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Original Research Article

Optimizing concrete strength through the incorporation of steel nails: a comprehensive engineering analysis

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Abstract: The primary materials utilized in contemporary buildings are concrete and reinforced concrete. Researchers applied many methods to improve their quality and reduce costs by adding additives. The primary focus of this investigation is the compressive strength of concrete. After adding varying amounts of steel nails to the concrete mixture, the ensuing changes in compressive strength are subjected to a comprehensive analysis. Mix design was conducted, and concrete cylinders having a diameter of 4" and height of 8" were produced with varying percentages of steel nails: 1%, 2%, 3%, 4%, and 5% of the cement weight. The mixture was prepared, maintaining a constant water-to-cement ratio of 0.5. The compressive strength of the concrete is measured at 3, 7, 14, and 28 days after the mixing process. It was determined that steel nail incorporation increased compressive strength. With a 5% mix, the highest strength measured is 4775 pounds per square inch, much higher than the normal strength required for most construction projects. Furthermore, using steel nails led to a cost reduction in concrete of up to 0.5%, alongside a strength enhancement of up to 24% compared to conventional concrete.

Keywords: ASTM standards, Steel nail, Nail-modified concrete, Compressive strength, Concrete properties, Materials innovation, Reinforced concrete, Concrete mixture.

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1. Introduction

Concrete is recognized for its adaptability in building, enabling it to be shaped into numerous forms and geometries. This adaptability has greatly facilitated the progress of concrete architecture in recent years (Jipa & Dillenburger, 2022; Makul, 2020). Although concrete demonstrates superior compressive strength, it is deficient in tensile strength, necessitating reinforcement in regions subjected to stress. This has traditionally been executed using normal reinforcing bars (reinforced concrete). The increasing need for sophisticated design concepts has created new reinforcing materials like steel fibre. Steel fibres enhance the load-bearing capacity and fracture resistance of concrete constructions. In certain instances, they might completely supplant conventional reinforcing techniques, offering engineers and architects enhanced design freedom (Zhang *et al.*, 2023; Wang *et al.*, 2021). Our study examines developments in reinforcing materials, namely using steel fibres in intricate geometries. Concrete is inherently brittle and weak under tensile stress. Historically, fibres have been used in construction materials to improve their qualities, a process that has existed for millennia. Initial instances include incorporating straw into mud bricks, horsehair into plaster, and asbestos into ceramics. The use of continuous reinforcing in concrete, termed reinforced concrete, improves its strength and ductility but necessitates accurate placement and proficient labour (Kośny & Yarbrough, 2022; Singh, 2022; Ottmann, 2022).

Global yearly production of ferrous materials has risen by over 60%, around 1300 million tons, in the past decade. Steel slag is a byproduct generated during the steel production process. Each ton of steel produces 130–200 kg of slag, contingent upon the composition and steelmaking methodology (Agwa *et al.*, 2020; Maslehuddin *et al.*, 2003). The predominant chemical constituents of steel slag are SiO_2, CaO, Fe_2O_3, Al_2O_3, and MnO. The principal mineral constituents of steel slag are C_3S, C_2S, C_4AF, RO phase, and free-CaO (Yang *et al.*, 2021). The predominant component of this byproduct, which is fragmented into minute particles, is calcium carbonate. These minerals serve as aggregates in concrete manufacture. China was the leading global steel producer in 2009, generating almost 740 million tonnes of steel slag. The steel slag aggregate replenishment pace significantly affects cement concrete's compressive strength. The compressive strength rose by 28.46%, 42.67%, and 55.89%, respectively, when substituting slag aggregate for 40%, 60%, and 80% of the coarse aggregate (Miah *et al.*, 2020). Researchers determined that replacing 50% coarse aggregate with steel slag yielded the highest compressive strength (Saxena & Tembhurkar, 2018). The splitting tensile and flexural strength of concrete utilizing coarse steel slag aggregate has been examined. Their investigations demonstrated that the breaking tensile strength of slag aggregate concrete after 28 days exceeded that of the control group at elevated replacement rates (75 and 100%) (Usama *et al.*, 2023; Wang *et al.*, 2015).

A variety of reinforcement solutions have been evaluated by several scholars (Bos *et al.*, 2018; Bos *et al.*, 2017; Mechtcherine *et al.*, 2018; Hambach & Volkmer, 2017; Farina *et al.*, 2016). The initial stage following concrete printing was the installation of steel wires or reinforcements at a designated place (Asprone *et al.*, 2018). In this instance, either ordinary pre-stressed concrete or reinforced concrete may be employed for the design and construction of the buildings. The current placement of the steel bars is not automated; however, some efforts aim to provide concurrent printing of concrete and steel (Mechtcherine *et al.*, 2018). A prevalent technique involves using fibres to enhance the structural integrity of printed concrete constructions (Ogura *et al.*, 2018; Ma *et al.*, 2019). Steel (Farina *et al.*, 2016), bio-based fibres (Sonebi *et al.*, 2019), polymeric fibres (Farina *et al.*, 2016), basalt fibres, and glass fibres (Khan *et al.*, 2021; Khan *et al.*, 2018; Shah *et al.*, 2020) have been investigated to improve the strength properties and ductility of 3D printed cementitious materials. They examined the impact of embedding a steel wire into the deposited layer as a potentially effective strengthening technique. The two preceding approaches failed to strengthen the interface between layers, which was considered a possible vulnerability of the printed structures (Ullah *et al.*, 2024; Ullah *et al.*, 2021; Putten *et al.*, 2019).

