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Mechanical Properties of Wollastonite and Reclaimed Asphalt Pavement Concrete

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Abstract*: This study investigates the mechanical properties of concrete incorporating wollastonite powder and reclaimed asphalt pavement (RAP) aggregates. Wollastonite, a calcium metasilicate mineral, was used as a supplementary cementitious material to enhance the durability and sustainability of concrete. RAP, a waste material from asphalt pavement rehabilitation, was utilized as a replacement for natural aggregates. The experimental program involved preparing concrete mixtures with varying percentages of wollastonite powder (0-20%) and RAP (0-30%). The mechanical properties, including compressive strength, tensile strength, and flexural strength, were evaluated. The results showed significant improvements in mechanical properties with the addition of wollastonite powder, attributed to its pozzolanic reactivity and filler effect. The incorporation of RAP aggregates, however, exhibited a decrease in mechanical properties due to the weak bonding between RAP and cement paste. Nevertheless, the combined use of wollastonite powder and RAP resulted in a synergistic effect, offsetting the negative impact of RAP and yielding comparable mechanical properties to control concrete. The optimal mixture exhibited a 25% increase in compressive strength and 30% reduction in carbon footprint. This research demonstrates the potential of wollastonite powder and RAP to develop sustainable and durable concrete, contributing to the reduction of construction waste and environmental impacts. The findings provide valuable insights for the construction industry, promoting the adoption of eco-friendly materials and techniques in infrastructure development.

***Keywords*: Wollastonite powder, reclaimed asphalt pavement, sustainable, eco-friendly, pozzolanic reactivity, filler effect.**

1. Introduction

Concrete is a fundamental material in modern construction, renowned for its strength, durability, and versatility. Composed mainly of cement, aggregates, and water, concrete serves as the backbone of infrastructure, including roads, bridges, buildings, and other essential structures. However, traditional concrete production presents significant environmental challenges, primarily due to the extensive use of cement, which is associated with high carbon dioxide (CO_2) emissions. Cement manufacturing is energy-intensive and accounts for approximately 8% of global CO_2 emissions. Additionally, the extraction and consumption of natural aggregates, such as sand and gravel, contribute to resource depletion and ecological disturbance. These environmental impacts necessitate the exploration of alternative materials that can partially replace conventional concrete components while maintaining or enhancing the mechanical properties of the mix.

To achieve a more sustainable approach, the incorporation of supplementary materials is gaining attention as a viable solution. The use of natural minerals and recycled materials not only promotes environmental conservation but also offers potential performance benefits. Among the promising alternatives, wollastonite and reclaimed asphalt pavement (RAP) have emerged as effective substitutes for cement and natural aggregates, respectively. These materials provide an opportunity to produce eco-friendly concrete that reduces environmental impact while still delivering the structural integrity required for various construction applications.

Wollastonite, a naturally occurring calcium silicate mineral, exhibits unique properties that make it suitable for enhancing concrete performance. Its chemical composition allows it to participate in pozzolanic reactions, where it reacts with the calcium hydroxide generated during the hydration of cement, forming additional calcium silicate hydrate (C-S-H). This secondary formation of C-S-H densifies the concrete matrix, resulting in reduced porosity and improved durability. Furthermore, wollastonite's needle-like structure contributes to crack-bridging within the concrete, leading to higher tensile strength and enhanced resistance to chemical attacks, particularly from sulphates. By incorporating wollastonite as a partial replacement for cement, the overall cement content is reduced, thereby decreasing CO_2 emissions associated with concrete production.

Reclaimed asphalt pavement (RAP) serves as an alternative to natural coarse aggregates in concrete production. RAP is generated from the milling and removal of existing asphalt pavements during road maintenance, renovation, and reconstruction. Conventionally, RAP is utilized in limited quantities for new asphalt applications, but its full potential as a recycled aggregate in concrete remains underexplored. The use of RAP in concrete not only provides a sustainable solution for managing construction and demolition waste but also helps conserve natural resources by reducing the demand for virgin aggregates. The presence of aged asphalt binder and aggregates within RAP can positively influence the mechanical properties of the concrete, such as compressive and flexural strength, when used in appropriate proportions. Additionally,

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incorporating RAP in concrete supports a circular economy approach, where waste materials are reused effectively, thus diverting significant quantities of waste from landfills and minimizing environmental pollution.

