – 7.

Figure 7 : Slump Value for Different Mix



The steel nails being rigid, can get entangled with each other and the other concrete ingredients. The presence of steel nails can disrupt the normal interaction between the concrete matrix. This interlocking effect increases the internal friction within the concrete mix, leading to higher viscosity. As a result, the concrete becomes less fluid, and its ability to flow and spread (as indicated by the slump) is reduced. Also this interaction of the fresh concrete and the steel nails hinder the movement of particles, making it more difficult for the mix to achieve the desired level of flowability. Also by the addition of steel nails the stiffening effect is introduced within the concrete matrix, proportional to the amount of steel nails content, leading to decrease in workability.

B. Compressive Strength

The Compressive strength test was conducted at 7, 14 and 28 of age over the casted specimens of various mix proportions under consideration. The results revealed with the addition of steel nails there was a variation in the compressive strength. The obtained results have been eloquently illustrated in Figure 8. The trend developed, reveal there is an expected increase in compressive strength as concrete ages, with mixes SN1C to SN6C consistently outperforming the reference mix (REF) at all three ages. Mix SN5C exhibits the highest compressive strength among all mixes. However, mix SN6C shows an anomaly with a decrease in compressive strength. The rate of strength gain varies among the mixes, suggesting different levels of reactivity and performance. Overall, the maximum gain of strength was observed in the mix SN5C, further in the following mix were the steel nail content was further enhanced showed a decreasing trend. Thus optimizing the steel nail content to 12.5%.

The enhancement of compressive strength, may be attributed to the reinforcing effect developed within the concrete matrix[9], providing additional strength by resisting tensile and shear forces. This reinforcing effect can help in redistributing applied loads within the concrete member. When stress is applied, the steel nails help distribute the load more evenly, reducing localized stresses and enhancing the concrete's ability to bear higher compressive loads. The steel nails introduced with the concrete increases the overall density of the concrete. Bond improvement between the steel nails and the surrounding concrete matrix by the steel nail inclusion enhances the load transfer mechanism leading to the improved compressive strength.