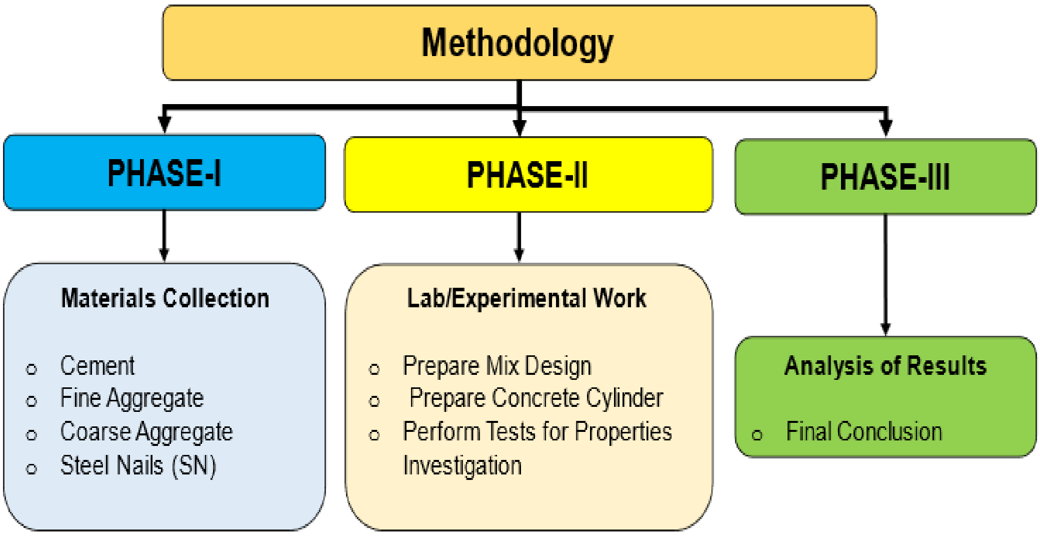
Researchers in these investigations have concentrated on the capacity of steel nails to improve several concrete qualities, such as minimizing cracking, shrinkage, and permeability through the modulation of fibre dosage. This research seeks to investigate the effect of incorporating steel nails into concrete to enhance its compressive strength through varying percentages. This study does not concentrate on tensile strength and other metrics, highlighting a gap in current research that might be addressed in future investigations.

The objective of this study is to ascertain the concrete cylinders' compressive strength and their performance in response to varying additions of steel nails. These levels, which consist of 1%, 2%, 3%, 4%, and 5% by weight, were assessed using a design mix ratio of 1:1.5:3 (cement: sand: coarse aggregate). Throughout the experiment, a constant water-to-cement (w/c) ratio of 0.5 is maintained to ensure consistency and reliability in the results.

2. Material and method

The research was conducted entirely in the laboratory, focusing on the compressive strength of concrete. The procedures followed are to the relevant ASTM standards (ASTM C39/C39M-21) for the compressive strength test of concrete cylinders. Different proportions of steel nails were added to the concrete mix, and the corresponding variations in compressive strength were meticulously analyzed.

Figure 1: Research methodology flowchart



2.1. Mix design sample preparation

In this research, a total of 72 concrete moulds were cast, including 12 cylinders of normal concrete and 60 cylinders of steel nail-modified concrete. Each mould had a diameter of 4 inches and a height of 8 inches.

2.2. Standard reference

The research followed the ASTM-C39 standard, which specifies the test method for measuring the compressive strength of cylindrical concrete specimens.

2.3. Material

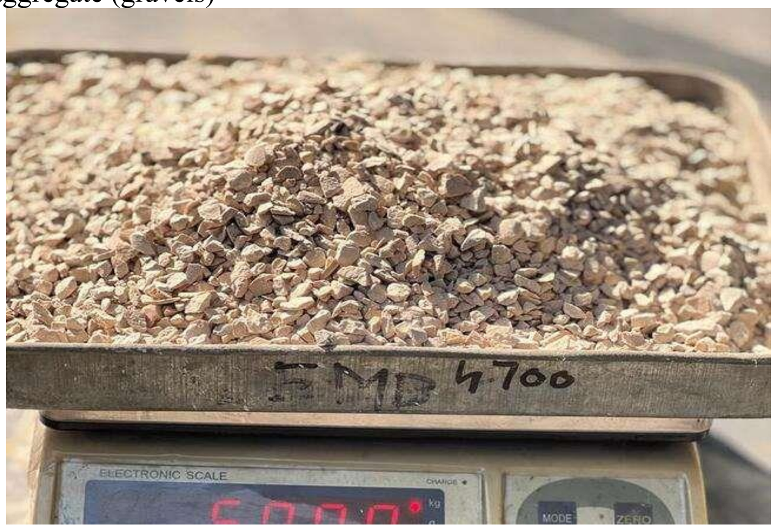
The materials utilized in the concrete process are as follows:

- Cement: Ordinary Portland Cement (OPC) was used in this test to prepare concrete cylinders for the laboratory experimental performance.
- Fine aggregate: Fine aggregate primarily consisted of sand passing through a No. 4 (4.75 mm) sieve. Figure 2 shows the fine aggregate used, which meets the specifications for coarse material content. The Fineness Modulus (FM) of the fine aggregate was 2.50.

Figure 2: Fine aggregate (sand)

- Coarse aggregate: The coarse aggregate had a maximum size of 12.5 mm. Figure 3 shows the stone chips used.

Figure 3: Coarse aggregate (gravels)



- Steel nails: Steel nails with a size of 25.4 mm or 1 inch were incorporated into the concrete mix. Figure 4 displays the steel fibers used in varying percentages of 1%, 2%, 3%, 4%, and 5%. This version provides a clearer and more concise explanation while maintaining a natural tone.