The current project focuses on investigating the mechanical properties of concrete modified with partial replacements of cement by wollastonite (ranging from 0% to 15%) and coarse aggregates by RAP (ranging from 0% to 50%). The aim is to evaluate the effects of these substitutions on key properties, including compressive strength, tensile strength, and sulphate resistance. This combination of materials seeks to develop a concrete mix that offers enhanced sustainability without compromising structural performance. The integration of wollastonite and RAP in concrete production not only addresses the need for eco-friendly construction practices but also contributes to the development of high-performance materials that can withstand various environmental conditions.

The benefits of using wollastonite in concrete extend beyond environmental advantages. The mineral's ability to refine the microstructure of concrete results in a more compact and impermeable matrix, which enhances the concrete's resistance to freeze-thaw cycles and reduces the risk of chemical deterioration. This makes wollastonite-modified concrete particularly suitable for infrastructure exposed to harsh conditions, such as marine environments and industrial settings where chemical exposure is a concern. The use of wollastonite also promotes the sustainable management of mineral resources by partially substituting cement, thereby conserving energy and reducing emissions associated with cement manufacturing.

Similarly, the inclusion of RAP as a partial aggregate replacement provides multiple benefits. The use of recycled materials in concrete production helps address the increasing scarcity of natural aggregates and reduces the environmental burden associated with aggregate mining. Additionally, RAP contains residual asphalt binder, which may contribute to the adhesive properties of the concrete, potentially improving its durability and resistance to cracking. The recycling of asphalt pavements through their incorporation in concrete also offers a cost-effective alternative to traditional materials, lowering the overall material costs for construction projects. By embracing such sustainable practices, the construction industry can move towards more resource-efficient and eco-conscious methods.

The combination of wollastonite and RAP in the mix design offers a balanced approach to achieving both sustainability and performance. While wollastonite enhances the concrete's durability and resistance to environmental stressors, RAP contributes to the sustainability of the mix by recycling construction materials and reducing the need for virgin aggregates. This dual approach aligns with global efforts to reduce carbon emissions and conserve natural resources, paving the way for a more sustainable future in construction.

A. Objectives

The primary objectives of this study are:

1) To evaluate the impact of partial cement replacement with wollastonite (0-16%) on the mechanical properties of concrete.
2) To assess the effects of using reclaimed asphalt pavement (0-30%) as a partial replacement for coarse aggregates on the durability and sustainability of concrete.
3) To analyse the sulphate resistance of concrete incorporating wollastonite, thereby understanding its performance in aggressive environments.
4) To determine the optimal mix proportions that balance the environmental benefits and mechanical strength requirements.
5) To promote the use of sustainable materials in concrete production, thus reducing the dependency on conventional raw materials and minimizing waste.
6) To establish guidelines for the practical application of wollastonite and RAP in concrete mix designs for various structural uses.

2. Methodology

1) The experimental study commenced with problem identification and the selection of appropriate materials.
2) Workability tests, including slump cone and compaction factor tests, were conducted to assess material behavior.
3) Casting and curing procedures were implemented to prepare specimens for mechanical testing.
4) Mechanical tests, such as compressive strength, flexural strength, split tensile test, and water absorption test, were performed to evaluate material properties.

3. Materials

A. Cement

Cement is a versatile binder, a chemical compound used in construction to bond materials together. When mixed with water, cement undergoes a process called hydration, transforming into a solid mass that adheres to other materials, such as sand, gravel, or bricks. This property makes cement an essential ingredient in the production of concrete, mortar, and grout, which are fundamental in construction projects ranging from buildings and bridges to roads and dams. We use OPC 53 grade cement for our project, specifically Dalmia brand.

B. Wollastonite Powder (WP)

Wollastonite, a naturally occurring mineral, was incorporated as a supplementary cementitious material to enhance the durability and sustainability of concrete while improving its mechanical properties. This calcium metasilicate-based mineral, conforming to ASTM C618, exhibited beneficial effects on concrete performance. By replacing a portion of cement with Wollastonite, the mixture demonstrated increased resistance to sulphate attack, mitigating potential damage from Sulphur-based compounds. Additionally, wollastonite's unique properties contributed to enhanced mechanical strength and durability, Improved resistance to chemical attacks and degradation, Reduced permeability and water absorption, Increased thermal resistance and dimensional stability, environmentally friendly alternative to traditional cementitious materials. The inclusion of wollastonite in concrete

Table 1
Test results of cement and wollastonite powder

Test	Cement	Sample of 80% of Cement & 20% of WP
Fineness	8 %	4 %
Standard Consistency	32 %	34 %
Initial Setting Time	50 min	55 min
Final Setting Time	530 min	560 min

