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Research Article

Feasibility of Modified Recycled Coarse Aggregates with Graphene Oxide Powder as Sustainable Structural Concrete: An Experimental Study for Agra, UP, India.

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ABSTRACT

Introduction: In the face of growing environmental concerns related to construction and demolition waste management, and the diminishing availability of fresh coarse aggregates, the reuse of recycled coarse aggregates poses both challenges and opportunities.

Objectives: This study investigates the potential of utilizing modified recycled coarse aggregates collected from a site at agra and from lab waste, UP in combination with graphene oxide as a sustainable substitute for fresh coarse aggregates in concrete production. A series of experimental investigations were conducted to evaluate the feasibility and performance of modified recycled coarse aggregates concrete mixtures with and without Graphene oxide powder.

Methods: Tests included assessments of compressive strength, modulus of elasticity, and poisons ratio after 28 days of curing. Various levels of replacement (e.g., 0%, 25%, 50%, 75%, and 100%) and treatment methods (e.g., thermal, mechanical, combined) were applied with and without graphene.

Results: The results revealed that the inclusion of graphene oxide powder with mechanical plus thermal modified recycled coarse aggregate significantly improved the compressive strength, with optimal performance observed at 52 % replacement level. Additional enhancements were observed in modulus of elasticity indicating better structural behavior.

Conclusions: These findings support the potential of using modified RCA with GO as a viable solution for sustainable, high-performance concrete in structural applications. It can offer an effective and environmentally friendly solution for construction and demolition waste management.

Keywords: Recycled Coarse Aggregate, Sustainable, Graphene Oxide Powder, Construction and demolition, Thermal and mechanical treatment, Adhered mortar.

INTRODUCTION

Currently, it is estimated that 11.5 billion tons of concrete are used annually worldwide. Projections suggest a significant increase in this figure, with estimates indicating that by the year 2050, global concrete consumption could surge to approximately 18 billion tons annually [1]. In India, construction and demolition waste (C&DW) is generated at an average annual rate of around 30 million tons. This account for around 20% to 25% of the total Municipal Solid Waste (MSW) produced in the country [2]. The utilization of recycled concrete aggregate (RCA) is steadily growing worldwide; however, the focus remains on optimizing its incorporation into structural concrete applications. Several studies have demonstrated that the presence of adhered mortar on recycled concrete aggregate (RCA) adversely impacts the properties of concrete. [3], [4], [5]. The presence of adhered mortar on recycled concrete aggregate (RCA) has been shown to delay or reduce the compressive strength of the concrete mix. Adhered mortar on RCA make an interfacial transition zone (ITZ) as shown in Fig 1. This ITZ increases the void ratio; water content gets high since the water absorption of RCA becomes high [6], [7].

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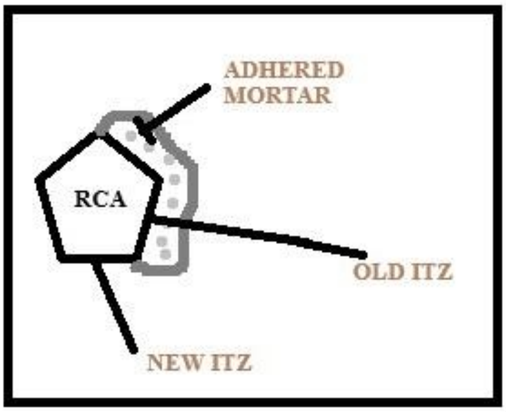

