

# Experimental Investigation on Sustainable Concrete Incorporating RAP Aggregates and Silica-Based Additives

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**Abstract**—In the process of recycling flexible pavement, a significant quantity of Reclaimed Asphalt Pavement (RAP) aggregate is produced, which ends up being disposed of both legally and illegally in nearby communities, creating various challenges for agencies. The use of these aggregates in cement concrete pavements appears to be an innovative approach and could offer numerous socio-economic and environmental advantages. In this research, standard concrete is produced by utilizing recycled aggregates combined with the addition of silica fume as an admixture in concrete. However, little research has been done to examine the potential of incorporating RAP Aggregates into concrete mix to replace conventional aggregate. The present study focused on the evaluation of mechanical properties of concrete mix made with real RAP materials through laboratory experiments. Two types of RAP materials (coarse and fine RAP) were used to replace an equal amount of conventional coarse and/or fine aggregate. The concrete mix is designed for target strength of M40 MPa. Coarse aggregate were partially replaced with RAP aggregate at 30 %, 45 % and 75%. The relative parameters influencing the strength of concrete were studied in terms of RAP aggregate and silica content respectively. Test results revealed concrete produced with 45% of RAP aggregate tend to reduce the strength by 15% whereas addition of silica fume into the matrix improved the physical, mechanical and chemical properties of concretes containing RAP. When the RAP aggregate is increased by more than 30%, a noticeable drop in compressive strength is observed.

**Index Terms**—Road construction, Reclaimed asphalt pavement, Silica fume, Cement concrete, Compressive strength test, Review performance, Durability.

## I. INTRODUCTION

### A. Background

Concrete is one of the most commonly used construction materials today. Concrete is a widely used construction material known for its durability and compression resistance, essential for load-bearing structures. It consists mainly of aggregate, cement, and water, with aggregate occupying at least 60% of its volume.

Urbanization is rapidly increasing, with people seeking a comfortable life that includes safe housing and well-connected transportation networks. Fulfilling these basic needs heavily relies on natural resources. While natural resources such as aggregates are often used, substituting them with locally available or waste materials, such as Reclaimed Asphalt Pavement (RAP), can offer economic and environmental benefits. The highway industry generates millions of tons of RAP annually, much of which ends up in landfills, contributing to pollution. Using RAP as aggregate in concrete mix provides a sustainable and cost-effective alternative. Studies show RAP concretes have similar mechanical properties to conventional concretes. Adding Silica Fume (SF) further enhances the compressive strength and performance of RAP concretes, offsetting the reduction in strength caused by increased recycled aggregate content.

In this paper, M40 grade concrete (minimum strength of 40 N/mm<sup>2</sup> after 28 days) is used, with SF as an admixture to improve both fresh and hardened properties. This combination demonstrates a sustainable approach to producing high-quality

concrete while addressing waste management challenges.

*B. Problem statement*

While extensive research has explored the use of various admixtures to improve concrete strength, few studies have investigated the combination of Recycled Asphalt Pavement (RAP) aggregates and silica fume in concrete. This practice remains uncommon but is promising for sustainable concrete production. Limited research has focused on how RAP aggregates and silica fume interact in concrete mixes, affecting properties like strength, durability, and workability. This study aims to fill that gap by exploring the effects of these materials and optimizing their combination for high-performance, sustainable concrete.

*C. Aim and objectives of the present study*

This research aims to assess the feasibility and impact of replacing natural aggregates with recycled aggregates, focusing on conserving resources and meeting the growing demand for construction materials. Key objectives include:

1. Evaluate concrete mixes with RAP aggregates and silica fume using slump cone test.
2. Use XRF to examine changes in concrete incorporating RAP and silica fume.
3. Develop M40 grade concrete with varying RAP (30%, 45%, and 75%) and silica fume replacements to optimize performance.
4. Conduct compressive and flexural strength tests on RAP-based and natural aggregate concrete.

The goal is to optimize RAP and silica fume usage for sustainable, high-performance concrete.