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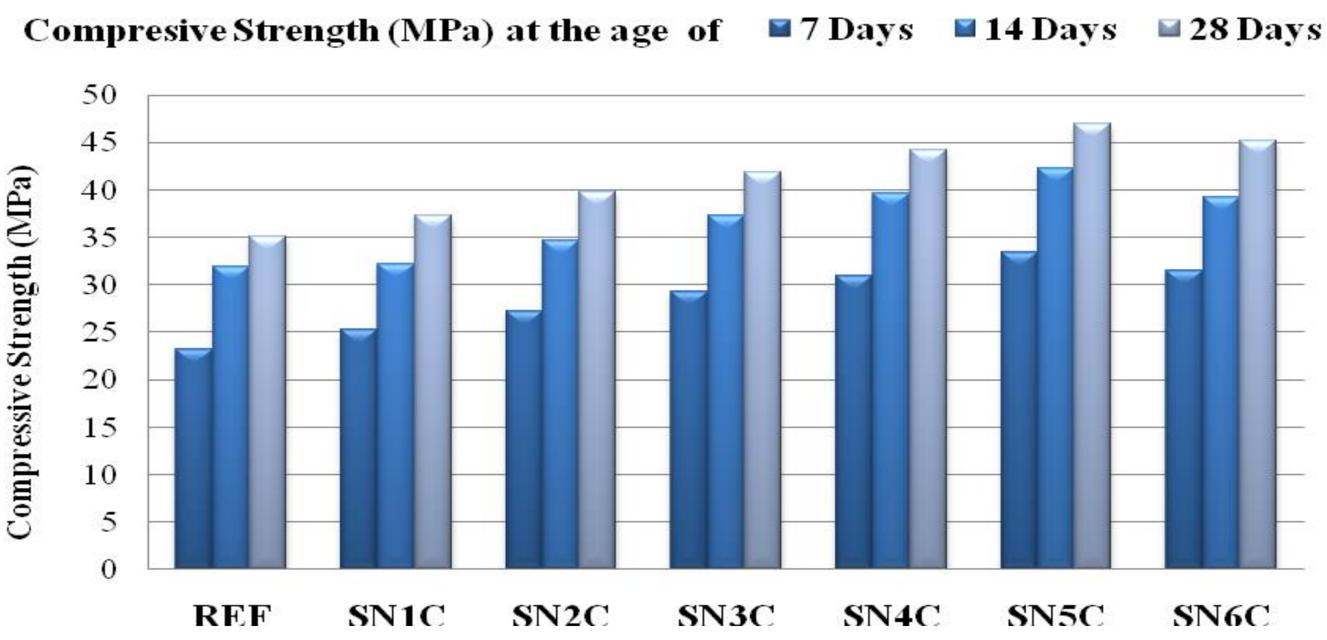
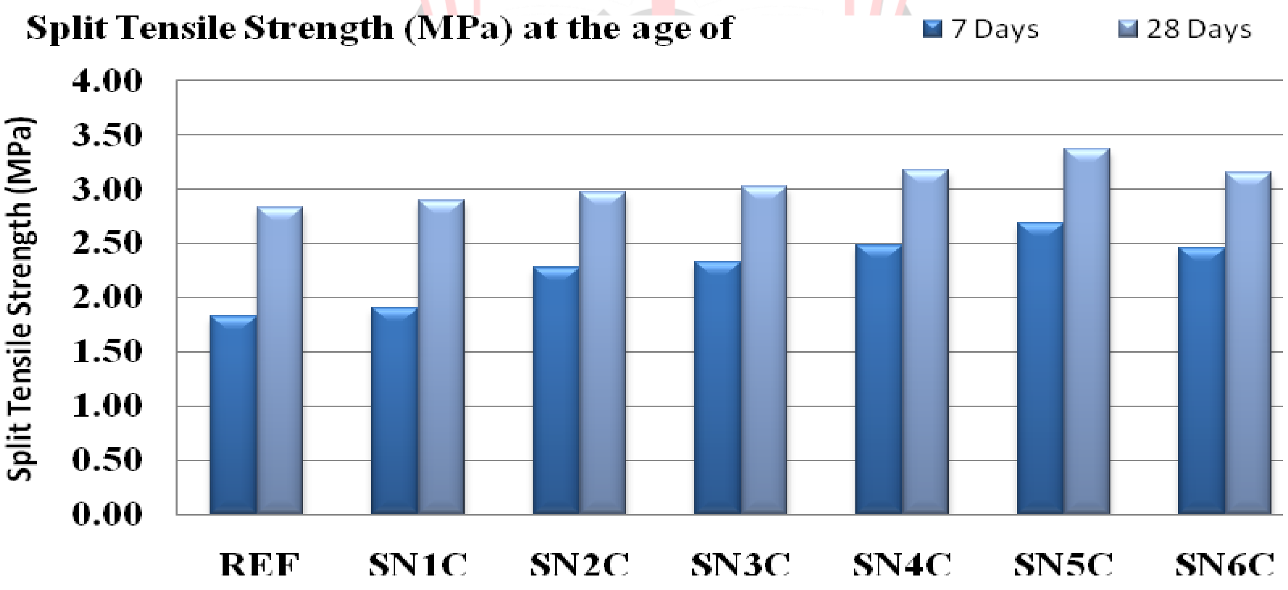
Figure 8 : Compressive Strength for Different Mix



C. Split Tensile Strength

The average split tensile strengths of cylindrical specimens were determined, after curing period of 7 and 28 days. The split tensile strength test results showed that addition of steel nails to concrete altered the split tensile strength of concrete as shown in Figure 9.

Figure 9 : Split Tensile Strength for Different Mix



As illustrated in Figure 9, the addition of Steel nails showed a marginal gain of 19% in mix SN5C. The linear increase was observed up-to 12.5% steel nails inclusion, further increment in the steel nail content showed the reverse effect. The reinforcement within the concrete matrix, provides an additional strength by resisting tensile forces. By this reinforcement Steel nails can help control and limit the propagation of cracks within concrete by bridging and arresting the development of crack ultimately enhancing split tensile strength [8]. Steel nails assist in redistributing applied loads within the member. In such situations where tensile forces are applied, the steel nails help distribute the load more evenly, reducing localized stresses and enhancing the concrete's ability to bear higher tensile loads. However at higher concentration level, the reverse effect induced may be arising due to the non uniform distribution of nails within the concrete, resulting due to the formation of nail chunks, which was also supported by the harsh concrete formation as depicted from slump value.

