DOI: https://doi.org/10.52756/ijerr.2024.v45spl.004 *Int. J. Exp. Res. Rev.*, Vol. 45: 41-55 (2024)

Original Article | Peer Reviewed | Open Access

International Journal of Experimental Research and Review (IJERR)

ISSN: 2455-4855 (Online)
www.iaph.in

Analyze the Effect of Steel Waste on Performance Characteristics of Concrete

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Article History:
Received: 08th May., 2024
Accepted: 22th Oct., 2024
Published: 30th Nov., 2024

Keywords:
Concrete, Durability, Environmental performance, Finer aggregate, Steel waste, Sustainable construction, Waste utilization

How to cite this Article:
Himani Bisen, Kruti B Jethwa, Maya Rajnarayan Ray, Umank Mishra, Kaushal Kumar, Pankaj Kumar, Nishant Yadav and Anoop Narain Singh (2024). Analyze the Effect of Steel Waste on Performance Characteristics of Concrete. *International Journal of Experimental Research and Review*, *45*, 41-55.
DOI: https://doi.org/10.52756/ijerr.2024.v45spl.004

Abstract: This study investigates the feasibility of incorporating steel waste as a sustainable alternative material for finer aggregate in concrete applications. The increasing volume of steel waste generated by industrial processes poses significant environmental challenges, making its efficient utilization imperative. Concrete, as one of the most widely used construction materials, offers a promising avenue for recycling steel waste and reducing environmental impact. The primary objective is to carry out experimental analysis to evaluate the strengths and workability performance of concrete incorporating various proportions of steel waste as replaced in place of sand in ordinary concrete. Replacement level of steel waste is restricted due to adverse effects on the workability of the concrete mix. From a strength standpoint, results show that 28 days of cured concrete incorporating steel waste achieved a significantly higher compressive strength than conventional concrete. However, the rate of strength gain in steel waste concrete is slow compared to conventional concrete. Concrete mixtures are prepared with different percentages of steel waste replacement for traditional aggregates and their properties, including compressive strength, flexural strength and durability. Additionally, the environmental footprint of steel waste-incorporated concrete is evaluated through a life cycle assessment to determine its sustainability compared to conventional concrete. The results of the study provide valuable insights into the potential benefits and challenges associated with utilizing steel waste in concrete applications, offering practical recommendations for optimizing mixture proportions and enhancing the sustainability of construction practices. Maximum flexural strength and compressive strength are found for the maximum curing stage and maximum replacement of finer aggregate through steel waste. Strategies to enhance workability and maintain or improve strength characteristics will be crucial for advancing the use of steel waste in sustainable concrete construction practices. By continuing to innovate and refine these approaches, the construction industry can move towards more sustainable and resource-efficient building materials.

Introduction

The construction industry is continuously exploring sustainable materials and innovative techniques to enhance the performance characteristics of concrete, a critical component in building and infrastructure development. One such innovation is the incorporation of industrial by-products and waste materials into concrete. Among these, steel waste derived from steel production processes has garnered significant attention. This study focuses on analyzing the effects of steel waste on the performance characteristics of concrete, aiming to contribute to sustainable construction practices and improved material performance (Nilimaa, 2023).

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Concrete, being the most widely used construction material globally, has traditionally relied on natural aggregates and cement as its primary constituents. However, cement production is highly energy-intensive and contributes substantially to global CO_2 emissions. Moreover, the extraction of natural aggregates has environmental implications, including habitat destruction and resource depletion. In this context, the utilization of industrial waste, such as steel slag, mill scale and other by-products of steel manufacturing, presents a promising avenue for reducing the environmental footprint of concrete production while potentially enhancing its mechanical and durability properties (Barbhuiya et al., 2024; Jain and Mulewa, 2024; Habert et al., 2020).

Steel waste materials offer several potential benefits when used as partial replacements for conventional concrete components. Steel slag, for instance, exhibits pozzolanic properties, which can contribute to the long-term strength and durability of concrete. Mill scale, another by-product, is rich in iron oxides and can enhance the density and strength of the concrete matrix. Furthermore, the recycling of steel waste not only mitigates the environmental burden associated with steel production but also reduces the need for landfill space, aligning with the principles of circular economy and waste minimization (Jahami et al., 2024; Kumar & Shukla, 2023; Song et al., 2021; Li et al., 2022).

Previous research has indicated that incorporating steel waste into concrete can improve various performance characteristics, such as compressive strength, tensile strength, and resistance to chemical attacks. However, the extent of these improvements is highly dependent on the type and proportion of steel waste used and the specific characteristics of the concrete mix. Therefore, a systematic analysis is necessary to understand the optimal conditions under which steel waste can enhance concrete performance (Jahami et al., 2024; Wan et al., 2024).

This study aims to investigate the effects of different types of steel waste on the performance characteristics of concrete. By examining parameters such as compressive strength, tensile strength, workability, and durability, this research provides a comprehensive understanding of how steel waste influences concrete properties. The findings of this study are expected to offer valuable insights for the construction industry, promoting the use of sustainable materials and contributing to the development of high-performance concrete with reduced environmental impact (Jahami et al., 2024; Shewalul, 2021; Chen et al., 2024; Wan et al., 2024).

The integration of steel waste into concrete production represents a significant opportunity to advance sustainable construction practices. This research will explore the potential of steel waste to improve the performance characteristics of concrete, thereby addressing both environmental and technical challenges associated with traditional concrete production. Through rigorous analysis and experimentation, this study aims to pave the way for innovative and eco-friendly construction materials that meet the growing demands of the modern built environment.

Literature review

In recent years, there has been a renewed focus on sustainable construction practices, which has driven increased interest in the utilization of metallic waste in concrete. As highlighted by (Najm and Ahmad, 2021; Nilimaa, 2023), contemporary research efforts aim to optimize mixture designs, develop standardized testing methods, and explore innovative techniques for maximizing the benefits of metallic waste utilization in concrete applications. These efforts contribute to environmental conservation and resource efficiency in the construction industry. The incorporation of metallic waste in concrete has shown promising results in enhancing various mechanical properties, including compressive strength, split tensile strength, impact resistance, abrasion resistance, bond strength, shear strength, modulus of elasticity, creep and shrinkage behavior, and fatigue resistance. These findings highlight the potential of metallic waste utilization as a sustainable approach to improving the performance and durability of concrete structures.

Several studies have investigated the effect of incorporating metallic waste on the compressive strength of concrete. According to Li and Wang (2019), Li and Wang (2019), concrete incorporating steel fibers exhibited improved compressive strength due to enhanced crack resistance and load-bearing capacity. The inclusion of metallic waste, such as steel fibers, in concrete mixes can bridge micro-cracks, delaying their propagation and thus enhancing the material's ability to withstand higher compressive loads. This enhancement is particularly beneficial in applications where high load-bearing capacity and durability are critical, such as in infrastructure and high-rise buildings.