Figure 4: Steel nails (Length: 25.4 mm)

2.4. Methodology

Once the materials were gathered, concrete mixes containing steel nails were prepared, and cylinders were cast. After curing periods of 3, 7, 14, and 28 days, the compressive strengths of the concrete were tested using a Universal Testing Machine (UTM). The detailed methodology is outlined below:

Table-1: Calculating the percent (%) measurement of steel nails

Sr. No.	Length (mm)	Percent (%)
1	25.4	1
2	25.4	2
3	25.4	3
4	25.4	4
5	25.4	5

2.5. Preparation for the concrete mixture increased by adding steel nails

The preparation procedure according to the methodology is as follows.

- The primary components for the concrete mix included cement, water, and both coarse and fine aggregates. After gathering these materials, a concrete mix with a ratio of 1:1.5:3 was prepared.
- Achieving durable and strong concrete requires precise proportioning and mixing of the ingredients. The dry cement, sand, and coarse aggregate were combined in the specified proportions.
- Steel nails were then cut into lengths of 25.4 mm, each size of steel nail was incorporated into the dry concrete mix to form three moulds, with steel nail content varying between 1% to 5% of the total cement weight.
- Finally, the appropriate amount of water was thoroughly blended into the dry mix to

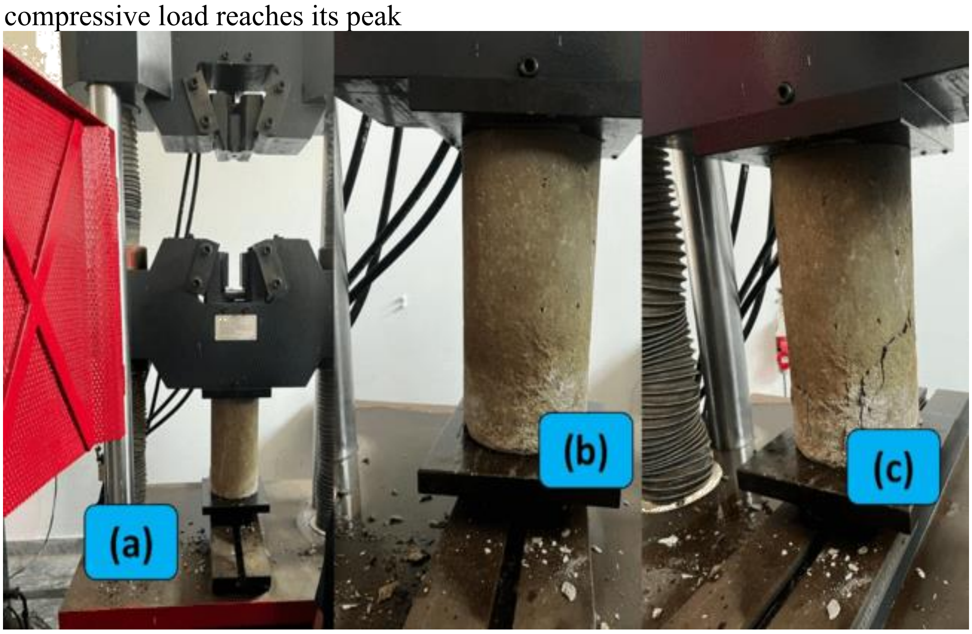
complete the concrete preparation, along with an admixture added to the mix. Figure 5 illustrates the preparation of the cylinder.

Figure 5: Preparation of concrete cylinders with steel nails

2.6. Determine the compressive strength by adding steel in concrete

- A Universal Testing Machine (UTM) was utilized to measure the compressive strength of the specimens.
- The load was applied steadily and uniformly, ensuring no abrupt shocks during testing.
- Loading plates were placed on the specimens ' surfaces to ensure even distribution of the load.
- During the initial half of the anticipated loading phase, a higher rate of loading was allowed and applied in a controlled manner to avoid shock loading on the specimens.
- The maximum load each specimen could withstand was recorded, and the fracture types were observed and noted. Figure 6 illustrate the testing process.

Figure 6: Compression testing of concrete cylinders in a Universal Testing Machine (UTM): (a) Initial setup of the specimen, (b) Load applied to the cylinder, and (c) Visible cracking as the compressive load reaches its peak



3. Results and discussions

Our research was primarily conducted in the laboratory, using various materials sourced from different locations. Initially, basic laboratory tests were conducted, and a series of concrete castings were performed, followed by curing by standard procedures. The specimens were subsequently crushed using a universal testing machine to determine the maximum compressive strength of the concrete containing steel nails.

Table-2: Evaluation of compressive strength for standard concrete (0% Steel Nails)

SR#	Condition	Days	Compressive Strength (Psi)		Average Compressive Strength (Psi)
01	Normal concrete (0% steel nails)	03	$\frac{126.8 \text{ X } 224.81}{12.56}$	2269	2923
02		07	$\frac{146.2 \text{ X } 224.81}{12.56}$	2616	
03		14	$\frac{165 \text{ X } 224.81}{12.56}$	2953	
04		28	$\frac{215.3\text{X } 224.81}{12.56}$	3853	

The tabular findings of the concrete's compressive strength show a consistent increase in strength when steel nails are added at various rates of 1%, 2%, 3%, 4%, and 5% by volume. The compressive strength increases proportionately with each increase in nail content, indicating that the steel nails improve the concrete's load-bearing capacity. This pattern shows how well steel nails strengthen concrete by showing a consistent increase in compressive performance at higher percentages without any reduction. The results of the study show that steel nails might be used as reinforcement in situations that require higher compressive strength.