D.Flexural Strength

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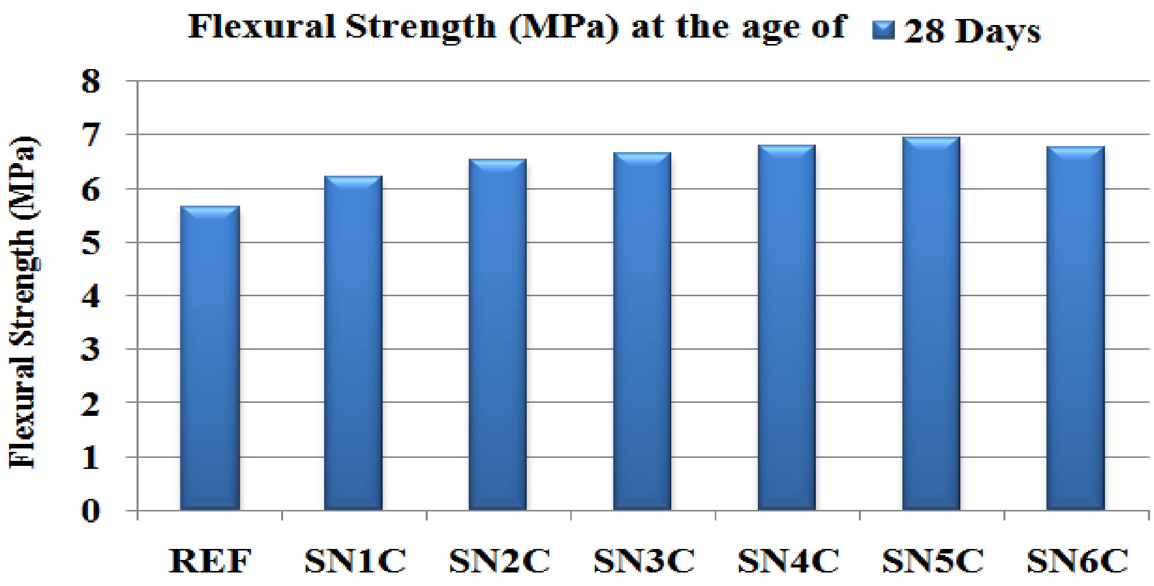
With the inclusion of steel nails, the flexural strength showed variation with repect to the steel nail content. The flexural strength at 28 days show a consistent trend of increasing values with the addition of steel nails (SN1C to SN6C) compared to the reference mix (REF). This trend supports the notion that steel nails effectively enhance the flexural strength of concrete. However with further addition of steel nails beyond 12.5% the trend showed the decreasing effect. The flexural strength was verified at the age of 28days. The results obtained with different mix have been illustrated in Figure 10.

Figure 10 : Flexural Strength for Different Mix



As depicted in the Figure 10, a total of 22% gain in flexural strength was noted with the mix containing 125% steel nails as compared to the reference mix. The increase in the flexural strength may be attributed to the enhanced discrete reinforcement within the concrete matrix, providing additional strength by resisting tensile forces. In flexural loading conditions, where the concrete is subjected to bending, the presence of steel nails helps distribute the applied loads more evenly, reducing tensile stresses and preventing premature cracking or failure. The steel nails help bridge and arrest the development of cracks, enhancing the concrete's ability to withstand bending stresses and increasing its overall flexural strength. The inclusion of steel nails also enhanced the ductility of the concrete, allowing it to deform more before experiencing structural failure. This improved ductility is particularly beneficial in flexural applications, as it enables the concrete to absorb more energy and resist bending without fracturing, resulting in higher flexural strength. At higher inclusion level, the steel nails form clusters due to agglomeration within the cement matrix. This clustering can create local stress concentrations and affect the uniform distribution of reinforcement, potentially leading to weakened zones and reduced flexural strength. due to which the added steel nails act as discrete reinforcement within the concrete matrix, providing additional strength by resisting tensile forces. In flexural loading conditions, where the concrete is subjected to bending, the presence of steel nails helps distribute the applied loads more evenly, reducing tensile stresses and preventing premature cracking or failure. The effective reinforcement of concrete by steel nails relies on their proper dispersion throughout the mix. If the mixing process is inadequate, and steel nails are not evenly distributed, certain areas of the concrete may lack the intended reinforcement, leading to variations in flexural strength.