DOI: https://doi.org/10.52756/ijerr.2024.v45spl.004

Literature Review

- Review relevant research and standards
- Define objectives and scope

Material Collection

- Collect cement
- Collect coarse aggregate
- Collect natural sand
- Collect waste steel slag

Mix Proportioning

- Design mix for M35 grade concrete
- Calculate proportions for varying steel slag replacements (1%, 2%, 3%, 4%, 5%)

Mix Preparation

Prepare concrete mix with:

- 0% Steel Slag (Control mix)
- 1% Steel Slag
- 2% Steel Slag
- 3% Steel Slag
- 4% Steel Slag
- 5% Steel Slag

Workability Test

- Perform slump test for each mix
- Record results

Casting and Curing

- Cast samples for each mix
- Cure samples as per standards

Strength Testing

- Conduct compressive strength test
- Conduct flexural strength test
- Record results

Durability Testing

- LCA

Data Analysis

- Analyze workability, strength, and durability data
- Compare with control mix and Indian standards

Conclusion and Recommendations

- Summarize findings
- Provide recommendations for optimal steel slag replacement

Figure 1. The schematic diagram for the methodology used in the study.

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Shear strength is another critical mechanical property of concrete, particularly in structural applications. Velychkovych et al. (2021), Yan et al. (2022) and Chu et al. (2023) conducted experiments on concrete containing steel fibers to evaluate its shear strength properties. Their findings indicated that the addition of steel fibers improved the shear strength of concrete, enhancing its resistance to shear forces. The presence of steel fibers within the concrete matrix helps to arrest the growth of cracks initiated by shear stresses, thereby increasing the material's overall shear capacity. This improvement is crucial for designing and constructing beams, columns, and other structural elements subjected to shear loads.

The modulus of elasticity is an important parameter for assessing concrete's stiffness and deformation characteristics. Research by Sharma and Singh (2023), Gupta and Sachdeva (2019) investigated the effect of incorporating steel slag on the modulus of elasticity of concrete. Their results showed that concrete with steel slag exhibited comparable or even higher modulus of elasticity compared to conventional concrete mixes. This finding suggests that concrete's stiffness and deformation characteristics can be maintained or enhanced by using metallic waste, providing an effective means of utilizing industrial by-products in construction.

Creep and shrinkage are essential considerations in structural design and durability assessment. (Shen et al., 2023; Russell and Shiu, 1982; Abid et al., 2019) studied the creep and shrinkage behavior of concrete containing metallic waste additives. Their research indicated that concrete with steel fibers exhibited reduced creep and shrinkage compared to conventional concrete, suggesting improved long-term performance. The reduction in creep and shrinkage can mitigate structural deformation and cracking issues over time, thereby extending the lifespan of concrete structures.

Fatigue resistance is crucial for structures subjected to cyclic loading, such as bridges and pavements. Research by Yang et al. (2017) and Mohod and Kadam (2020) investigated the fatigue resistance of concrete containing steel fibers. Their findings demonstrated that adding steel fibers improved concrete fatigue resistance, prolonging structures' service life subjected to repeated loading cycles. This improvement is attributed to the fibers' ability to distribute and absorb stress more effectively, reducing the likelihood of fatigue failure in critical infrastructure.

Furthermore, the environmental impact of metallic waste utilization in concrete extends beyond the production phase to the end-of-life stage. Sharma and Singh (2023) and Gupta and Sachdeva (2019) and Bakhoum and Mater (2022) investigated the environmental implications of concrete containing steel slag aggregates in terms of end-of-life disposal options. Their research evaluated the environmental benefits of recycling steel slag concrete compared to conventional concrete demolition waste disposal. The results indicated that recycling steel slag concrete led to significant reductions in energy consumption, greenhouse gas emissions, and landfill space requirements, highlighting the potential for circular economy principles in concrete waste management. Overall, the environmental impact of metallic waste utilization in concrete is a multifaceted issue that encompasses various aspects of concrete production, use, and disposal. Through life cycle assessment (LCA) studies and waste management analyses, researchers have demonstrated the potential environmental benefits of incorporating metallic waste into concrete mixes, including reduced greenhouse gas emissions, energy consumption, and waste generation. These findings underscore the importance of considering environmental sustainability in concrete material selection and highlight the potential for metallic waste utilization to contribute to a more environmentally friendly construction industry. Objective Define: Define the objective of the experimental investigation clearly. This could determine the effect of steel waste on concrete strength, durability, or other properties and identify the optimal proportion for maximum benefit.

Methodology

Schematic diagram for methodology used in study is presented in figure 1.

Workability Test

Slump testing is a fundamental procedure used to assess the workability and consistency of freshly mixed concrete. It provides valuable insights into concrete flow properties and behavior, enabling engineers and technicians to adjust mix proportions and ensure compliance with project specifications. The procedure involves the following steps: Firstly, a slump cone, a mold with specific dimensions, is placed on a smooth, flat surface. The cone is then filled with freshly mixed concrete in three equal layers, each compacted with a standard rod or tamping rod to ensure uniform distribution and eliminate air voids. After filling, the cone is carefully lifted vertically, allowing the concrete to flow freely and settle. Once the cone is removed, the concrete slump is measured as the vertical displacement of the concrete surface from the original height of the cone. This measurement indicates the concrete's consistency and workability, with higher slumps indicating greater flowability. Slump testing is essential for verifying the quality and performance of concrete mixes, aiding in optimizing mix designs and construction processes to achieve desired structural integrity and durability.

Samples Preparation:

In the context of this study, a total of 54 beams and 54 columns are prepared, with variations in the mix design to evaluate the effects of replacing sand with steel waste. Specifically, 18 beams and 18 columns are prepared for each mix design, three of which are conventional concrete, while the remaining are modified by replacing sand with steel waste. For each mix design, three samples are prepared. The concrete paste is created by mixing the necessary components in precise amounts, maintaining stringent environmental conditions to ensure proper curing. The samples are stored in a humidity chamber at a temperature range of 20-21 degrees Celsius and a humidity level of approximately 96-97 percent for one day after the initial setting. These conditions are consistently maintained throughout the testing periods of 7, 21, and 28 days. The compressive strength of the samples is tested using a machine with a capacity of 200 kN, with the accuracy of the measurements specified to be within 1% of the primary test value. This meticulous approach to sample preparation and testing ensures the reliability and validity of the results, which are critical for assessing the performance and potential benefits of using steel waste as a sand replacement in concrete mixes.

Results and discussion

The cement content in concrete mixtures is experimentally replaced with steel waste in varying proportions from 1% to 5%. The experiments are meticulously scheduled, and observations are critically analysed to understand the impact of steel waste substitution on concrete properties. The mix proportions for M35 grade concrete are designed following the Indian Standard Code, which is widely recognized for its reliability in selecting appropriate mix proportions for heavyweight concrete. This standard practice ensures that the concrete mix achieves the desired characteristic strength and workability, facilitating the production of robust and durable concrete structures.

In the mix designation M35, "M" stands for Mix, and "35" represents the characteristic compressive strength (fck) of 35 MPa. The concrete mix ratio for M35 is 1:1.6:2.9 (cement: sand: aggregate). For this study, the fine aggregate (sand) was partially replaced with steel waste in varying percentages: 0%, 1%, 2%, 3%, 4% and 5%. Each variation is carefully labelled to reflect the percentage of steel waste used. For instance, Mx-0 represents the control mix with no steel waste, Mx-1 represents the mix with 1% of the fine aggregate replaced by steel waste. Similarly, Mx-2, Mx-3, and Mx-5 represent mixes with 2%, 3%, and 5% of the fine aggregate replaced by steel waste.

The experimental procedure involved preparing the different concrete mixes and evaluating their properties through a series of standardized tests. These tests aimed to measure parameters such as compressive strength, workability, and durability. The observations are systematically recorded and analyzed to determine the effects of steel waste inclusion on the concrete's performance. The analysis revealed trends and correlations between the percentage of steel waste and the resulting concrete properties, providing insights into the feasibility and benefits of using steel waste as a partial replacement for fine aggregate in concrete mixes.