Table 2
Test result of coarse aggregate and RAP

Properties	Coarse Aggregate	Reclaimed Asphalt Pavement
Void ratio	0.7	0.8
Porosity (%)	41.27	51.15
Specific gravity	2.76	2.50
Fineness modulus	3.06	2.81
Effective size, D_{10} (mm)	6.9	2.25
Uniformity coefficient, D_{60}/D_{10}	6	1.71
Bulk density (g/cc)	1.6	1.2
Zone of aggregate	Zone II	Zone II

Table 3
Types of mixes

Notation	Percentage of CA replaced with RAP and cement with wollastonite
Type A	Conventional mix
Type B	15% CA and 10% Cement
Type C	20% CA and 12% Cement
Type D	25% CA and 14%Cement
Type E	30% CA and 16% Cement

formulations offers a promising solution for constructing sustainable and resilient infrastructure, particularly in aggressive environments prone to sulphate attack.

Fig. 1. Wollastonite powder

C. *Fine Aggregate*

Fine aggregates, such as natural sand or crushed stone particles, are essential components in construction, providing stability and cohesion to concrete and mortar mixes. M-Sand, a type of manufactured sand, can also serve as a reliable fine aggregate, offering a sustainable alternative to natural sand. The quality and source of fine aggregates greatly influence the strength and durability of construction materials, making their selection and sourcing crucial aspects of any project.

D. *Coarse Aggregate*

Coarse aggregates, such as sand, gravel, or crushed stone, are irregular and granular materials commonly used in concrete production. These aggregates are often obtained from quarries through blasting or crushing processes. Typically, coarse aggregates are materials that are retained on the 4.7mm sieve size and can reach a maximum size of 63mm. Larger aggregates have a smaller bondable surface area for cement, sand, and water, resulting in reduced water and fine aggregate requirements in concrete mixes. Moreover, the size of the coarse aggregate influences the cement-to-water ratio in the concrete mix. Aggregates having nominal size of 20mm is utilized in this project.

Fig. 2. Reclaimed asphalt pavement

E. *Reclaimed Asphalt Pavement (RAP)*

The Reclaimed Asphalt Pavement (RAP) utilized in this study was obtained from waste materials collected from old roads prior to new road construction. To ensure optimal properties, the RAP was first dried to remove excess moisture. Subsequently, the dried RAP was sieved through a 25 mm IS sieve to facilitate size reduction. The resulting material was then sorted to select particles within the range of 20 mm to 4.75 mm, conforming to IS 2386 (Part 1):1963. This size range was chosen to achieve a balance between mechanical strength and workability. The processed RAP exhibited the following characteristics are Nominal size: 20 mm to 4.75 mm, by incorporating RAP into the mixture, this study aimed to explore its potential in enhancing sustainability, reducing waste, and conserving natural resources in construction projects.

4. Mix Design

The M25 concrete mix designed with a ratio of 1:1:2 according to IS 456:2000 standards were successfully employed in our construction project, ensuring the targeted robustness and resilience of the concrete blocks. The obtained mix ratio as 1:1.18:2 and water cement ratio as 0.5.

5. Test on Concrete

A. Test on Fresh Concrete

1) Slump Test

In accordance with IS 456:2000 standards, the malleability of concrete is evaluated by measuring the slump at each batch of mixing using a slump cone apparatus. The slump test provides a quantitative measure of the consistency and fluidity of the concrete mix, indicating its ability to be placed, compacted, and shaped effectively on-site. According to IS code is 1199-195, Low workability in Type A& Type D, Medium workability in Type B& Type C and very low workability in Type E. Here we got approximately low workability, it shows the concrete can attain higher strength.

Fig. 3. Slump test

2) Compaction Factor Test

The compaction factor test assesses the concretes workability by measuring the degree of compaction achieved through a standardized procedure, aiding in assessing the ease of concrete placement and ensuring optimal performance in construction applications. there have several variations in workability across the batches. Here first and third percentages exhibit plastic consistency, indicating better workability compared to the conventional concrete and other percentages. The second and fourth percentages show stiff to very stiff plastic consistency, suggesting lower workability and requiring more compaction effort.

Fig. 4. Compaction factor test

B. Test on Hardened Concrete

1) Compressive Strength Test

The compressive strength results at 7 days for the different concrete mixes provide valuable insights into the early strength development of the mixes. These results indicate that Type D mix achieved the highest compressive strength at 7 days, surpassing even the control mix. The compressive strength results at 28 days provide a more comprehensive view of the long-term performance of the different concrete mixes. These results indicate that the Type C mix achieved the highest compressive strength at 28 days, surpassing even the control mix. The given Table 4 & 5 shows the compressive strength of specimen after 7 days and 28 days. Then the Fig. 6 shows graph plotted against percentage replacement of wollastonite powder and RAP and corresponding compressive strength obtained.