Fig 1. Schematic of RCA

Singh et al. [8] has investigated the application of recycled concrete aggregate (RCA) for non-structural concrete purposes. Shuvo dip data et al. [9] experimentally evaluated the properties of RCA by destructive tests and non-destructive tests and generated analytical relationships between them to understand the behavior of RAC. X Liu et al. [10] attempted to evaluate the physical and mechanical properties of structural concrete using a unified elastic modulus model of Recycled Aggregate Concrete (RAC). Gebremariam et al. [11] emphasized various factors influencing Recycled Concrete Aggregate (RCA) properties, encompassing parent concrete composition, strength, and aggregate grading, alongside crusher type, number of crushing stages, RCA particle size, and the sequence of size reduction. According to Ouyang et al. [12], Pretreatment methods have the potential to bring about a significant reduction in mercury intrusion porosity, averaging a decrease of 41.3%, as well as a decrease in water absorption, averaging 24.5%, for Recycled Concrete Aggregate (RCA), while also significantly enhancing its mechanical properties [16]. Wang et al. [13] experimental findings demonstrate that treated coarse Recycled Concrete Aggregate (RCA) improves the mechanical strength and permeability properties of Recycled Aggregate Concrete (RAC). Nevertheless, numerous countries are actively engaged in extensive research aimed at assessing the performance of RCAs in structural applications with addition of nano particles too.

Research has examined the implementation of graphene oxide (GO) in concrete during the use of recycled coarse aggregates (RCA) to strengthen both mechanical behavior and durability characteristics positively. Research shows GO addition to RCA-based concrete enhances the compressive and tensile strengths because it strengthens the bond between cement matrix and aggregate particles.(14).The addition of GO as a nanofiller helps strengthen the interfacial transition zone (ITZ) while decreasing porosity levels and improving microstructural refinement of concrete backgrounds.(15).Additionally, investigations have demonstrated that RCA replacement with GO modification enhances the load-bearing capacity of concrete, making it a viable option for sustainable construction((14).Scientific research establishes that the optimal amount of GO in RCA concrete should be between 0.05% and 0.1% by weight of the binder for optimal strength combined with durability and workability properties(15). The incorporation of GO in RCA concrete not only contributes to sustainable waste management by reducing dependency on natural aggregates but also improves environmental resilience, making it suitable for long-term applications.

The effective utilization of recycled coarse aggregates is vital for reducing environmental degradation caused by excessive extraction of natural materials and unmanaged construction waste (CDW Strategy, 2018; Circular Economy Report, 2021). As highlighted by national policy frameworks, integrating RCA into construction practices promotes circularity, conserves resources, and supports sustainable urban development (CAG Report, 2022).This research fills the void by performing experiments that evaluate graphene oxide powder together with modified RCA on concrete strength characteristics. The research evaluates the suitability of this modified version of RCAC for use as a structural material in sustainable construction projects located in Agra, Uttar Pradesh, India. Lab evaluation of this study delivered essential knowledge about proper RCA treatment methods for strengthening its performance and make the environment sustainable.

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OBJECTIVES

In this experimental study, the effect of modified recycled coarse aggregate concrete (RCAC) with graphene oxide (GO) powder was investigated to assess its feasibility as a structural concrete material. Recycled Concrete Aggregates (RCA) were sourced from two distinct locations: demolition waste from an old structure and controlled laboratory sources. The study focused on evaluating the impact of varying RCA percentages (0%, 25%, 50%, 75%, and 100%) on the mechanical properties of concrete, specifically compressive strength, modulus of elasticity, and Poisson's ratio at 28 days of curing. The RCA was subjected to three modification techniques—Thermal Modification (TM), Mechanical Modification (MM), and a combination of both (TM+MM)—to improve its performance and address the inherent weaknesses compared to natural aggregates. Additionally, graphene oxide was incorporated at a fixed dosage of 0.05% by weight of cement to further enhance the mechanical properties and durability of the concrete. The Slump: 80–100 mm for mix cases. The experimental program was designed to evaluate the effects of RCA content, modification treatments, and graphene addition on the concrete's properties. Concrete mixes were prepared with varying RCA percentages, sourced from both the old structure and the laboratory, and with or without graphene oxide. Concrete mix designs of M30 grade were conducted as per IS 456 (2000) and IS 10262 (2019). Concrete samples were molded and cured for a period of 28 days, and the mechanical characteristics—compressive strength following IS 516 (1959) standards, modulus of elasticity according to ASTM C 469:2002, and Poisson's ratio were tested and compared. The findings were analyzed to assess the influence of RCA replacement, modification treatments, and graphene oxide on concrete performance, with results compared against control mixes and non-modified RCAC. This methodology provided valuable insights into the potential of using modified RCAC with graphene oxide as a sustainable material for structural concrete, particularly in regions like Agra, Uttar Pradesh, India has a growing need for sustainable construction options.