The incorporation of steel waste into concrete mixes not only has the potential to enhance certain properties of the concrete but also offers an environmentally friendly solution to waste management in the steel industry. By replacing a portion of the fine aggregate with steel waste, the study explores sustainable practices in concrete production, contributing to the reduction of industrial waste and promoting the use of recycled materials in construction. The findings from this research could pave the way for more extensive applications of steel waste in the concrete industry, aligning with the principles of sustainable development and circular economy.

Table 1. Mix design of the experimentation for compressive strength.

Mix Design	Cement	Fine aggregate	Coarse aggregate	Steel Waste
Mx 0	100%	100%	100%	0%
Mx 1	100%	99	100%	1%
Mx 2	100%	98	100%	2%
Mx 3	100%	97	100%	3%
Mx 4	100%	96	100%	4%
Mx 5	100%	95	100%	5%

Workability Analysis

Comprehensive workability tests are conducted on various mix designs before evaluating the strength characteristics of the concrete mixtures, as outlined in the preceding section. These preliminary assessments are crucial for understanding the practical aspects of handling and placing the concrete. Table 2 enumerates the measured slump values for each mix design, while Figure 2 illustrates these values. In concrete technology, the slump test is a standard method used to gauge the workability of fresh concrete. The term "workability" encompasses the concrete's ease of mixing, transporting,

DOI: https://doi.org/10.52756/ijerr.2024.v45spl.004

placing, and compacting without segregation or excessive bleeding.

An increase in the slump value generally signals an enhancement in the workability of the concrete mix. Higher slump values indicate a more fluid mixture, which translates to improved ease of handling during construction. This fluidity is particularly beneficial in various construction scenarios, including pouring concrete in complex structures with dense reinforcement or intricate formworks. Enhanced workability ensures that the concrete can flow smoothly around obstacles, fill voids completely, and achieve uniform compaction, thereby reducing the likelihood of defects and ensuring better structural integrity.

Moreover, higher workability facilitates quicker and more efficient placement and finishing operations. This can lead to significant time and labor savings on the construction site, improving overall productivity. However, it is essential to balance the mix design to maintain the desired strength and durability characteristics of the hardened concrete while achieving the required workability. Excessive fluidity can lead to segregation, where the aggregate separates from the cement paste, or bleeding, where excess water rises to the surface, both of which can compromise the structural performance and longevity of the concrete. Therefore, achieving an optimal slump value is critical for ensuring that the concrete is easy to work with and meets the required performance standards for the intended application.

Table 2. Slump values for different ratios of replacements.

Steel waste%	Final value of Slump
0%	65
1%	66
2%	67
3%	64
4%	65
5%	64

Strength Analysis

Strength analysis is a critical aspect of concrete testing, providing essential data for ensuring concrete elements' structural integrity and performance in construction projects. This analysis focuses on determining the material's compressive strength, which is its ability to withstand axial loads without failure. Compressive strength is a fundamental property that indicates how well concrete can perform under load-bearing conditions. Strength analysis typically follows standard procedures outlined in codes and standards such as ASTM (American Society for Testing and Materials) or EN (European Norms) specifications to ensure consistency and accuracy. These standards prescribe the size and shape of test specimens, the curing conditions, and the loading rates during testing, ensuring that results are comparable and reliable across different testing scenarios.

During compressive strength testing, a concrete specimen, usually a cylinder or cube, is subjected to a gradually increasing load until failure occurs. The load is applied uniformly and continuously using a compression testing machine. As the load increases, the specimen undergoes stress and strain, leading to micro cracking and eventually, macroscopic failure. The maximum load sustained by the specimen before failure is recorded, and the compressive strength is calculated by dividing this load by the cross-sectional area of the specimen. This calculated strength value is crucial for determining whether the concrete meets the design requirements and can safely support the intended loads in the structure. For instance, if a concrete mix is designed to achieve a specific compressive strength, the test results will confirm if the mix meets the required standards or if adjustments are needed.

The initial and final stages of compressive testing reveal significant information about the concrete's behaviour under load. Initially, a clean, undamaged block is subjected to increasing pressure. As the test progresses,

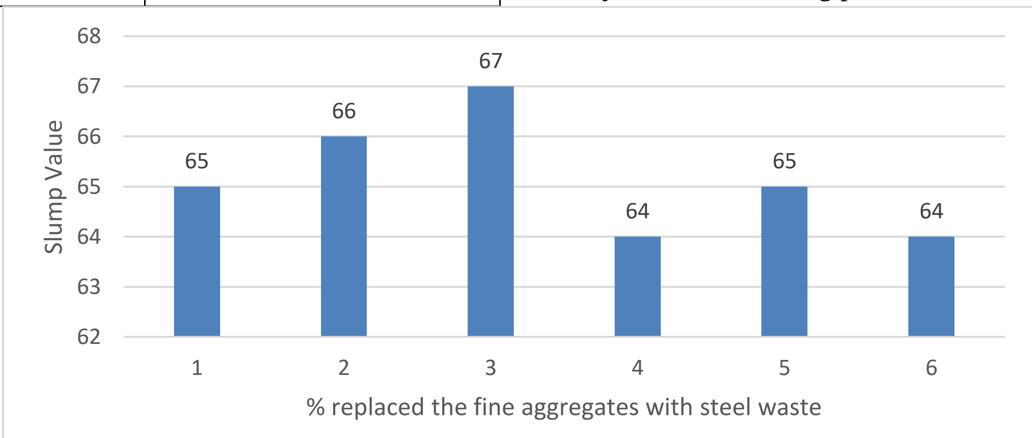

Figure 2. Analysis of slump values as per mix design.

DOI: https://doi.org/10.52756/ijerr.2024.v45spl.004

the block undergoes deformation and eventually breaks, indicating its failure point. Figure 3 illustrates this process, showing the intact block at the start and the broken or deformed block at the point of failure. This visual representation helps in understanding the concrete's structural response and the modes of failure it might experience under actual loading conditions. The insights gained from such testing are invaluable for engineers and construction professionals as they guide concrete structures' mix design, quality control, and overall safety measures.

Compressive strength assessment is performed using specialized testing methods to ensure the overall performance and longevity of the concrete structure. These methods include the preparation of standard specimens, controlled curing environments, and precise loading techniques to replicate the conditions the concrete will face in real-world applications. The results of strength analysis not only confirm the adequacy of the concrete mix but also provide critical data for future reference, aiding in the optimization of mix designs and construction practices. By thoroughly understanding and validating the compressive strength of concrete, construction professionals can ensure that structures are built to withstand the demands of their intended use, enhancing durability and safety.

