EXPERIMENTAL INVESTIGATION ON DURABILITY AND SUSTAINABILITY OF CONCRETE INCORPORATING IRON FILINGS AND GRANITE WASTE AS PARTIAL REPLACEMENT OF COARSE AGGREGATE

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ABSTRACT

The rapid expansion of the construction industry has led to excessive use of natural aggregates and increased generation of industrial and quarry waste, causing resource depletion and environmental degradation; to address this issue, the study investigates the use of iron filings and granite waste as partial replacements for coarse aggregates in concrete to support sustainable construction practices. Concrete mixes with varying replacement levels were tested against conventional mixes using standard specimens such as cubes, cylinders, and prisms, evaluating properties like compressive strength, split tensile strength, flexural strength, water absorption, sorptivity, and durability. The results indicate that at optimum replacement levels, the inclusion of iron filings enhances density and bonding within the concrete matrix, while granite waste improves aggregate interlocking and overall structural stability. However, higher replacement percentages negatively affect workability and may reduce strength due to increased angularity and differences in material properties. The study highlights that careful proportioning is essential to achieve balanced performance. It also emphasizes that the reuse of such industrial by-products reduces landfill burden and promotes efficient waste management. Furthermore, the approach contributes to lowering the demand for natural aggregates, conserving natural resources, and reducing environmental impact. Overall, the research demonstrates that iron filings and granite waste can be effectively utilized in concrete, offering a sustainable and economical alternative suitable for non-structural and moderate structural applications. Additionally, the findings encourage further research on optimizing mix design and expanding its application in advanced construction practices.

Keywords: Sustainable concrete, Iron filings, Granite waste, Waste utilization, Durability of concrete, Sustainable construction.

1. INTRODUCTION

Concrete is the most widely used construction material due to its strength, durability, and cost-effectiveness, with coarse aggregates forming about 60–70% of its volume. However, rapid urbanization has significantly increased the demand for concrete, leading to excessive extraction of natural aggregates and causing environmental issues such as resource depletion, pollution, and ecological imbalance. At the same time, large quantities of industrial and quarry wastes like iron filings and granite waste are generated, creating disposal challenges. Utilizing these waste materials in concrete offers a sustainable solution by reducing environmental impact while conserving natural resources.

Sustainable construction focuses on minimizing environmental damage and promoting efficient use of resources by incorporating waste materials into construction practices. Materials such as fly ash, silica fume, and industrial by-products have already been used successfully in concrete. Similarly, iron filings and granite waste have shown potential as partial replacements for coarse aggregates. Granite waste, with its high strength and durability, and iron filings, with their density and metallic properties, can enhance concrete performance. Their use supports waste management, reduces landfill burden, and contributes to eco-friendly and resource-efficient construction.

Granite waste generated during quarrying and processing possesses favorable properties like hardness, compressive strength, and abrasion resistance, making it suitable for concrete applications. Its use can improve bonding and strength due to its angular shape while reducing dependence on natural aggregates. Similarly, iron filings, produced from machining processes, can increase concrete density, strength, and crack resistance by acting as micro-reinforcements. However, their usage must be optimized, as excessive amounts may affect workability, increase weight, or lead to corrosion concerns.

The present study aims to evaluate the feasibility of using granite waste and iron filings as partial replacements for coarse aggregates in concrete. It focuses on assessing workability, mechanical properties, durability, and sustainability through experimental investigation. The study also seeks to determine optimal replacement levels and compare modified concrete with conventional mixes. Overall, this research contributes to developing eco-friendly construction materials by promoting waste utilization, improving concrete performance, and supporting sustainable construction practices.

2. LITERATURE REVIEW

Sharma et al. (2025)
Sharma et al. (2025) investigated the combined use of granite waste and iron filings in concrete for sustainable construction. Their study revealed that partial replacement of coarse aggregates improves compressive strength and durability up to an optimum level. The research highlighted reduced water absorption and enhanced density due to better particle packing. However, excessive replacement negatively affected workability. The study concluded that waste-based concrete is an eco-friendly solution that reduces environmental impact and supports resource conservation in modern construction practices.

Reddy and Kumar (2024)
Reddy and Kumar (2024) studied the effect of industrial waste materials like iron filings on concrete performance. Results showed improved tensile strength and crack resistance due to micro-reinforcement behavior of iron particles. The study emphasized that optimal dosage is critical, as higher content reduces workability and increases weight. Durability tests indicated better resistance to permeability and environmental damage. The research supports the use of industrial waste in concrete to enhance mechanical properties while promoting sustainable and cost-effective construction methods.

