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Modulus of Elasticity of Recycled Aggregate Concrete

Prof. More A. V., Prof. Jamale A. D., Lende Abhishek Mahadeo
Mhase Shradha Suresh, Nanaware Vivek Dada
Department of Civil Engineering.
Adsul Technical Campus, Chas , Ahilyanagar, Maharashtra

Abstract: *The increasing demand for construction materials and the growing generation of construction and demolition waste have encouraged the use of recycled aggregates in concrete. This study investigates the modulus of elasticity and strength characteristics of Recycled Aggregate Concrete (RAC) with different replacement levels of recycled aggregates. Concrete mixes of M25, M30, M35, and M40 grades were tested to evaluate compressive strength and elastic behavior. Results indicate that although the modulus of elasticity decreases with increasing recycled aggregate content, RAC can still provide satisfactory structural performance and contribute to sustainable construction practices*

Keywords: Recycled Aggregate Concrete, Recycled Aggregates, Modulus of Elasticity, Compressive Strength, Sustainable Construction

I. INTRODUCTION

The construction industry is one of the largest consumers of natural aggregates, which are essential components of concrete. Rapid urbanization and infrastructure development have significantly increased the demand for these materials, leading to excessive exploitation of natural resources and environmental degradation. At the same time, large quantities of construction and demolition (C&D) waste are generated worldwide, creating serious disposal and land-use problems.

Recycled Aggregate Concrete (RAC) has emerged as an environmentally friendly alternative to conventional concrete. Recycled aggregates obtained from demolished concrete structures can be processed and reused in new concrete production. This practice reduces the consumption of natural aggregates, minimizes waste disposal issues, and supports sustainable construction practices. The use of recycled aggregates also contributes to conserving natural resources and reducing the environmental impact of the construction sector.

The modulus of elasticity is one of the most important mechanical properties of concrete, representing its stiffness and resistance to deformation under applied loads. It plays a crucial role in the design and analysis of structural members such as beams, columns, and slabs. Since recycled aggregates generally contain adhered mortar and possess higher porosity and water absorption than natural aggregates, the elastic behavior of RAC may differ from that of conventional concrete.

This study focuses on evaluating the modulus of elasticity of Recycled Aggregate Concrete with various replacement levels of recycled aggregates. Concrete mixes of different grades are prepared and tested to determine their strength and deformation characteristics. The investigation aims to establish the relationship between compressive strength and modulus of elasticity and to assess the suitability of RAC for structural applications while promoting sustainable and eco-friendly construction practices.

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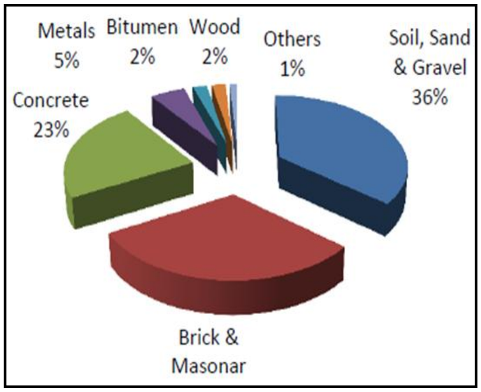

Fig 1: Composition of C&D waste (Ref. JNNURM Report- Dept. of Urban Development, Govt. of Delhi)

II. PROBLEM STATEMENT

The rapid growth of construction activities has led to increased consumption of natural aggregates and the generation of large amounts of construction and demolition (C&D) waste. Excessive extraction of natural aggregates causes depletion of natural resources and environmental degradation, while improper disposal of demolition waste creates serious environmental and land management problems. Recycled aggregates obtained from demolished concrete offer a sustainable alternative; however, their use in structural concrete is limited due to concerns regarding strength and stiffness characteristics.

The modulus of elasticity is a critical parameter in the design of concrete structures, as it governs deformation and serviceability performance. Since recycled aggregates possess different physical properties compared to natural aggregates, the elastic behavior of Recycled Aggregate Concrete (RAC) may vary significantly. Therefore, it is necessary to experimentally evaluate the modulus of elasticity and strength properties of RAC at different replacement levels. This study aims to investigate the effect of recycled aggregate replacement on the modulus of elasticity of concrete and assess its suitability for structural applications.