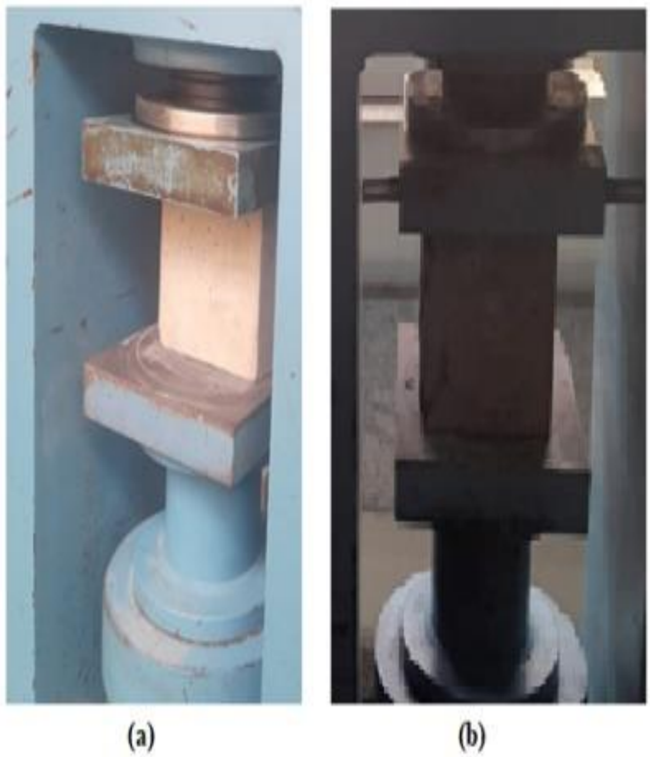

Figure 3. (a) Initial (b) Final stage of sample.

Compressive strength:

The observation of experimental results is shown in Table 3 below.

Table 3. Results of compressive strength with respective to 1% replaced steel waste.

Steel Waste%	Curing Age 7 days	Curing Age 14 days	Curing Age 28 days
0%	28.22	35.33	39.10
1%	28.80	35.69	39.82

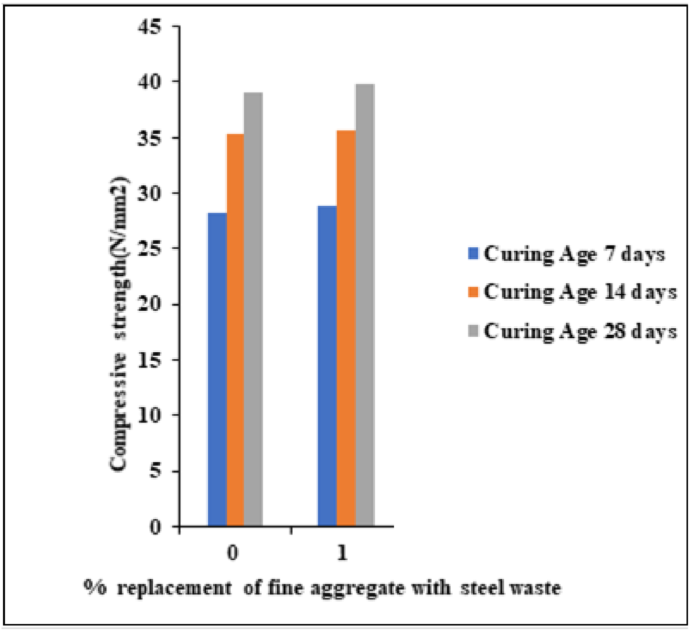

Figure 4. Graphical representation of compressive strength with 1% replaced steel waste.

The experimental analysis detailed in Figure 4 and Table 3 demonstrates a significant impact on the compressive strength of concrete when fine aggregates are partially replaced with steel waste. Specifically, a 1% substitution of fine aggregate with steel waste leads to a noticeable improvement in compressive strength compared to ordinary concrete. This innovative concrete mix achieves a maximum compressive strength of 39.82 MPa after a 28-day curing period, which is considerably higher than the 28.22 MPa observed for the conventional concrete under the same curing conditions. The data suggest that the inclusion of steel waste enhances the structural integrity of the concrete, possibly due to the improved bonding and load distribution characteristics imparted by the steel particles.

Further, the study underscores the importance of curing time on the mechanical properties of both conventional and modified concrete. It is observed that an extended curing period results in increased compressive strength for both types of concrete. This trend indicates that the hydration process and the subsequent development of the concrete's microstructure continue to evolve, leading to greater strength with prolonged curing. The increase in strength over time is a well-documented phenomenon in concrete technology, where adequate curing allows for the continuation of chemical reactions essential for the concrete's hardening process.

Additionally, the analysis is extended to examine the effects of a 2% replacement of fine aggregates with steel waste, as detailed in Table 4 and illustrated in Figure 5. These results provide further insights into the performance of concrete with higher proportions of steel waste. The data indicate a continued trend of strength improvement, suggesting that increasing the proportion of steel waste can further enhance the compressive strength of the concrete. This series of experiments confirms that the strategic incorporation of industrial by-products like steel waste contributes to waste reduction and enhances the mechanical properties of construction materials.

The findings collectively indicate that the partial replacement of fine aggregates with steel waste is a viable method to improve the compressive strength of concrete. This approach provides an environmentally friendly solution for waste management and results in a superior construction material. As such, these insights are valuable for developing sustainable construction practices and materials engineering, promoting the utilization of waste materials to achieve enhanced performance characteristics in concrete.

Table 4. Results of compressive strength with respective to 2% replaced steel waste.

Steel Waste%	Curing Age 7 days	Curing Age 14 days	Curing Age 28 days
0%	28.22	35.33	39.10
2%	29.28	36.04	40.45

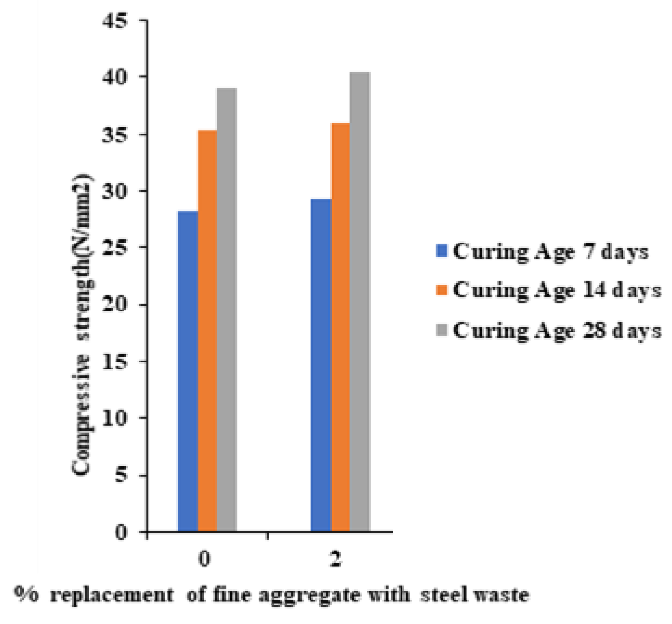

Figure 5. Graphical representation of compressive strength respective to 2% replaced steel waste.

The analysis of the data presented in Figure 5 and Table 4 reveals a notable improvement in the compressive strength of concrete when 2% of its fine aggregate is replaced with steel waste. Specifically, this modification results in a significant enhancement in the structural integrity of the newly formulated concrete compared to traditional concrete mixes. After a curing period of 28 days, the modified concrete's compressive strength reaches a peak value of 40.45 MPa. In stark contrast, ordinary concrete, under identical conditions, exhibits a lower compressive strength of 28.22 MPa. This substantial difference underscores the beneficial impact of incorporating steel waste into the concrete mix, suggesting a potential pathway for enhancing the mechanical properties of concrete through material substitution.

Furthermore, the effect of curing time on compressive strength is evident in both the modified and ordinary concrete samples. As curing time progresses, there is a consistent increase in compressive strength across both types of concrete. This trend highlights the critical role of adequate curing in achieving optimal strength development in concrete. The extended curing period allows for more complete hydration of the cement particles, which in turn contributes to the densification of the concrete matrix and improvement in its load-bearing capacity.