*D. Scope of work*

This literature review focuses on evaluating the use of Reclaimed Asphalt Pavement (RAP) in concrete construction through scholarly articles, conference papers, and industry reports. The study scope includes:

1. Laboratory Investigation: Testing RAP-concrete mixes at 7, 14, 28, 45, and 90 days for a characteristic strength of 40 N/mm<sup>2</sup>.
2. RAP Replacement Levels: Analyzing 30%, 45%, and 75% replacement of natural coarse aggregates.
3. Standards Compliance: Following IS Code 10262:2009 for aggregate selection and cube size determination.

4. Fresh Concrete Test: Conducting slump tests to evaluate workability.
5. Hardened Concrete Tests: Assessing strength and durability through compression, and flexural strength.
6. The study compares the effects of RAP percentages on concrete performance.



Figure 1 Collection of RAP aggregate for testing

II. MATERIAL AND METHODOLOGY

*A. Cement*

In this study, Ordinary Portland Cement (OPC) 53 grade, conforming to IS 12269-2004, was source from J. Kumar Laboratory (BKC).

*B. Coarse Aggregate*

Crushed stone pieces with a maximum nominal size of 20mm and down to 10mm were used as coarse aggregates, conforming to IS 383-2004.

*C. Fine Aggregate (Crushed Sand)*

Fine aggregate is made from crushed sand. According to IS 383-2004, the sand used here belongs to zone-II.

*D. Silica Fume*

Silica fume (Micro-silica) used in this study was procured from local chemical dealers confirming to IS 15388- 2013. Physical and chemical properties of Micro-silica are given in Table I and Table II respectively.

Table I Physical properties of silica fume

Test	Result
Specific Gravity	2.15
Fineness (%)	--
Specific Surface Area (kg/m <sup>2</sup> )	496
Standard Consistency (%)	31
Initial / Final setting time	120 / 300

An X-Ray Fluorescence Machine was used to test the chemical properties of Silica fume at the J.Kumar Laboratory in BKC.

Table II Chemical properties of silica fume

Test	Result %
Silica (SiO <sub>2</sub> )	95
Alumina Oxide (Al <sub>2</sub> O <sub>3</sub> )	1.12
Iron Oxide ((Fe <sub>2</sub> O <sub>3</sub> )	1.46
Ferric Oxide (Fe <sub>2</sub> O <sub>3</sub> )	1.3
Calcium Oxide (CaO)	0.2-0.8
Magnesium Oxide (MgO)	
Sodium oxide (Na <sub>2</sub> O)	0.5-1.2
Potassium oxide (K <sub>2</sub> O)	
Loss on Ignition	Less than 0.6

*E. RAP Aggregates*

Some of the physical and mechanical properties of aggregates typically include specific gravity, water absorption, bulk density, abrasion resistance, crushing strength, and impact resistance. These key properties are essential for evaluating the quality of aggregates used in the concrete mix.



Figure 2 RAP aggregates

The data presented in Table III was derived as an average by considering various research findings from different researchers. This data enables the assessment of the quality of RAP aggregates in comparison to the available natural aggregates.

Table III Physical and Mechanical properties of RAP

Sr. No	PROPERTIES	COARSE RAP (20mm)	COARSE RAP (10mm)
1	Specific Gravity	2.2-2.6	1.81-2.49
	Absorption (%)	1.8-2.9	1.8-2.8
3	Bulk density (Kg/m <sup>3</sup> )	1940-2300	1600-2200
4	Crushing value (%)	16-20	-
5	Impact value (%)	4.3-33	-
6	Abrasion resistance (%)	18-30	-

RAP consists of 93% to 97% mineral aggregates by weight, with 3% to 7% hardened asphalt cement. Its chemical composition is similar to that of natural aggregates.