METHODS AND MATERIALS USED

This section of the research paper outlines the materials and techniques employed to conduct the study.

Cement

53 Grade Ordinary Portland Cement (OPC) is employed as the concrete binder, adhering to the guidelines set forth in IS 12269: 2013 [25]. Fineness of OPC 53 Grade cement is 225 (m^2/kg).

Table 1: Physical Characteristics of Ordinary Portland cement 53 Grade

SI. No	Tests	IS CODE	Results
1	Specific Gravity	IS4031 (Part11) 1988	3.14
2	Setting Time (initial)	IS 12269: 2013	105 min
3	Setting time (Final)	IS 12269: 2013	256 min

Fresh Coarse Aggregate(FCA) & Recycled Coarse Aggregate(RCA)

The maximum sizes of 20 mm Fresh Coarse Aggregate (FCA) & 16 mm Recycled Concrete Aggregate (RCA) were assessed via sieve analysis following the guidelines stipulated in IS 383:1970 Code Specifications. It's noteworthy that all coarse aggregates employed in the investigation possess a size smaller than 16 mm and greater than 5 mm obtained from C&D waste after crushing.

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Table 2: Physical Characteristics of FCA & RCA

SI. No	Physical Characteristics	IS CODES	FCA	Old Structure RCA (Unmodified)	Laboratory RCA (Unmodified)
1	Water Absorption (%)	IS 2386-1963 (Part iii)	0.64	9.45	6.54
2	Crushing value (%)	IS 2386-1963 (Part iv)	23	41	30
3	Specific Gravity	IS 2386-1963 (Part iv)	2.79	2.4	2.47
4	Impact Value (%)	IS 2386-1963 (Part iv)	23	42	34
5	Abrasion (%)	IS 2386-1963 (Part iv)	25	45	42

Table 3 Sieve Analysis Fresh Coarse Aggregate

Sieve Size (mm)	% Weight Passing	IS 383:2016, Code Specification	GRADATION
40	100	100	Graded Aggregate of Nominal size 20 mm
20	97	90-100	
16	75	-	
12.5	55	-	
10	30	25-55	
4.75	0	0-10	

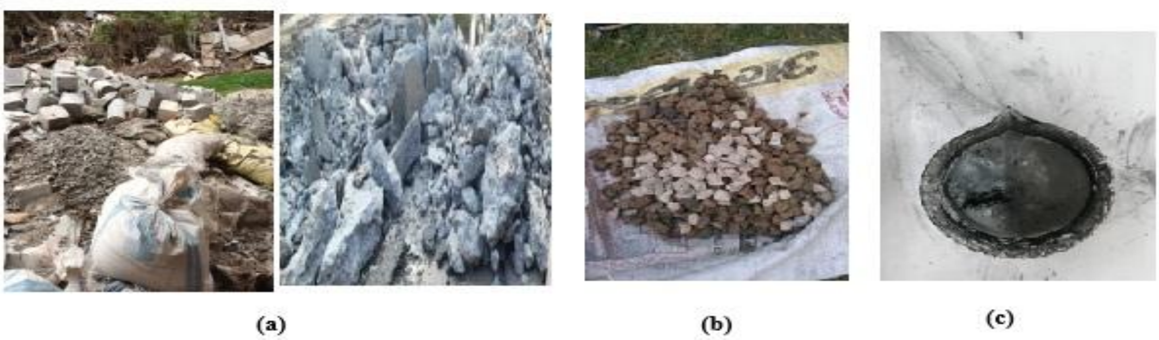

Fig 2: Photos (a) C&D waste (b) Crushed C&D Waste (c) Graphene used

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Natural Fine Aggregate (NFA)