Patel et al. (2023)
Patel et al. (2023) examined the utilization of granite waste as a partial replacement for coarse aggregates in concrete. Their findings indicated that up to 30% replacement yields comparable or improved compressive strength due to better interlocking and particle packing. The study also observed reduced permeability and improved durability characteristics. However, higher replacement levels affected workability. The research concluded that granite waste can effectively reduce natural resource consumption and environmental pollution while maintaining structural performance of concrete.

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Singh and Verma (2022)
Singh and Verma (2022) focused on sustainable concrete using quarry and industrial wastes. Their research showed that combining different waste materials enhances both strength and durability when used in optimum proportions. The study highlighted improvements in flexural and tensile strength due to enhanced bonding. Durability tests revealed reduced water absorption and increased resistance to chemical attacks. The authors concluded that waste-based concrete is a viable alternative for sustainable infrastructure development with reduced environmental impact.

Kumar et al. (2021)
Kumar et al. (2021) analyzed the mechanical properties of concrete incorporating metal waste such as iron filings. The study reported increased compressive strength and density due to the presence of metallic particles. Iron filings acted as crack arresters, improving durability and resistance to stress. However, excessive inclusion reduced workability and increased corrosion risks. The study emphasized proper mix design for achieving balanced performance. It concluded that industrial waste utilization contributes to sustainable construction practices and waste management.

Ali et al. (2020)
Ali et al. (2020) investigated the role of waste materials in improving concrete sustainability. Their findings showed that partial replacement of aggregates with waste materials enhances strength and durability while reducing environmental pollution. The study highlighted improvements in compressive strength and reduced permeability. It also emphasized the economic benefits of using waste materials. However, careful proportioning is required to maintain workability. The research supports the adoption of eco-friendly materials in construction for sustainable development.

Research Gaps Identified from Literature

A critical review of existing literature on the use of granite waste and iron filings in concrete reveals that several researchers have studied their individual feasibility, strength characteristics, durability aspects, and sustainability benefits. However, despite numerous investigations, certain gaps and limitations remain unaddressed. Identifying these research gaps is essential to justify the present study and highlight its contribution to sustainable concrete technology. Based on the review of existing literature, the following research gaps were identified:

- Limited studies on the combined use of granite waste and iron filings in concrete
- Lack of clearly defined optimum replacement levels for both materials
- Insufficient focus on durability aspects such as permeability and chemical resistance
- Limited comprehensive evaluation of sustainability, cost, and overall performance

3. MATERIALS AND METHODOLOGY

MATERIALS USED

The study utilized cement, fine aggregate, coarse aggregate, granite waste, iron filings, and water. All materials were tested according to Indian Standard (IS) codes to ensure suitability for concrete production. Proper selection and characterization of these materials are essential for achieving desired strength and durability.

1. Cement

Cement acts as the primary binding material in concrete through the hydration process, forming compounds that provide strength and durability. In this study, OPC 53 grade cement was used due to its high early strength and reliability. Key properties such as fineness, consistency, setting time, soundness, and compressive strength were tested and found to meet IS standards, ensuring quality concrete production.

2. Fine Aggregate

Fine aggregate (river sand) fills voids between coarse aggregates and improves workability and cohesion of concrete. The sand used in this study conformed to IS 383:2016 and was clean, well-graded, and free from impurities. Proper grading enhances bonding with cement paste and contributes to strength and durability.

Fig.1*Fine Aggregate*

3. Coarse Aggregate

Coarse aggregates form the main structural component of concrete, influencing strength and durability. Crushed granite aggregates of 20 mm size were used due to their hardness and durability. Their angular shape improves interlocking and bonding with cement paste. Test results confirmed compliance with IS standards, ensuring suitability for structural applications.

Fig.2*Coarse Aggregate*

4. Granite Waste

Granite waste, generated from quarrying and processing industries, was used as a partial replacement for coarse aggregates. Due to its hardness and durability, it enhances concrete properties while reducing environmental impact. Its utilization helps conserve natural resources and promotes sustainable construction practices.

Fig.3 *Granite Waste*

5. Iron Filings

Iron filings are industrial waste obtained from machining processes. When incorporated into concrete, they improve density, strength, and impact resistance. Their use reduces waste disposal issues and contributes to sustainable material utilization. Proper cleaning and grading were performed before use to ensure effective bonding in concrete.