Table IV Chemical compositions of RAP aggregates

Element compound	Test result (% by weight)
SiO <sub>2</sub>	38
Fe <sub>2</sub> O <sub>3</sub>	26.8
CaO	16.3
Al <sub>2</sub> O <sub>3</sub>	11
SO <sub>3</sub>	2.9
TiO <sub>2</sub>	1.8
K <sub>2</sub> O	1.73
MnO	0.585
SrO	0.37
CuO	0.13
V <sub>2</sub> O <sub>5</sub>	0.11
BaO	0.2
Re <sub>2</sub> O <sub>7</sub>	0.06
ZrO <sub>2</sub>	0.055
ZnO	0.045

*F. Research Methodology*

This section outlines the methodology used to achieve the objectives of this study, focusing on the materials (Cement, Water, Natural aggregates, Silica fume, Admixture, and RAP aggregates) for producing RAP concrete. Concrete testing, including slump, compressive strength and flexural strength test of RAP was conducted at the Concrete Testing Laboratory (RMC Plant), J. Kumar Infra Projects

Ltd. (Mumbai). The materials employed included OPC 53 Grade Cement, fine and coarse aggregates, water, silica-fume, admixtures and different proportions of RAP. As RAP concrete is a new method, the mix design was based on trial mixes, with compressive strength determined using 150 x 150 x 150mm cube tests.

*G. Methods of testing*

1. Curing

After casting and compaction, the concrete specimens were cured in the laboratory for 24 hours. After that, they were de-moulded and cured in a fog room maintained at 20 ~ and 99% and placed in a curing tank, filled with water until testing for 7, 14, 28, 45 & 90 days. Then the specimens were removed from curing tank and tested immediately under Compression Testing Machine / Flexural Testing Machine.



Figure 3 Curing concrete cube

2. Slump test

The slump test is primarily used to evaluate the workability of a concrete mix. Concrete strength is influenced by how easily it can be poured and compacted, so the mix needs to be sufficiently workable. Factors such as water content, aggregate size and shape, and the water-cement ratio affect workability. According to IS: 1199-1959, the slump test cone has a height of 12 inches, a bottom diameter of 8 inches, and a top diameter of 4 inches. The test was performed following the guidelines outlined in IS: 1199-1959.

3. Compressive Strength Test

For cube tests, aggregates are typically formed into cubes of either 15 cm x 15 cm x 15 cm or 10 cm x 10 cm x 10 cm, depending on the size of the aggregate. Cubical molds of 15 cm x 15 cm x 15 cm are commonly used for most projects. These specimens

are tested using a compression testing machine after curing periods of 7, 14, 28, 45 and 90 days.

4. Flexural Strength Test

Flexural strength is a key property of concrete, typically determined using beam specimens with a prismatic shape. Standard beam sizes for testing are 150 mm x 150 mm x 700 mm or 100 mm x 100 mm x 700 mm. The flexural strength is expressed in N/mm<sup>2</sup> or MPa and is determined according to IS 516-1959 standards.

III. MIX DESIGN

The mix design for M40 grade concrete was carried out according to IS 456-2000, using the volume batching method for proportioning all materials. Conventional concrete and concrete containing recycled RAP aggregates at 30%, 45%, and 75% were prepared with the appropriate dosage of silica fume. The resulting homogeneous concrete mix was then tested for workability using the slump cone test. Based on these material properties, the Mix Design is prepared for Mix 1 (75% RAP), Mix 2 (45% RAP) and Mix 3 (30% RAP). The proportions and details of the mix are determined using the IRC: 44-2008 method.

Cube specimens of 150 mm x 150 mm x 150 mm were cast to determine the compressive strength. Similarly, prism specimens with dimensions of 700 mm x 150 mm x 150 mm were cast to evaluate the concrete flexural strength.

All specimens were de-moulded after 24 hours and then subjected to water curing at room temperature. A sufficient number of specimens were cast to conduct compressive strength tests at 7, 14, 28, 45, and 90 days.



Figure 4 Concrete Batching Apparatus

Table V Mix Details

Mix	NC	75% RAP (Mix 1)	45% RAP (Mix 2)	30% RAP (Mix 3)
W/C Ratio	0.35	0.35	0.35	0.35
Cement kg/cum	240	240	240	240
FA (Classified Sand) kg/cum	389	389	389	389
FA (C / SAND) kg/cum	391	391	391	391
CA 20MM	579	144.75	318.45	405.3
CA 10MM	431	107.75	237.05	301.7
RAP Kg/cum (20mm +10mm)	0.00	757.5	454.5	303
MICROSILICA	20	20	20	20
GGBS	240	240	240	240
Water kg/cum	175	175	175	175
Density of Concrete in kg/cum	2465	2299.79	2354.8	2383.06

IV. RESULT AND DISCUSSION

Following are the results of various tests such as Slump test, Compressive test and Flexural strength test conducted to see the effect of the conventional concrete and concrete with recycled RAP aggregate content of 30 %, 45 % & 75% were cast with appropriate dosage of silica fume. The cubes were tested for 7, 14, 28, 45 & 90 days for each test.