III. OBJECTIVES

- To study the physical and mechanical properties of recycled aggregates and compare them with conventional natural aggregates used in concrete production.
- To design and prepare M25, M30, M35, and M40 grade concrete mixes with different recycled aggregate replacement levels such as 0%, 30%, 70%, and 100%.
- To evaluate the compressive strength of Recycled Aggregate Concrete (RAC) at various replacement percentages of recycled aggregates.
- To experimentally determine the modulus of elasticity of RAC and analyze the effect of recycled aggregate content on concrete stiffness.
- To establish the relationship between compressive strength and modulus of elasticity of Recycled Aggregate Concrete and assess its suitability for structural applications.

IV. LITERATURE SURVEY

Paper 1
Title: Influence of Size and Content of Recycled Aggregate on Mechanical Properties and Elastic Modulus of Concrete
Authors: H. Liu et al.
Year: 2025

The study investigated the effect of recycled aggregate size and replacement percentage on the mechanical properties of recycled aggregate concrete (RAC). Experimental results showed that compressive strength, tensile strength, and modulus of elasticity decreased with increasing recycled aggregate content. Larger recycled aggregate particles provided better stiffness and higher elastic modulus compared to smaller particles. The study concluded that aggregate size significantly influences the elastic behavior of RAC.

Paper 2

Title: Studying the Usability of Recycled Aggregate to Produce New Sustainable Concrete

Authors: O.A. Qasim et al.

Year: 2024

This research evaluated the physical and mechanical properties of recycled aggregates obtained from demolished concrete. The authors observed that recycled aggregates have lower density and higher water absorption than natural aggregates, affecting the strength and stiffness of concrete. The study confirmed that recycled aggregate concrete can be successfully used in structural applications when proper mix design and quality control measures are adopted.

Paper 3

Title: Evaluation of Modulus of Elasticity of Concrete Containing Both Natural and Recycled Concrete Aggregates

Authors: Various Researchers

Year: 2024

The study proposed analytical methods for evaluating the modulus of elasticity of concrete containing recycled aggregates. Results indicated that the elastic modulus decreases as the percentage of recycled aggregate increases due to the presence of adhered mortar and increased porosity. The research emphasized the importance of accurately estimating elastic modulus for structural design purposes.

Paper 4

Title: More Trustworthy Prediction of Elastic Modulus of Recycled Aggregate Concrete Using Machine Learning Techniques

Authors: W.T. Lu et al.

Year: 2025

This research applied advanced machine learning models to predict the modulus of elasticity of recycled aggregate concrete. The findings revealed that compressive strength is the most influential parameter affecting the elastic modulus of RAC. The developed predictive model demonstrated high accuracy and can assist engineers in estimating elastic modulus without extensive laboratory testing.

Paper 5

Title: Evaluating Properties and Applications of Innovative Recycled Concrete Aggregates: A Review

Authors: K. Sahani et al.

Year: 2025

This review paper examined recent developments in recycled concrete aggregate technology and its applications in sustainable construction. The study reported that moderate replacement levels of recycled aggregates provide acceptable mechanical properties while significantly reducing environmental impacts. The authors concluded that RAC has strong potential for future structural applications when supported by proper material characterization and design practices.

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V. WORKING OF SYSTEM

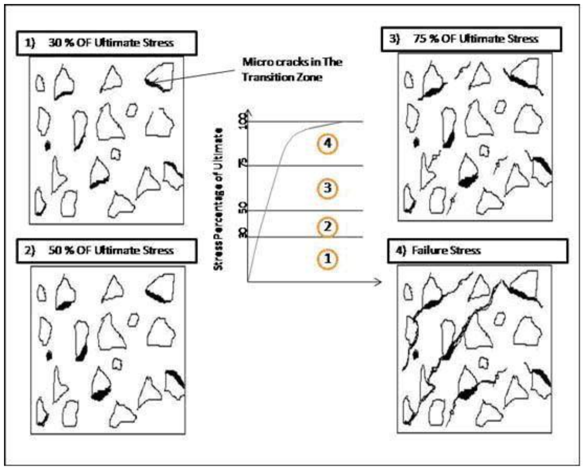

Fig 2: Stress-strain relationship for ordinary concrete

A. Collection and Processing of Recycled Aggregates

Construction and demolition (C&D) waste is collected from demolished concrete structures. The waste concrete is crushed, screened, and cleaned to remove impurities such as steel, wood, plastic, and other unwanted materials. The processed material is then converted into recycled aggregates suitable for concrete production.

B. Material Testing and Mix Design

The recycled aggregates are tested for physical and mechanical properties including specific gravity, water absorption, impact value, abrasion value, and crushing value. Based on the test results, concrete mixes of grades M25, M30, M35, and M40 are designed according to IS 10262:2009 with recycled aggregate replacement levels of 0%, 30%, 70%, and 100%.