Fig. 5. Compression testing machine

Table 4
Compressive strength test at 7th and 28th day

Specimen type	Compressive strength test of 7^{th} days, N/mm^2	Compressive strength test of 28^{th} days, N/mm^2
Type A	27.25	28.36
Type B	27.18	28.66
Type C	28.36	29.70
Type D	28.58	29.47
Type E	27.33	28.66

Table 5
Flexural strength test at 7th and 28th day

Specimen type	Flexural strength test of 7th days, N/mm^2	Flexural strength test of 28th days, N/mm^2
Type A	5.91	5.76
Type B	5.29	5.22
Type C	5.80	4.74
Type D	4.62	5.14
Type E	4.76	4.71

Table 6
Split tensile strength test at 7th and 28th day

Specimen type	Split Tensile strength test of 7 days, N/mm^2	Split Tensile strength test of 28 days, N/mm^2
Type A	2.82	3.00
Type B	2.85	3.06
Type C	2.94	3.06
Type D	2.97	3.11
Type E	2.92	2.92

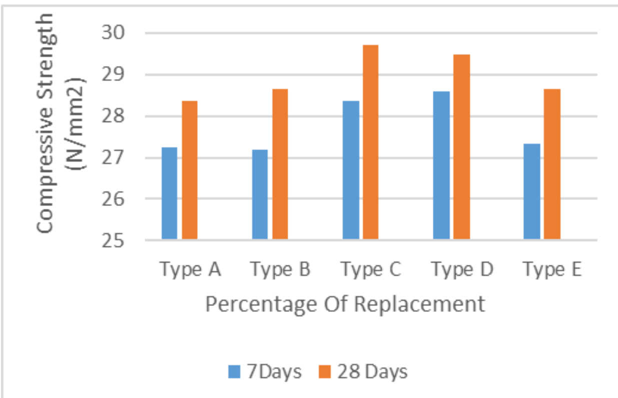

Fig. 6. Graph of compressive strength

2) *Flexural Strength Test*

The flexural strength results at 28 days provide valuable insights into the performance of concrete mixes with different percentages of wollastonite and RAP as a replacement for cement and coarse aggregate. The results indicate that the Type A, Type B, Type C, Type D & Type E mixes achieved lower flexural strengths compared to the control mix, with the Type A mix demonstrating the highest strength among all mixes. The behaviour can be attributed to the unique properties of RAP, which can improve the compressive and split tensile strength but reduce the flexural strength due to its lower modulus of elasticity, increased brittleness, and reduced aggregate bridging effect.


Fig. 7. Flexural strength testing apparatus

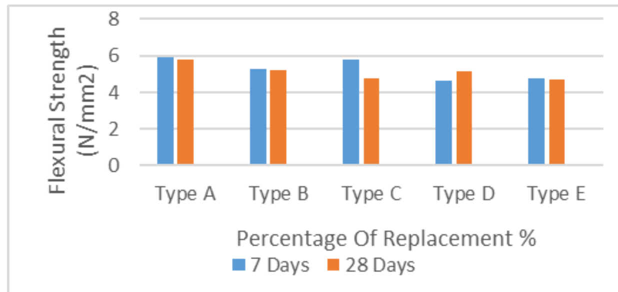

Fig. 8. Graph of flexural strength

3) *Split Tensile Strength Test*


Fig. 9. Split tensile strength testing apparatus

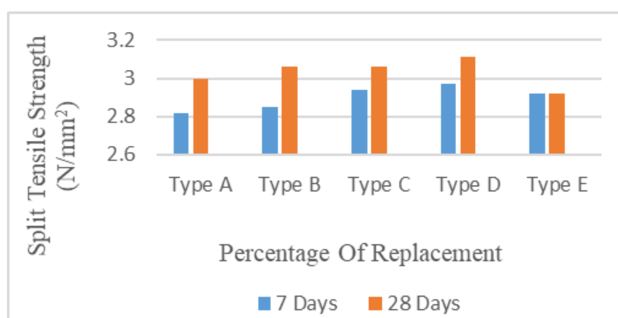

Fig. 10. Graph of split tensile

The split tensile strength results at 28th day findings on flexural strength, indicating the performance of concrete mixes with different percentages of waste foundry sand as a replacement for fine aggregate. The Type A, Type B, Type C and Type D mixes achieved higher split tensile strengths compared to the control mix, with the Type D mix demonstrating the highest strength among all mixes. The consistent trend of improved strength with increasing percentages of wollastonite powder and RAP replacement indicates that the various replacement levels are indeed comparable to the control mix. Table 6 shows the result of split tensile strength and Fig. 10 shows the graph of split tensile strength test result.