Table-3: Evaluation of compressive strength for steel nail-modified concrete (1% to 5%)

SR#	Condition	Days	Percent (%) measurement of steel nails	Compressive Strength (Psi)		Average Compressive Strength (Psi)
01	Steel nail modified concrete	3	1%	$\frac{129.4\text{X } 224.81}{12.56}$	2316	3043
02		7		$\frac{139.5\text{X } 224.81}{12.56}$	2496	
03		14		$\frac{190.5\text{X } 224.81}{12.56}$	3409	
04		28		$\frac{220.8\text{X } 224.81}{12.56}$	3952	

SR#	Condition	Days	Percent (%) measurement of steel nails	Compressive Strength (Psi)		Average Compressive Strength (Psi)
01	Steel nail modified concrete	3	2%	$\frac{132\text{X } 224.81}{12.56}$	2362	3246
02		7		$\frac{149.5\text{X } 224.81}{12.56}$	2675	
03		14		$\frac{207.6\text{X } 224.81}{12.56}$	3715	

SR#	Condition	Days	Percent (%) measurement of steel nails	Compressive Strength (Psi)		Average Compressive Strength (Psi)
04		28		$\frac{236.5X\ 224.81}{12.56}$	4233	

SR#	Condition	Days	Percent (%) measurement of steel nails	Compressive Strength (Psi)		Average Compressive Strength (Psi)
01	Steel nail modified concrete	3	3%	$\frac{144X\ 224.81}{12.56}$	2577	3418
02		7		$\frac{156.5X\ 224.81}{12.56}$	2801	
03		14		$\frac{216.8X\ 224.81}{12.56}$	3880	
04		28		$\frac{246.7X\ 224.81}{12.56}$	4415	

SR#	Condition	Days	Percent (%) measurement of steel nails	Compressive Strength (Psi)		Average Compressive Strength (Psi)
01	Steel nail modified concrete	3	4%	$\frac{151.8X\ 224.81}{12.56}$	2717	3654
02		7		$\frac{172X\ 224.81}{12.56}$	3078	
03		14		$\frac{235.5X\ 224.81}{12.56}$	4215	
04		28		$\frac{257.5X\ 224.81}{12.56}$	4608	

SR#	Condition	Days	Percent (%) measurement of steel nails	Compressive Strength (Psi)		Average Compressive Strength (Psi)
01	steel nail modified concrete	3	5%	$\frac{162.5X\ 224.81}{12.56}$	2908	3840
02		7		$\frac{181X\ 224.81}{12.56}$	3239	
03		14		$\frac{248X\ 224.81}{12.56}$	4438	
04		28		$\frac{266.8X\ 224.81}{12.56}$	4775	

3.1. Graphical representation of results

The graphs indicate the values shown in the below table that how the addition of steel nails to concrete affects compressive strength variations.

Table-4: Overall compressive strength values of controlled and modified samples of concrete

Description of concrete	03 Days	07 Days	14 Days	28 Days
Adding 1% (SN)	2316	2496	3409	3952
Adding 2% (SN)	2362	2675	3715	4233
Adding 3% (SN)	2577	2801	3880	4415
Adding 4% (SN)	2717	3078	4215	4608
Adding 5% (SN)	2908	3239	4438	4775
Regular Concrete 0% (SN)	2269	2616	2953	3853

The results display the compressive strength values for the modified and controlled concrete samples. Overall, the modified samples show a variety of strength levels based on the modifications made; some even perform better than the controlled samples. This comparison shows how well specific alterations or additions may boost concrete's strength.

Figure 7: Compressive strength (normal concrete) vs. days

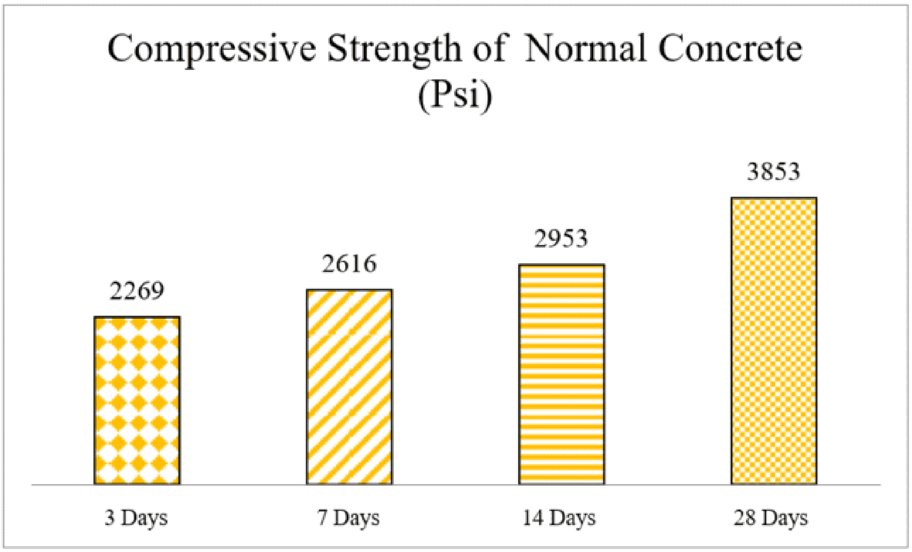


Figure 8 shows the compressive strength of concrete samples amended with different proportions of steel nails following three days of curing. As the steel nail concentration increases from 1% to 5%, the compressive strength shows notable changes, indicating that steel nail reinforcement could impact the strength of early-age concrete. The initial strengthening impact of steel nails is highlighted in this pattern, which might be useful in circumstances when more early compressive strength is required.