Tests adopted for the measurement of the workability of the concrete mix in the present investigation are,

1. Slump Test
2. Compacting Factor Test.

The results of workability tests are tabulated in Table VI

Table VI Measurement of Workability

Sr. No	Name of the Test	NC	75% RAP (Mix 1)	45% RAP (Mix 2)	30% RAP (Mix 3)
1	Slump cone Test (mm)	145	90	110	150
2	Compaction factor Test	0.86	0.82	0.85	0.88

A. Compressive Strength test

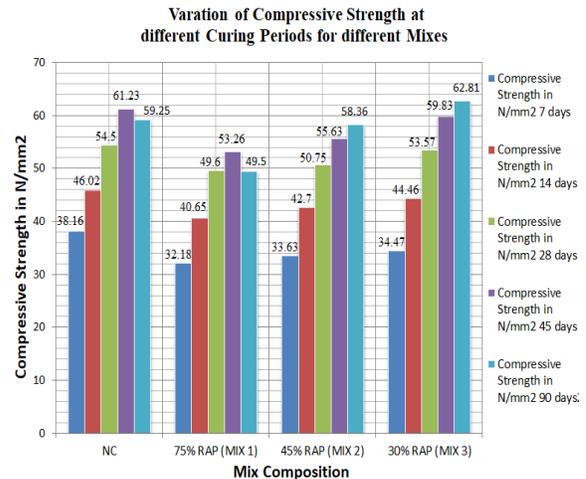
The cube specimens were tested in Compression Testing Machine (CTM) after specified curing period for different % of RAP replacement 30%, 45% and 75%. The compressive strengths after respective curing periods are noted in Table VII.

Table VII Compressive Strength Test Result for Replacement of RAP Aggregates %

Composition	Compressive Strength N/mm <sup>2</sup>				
	7 days	14 Days	28 days	45 days	90 days
NC	38.16	46.02	54.50	61.23	59.25
75% RAP (MIX 1)	32.18	40.65	49.60	53.26	49.50
45% RAP (MIX 2)	33.63	42.7	50.75	55.63	58.36
30% RAP (MIX 3)	34.47	44.46	53.57	59.83	62.81

Discussion on Compressive Strength Results:

(Mix 3) is giving maximum strength of 97.71 % of NC strength, 59.83 N/mm<sup>2</sup> which is very nearer to Normal Concrete Mix Strength for 45 days curing period. And also (Mix 3) is showing good early strength of 34.47 N/mm<sup>2</sup> for 7 day curing period, 1 which is of 90.33% of strength gain with respect to NC Mix.



Graph 1 Showing Compressive Strength Development of Different Mixes

**B. Flexural Strength Test**

The specimens were tested using a flexural testing machine, and the flexural strength was calculated based on the position of the failure plane relative to the supports. The values obtained for concrete with varying RAP replacement levels are presented in Table VIII

Table VIII Flexural Strength Test Result for Replacement of RAP Aggregates %

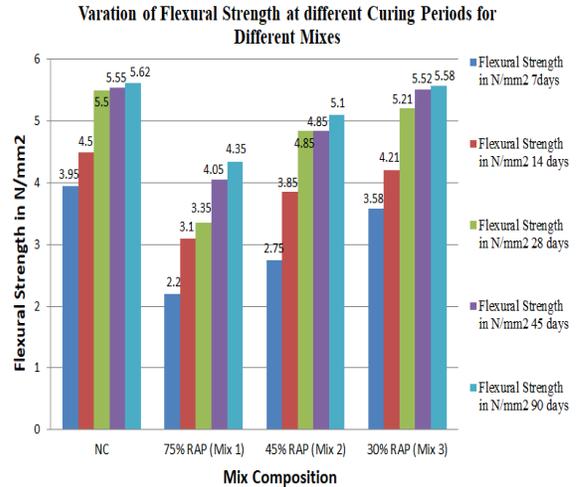
Compositi on	Flexural Strength N/mm <sup>2</sup>				
	7 days	14 Days	28 days	45 days	90 days
NC	3.95	4.50	5.50	5.55	5.62
75% RAP (MIX 1)	2.2	3.1	3.35	4.05	4.35
45% RAP (MIX 2)	2.75	3.85	4.60	4.85	5.10
30% RAP (MIX 3)	3.58	4.21	5.21	5.52	5.58