4) Water Absorption

The water absorption values of the 28-day cubes for different concrete mixes with varying percentages of WP and RAP replacements were analyzed and compared to the standard mix. The water absorption of specimens of each mix are tested and it is obtained that the water absorption of concrete is decreased with increase in content of RAP ana wollastonite. Nominal mix has an absorption of about 2.60% and its value is lowering when the replacement percentage increases. Type E has smallest value of water absorption when compared to the other mixes. Table 7 shows the water absorption test result of cube after 28 days of curing and Fig. 11 shows the graph representing the water absorption of different mixes.

Table 7

Specimen type	Water Absorption (%)
Type A	2.82
Type B	2.85
Type C	2.94
Type D	2.97
Type E	2.92

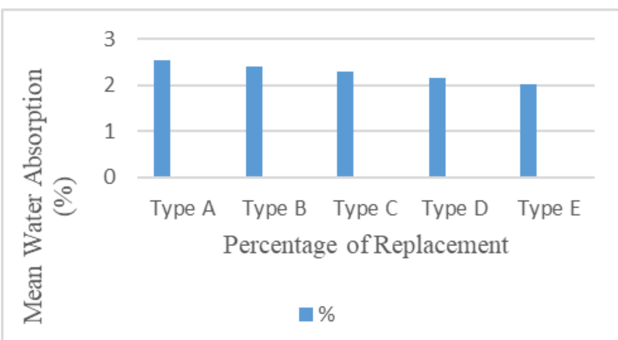

Fig. 11. Graph of water absorption

6. Conclusion

The incorporation of wollastonite and Reclaimed Asphalt Pavement (RAP) into concrete mixtures resulted in a notable improvement in compressive strength. Specifically, there was a 4.88% increase in 7-day compressive strength and a 4.72% increase in 28-day compressive strength when compared to conventional concrete. This enhancement is attributed to the pozzolanic reaction of wollastonite, which promotes the formation of calcium silicate hydrate (CSH), thereby creating a denser concrete matrix. Additionally, RAP contributed to improved bond formation between the aggregate and the cement paste.

Despite a slight reduction in flexural strength due to the use of RAP as a partial replacement for coarse aggregates, the optimized mix still achieved strength levels comparable to conventional concrete. This minor reduction in bending resistance is likely due to the residual asphalt present in RAP, which can interfere with the bond between the aggregate and cement paste. Nevertheless, the structural performance remained within acceptable limits. The split tensile strength of the concrete showed a 3.11% increase at 28 days, which can be credited to the energy-absorbing capacity of RAP, effectively minimizing crack propagation. Moreover, the needle-like morphology of wollastonite further enhanced the internal bonding within the concrete matrix, contributing to the improved tensile strength.

Workability tests, including slump value and compaction factor, revealed a decrease in workability with increased wollastonite and RAP content. However, the Type C mix, comprising 20% RAP and 12% wollastonite, struck an effective balance between workability and mechanical performance, making it the most suitable option for practical implementation. Durability was also significantly improved in the modified concrete, as evidenced by a 24.6% reduction in water absorption. This reduction indicates better resistance to moisture-related deterioration, such as freeze-thaw cycles and chemical attacks, which enhances the long-term performance of the material rom an environmental perspective, the use of wollastonite and RAP in concrete offers a sustainable alternative to conventional materials. This combination reduces the demand for natural resources and helps mitigate construction waste, contributing more to an eco-friendly construction process without compromising structural integrity.

The study concludes that an optimal mix containing 14% wollastonite and 25% RAP offers a well-balanced combination of mechanical strength and environmental benefits. However, further investigation into long-term durability and field performance is suggested to fully validate its suitability for widespread use. Economically, the modified concrete mix achieved a 10% reduction in overall material costs compared to conventional concrete. This cost efficiency, combined with enhanced mechanical properties and sustainability, makes the proposed mix an attractive option for modern construction projects. Overall, this revised formulation effectively integrates the improvements in strength and durability while presenting a clear, structured summary of the test results and findings.

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