Figure 8: Compressive strength of steel nail-modified concrete represents the compressive strength of concrete samples with varying percentages of steel nails (ranging from 1% to 5%) after 3 days of curing.

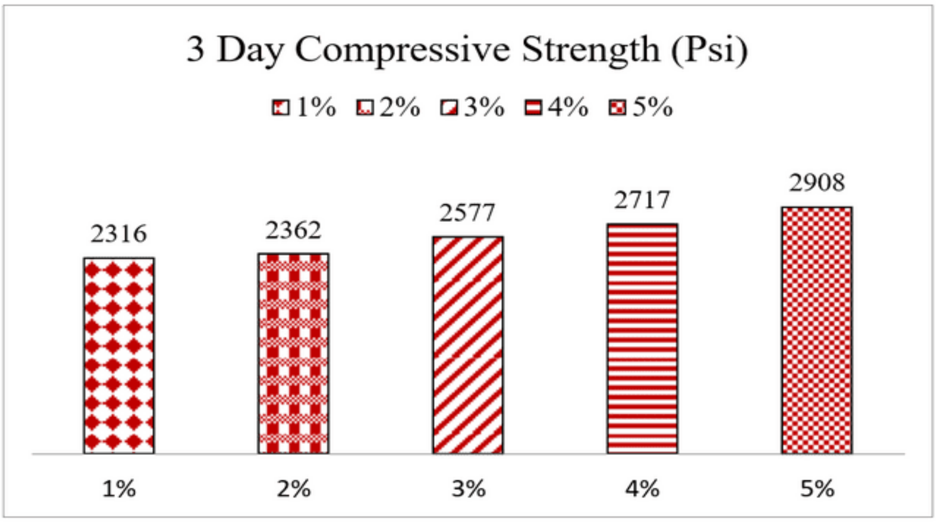


Figure 9 displays the compressive strength of steel nail-modified concrete samples with varying steel nail contents (from 1% to 5%) following seven days of curing. Its wide pattern of strength variation may indicate that while an extremely high or low proportion of steel nails may result in lower strength, a reasonable proportion may increase compressive strength. This suggests that the early-age strength properties of concrete may be impacted by the insertion of steel nails; however, the effect varies depending on the amount used.

Figure 9: Compressive strength of steel nail-modified concrete represents the compressive strength of concrete samples with varying percentages of steel nails (ranging from 1% to 5%) after 7 days of curing

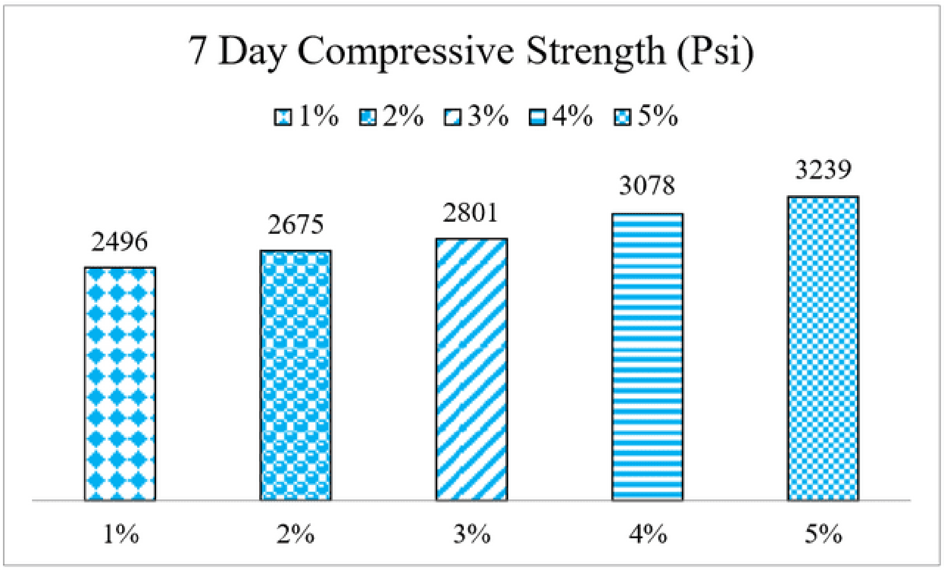


Figure 10 displays the compressive strength results for concrete samples modified with steel nails at different percentages of steel nail additions (1% to 5%) following 14 days of cure. The results indicate a pattern where the compressive strength varies with the number of steel nails, indicating that the addition of steel nails has a noticeable impact on the structural performance of the concrete. In certain samples, compressive strength may fluctuate as steel nail percentages rise or fall, suggesting an optimal range for improvement.

Figure 10: Compressive strength of steel nail-modified concrete represents the compressive strength of concrete samples with varying percentages of steel nails (ranging from 1% to 5%) after 14 days of curing