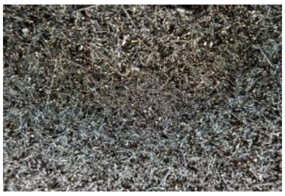

Fig.4 *Iron Fillings*

6. Water

Water is essential for the hydration of cement and directly influences strength and workability. Clean potable water was used in this study as per IS 456:2000 guidelines. Proper water quality ensures adequate hydration, strength development, and durability of concrete.

MIX DESIGN

The concrete mix was designed based on IS 10262:2019 guidelines to achieve M30 grade concrete. The target mean strength was calculated considering standard deviation to ensure reliability. Key parameters included water-cement ratio (0.45), cement content, and aggregate proportions. Trial mixes were conducted to finalize the mix ensuring required workability and strength.

Table 1: Mix Design Parameters

Parameter	Value
Grade of Concrete	M30
Water-Cement Ratio	0.45
Cement Content	420 kg/m³
Fine Aggregate	650 kg/m³
Coarse Aggregate	1150 kg/m³
Water	189 litres

MIX PROPORTIONS:

Tabel 2: Mix Proportions

Mix ID	Granite Waste (%)	Iron Filings (%)
M1	0	0
M2	10	2
M3	20	4
M4	30	6
M5	40	8

Different concrete mixes were prepared by replacing coarse aggregates with varying percentages of granite waste and iron filings. These mixes were tested to determine optimal replacement levels that provide good strength and durability while promoting sustainability.

Preparation of Specimens

Concrete specimens were prepared through systematic steps including material weighing, mixing, water addition, molding, compaction, and surface finishing. Proper preparation ensured uniformity and accuracy in test results.

Types of Specimens

Cube, cylinder, and prism specimens were cast to evaluate compressive strength, tensile strength, and flexural strength respectively. These standard specimen types help assess different mechanical properties of concrete.

Curing of Specimens

Curing was carried out by immersing specimens in water for 7 and 28 days after initial setting. Proper curing ensures continuous hydration, leading to improved strength and durability while preventing cracks and shrinkage.

Table 3: Specimens Prepared

Specimen Type	Size	Test Conducted
Cube	150 × 150 × 150 mm	Compressive Strength
Cylinder	150 × 300 mm	Split Tensile Strength
Prism	100 × 100 × 500 mm	Flexural Strength

EXPERIMENTAL PROGRAM

The experimental study included tests such as slump test, compressive strength test, split tensile strength test, flexural strength test, water absorption test, and sorptivity test to evaluate both mechanical and durability properties of concrete.

1. Slump Test (Workability)

The slump test determines the workability of fresh concrete. Higher slump indicates better flowability, while lower slump indicates a stiffer mix. It ensures proper handling and placement of concrete.

Fig.5 *Slump Test*

2. Compressive Strength Test

This test evaluates the load-carrying capacity of concrete. Cube specimens were tested after curing, and strength was calculated using load and area. It is the most important parameter for structural performance.

3. Split Tensile Strength Test

This test measures the tensile strength of concrete indirectly using cylindrical specimens. It helps evaluate cracking resistance, as concrete is weak in tension.

Fig.6 *Strength Test*

4. **Flexural Strength Test:** Flexural strength determines the ability of concrete to resist bending. Prism specimens were tested to evaluate performance in beams and slabs.

5. Water Absorption Test

This test measures the porosity of concrete by calculating the amount of water absorbed. Lower absorption indicates higher durability and better-quality concrete. **Fig.7** *Water Absorption Test*

6. Sorptivity Test

Sorptivity evaluates the rate of water absorption through capillary action. It indicates permeability and durability of concrete. Lower sorptivity values signify better resistance to moisture and environmental damage.

4. RESULTS AND DISCUSSION

This chapter presents the experimental investigation of concrete incorporating granite waste and iron filings as partial replacement materials for coarse aggregates. The main objective of the study is to evaluate the feasibility of utilizing these industrial by-products and to analyze their effect on the mechanical and durability properties of concrete. The use of such waste materials helps in reducing environmental pollution, conserving natural resources, and promoting sustainable construction practices. Granite waste generated from stone industries and iron filings from machining processes were used as alternative materials. A series of laboratory tests including workability, compressive strength, tensile strength, flexural strength, water absorption, and sorptivity tests were conducted to assess the performance of modified concrete mixes in comparison with conventional concrete.

MIX PROPORTIONS

Five different concrete mixes were prepared by varying the percentage of granite waste and iron filings. The control mix (M1) consisted of conventional concrete, while mixes M2 to M5 incorporated increasing proportions of replacement materials. These variations were used to study the influence of waste materials on concrete properties and to identify the optimum mix.