*Discussion on Flexural Strength Results:*

From the test results of flexural strength, it is observed that NC shows higher flexural strength compared to different RAP replacement levels. (Mix 3) shows higher flexural strength of 5.21 N/mm<sup>2</sup> for 28 days curing period, which is very nearer (94.72% of NC Strength) to strength of Normal Concrete 5.50 N/mm<sup>2</sup>.



Figure 8 Placing Beam Specimen under Flexural Testing machine



Graph 2 Showing Flexural Strength Development of Different Mixes

**V. CONCLUSIONS**

This study explores potential approaches for incorporating RAP recycled aggregates into rigid pavement construction, presenting a sustainable solution for future generations. RAP aggregates provide a valuable resource for road construction while serving as an eco-friendly alternative to natural aggregates. The primary conclusions drawn from the study are as follows:

1. **Compressive Strength:** The study found that increasing RAP aggregates in concrete reduces compressive strength due to weak bonding between the asphalt film and cement paste. However, treated RAP aggregates free from dirt performed better. A 30% RAP replacement (Mix3) for 90 days showed the highest compressive strength, exceeding normal concrete strength by 6%. Flexural strength also peaked at 30% RAP (Mix3), nearly matching normal concrete (99.28%).
2. **Workability:** The workability of concrete containing RAP aggregates decreased due to their high porosity and low density, requiring more water to achieve the desired slump. Workability decreased further as RAP content increased, with a slight reduction in workability observed at 45% and 75% RAP mixes.
3. **Silica Fume Enhancement:** Adding silica fume improved the compressive and flexural strength of RAP concrete, particularly at early ages, due

to its pozzolanic effect. The best results were observed when silica fume was used within a 2-4% range by cement weight, with 3.5% silica fume enhancing the strength of RAP mixes (Mix3 and Mix4).

4. Remedial Measures for RAP: To improve RAP properties, surface treatment or stockpiling in open environments to induce oxidation can make the asphalt film brittle, allowing better interaction with mortar. Chemical treatments like nitric acid or sodium hydroxide can also help remove the asphalt film but may increase project costs.

The following arguments are made in favour of the usage of RAP Mix:

A. Flexible pavement that is simple to remove; use of its material in the construction of concrete pavement. As a result, the price of transportation and natural aggregates is decreased.

B. Using RAP aggregates reduces the demand for natural coarse aggregates, which is rising due to the construction of new roads.

C. Removing natural material from a quarry contributes to reducing pollution and environmental imbalances.

#### A. Recommendation

The review of literature on RAP (Recycled Asphalt Pavement) concrete mixes highlights its potential for sustainable construction, despite some challenges in structural and functional performance. Coarse RAP, especially at a 50% inclusion rate, shows more promise than fine RAP or total RAP. RAP concrete is cost-effective, reduces reliance on natural aggregates, and has benefits such as lower environmental impact and waste reduction. Concrete with up to 45% RAP and 3-5% silica fume (SF) meets the strength requirements for both rural and urban road pavements. Durability tests also indicate better permeability resistance. Therefore, using RAP in concrete pavements is a sustainable solution, offering both environmental and economic advantages.

#### B. Future research direction

Future research on RAP (Recycled Asphalt Pavement) concrete should focus on long-term performance, environmental impacts, and economic feasibility. Key areas include assessing RAP concrete under different environmental conditions, optimizing RAP content and gradation, improving mix designs, and evaluating behavior under dynamic loading.

Standardized testing methods, guidelines, and design codes for RAP concrete are necessary for consistent quality control and broader adoption. This research will support the construction industry's transition to more sustainable and cost-effective practices.

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