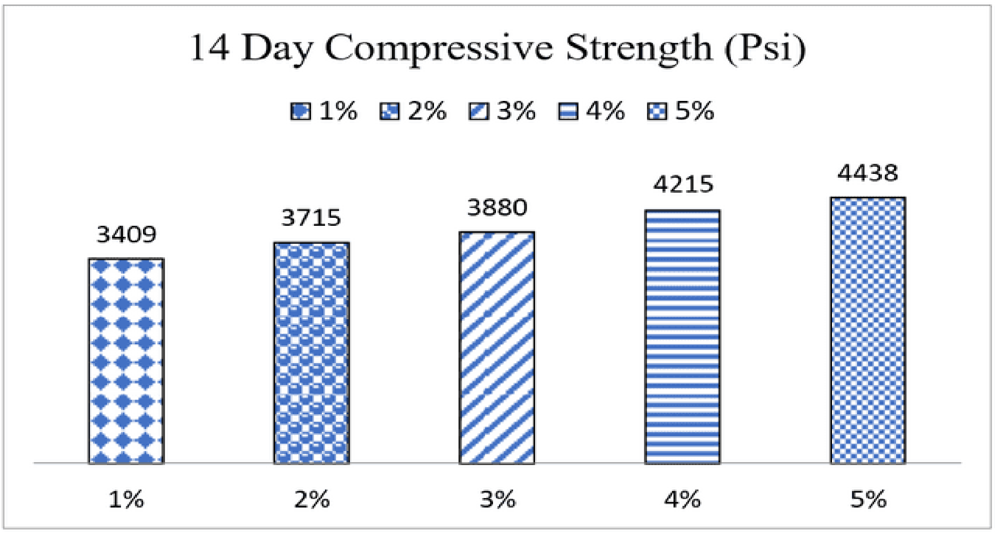


Figure 11 displays the compressive strength results for concrete samples amended with varying percentages of steel nails (ranging from 1% to 5%) following a 28-day curing period. The graph's trend indicates a positive link between concrete strength and steel nail content, showing that higher percentages of steel nails generally result in higher compressive strength. This suggests that adding steel nails might improve the concrete's weight-bearing capacity.

Figure 11: Compressive strength of steel nail-modified concrete represents the compressive strength of concrete samples with varying percentages of steel nails (ranging from 1% to 5%) after 28 days of curing.

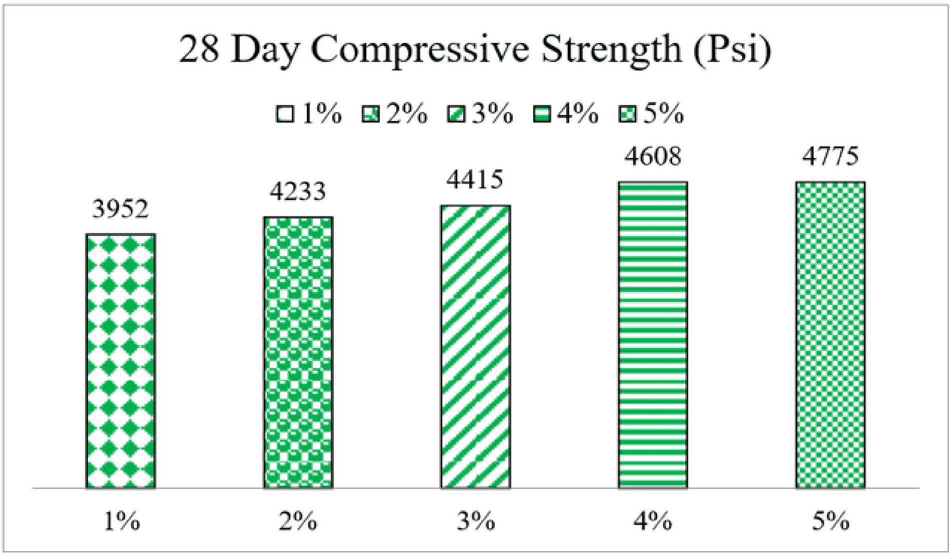
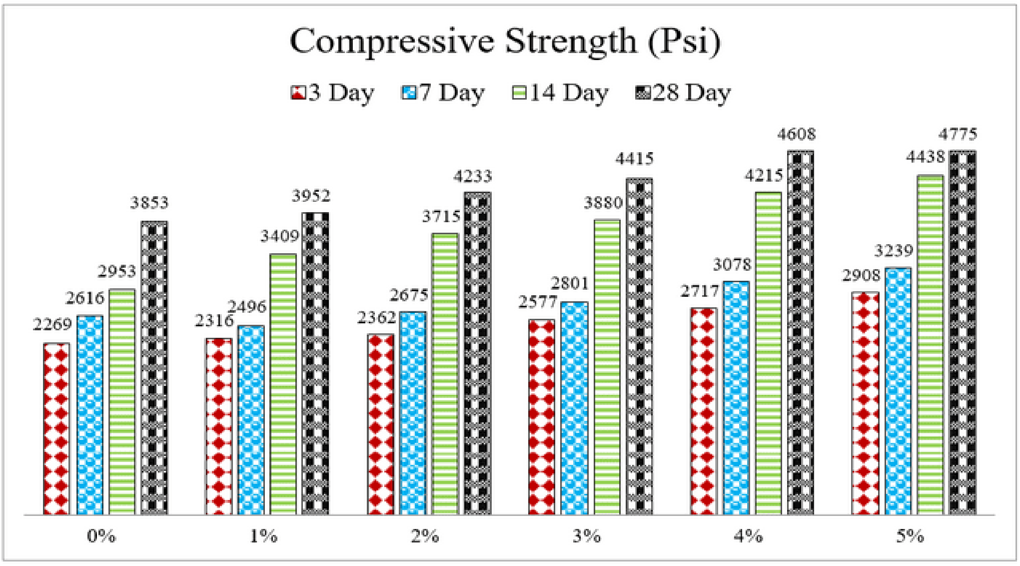


Figure 12 displays the compressive strength of concrete samples tested over 3, 7, 14, and 28 days with varying concentrations of steel nails (1% to 5%). The results show the compressive strength typically increases with the duration of the curing time, peaking at 28 days. Additionally, a specific percentage of steel nails appear to increase strength; nevertheless, an excessive number of nails may lead to deteriorating performance or even a reduction in strength.