E. Electrical Conductivity

The data presented in the Table 6, illustrates that with different mix ratios, there is a consistent pattern of lower voltage consumption. This tendency coincides with a sudden drop in resistance, leading to an observable increase in conductivity. The table highlights the dynamic relationship between these electrical parameters, showcasing the impact of varied mix ratios on the behavior of the material system.

Table 6: Electric Conductivity for Different Mix (After 28 Days)

	V (V)	I (A)	R (Ω)	ρ (Ω cm)	σ (1/Ω cm) x 10^{-3}
REF	310	0.08	3875	16662	0.060
SN1C	255	0.08	3553	15278	0.065
SN2C	220	0.08	3200	13760	0.072
SN3C	210	0.08	3015	12965	0.077
SN4C	200	0.08	2834	12186	0.082
SN5C	180	0.08	2400	10320	0.096
SN6C	180	0.08	2130	9159	0.109

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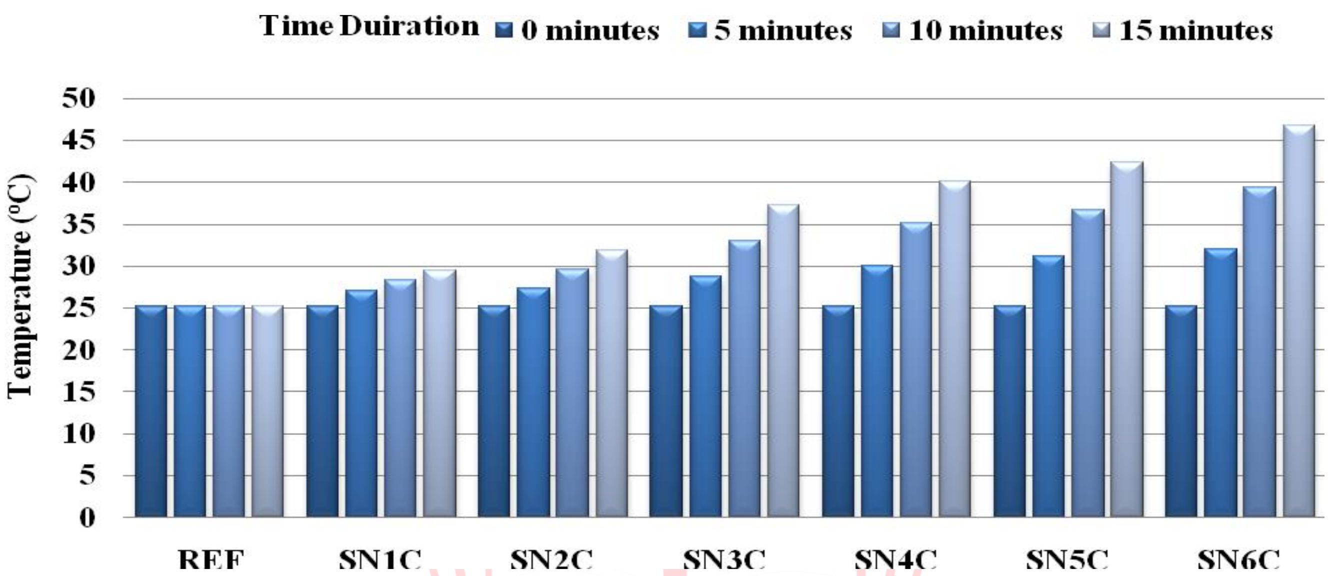
Using different approximations of mixes Lesser voltage is consumed due to this there is sudden drop in resistance which leads to increase in conductivity and vice versa[10].