Expanding on the findings, Table 5 and Figure 6 provide insights into the outcomes when the fine aggregate replacement is increased to 3%. The results from this set of experiments further support the earlier observations, demonstrating that increasing the proportion of steel waste can continue to enhance the compressive strength of concrete. These findings suggest that there is a threshold at which the replacement ratio optimally benefits the concrete's mechanical properties, and further research could help pinpoint the most effective replacement percentages for various types of applications. The inclusion of steel waste as a partial replacement for fine aggregate in concrete significantly improves its compressive strength. The data clearly indicate that with a proper curing regimen, the modified concrete not only meets but surpasses the performance of ordinary concrete. This approach offers a method for recycling industrial waste and contributes to developing more durable and robust construction materials. Future studies could explore the long-term durability and other mechanical properties of such concrete, as well as the environmental and economic benefits of using industrial by-products in construction.

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Table 5. Results of compressive strength with respective to replaced steel waste.

Steel Waste%	Curing Age 7 days	Curing Age 14 days	Curing Age 28 days
0%	28.22	35.33	39.10
3%	29.67	36.35	40.98

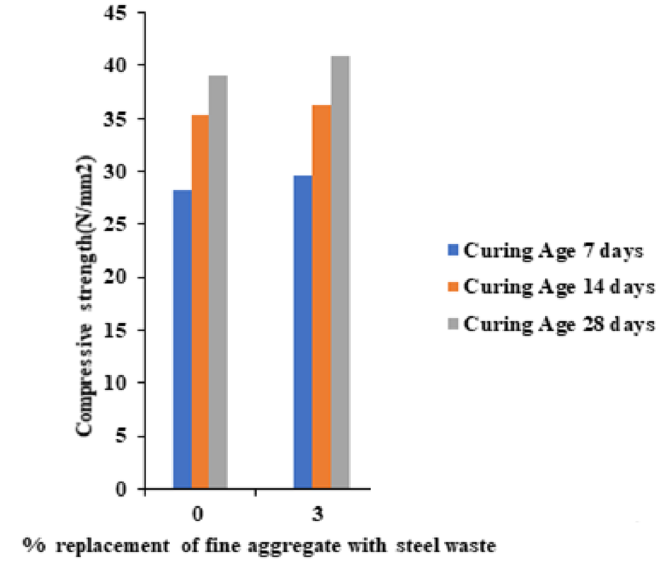

Figure 6. Graphical representation of compressive strength with 3% replaced steel waste.

The experimental data presented in Figure 6 and Table 5 indicate a significant improvement in the compressive strength of concrete when fine aggregates are partially replaced with 3% steel waste. This modification results in the formation of a novel concrete mixture that outperforms ordinary concrete in terms of strength. The compressive strength of the newly formulated concrete, after 28 days of curing, reaches a maximum of 40.98 MPa, which is substantially higher than the minimum strength of 28.22 MPa observed for ordinary concrete under the same curing conditions. This enhancement can be attributed to the incorporation of steel waste, which likely contributes to a denser and more robust microstructure within the concrete matrix.

The curing process plays a crucial role in the development of concrete strength. As evidenced by the data, both ordinary and modified concrete mixtures exhibit an increase in compressive strength with extended curing periods. This trend highlights the importance of proper curing in achieving optimal mechanical properties in concrete. The hydration reactions continue over time, resulting in the progressive formation of calcium silicate hydrate (C-S-H) gel, which is responsible for the material's strength gain. Therefore, the extended curing period facilitates the completion of these chemical reactions, leading to improved structural integrity.

The study also examines the effects of a higher percentage of steel waste replacement. Table 6 and Figure 7 provide insights into the performance of concrete with a 4% replacement of fine aggregates by steel waste. These observations suggest that varying the replacement percentage alters the mechanical properties of the concrete. By comparing the results from different replacement levels, it becomes evident that optimizing the proportion of steel waste is crucial for maximizing the compressive strength and overall performance of the concrete. The data imply a complex interplay between the aggregate composition and the resultant concrete properties, necessitating further investigation to determine the optimal replacement ratio for various applications.

Table 6. Results of compressive strength with respective to replaced steel waste.

Steel Waste%	Curing Age 7 days	Curing Age 14 days	Curing Age 28 days
0%	28.22	35.33	39.10
4%	30.20	36.61	41.39

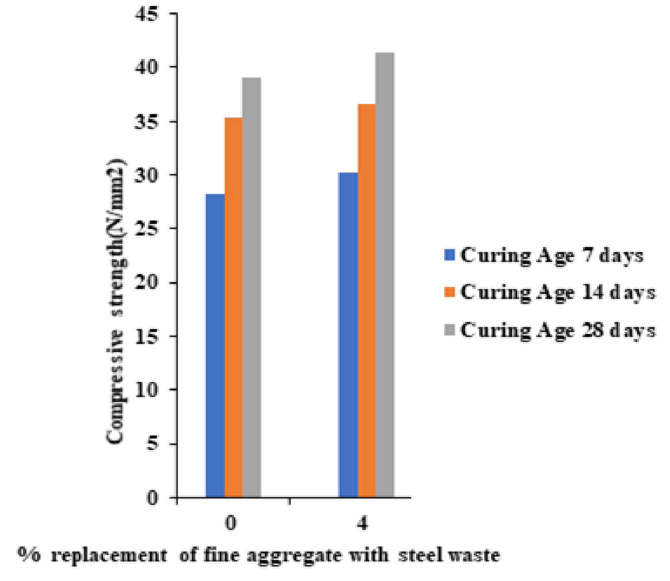

Figure 7. Graphical representation of compressive strength with 4% replaced steel waste.

Table 7. Results of compressive strength with respective to 5% replaced steel waste.

Steel Waste%	Curing Age 7 days	Curing Age 14 days	Curing Age 28 days
0%	28.22	35.33	39.10
5%	30.61	36.81	41.69

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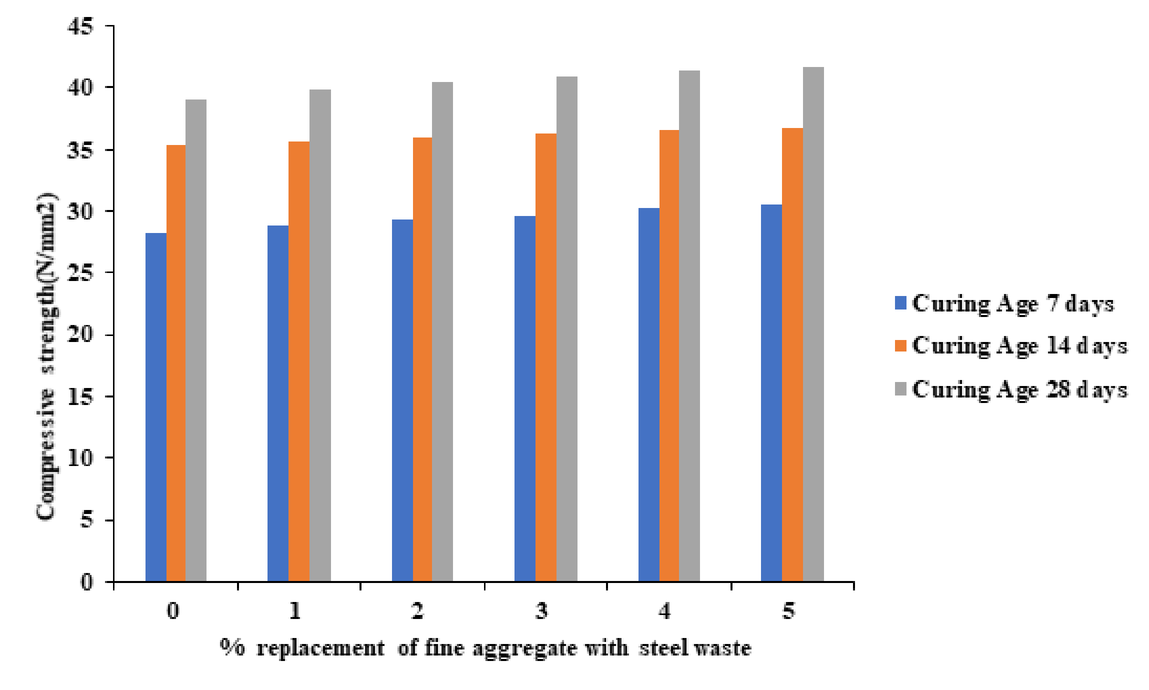

Figure 9. Graphical representation of Compressive strength.