Figure 12: This graph represents the compressive strength of concrete with varying percentages of steel nails (1% to 5%) measured at 3, 7, 14, and 28 days



3.2. Critical analysis

Findings show that concrete's compressive strength is greatly increased by the addition of steel nails, particularly when the nail quantity is between 1% and 5%. This strength increase was consistently seen at different curing intervals (3, 7, 14, and 28 days), with the biggest increase happening as the percentage of steel nails increased. The results suggest that adding steel nails to concrete might be a practical method of improving its structural properties, especially for applications requiring more durability and strength. Unlike previous studies, this study adds to the growing body of work exploring the use of materials to enhance concrete's properties. The apparent paucity of study on the specific impacts of steel nails as an addition provides a new perspective on material enhancement in concrete mixtures. Future research should examine long-term cost-effectiveness, durability for practical applications, and the optimal mix design.

4. Conclusion and recommendations

The findings of this research indicate that the addition of steel nails to concrete leads in a considerable improvement in the material's compressive strength, particularly when the quantity of nails is between one percent and five percent. The curing timeframes range from three to fourteen to twenty-eight days. This strength increase was consistently seen, with the most significant increase occurring as the percentage of steel nails rose. Adding steel nails to concrete may be a viable way to enhance its structural qualities, particularly for uses that call for greater strength and longevity. When 5% steel nails were used, the resulting compressive strength was measured to be 4775 pounds per square inch, which is far higher than the range that is considered suitable for use in construction. In terms of cost, steel nail-modified concrete was shown to be more cost-effective than ordinary concrete. It was found to reduce expenses by 0.5% in comparison to conventional concrete while concurrently boosting compressive strength by up to 24%.

The recommendations ad future scope of this research study is given as follows.

- The investigation utilized steel nail percentages ranging from one percent to five percent. However, more studies might be conducted to investigate the effectiveness of raising this proportion beyond 5% to monitor any changes that may occur in the concrete's strength. It is also possible to change the material's qualities by modifying the quantities of water to cement and mixing the three.
- This study did not investigate the durability of steel nail-reinforced concrete, even though compressive strength was the major focus of the investigation. In the future, research should incorporate a comprehensive durability investigation to evaluate its performance over the long and short term.
- During this investigation, particular kinds of fine and coarse aggregate, as well as binding materials were utilized. The investigation of various versions of these materials could provide varied outcomes, and it is something that should be investigated further in further research.
- In this piece of study, the fibres' orientation during the mixing procedure was not taken into consideration. This element should be taken into consideration in future research since it has the potential to influence the behaviour and strength of the material.
- The performance of steel fibre-reinforced concrete under cyclic stress still needs to be studied in this work. Cyclic loading is being applied to the concrete. This is another area that might be investigated in the future to have a better understanding of the material behaviour when subjected to recurrent stress.

Declaration of conflict of interest

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References

Agwa, I. S., Omar, O. M., Tayeh, B. A., & Abdelsalam, B. A. (2020). Effects of using rice straw and cotton stalk ashes on the properties of lightweight self-compacting concrete. *Construction and Building Materials, 235,* 117541. https://doi.org/10.1016/j.conbuildmat.2019.117541

Asprone, D., Auricchio, F., Menna, C., & Mercuri, V. (2018). 3D printing of reinforced concrete elements: technology and design approach. *Construction and Building Materials, 165*, 218–231. https://doi.org/10.1016/j.conbuildmat.2018.01.018

Bos, F., Ahmed, Z., Jutinov, E., & Salet, T. (2017). Experimental exploration of metal cable as reinforcement in 3D printed concrete. *Materials, 10*(11), 1314. https://doi.org/10.3390/ma10111314

Bos, F., Wolfs, R., Ahmed, Z., & Salet, T. (2018). Large Scale Testing of Digitally Fabricated Concrete (DFC) elements. In *First RILEM International Conference on Concrete and Digital Fabrication – Digital Concrete* (pp. 129–147). https://doi.org/10.1007/978-3-319-99519-9_12

Farina, I., Fabbrocino, F., Carpentieri, G., Modano, M., Amendola, A., Goodall, R., Feo, L., & Fraternali, F. (2016). On the reinforcement of cement mortars through 3D printed polymeric and metallic fibers. *Composites Part B: Engineering, 90*, 76–85. https://doi.org/10.1016/j.compositesb.2015.12.006

Hambach, M., & Volkmer, D. (2017). Properties of 3D-printed fiber-reinforced Portland cement paste. *Cement and Concrete Composites, 79*, 62–70. https://doi.org/10.1016/j.cemconcomp.2017.02.001

Jipa, A., & Dillenburger, B. (2022). 3D printed formwork for concrete: state-of-the-art, opportunities, challenges, and applications. 3D *Printing and Additive Manufacturing, 9*(2), 84–107. https://doi.org/10.1089/3dp.2021.0024

Khan, M. S., Tufail, M., & Mateeullah, M. (2018). effects of waste glass powder on the geotechnical properties of loose subsoils. *Civil Engineering Journal, 4*(9), 2044. https://doi.org/10.28991/cej-03091137

Khan, M. S., Matheeullah, Khattak, A. A. J, Yaqoob, M., & Alam, K. (2021). Strength and thermal conduction assessment of lightweight aromatic hydrocarbon waste polystyrol glass concrete. *Journal of Engineering Science and Technology*, *16*(2), 1082-1097. https://jestec.taylors.edu.my/Vol%2016%20issue%202%20April%202021/16_2_14.pdf