C. Casting and Curing of Specimens

The required quantities of cement, fine aggregate, recycled aggregate, water, and admixtures are mixed thoroughly to obtain a uniform concrete mix. Standard cylindrical specimens are cast and allowed to cure in water for 28 days to achieve the desired strength and durability.

D. Testing and Performance Evaluation

After curing, the concrete specimens are tested for compressive strength and modulus of elasticity using appropriate testing equipment. Stress-strain data are recorded and analyzed to determine the stiffness and deformation characteristics of the concrete. The results are compared for different replacement percentages of recycled aggregates to assess the suitability of Recycled Aggregate Concrete for structural applications.

VI. SYSTEM DESIGN

Part I: Material testing: -

1) Aggregate:-

1. Impact Value test.
2. Abrasion Value test.
3. Crushing Value test.
4. Specific Gravity and Water Absorption test.
5. Fineness Modulus test.
6. Shape test (Elongation Index and Flakiness Index)

2) Cement:- Ordinary Portland Cement (OPC 43 Grade) was procured from a local vendor. The test certificate and material properties provided by the manufacturer were used for the study.

3.3 PART II: Mix design as per IS 10262:2009 for Grade M25, M30, M35 and M40:-

Mix design is defined as the process of selecting suitable ingredients of concrete and determining their relative proportions to produce concrete of the required strength, workability and durability at an economical cost. Mix design of concrete will be done using IS:10262:2009 [27]. The design for various grades of concrete for different water-cement ratio are listed in table 1.1

Grade of concrete	Water–cement ratio
M25	0.45
M30	0.45
M35	0.45
M40	0.45

Mix Design:

A- M25 Mix Design as per IS - 10262 – 2009

A-1 Stipulations For Proportioning

a) Grade designation : M25
b) Type of cement : OPC 43 grade conforming to IS 8112
c) Max. nominal size of aggregate : 20 mm
d) Min. cement content : 320kg/m^3
e) Max. water cement ratio : 0.45
f) Workability : 100 mm (slump)
g) Exposure condition : Severe (for reinforced concrete)
h) Method of concrete placing : Manual
i) Degree of supervision : Good
j) Type of aggregate : Crushed angular aggregate
k) Max. cement content : 450 kg/m^3
l) Chemical admixture type : Super plasticizer

A-2 Test Data For Materials

a) Cement used : OPC 43 grade conforming to IS 8112
b) Specific gr. of cement : 3.15
c) Chemical admixture : super plasticizer conforming to IS 9103
d) Specific gravity of:
   1) Coarse aggregate : 2.74
   2) Fine aggregate : 2.74
e) Water absorption :
   1) Coarse aggregate : 0.5 %
   2) Fine aggregate : 1%

A-3 Target Strength For Mix Proportioning

$$f'_{ck} = f_{ck} + 1.65s$$

where,
f'_{ck} = target avg. compressive strength at 28 days,
f_{ck} = characteristic compressive strength at 28 days, and
s = standard deviation.

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From Table no. 1 s= 4 N/mm^2[27].
Therefore, target strength = 25+1.65*4=31.6 N/ mm^2.

A-4 Selection Of Water Cement Ratio

From Table 5 IS 456,maximum w/c ratio= 0.45 [28],
Therefore, 0.45is adopted. Hence ok.

A-5 Selection Of Water Content

From Table 2, maximum water content = 186 liter (for 25 to 50 mm slump range) for 20 mm aggregate.

Estimated water content for 100 mm slump = 186+6% of 186
= 197 liter.

As super plasticizer is used, the water content can be reduced up to 20% and above.

Based on trials with super plasticizer water content reduction of 29 % has been achieved. Hence, the available water content = 197 * 0.71 = 140 liter.

A-6 Calculation Of Cement Content

Water cement ratio = 0.45
Cement content = 140/0.45
= 311.11 kg/m^3

From Table no. 5 of IS 456, minimum cement content for 'severe' exposure condition = 320 kg/m^3 [28].

So , adopt 320 kg/m^3. Hence ok.

A-7 Proportion Of Volume Of Coarse Aggregate And Fine Aggregate Content

From Table 3, volume of CA corresponding to 20 mm size aggregate and FA for w/c ratio of 0.5=0.6.

In present case w/c ratio is 0.4. At the rate of -/+ 0.01 for every +/-0.05 change I w/c ratio. Therefore , Volume of CA for w/c ratio of 0.45 = 0.61.