F. Surface Temperature

The temperature variations were systematically observed across different time intervals for samples featuring varying steel nail content. The recorded data, measured at 0 minutes, 5 minutes, 10 minutes, and 15 minutes, provides insight into the surface temperature changes by maintaining a constant voltage of 180 volts. The surface temperature observed for different mix at time interval of 5minutes upto 15 minutes has been illustrated in Figure 11.

Figure 11: Surface Temperature observed for Different Mix



The reference mix labeled "REF" consistently maintained a temperature of 25.2°C throughout all time points, serving as a baseline. Conversely, samples SN1C, SN2C, SN3C, SN4C, SN5C, and SN6C exhibited increasing temperatures over time, highlighting the impact of steel nail content on temperature fluctuations. During a 15-minute testing period with an applied voltage of 180 V, temperature measurements at the 15-minute mark revealed distinct thermal responses. The reference mixture exhibited a temperature of 25 °C, while the mixture containing 7.5% steel nails recorded 37 °C (12 °C above the reference). Similarly, the mixture with 10% steel nails reached 40 °C (15 °C above the reference), the 12.5% steel nail mixture recorded 42 °C (17 °C above the reference), and the 15% steel nail mixture registered 46 °C (21 °C above the reference). Corresponding average heating rates were 0.65 °C/min (7.5% steel nails), 1.6 °C/min (10% steel nails), 2.65 °C/min (12.5% steel nails), and 2.95 °C/min (15% steel nails). These findings illustrate a clear relationship between steel nail content and the resulting temperature variations, providing valuable insights into the thermal behavior of the mixtures under the specified testing conditions. As anticipated, the escalating steel nail content led to increased conductivity and heating rates, ensuring that the final surface temperature of the concrete did not surpass 46 °C within the shortened 15-minute testing duration.

V. CONCLUSION

- The workability of the fresh concrete mix was negatively influenced by the addition of steel nails, as indicated by a decrease in slump values as the steel nail content increased.
- The compressive strength of concrete increased with the addition of steel nails, reaching a maximum in mix SN5C with 12.5% steel nails.
- Addition of steel nails led to a marginal gain in split tensile strength, peaking at 19% in mix SN5C.
- Flexural strength increased with the inclusion of steel nails, peaking at a 22% gain in mix SN5C.
- A consistent pattern of reduced voltage consumption leading to an increase in conductivity was observed across a range of mix ratios. The influence of steel nail content on material behavior was brought to light by this dynamic relationship between mix ratios and electrical parameters.
- Variations in surface temperature over time intervals showed an increasing trend as the amount of steel nails increased.
- The final surface temperature remained below 46 °C during the 15-minute testing period due to increased

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conductivity and heating rates brought about by the increased content of steel nails.

Overall, the addition of steel nails influenced both the mechanical and thermal properties of the concrete, demonstrating potential benefits in terms of strength enhancement but also highlighting the importance of optimizing steel nail content for desired properties.

VI. FUTURE SCOPE

The future scope of research in this field involves a comprehensive exploration of concrete durability with integrated steel nails. Investigating the long-term performance will prioritize examining resistance to corrosion and other environmental factors, ensuring sustained structural integrity over an extended lifespan. Furthermore, delving into the impact of various steel nail characteristics, such as size, shape, and surface treatment, on both mechanical and thermal properties will offer a more nuanced understanding of the reinforcement mechanisms. This research avenue aims to identify optimal steel nail configurations for enhanced concrete performance. Additionally, evaluating the environmental sustainability of concrete with steel nails is crucial. This assessment, encompassing factors like embodied energy and life cycle considerations, will contribute to understanding the ecological footprint of such concrete formulations, guiding the development of environmentally friendly construction materials and practices. Overall, future investigations should strive to address these critical aspects, advancing our knowledge and facilitating the development of resilient and sustainable concrete composites.

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