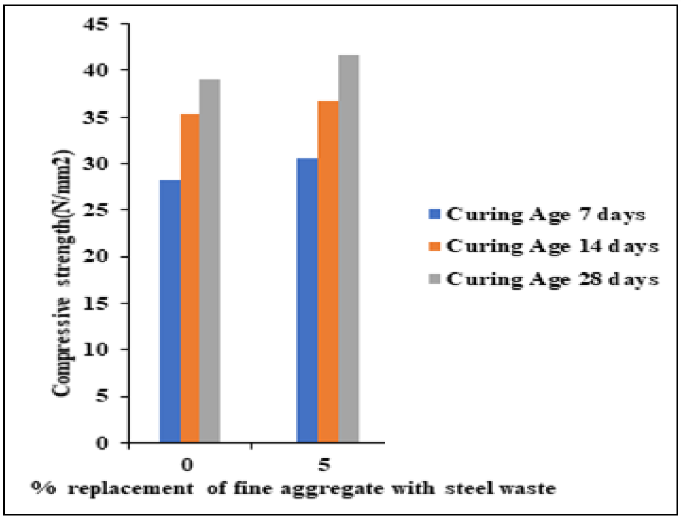

Figure 8. Graphical representation of compressive strength with 5% replaced steel waste.

Table 8. Results of compressive strength with respective to replaced steel waste.

Steel Waste%	Curing Age 7 days	Curing Age 14 days	Curing Age 28 days
0%	28.22	35.33	39.10
1%	28.80	35.69	39.82
2%	29.28	36.04	40.45
3%	29.67	36.35	40.98
4%	30.20	36.61	41.39
5%	30.61	36.81	41.69

The integration of steel waste as a partial replacement for fine aggregate in concrete has been analyzed for its impact on compressive strength. According to the data presented in Figure 9 and Table 8, the substitution of fine aggregate with 1-5% steel waste significantly enhances the compressive strength of the concrete. Specifically, newly formulated concrete incorporating steel waste demonstrates superior strength compared to conventional concrete. This improvement in strength is attributed to the steel waste's inherent properties, which likely contribute to better compaction and load distribution within the concrete matrix. The compressive strength shows a positive correlation with the increasing percentage of steel waste up to a certain limit, suggesting an optimal range for enhancement.

However, the increase in compressive strength rate is not uniform across different percentages of steel waste replacement. At the lower end of the spectrum, specifically at 1% replacement, the increment in strength is notably higher. This suggests that even a small addition of steel waste can significantly impact the structural integrity of the concrete. Conversely, at the higher end, such as a 5% replacement, the rate of increase in strength diminishes. This indicates a diminishing return effect, where additional steel waste does not proportionally enhance compressive strength beyond a certain threshold. Instead, it may lead to potential issues such as poor workability or segregation, which can adversely affect the concrete's overall performance.

The maximum compressive strength observed is 41.69 MPa after 28 days of curing for the newly formed concrete with steel waste. Ordinary concrete exhibited a minimum compressive strength of 28.22 MPa under the same curing conditions. This substantial difference underscores the beneficial impact of steel waste on

DOI: https://doi.org/10.52756/ijerr.2024.v45spl.004

enhancing concrete strength. Moreover, the curing process plays a crucial role in the development of concrete strength. As the curing period extends, ordinary and modified concrete exhibit increased compressive strength. This increase is due to the continued hydration of cement particles, leading to a denser and more robust microstructure. The partial replacement of fine aggregate with steel waste in concrete formulations presents a viable method for improving compressive strength, especially when optimized within certain percentage ranges. The findings indicate that while small additions of steel waste can substantially enhance strength, there is a threshold beyond which the benefits plateau or even decrease. The data also highlight the importance of proper curing to achieve the full potential of strength development in both ordinary and modified concrete.

Flexural Strength

After compressive strength, the concrete samples' flexural strength is calculated using the IS procedure. The results based on 1% replacement of finer aggregates are shown in table 8 and presented in figure 10 below-

Table 8. Results of flexural strength with a percentage of 1% replaced steel waste.

Steel Waste%	Curing Age 7 days	Curing Age 21 days	Curing Age 28 days
0%	1.02	1.30	1.52
1%	1.11	1.37	1.59

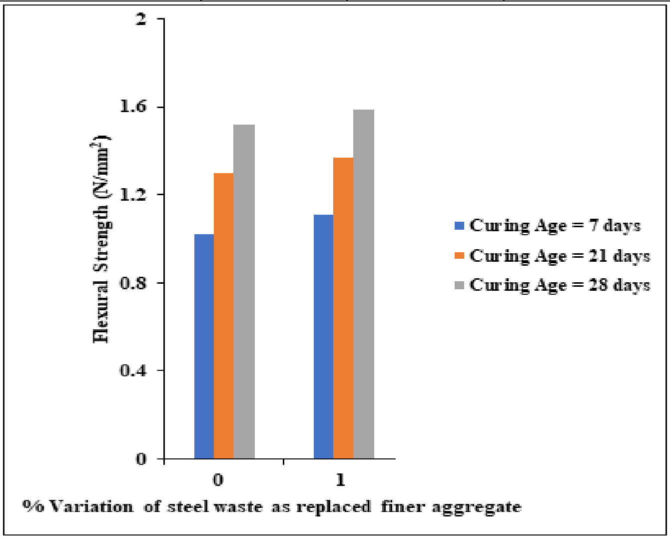

Figure 10. Graphical representation of flexural strength with respective to 1% replaced steel waste.

Figure 10 and Table 8 show that the replacement of fine aggregate of concrete, about 1% of steel waste, has had an impact in terms of an increase in flexural strength. Ordinary concrete has less strength than newly formed concrete. 1.59 is the maximum strength with 28 days of curing of newly formed concrete, while the minimum strength is 1.02 for ordinary concrete. The effect of curing is also shown that with an increase in curing time, the strengths increase in both the concrete. Similarly, the observation for the results based on 2% replacement of finer aggregates are shown in table 9 and presented in Figure 11 below-

Table 9. Results of flexural strength with respective to 2% replaced steel waste.