Volume of FA content = 1- 0.61
= 0.39.

A-8 Mix Calculations

a) Volume of concrete = 1 m^3

b) Volume of cement = mass of content / specific gravity of cement x 1000
= 320 / (3.15 x 1000)
= 0.101 m^3.

c) Volume of water = mass of water / specific gravity of water x 1000
= 140 / 1000
= 0.140 m^3

d) Volume of chemical admixture

(super plasticizer @ 2 % by mass
Of cementitious material) = mass of chemical admixture / specific gravity of admixture x 1000
= 6.4 / (1.145 x1000)
= 0.005 m^3

e) Volume of all in aggregate = [a – (b +c +d)]
= 1-(0.101 + 0.140 + 0.005)
= 0.754 m^3

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f) Mass of coarse aggregate = e x volume of CA x specific gravity of CA x 1000
= 0.754 x 0.61 x 2.74 x 1000
= 1260.23 ≈ 1261 kg.

g) Mass of fine aggregate = e x volume of FA x specific gravity of FA x 1000
= 0.754 x 0.39 x 2.74 x 1000
= 805.72 ≈ 806 kg

A-9 Mix Proportions For M25

Cement = 320 kg/m^3
Fine aggregate = 806 kg
Coarse aggregate = 1261 kg
Water = 140 kg/m^3
Chemical admixture = 6.4 kg/m^3
water cement ratio = 0.45

B- M30 Mix Design as per IS - 10262 – 2009

B-1 Stipulations For Proportioning

a) Grade designation : M30
b) Type of cement : OPC 43 grade conforming to IS 8112
c) Max. nominal size of aggregate : 20 mm
d) Min. cement content : 320kg/m^3
e) Max. water cement ratio : 0.45
f) Workability : 100 mm (slump)
g) Exposure condition : Severe (for reinforced concrete)
h) Method of concrete placing : Manual
i) Degree of supervision : Good
j) Type of aggregate : Crushed angular aggregate
k) Max. cement content : 450 kg/m^3
l) Chemical admixture type : Super plasticizer

B-2 Test Data For Materials

Cement used : OPC 43 grade conforming to IS 8112
Specific gr. of cement : 3.15
Chemical admixture : super plasticizer conforming to IS 9103
Specific gravity of:
1)Coarse aggregate : 2.74
2)Fine aggregate : 2.74
Water absorption :
1)Coarse aggregate : 0.5 %
2)Fine aggregate : 1%

B-3 Target Strength For Mix Proportioning

$$f'_{ck} = f_{ck} + 1.65s$$

where,
f'_{ck} = target avg. compressive strength at 28 days,
f_{ck} = characteristic compressive strength at 28 days, and

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s = standard deviation.
From Table no. 1 s= 5 N/mm^2[27].
Therefore, target strength = 30+1.65*5=38.25N/ mm^2.

B-4 Selection Of Water Cement Ratio
From Table 5 IS 456,maximum w/c ratio= 0.45 [28],
Therefore, 0.45is adopted. Hence ok.

B-5 Selection Of Water Content
From Table 2, maximum water content = 186 liter (for 25 to 50 mm slump range)
for 20 mm aggregate.
Estimated water content for 100 mm slump = 186+6% of 186
= 197 liter.
As super plasticizer is used, the water content can be reduced up to 20% and above.
Based on trials with super plasticizer water content reduction of 29 % has been achieved. Hence, the available water content = 197 * 0.71 = 140 liter.

B-6 Calculation Of Cement Content
Water cement ratio = 0.45
Cement content = 140/0.45
= 311.11 kg/m^3
From Table no. 5 of IS 456, minimum cement content for 'severe' exposure condition
= 320 kg/m^3 [28].
So , adopt 320 kg/m^3. Hence ok.

B-7 Proportion Of Volume Of Coarse Aggregate And Fine Aggregate Content
From Table 3, volume of CA corresponding to 20 mm size aggregate and FA for w/c ratio of 0.5=0.6.
In present case w/c ratio is 0.4. At the rate of -/+ 0.01 for every +/-0.05 change I w/c ratio. Therefore , Volume of CA for w/c ratio of 0.45 = 0.61.
Volume of FA content = 1- 0.61
= 0.39.