Kosny, J., & Yarbrough, D. W. (2022). Short history of thermal insulation and radiation control technologies used in architecture. In J. Kośny, & D. W. Yarbrough (eds), *Thermal Insulation and Radiation Control Technologies for Buildings* (pp. 1–35). Springer Nature. https://doi.org/10.1007/978-3-030-98693-3_1

Ma, G., Li, Z., Wang, L., Wang, F., & Sanjayan, J. (2019). Mechanical anisotropy of aligned fiber reinforced composite for extrusion-based 3D printing. *Construction and Building Materials, 202*, 770–783. https://doi.org/10.1016/j.conbuildmat.2019.01.008

Makul, N. (2020). Advanced smart concrete - a review of current progress, benefits and challenges. *Journal of Cleaner Production, 274,* 122899. https://doi.org/10.1016/j.jclepro.2020.122899

Maslehuddin, M., Sharif, A. M., Shameem, M., Ibrahim, M., & Barry, M. S. (2003). Comparison of properties of steel slag and crushed limestone aggregate concretes. *Construction and Building Materials*, *17*(2), 105–112. https://doi.org/10.1016/s0950-0618(02)00095-8

Mechtcherine, V., Grafe, J., Nerella, V. N., Spaniol, E., Hertel, M., & Füssel, U. (2018). 3D-printed steel reinforcement for digital concrete construction – Manufacture, mechanical properties and bond behaviour. *Construction and Building Materials, 179,* 125–137. https://doi.org/10.1016/j.conbuildmat.2018.05.202

Miah, M. J., Patoary, Md. M. H., Paul, S. C., Babafemi, A. J., & Panda, B. (2020). Enhancement of mechanical properties and porosity of concrete using steel slag coarse aggregate. *Materials, 13*(12), 2865. https://doi.org/10.3390/ma13122865

Ogura, H., Nerella, V. N., & Mechtcherine, V. (2018). Developing and testing of Strain-Hardening Cement-Based Composites (SHCC) in the context of 3D-printing. *Materials, 11*(8), 1375. https://doi.org/10.3390/ma11081375

Ottmann, D. A. (2022). Potentials for new ecological building materials in deserts and drylands. Ecological building materials for deserts and drylands, 113–118. https://doi.org/10.1007/978-3-030-95456-7_9

Putten, J. V. D., Deprez, M., Cnudde, V., De Schutter, G., & Van Tittelboom, K. (2019). Microstructural characterization of 3d printed cementitious materials. *Materials, 12*(18), 2993. https://doi.org/10.3390/ma12182993

Saxena, S., & Tembhurkar, A. R. (2018). Impact of use of steel slag as coarse aggregate and wastewater on fresh and hardened properties of concrete. *Construction and Building Materials, 165*, 126–137. https://doi.org/10.1016/j.conbuildmat.2018.01.030

Shah, M. M., Yaqoob, M., Jibran, A. A., Rashid, A., Kundi, H. M., & Khan, M. S. (2020). Integrating heat repulsion and strength evaluation of cost-effective GLP concrete redeeming the cement proportions utilizing thermocouples. International *Journal of Technology and Engineering Studies, 6*(2). https://doi.org/10.20469/ijtes.6.40003-2

Sonebi, M., Amziane, S., & Perrot, A. (2019). Mechanical behavior of 3D printed cement materials. In *3D printing of concrete: state of the art and challenges of the digital construction revolution* (pp. 101–124). Wiley. https://doi.org/10.1002/9781119610755.ch4

Singh, M. (2022). Standardisation of gypsum and gypsum products. In *Gypsum & Gypsum Products* (pp. 325–349). CRC Press. https://doi.org/10.1201/9781003345008-11

Ullah, E. S., Shahid, M. R., Shadab Tariq, & Khan, A. A. (2021). Influence of waste marble powder and waste granite powder on the mechanical and durability performance of concrete. *Neutron*, *21*(1), 46–51. https://doi.org/10.29138/neutron.v21i1.134

Ullah, S., Bilal, H., Qadeer, A., Usman, A., Khan, A., & Akhtar, N. (2024). Synergic effects of recycled concrete aggregate and Styrene Butadiene Rubber (SBR) latex on mechanical properties of concrete. *International Journal of Membrane Science and Technology*, *11*(1), 506–522. https://doi.org/10.15379/ijmst.v11i1.3682

Usman, A., Haris Javed, M., Abbas, F., Ali Channa, F., & Ullah, S. (2023). Synergic influence of river gravels and crushed aggregates on the mechanical properties of concrete. *Journal of ICT, Design, Engineering and Technological Science, 7*(1). https://doi.org/10.33150/jitdets-7.1.4

Wang, Q., Shi, M., & Zhang, Z. (2015). Hydration properties of steel slag under autoclaved condition. *Journal of Thermal Analysis and Calorimetry*, *120*(2), 1241–1248. https://doi.org/10.1007/s10973-015-4397-3

Wang, X., Fan, F., Lai, J., & Xie, Y. (2021). Steel fiber reinforced concrete: a review of its material properties and usage in tunnel lining. *Structures*, *34*, 1080–1098. https://doi.org/10.1016/j.istruc.2021.07.086

Yang, S., Mo, L., & Deng, M. (2021). Effects of ethylenediamine tetra-acetic acid (EDTA) on the accelerated carbonation and properties of artificial steel slag aggregates. *Cement and Concrete Composites, 118,* 103948. https://doi.org/10.1016/j.cemconcomp.2021.103948

Zhang, P., Wang, C., Gao, Z., & Wang, F. (2023). A review on fracture properties of steel fiber reinforced concrete. *Journal of Building Engineering*, *67*, 105975. https://doi.org/10.1016/j.jobe.2023.105975