Table 4: mix proportions used in the experimental program

Mix ID	Granite Waste (%)	Iron Filings (%)
M1	0	0
M2	10	2
M3	20	4
M4	30	6
M5	40	8

1. Compressive Strength Results

Compressive strength is a key indicator of concrete performance. The results showed that compressive strength increased progressively from the control mix up to mix M3 and then slightly decreased for higher replacement levels. The maximum strength was achieved in mix M3, which contained 20% granite waste and 4% iron filings. This improvement is attributed to better particle packing, reduced voids, and increased density due to the presence of granite waste and iron filings. However, beyond the optimum level, the strength decreased slightly due to poor workability, segregation, and inadequate compaction. Overall, the results confirm that proper proportions of waste materials can enhance the compressive strength of concrete.

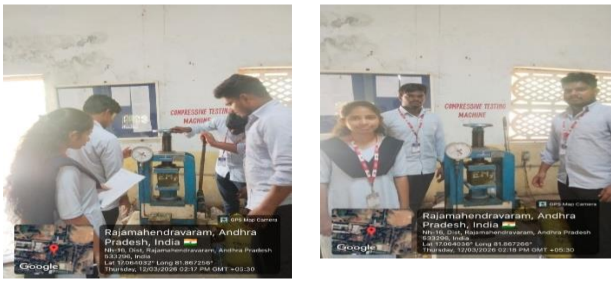

Fig. 8 *Compressive Strength Performance*

Table 6: Compressive Strength Results

Mix ID	7-Day Strength (MPa)	28-Day Strength (MPa)
M1	24.5	32.8
M2	26.1	34.6
M3	28.4	37.2
M4	27.0	35.5
M5	24.9	33.1

2. Split Tensile Strength Results

The split tensile strength test evaluates the resistance of concrete to tensile stresses. The results indicated that tensile strength improved with the addition of granite waste and iron filings up to mix M3, after which a slight decrease was observed. The improvement is mainly due to enhanced bonding between cement paste and aggregates, as well as the crack-bridging effect of iron filings acting as micro-reinforcement. Mix M3 showed the highest tensile strength, indicating the effectiveness of the optimum combination of materials. Higher replacement levels resulted in reduced performance due to weaker bonding and reduced workability.

Fig.9 Split Tensile Strength

Table 7: Split Tensile Strength

Mix ID	Tensile Strength (MPa)
M1	2.85
M2	3.02
M3	3.26
M4	3.10
M5	2.92

3. Flexural Strength Results

Flexural strength represents the resistance of concrete to bending stresses. The results demonstrated a gradual increase in flexural strength up to mix M3, followed by a slight decrease for higher replacement levels. The improvement is attributed to enhanced interlocking of particles, increased matrix density, and crack resistance provided by iron filings. Mix M3 exhibited the highest flexural strength, indicating improved load-carrying capacity under bending. However, excessive replacement affected bonding and resulted in a slight reduction in strength.

Fig.10 Flexural Strength

Table 8: Flexural Strength Results

Mix ID	Flexural Strength (MPa)
M1	4.1
M2	4.4
M3	4.8
M4	4.6
M5	4.3

4. Water Absorption Results

Water absorption is an important durability parameter indicating the porosity of concrete. The results showed a decrease in water absorption from mix M1 to M3, indicating a denser and more compact structure. The lowest absorption was observed in mix M3, suggesting improved durability and resistance to moisture penetration. This improvement is due to the filler effect of granite waste, which reduces voids in the concrete matrix. However, at higher replacement levels, a slight increase in water absorption was observed due to poor compaction and increased void formation.

Table 9: Water Absorption

Mix ID	Water Absorption (%)
M1	3.2
M2	3.0
M3	2.7
M4	2.9
M5	3.1

Overall Performance Evaluation

The overall performance evaluation indicates that the incorporation of granite waste and iron filings significantly enhances both strength and durability of concrete when used in appropriate proportions. Granite waste improves particle packing and reduces voids, while iron filings act as reinforcing elements that enhance crack resistance. However, excessive replacement negatively affects workability and bonding. The results confirm that sustainable concrete with improved performance can be achieved using industrial waste materials.

Optimum Mix Identification

Based on the experimental results, mix M3 containing 20% granite waste and 4% iron filings was identified as the optimum mix. This mix provided the highest compressive, tensile, and flexural strengths along with the lowest water absorption and sorptivity values. The improved performance is due to enhanced density, better bonding, and efficient particle packing. Therefore, this mix is recommended for sustainable concrete production as it offers both structural efficiency and environmental benefits.