B-8 Mix Calculations
a) Volume of concrete = 1 m^3
b) Volume of cement = mass of content / specific gravity of cement x 1000
= 320 / (3.15 x 1000)
= 0.101 m^3.
c) Volume of water = mass of water / specific gravity of water x 1000
= 140 / 1000
= 0.140 m^3
d) Volume of chemical admixture
(super plasticizer @ 2 % by mass
Of cementitious material) = mass of chemical admixture / specific gravity of admixture x 1000
= 6.4 / (1.145 x1000)
= 0.005 m^3
e) Volume of all in aggregate = [a – (b +c +d)]
= 1-(0.101 + 0.140 + 0.005) = 0.754 m^3

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f) Mass of coarse aggregate = e x volume of CA x specific gravity of CA x 1000
= 0.754 x 0.61 x 2.74 x 1000
= 1260.23 ≈ 1261 kg.

g) Mass of fine aggregate = e x volume of FA x specific gravity of FA x 1000
= 0.754 x 0.39 x 2.74 x 1000
= 805.72 ≈ 806 kg

B-9 Mix Proportions For M30

Cement = 320 kg/m^3
Fine aggregate = 806 kg
Coarse aggregate = 1261 kg
Water = 140 kg/m^3
Chemical admixture = 6.4 kg/m^3
water cement ratio = 0.45.

C- M35 Mix Design as per IS - 10262 – 2009

C-1 Stipulations For Proportioning

a) Grade designation : M35
b) Type of cement : OPC 43 grade conforming to IS 8112
c) Max. nominal size of aggregate : 20 mm
d) Min. cement content : 320kg/m^3
e) Max. water cement ratio : 0.45
f) Workability : 100 mm (slump)
g) Exposure condition : Severe (for reinforced concrete)
h) Method of concrete placing : Manual
i) Degree of supervision : Good
j) Type of aggregate : Crushed angular aggregate
k) Max. cement content : 450 kg/m^3
l) Chemical admixture type : Super plasticizer

C-2 Test Data For Materials

Cement used : OPC 43 grade conforming to IS 8112
Specific gr. of cement : 3.15
Chemical admixture : super plasticizer conforming to IS 9103
Specific gravity of:
1)Coarse aggregate : 2.74
2)Fine aggregate : 2.74
Water absorption :
1) Coarse aggregate : 0.5 %
2) Fine aggregate : 1%

C-3 Target Strength For Mix Proportioning

$$f'_{ck} = f_{ck} + 1.65s$$

where,
f'_{ck} = target avg. compressive strength at 28 days,
f_{ck} = characteristic compressive strength at 28 days, and

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s = standard deviation.
From Table no. 1 s= 5 N/mm^2[27].
Therefore, target strength = 35+1.65*5=43.25N/ mm^2.

C-4 Selection Of Water Cement Ratio
From Table 5 IS 456,maximum w/c ratio= 0.45 [28],
Therefore, 0.45is adopted. Hence ok.

VII. RESULTS

For the M25 grade concrete with 0% recycled aggregate replacement (control concrete), the average compressive strength obtained after 28 days of curing was 41.28 N/mm^2. The corresponding cylinder strength was calculated as 37.53 N/mm^2, and the loading stress for modulus of elasticity evaluation was determined as 12.51 N/mm^2. The specimen was subjected to a maximum load of 230 kN during testing.

The stress-strain behavior of the specimen showed an initially linear relationship between applied stress and strain, indicating elastic deformation. As the load increased, strain values gradually increased with corresponding stress values, demonstrating the normal behavior of concrete under compression. The maximum recorded stress during the test was 13.02 N/mm^2, with a corresponding strain of approximately 0.0003.

The experimentally determined Modulus of Elasticity (MOE) for the specimen was found to be 49,366 N/mm^2 (49.37 GPa). The high modulus value indicates good stiffness and resistance to deformation under applied loads. The stress-strain curve exhibited a nearly linear pattern within the elastic range, confirming the satisfactory mechanical performance of the control concrete mix.

From the results, it can be concluded that the M25 control concrete achieved the required strength and exhibited excellent elastic properties. These values serve as a reference for comparing the performance of concrete mixes containing different percentages of recycled aggregates. The reduction or improvement in modulus of elasticity and strength for recycled aggregate concrete can be evaluated relative to this control specimen.