Steel Waste%	Curing Age 7 days	Curing Age 21 days	Curing Age 28 days
0%	1.02	1.30	1.52
2%	1.19	1.43	1.65

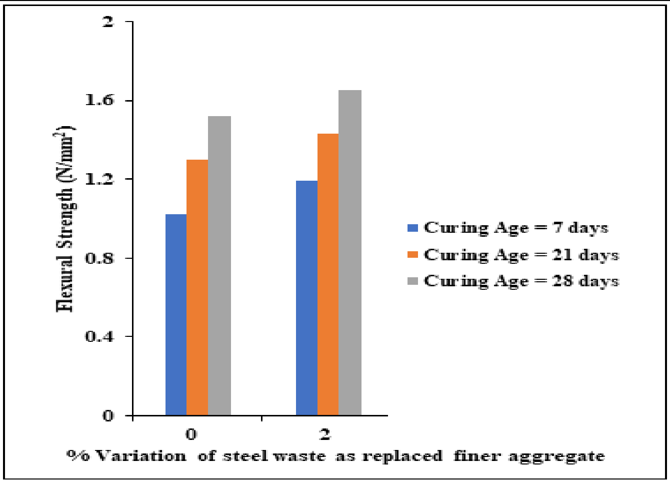

Figure 11. Graphical representation of flexural strength with respective to 2% replaced steel waste.

Figure 11 and table 9 show that the replacement of fine aggregate of concrete, about 1% of steel waste, has shown an impact in terms of an increase in flexural strength. Ordinary concrete has less strength than newly formed concrete. 1.65 is the maximum strength with 28 days of curing of newly formed concrete, while the minimum strength is 1.02 for ordinary concrete. The effect of curing is also shown, and with the increase in curing time, the strengths increase in both concretes.

Similarly, the observation for the results based on 3% replacement of finer aggregates are shown in table 10 and presented in figure 12 below-

Table 10. Results of flexural strength with respective to 3% replaced steel waste.

Steel Waste%	Curing Age 7 days	Curing Age 21 days	Curing Age 28 days
0%	1.02	1.30	1.52
3%	1.26	1.48	1.69

Figure 12 and table 10 show that the replacement of fine aggregate of concrete, about 3% of steel waste, has shown impact in terms of an increase in flexural strength. Ordinary concrete has less strength than newly formed concrete. 1.69 is the maximum strength with 28 days of newly formed concrete curing, while the minimum strength is 1.02 for ordinary concrete. The effect of curing is also shown, and with the increase in curing time, the strengths increase in both concretes.

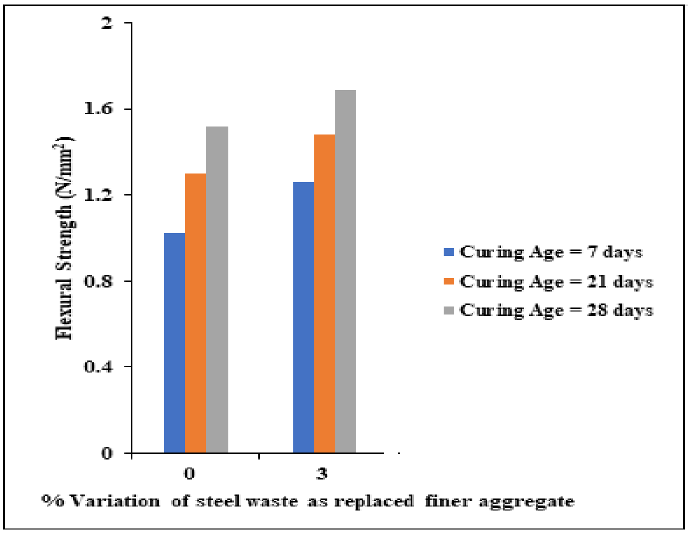

Figure 12. Graphical representation of flexural strength with respective to 3% replaced steel waste.

Similarly, the observation for the results based on the 4% replacement of finer aggregates are shown in table 11 and presented in figure 13 below-

Table 11. Results of flexural strength with respective to 4% replaced steel waste.

Steel Waste%	Curing Age 7 days	Curing Age 21 days	Curing Age 28 days
0%	1.02	1.30	1.52
4%	1.32	1.53	1.73

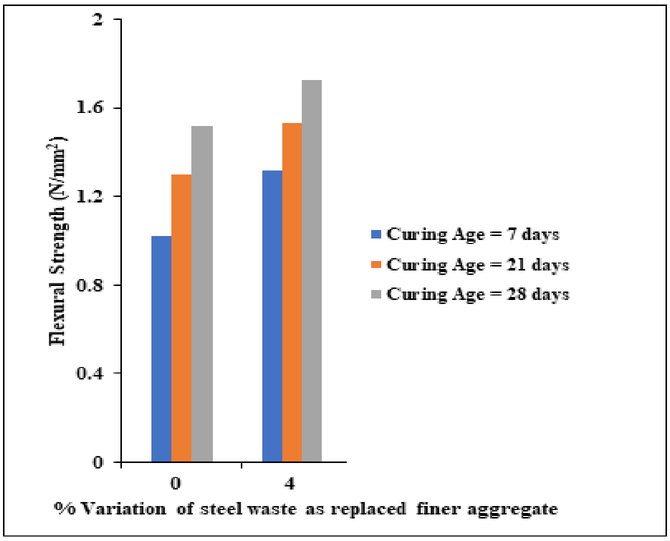

Figure 13. Graphical representation of flexural strength with respective to 4% replaced steel waste.

Figure 19 and table 14 show that replacement of fine aggregate of concrete about 4% of steel waste has shown an impact in terms of an increase in flexural strength. Ordinary concrete has less strength as compared to newly formed concrete. 1.73 is the maximum strength with 28 days of curing newly formed concrete, While the minimum strength is 1.02 for ordinary concrete. The effect of curing is also shown, and with an increase in curing time, the strengths increase in both concretes. Similarly, the observation for the results based on 5% replacement of finer aggregates are shown in table 12 and presented in figure 20 below-

Table 12. Results of flexural strength with respective to 5% replaced steel waste.

Steel Waste%	Curing Age 7 days	Curing Age 21 days	Curing Age 28 days
0%	1.02	1.30	1.52
5%	1.36	1.55	1.75

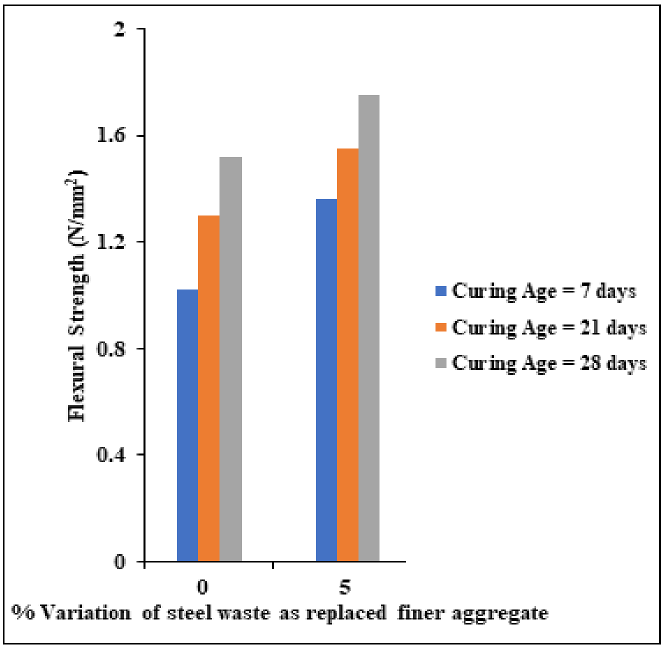

Figure 14. Graphical representation of flexural strength with respective to 5% replaced steel waste.