5. SUSTAINABILITY ASSESSMENT

5.1 Introduction

The construction industry consumes vast amounts of natural resources such as cement, sand, and aggregates, leading to environmental degradation, resource depletion, and ecological imbalance. Simultaneously, industrial activities generate large quantities of waste materials like granite waste and iron filings, which are often improperly disposed of, causing pollution and land degradation. Sustainable construction practices promote the use of such waste materials in concrete to reduce natural resource consumption and improve environmental performance. Granite waste offers strength and durability, while iron filings influence mechanical properties due to their density. This study evaluates their use as partial replacements for coarse aggregates, focusing on environmental, economic, and sustainability benefits.

5.5 Reduction in Natural Aggregate Consumption

Coarse aggregates form 60–70% of concrete, making their excessive use a major environmental concern. The study replaces natural aggregates with 20% granite waste and 4% iron filings, achieving a total 24% replacement. This significantly reduces dependency on natural resources and promotes sustainable construction practices while maintaining acceptable concrete performance.

Table 12: Reduction in Natural Aggregate Usage

Mix Type	Natural Aggregate (%)	Waste Materials (%)
Conventional Concrete	100	0
Modified Concrete	76	24

This table shows the comparison between conventional and modified concrete, highlighting a 24% reduction in natural aggregate usage.

5.6 Waste Utilization Potential

Concrete production offers a large-scale opportunity to utilize industrial waste materials. Granite waste reduces quarrying activities and conserves natural resources, while iron filings enhance strength and act as micro-reinforcement. Their use provides environmental, economic, and technical benefits such as reduced landfill waste, cost savings, and improved concrete performance. This approach supports circular economy principles and sustainable construction practices.

Table 13: Waste Utilization Benefits

Waste Material	Source	Benefit
Granite Waste	Quarry Industry	Aggregate replacement
Iron Filings	Machining Industry	Strength improvement

This table summarizes the sources and benefits of granite waste and iron filings in concrete.

5.7 Environmental Impact Reduction

Using waste materials in concrete reduces quarrying activities, minimizes waste disposal, and lowers carbon emissions. It decreases environmental degradation by reducing resource extraction and energy consumption. Additionally, it promotes recycling and sustainable waste management, contributing to a lower environmental footprint in construction activities.

Table 14: Environmental Benefits

Parameter	Conventional Concrete	Modified Concrete
Natural Resource Consumption	High	Reduced
Waste Disposal	High	Reduced
Environmental Impact	High	Lower

This table compares conventional and modified concrete, showing reduced environmental impact in waste-based concrete.

5.9 Sustainability Indicators

Sustainability indicators such as resource conservation, waste reduction, environmental impact, and economic feasibility are used to evaluate concrete performance. Waste-based concrete shows improved sustainability by reducing resource consumption, minimizing waste, lowering environmental impact, and enhancing cost efficiency compared to conventional concrete.

Table 16: Sustainability Indicators

Indicator	Conventional Concrete	Waste-Based Concrete
Resource Conservation	Low	High
Waste Utilization	None	Significant
Environmental Impact	High	Reduced
Economic Benefit	Moderate	Improved

This table provides a comparative analysis between conventional and waste-based concrete.

5.10 Advantages of Waste-Based Concrete

Waste-based concrete offers several advantages, including conservation of natural aggregates, reduction in environmental pollution, effective utilization of industrial waste, improved mechanical properties at optimal replacement levels, and reduced construction costs. These benefits make it a sustainable and economical alternative to conventional concrete.

6. CONCLUSIONS

From the experimental investigation, the following conclusions are drawn:

1. Study focuses on using granite waste and iron filings as partial replacements for coarse aggregates. It aims to improve sustainability and reduce environmental impact in concrete production.
2. Workability decreases with increasing waste content due to angular particles and higher surface area. However, the concrete remains workable within acceptable construction limits.
3. Compressive strength increases with replacement up to an optimum level. Beyond this level, strength decreases due to poor bonding and workability issues.
4. The optimum mix is 20% granite waste and 4% iron filings. This combination achieved the highest compressive strength (~37 MPa).
5. Strength improvement is due to better aggregate interlocking and increased density. Reduced voids and improved bonding also enhance overall performance.
6. Split tensile strength improves due to better bonding and crack resistance. Iron filings help in bridging micro-cracks and delaying crack propagation.
7. Flexural strength increases up to the optimum level similar to compressive strength. Improved interlocking and reduced micro-cracks enhance bending resistance.
8. Study concludes that waste-based concrete is a viable and eco-friendly alternative. Further research is needed on long-term durability and large-scale applications.

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