GRADE OF CONCRETE : M25	REPLACEMENT RATIO : 0%	SPECIMEN NO. : 1
COMPRESSIVE STRENGTH : 41.28 N/mm^2	STRENGTH FOR CYLINDER : 0.8 × 41.28 = 37.528 N/mm^2	DATE OF TESTING : 04/03/2026
FOR LOADING STRENGTH : 37.528 / 3 = 12.509 N/mm^2	MAXIMUM LOAD GIVEN : 230 KN	

LOAD (kN)	OUTER DIAL READING	DEFLECTION (mm)	INNER DIAL READING	ACTUAL DEFLECTION (mm)	GAUGE LENGTH (mm)	AREA (mm^2)	STRAIN	STRESS (N/mm^2)	RESULT
9	0	0	0	0	150	17671	0	0.509	STRAIN
20	0	0	0	0	150	17671	0	1.132	0.00025
30	0	0	0	0	150	17671	0	1.698	
40	0	0	0	0	150	17671	0	2.264	
50	0	0	0	0	150	17671	0	2.829	STRESS
60	0	0	0	0	150	17671	0	3.395	12.506
70	0	0	0	0	150	17671	0	3.961	
80	0.2	0.002	0	0.001	150	17671	7E-06	4.527	
80	0.8	0.008	0	0.004	150	17671	3E-05	5.093	MOE
100	1	0.01	0	0.005	150	17671	3E-05	5.659	49366
110	1.4	0.014	0	0.007	150	17671	5E-05	6.225	
120	1.6	0.016	0	0.008	150	17671	5E-05	6.791	
130	2.4	0.024	0	0.012	150	17671	8E-05	7.356	
140	2.8	0.028	0	0.014	150	17671	9E-05	7.922	
150	3.4	0.034	0	0.017	150	17671	0.0001	8.488	
160	3.8	0.038	0	0.019	150	17671	0.0001	9.054	
170	4.4	0.044	0	0.022	150	17671	0.0001	9.620	
180	5	0.05	0	0.025	150	17671	0.0002	10.19	
190	5.6	0.056	0	0.028	150	17671	0.0002	10.75	
200	6	0.06	0	0.030	150	17671	0.0002	11.32	
210	6.6	0.066	0	0.033	150	17671	0.0002	11.88	
220	7.2	0.072	0	0.036	150	17671	0.0002	12.45	
230	7.6	0.076	0	0.038	150	17671	0.0003	13.02	

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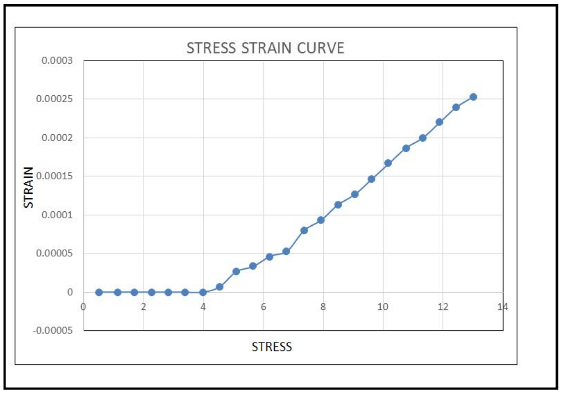

Fig 3: Graph 1

VIII. CONCLUSION

This study investigated the modulus of elasticity and strength characteristics of Recycled Aggregate Concrete (RAC) using different replacement levels of recycled aggregates. The experimental results showed that recycled aggregates possess higher water absorption and lower density compared to conventional aggregates. As the percentage of recycled aggregate increased, a gradual reduction in compressive strength and modulus of elasticity was observed due to the presence of adhered mortar and weaker interfacial bonding.

However, concrete containing moderate percentages of recycled aggregates exhibited satisfactory mechanical performance and can be effectively used for structural applications. The experimentally determined modulus of elasticity values showed a strong correlation with compressive strength, confirming that RAC can provide adequate stiffness when properly designed. The use of recycled aggregates also contributes to sustainable construction by reducing construction and demolition waste and conserving natural aggregate resources. Therefore, Recycled Aggregate Concrete is a viable and environmentally friendly alternative to conventional concrete.

IX. FUTURE SCOPE

- Investigate the long-term durability properties of RAC under different environmental conditions.
- Study the effect of supplementary cementitious materials such as fly ash, silica fume, and GGBS on the modulus of elasticity of RAC.
- Evaluate the performance of RAC in reinforced concrete structural elements such as beams, columns, and slabs.
- Develop advanced treatment methods for recycled aggregates to improve their quality and mechanical properties.
- Analyze the behavior of RAC under cyclic, dynamic, and seismic loading conditions.
- Establish predictive models using artificial intelligence and machine learning for estimating the modulus of elasticity of RAC.
- Conduct large-scale field applications to assess the practical feasibility of RAC in sustainable infrastructure projects.
- Develop standardized guidelines and design recommendations for the widespread use of recycled aggregate concrete in construction industries.

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