Figure 14 and table 12 show that the replacement of fine aggregate of concrete, about 1% of steel waste, has shown an impact in terms of an increase in flexural strength. Ordinary concrete has less strength than newly formed concrete. 1.75 is the maximum strength with 28 days of curing of newly formed concrete, while the minimum strength is 1.02 for ordinary concrete. The effect of curing is also shown, and with an increase in curing time, the strengths increase in both concretes. Similarly, the observation for the results based on 1-5% replacement of finer aggregates are shown in table 13 and presented in figure 15 below

DOI: https://doi.org/10.52756/ijerr.2024.v45spl.004

Table 13. Results of flexural strength with respective to 1-5% replaced steel waste.

Steel Waste%	Curing Age 7 days	Curing Age 21 days	Curing Age 28 days
0%	1.02	1.30	1.52
1%	1.11	1.37	1.59
2%	1.19	1.43	1.65
3%	1.26	1.48	1.69
4%	1.32	1.53	1.73
5%	1.36	1.55	1.75

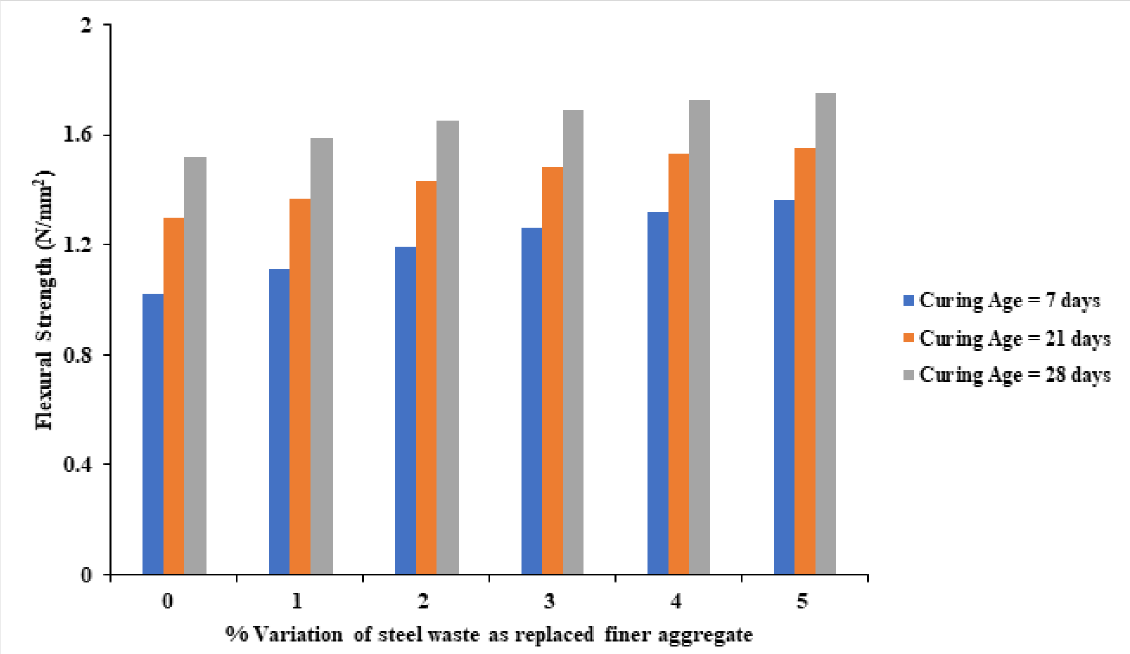

Figure 15. Graphical representation of flexural strength with respective to 1-5% replaced steel waste.

Figure 15 and table 13 show that the replacement of fine aggregate of concrete about 1-5% of steel waste has shown an impact in terms of an increase in flexural strength. Ordinary concrete has less strength than newly formed concrete. The strength of concrete is found to increase with an increase in the amount of steel waste as a replacement for coarser aggregate. However, the rate of increment is not quite stable. It decreases with an increase in the amount of steel waste. From 1% replacement of steel waste, it is observed that the increment rate is higher but is lower than the analyzed case of 5% replacement. 1.75 is found as the maximum strength with 28 days curing of newly formed concrete, while the minimum strength is found as 1.02 for ordinary concrete with the case of curing of 7 days. The effect of curing is also shown that with an increase in curing time, the strengths increase in both the concrete.

Conclusion

In concrete technology, using sand as a primary fine aggregate is conventional due to its abundance in the Earth's crust. However, the finite nature of this resource has prompted exploration into alternative materials. In a recent study, steel waste is investigated as a potential replacement for sand in concrete production. This initiative aims to mitigate the depletion of natural sand and explore the engineering properties of steel waste in this application.

The study underscores several significant conclusions. Firstly, steel waste demonstrates promising potential as a substitute material for fine aggregate in concrete. Researchers observed that the newly formulated concrete blocks exhibited a maximum compressive strength of 41.69 MPa after 28 days of curing. In contrast, conventional concrete blocks achieved a minimum compressive strength of 28.22 MPa after 7 days of curing. This comparison suggests that concrete incorporating steel waste can achieve comparable or even superior strength characteristics over time.

Compressive strength as well as flexural strengths increase with the replacement of finer aggregate through steel waste. 1.75 after curing of 28 days for new concrete while minimum compressive strength is found as 1.02 after curing of 7 days for ordinary concrete beam.

However, it is notable that while the compressive strengths of the steel waste concrete are increasing, the rate of increment slowed down compared to conventional concrete. This phenomenon indicates that further optimization may be necessary to enhance the rate of strength development and overall performance.

One critical aspect highlighted by the study is the effect on workability when replacing fine aggregate with steel waste. Workability refers to the ease and homogeneity with which freshly mixed concrete can be handled and placed. The researchers observed a decrease in workability with the incorporation of steel waste. This reduction can be attributed to the angular and irregular shape of steel waste particles, which can affect the flow and cohesion of the concrete mix.

To address this challenge, the study recommends the exploration of additives and binders that can improve the workability of concrete containing steel waste. These additives could enhance the lubrication and dispersion of particles within the mix, thereby potentially improving the overall workability without compromising the desired compressive strength and durability.

In conclusion, while steel waste shows promise as a viable alternative to natural sand in concrete production, further research and development are essential to optimize its performance. Further study on Microstructure and the difference in hydrated products formed in the concrete produced by using the steel waste using combinations of other mineral admixtures and chemical admixtures to enhance workability which will enable to produce dense, well compacted concrete with better service life and durability. Strategies to enhance workability and maintain or improve strength characteristics will be crucial in advancing the utilization of steel waste in sustainable concrete construction practices. By continuing to innovate and refine these approaches, the construction industry can move towards more sustainable and resource-efficient building materials.

Conflict of Interest

I, Umank Mishra, declare that I have no conflict of interest related to this research paper. I have no financial or personal relationships that could inappropriately influence my work. I have not received any financial support or funding that could be perceived as a conflict of interest. My contribution to this research was conducted independently and without bias.

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How to cite this Article:

Himani Bisen, Kruti B Jethwa, Maya Rajnarayan Ray, Umank Mishra, Kaushal Kumar, Pankaj Kumar, Nishant Yadav and Anoop Narain Singh (2024). Analyze the Effect of Steel Waste on Performance Characteristics of Concrete. *International Journal of Experimental Research and Review*, *44*, 41-55.

DOI : https://doi.org/10.52756/ijerr.2024.v45spl.004