Table 4: Sieve Analysis of Natural Fine Aggregate

Sieve Size (mm)	Percentage Passing	Percentage Passing for Grading Zone II as per IS: 383-2016	Natural Fine Aggregate Grading Zone
10	100	100	Grading Zone II
4.75	93	90-100	
2.36	78	75-100	
1.18	64	55-90	
0.6	48	35-59	
0.3	22	8-30	
0.15	0	0-10	

Table 5: Physical Properties of Natural Fine Aggregate (NFA)

S.No	Physical Properties	IS CODE	Results (%)
1	Water Absorption	IS 2386-1963 (Part iii)	1.2
2	Specific Gravity	IS 2386-1963 (Part iv)	2.59

Fig 3 : RCA waste collecting location map

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Graphene

Graphene oxide was availed commercially. Shilpent Reduced Graphene Oxide is used in the study, used to enhance the mechanical properties of concrete. This graphene oxide, known for its excellent reinforcement potential, was added at a dosage of 0.05% by weight of cement in the mix design having bulk density 0.5g/cc, surface area- 110-250m²/g.

Superplasticizer

A high-grade naphthalene-based superplasticizer (Ceraplast 300) as per IS 9103 incorporated at 2.5% by weight of cement to enhance the workability and flowability of the concrete mixes & adjusted as per situation. Specific gravity of ceraplast 300 is 1.23 g/cc. Its addition aimed to mitigate the reduced workability caused by the high water absorption of treated recycled aggregates.

Water

According to IS guidelines, concrete was mixed and cured using potable water. It contained no toxic materials that would have impacted the cement's setting and strength development.

Modification of RCA

As mentioned previously, recycled coarse aggregate often contains adhered mortar, reducing the physical and mechanical properties of concrete. To address this, modifications have been made in the current research. After collecting recycled aggregate and investigating its properties as shown in Table 2, the total volume is divided into four equal batches. The first batch is classified as non-modified recycled aggregate (NM), while the second batch undergoes mechanical modification (MM) [26]. The third batch is subjected to mechanical plus thermal treatment (MTM) [27], and the fourth batch undergoes thermal treatment (TM) [28]. These batches are sourced from locations L1 & S1 as mentioned earlier.

Mechanical modification

During this treatment process, samples from S1 and L1 are loaded into the drum of a Los Angeles machine. The drum undergoes rotations, with 200 rotations performed initially, followed by 300 rotations, each lasting 12 minutes. These rotations are conducted both with the addition of a single steel ball. After that, the aggregates are sieved and the mortar that has adhered is removed. This sieving process yields mechanically modified recycled coarse aggregates, designated as MMS1 and MML1, corresponding to the respective source samples. This method facilitates the removal of adhered mortar from the aggregates, resulting in mechanically modified recycled coarse aggregates suitable for various construction applications.

Thermal modification

The thermal treatment process is applied to aggregates obtained from particles S1 and L1 to eliminate adhered mortar. This involves subjecting the aggregates to laboratory oven with gradual increment in temperatures of 110°C, 210°C, and 310°C in an oven for 3 hours. Following this, the heated aggregates are allowed to put in water at room temperature. The sudden change in temperature removes the adhered mortar, resulting in the formation of thermally treated recycled concrete aggregates (RCA)[29]. These treated aggregates are denoted as three samples: TMS1 and TML1, corresponding to the respective source particles. This method effectively enhances the suitability of the aggregates for reuse in various construction applications by eliminating adhered mortar.

Mechanical plus thermal modification

In the mechanical plus thermal treatment, both processes are sequentially applied, one after the other, to the aggregates obtained from two distinct sources. Upon completion of this integrated treatment, the resultant aggregates are designated as MTMS1 and MTML1, corresponding to their specific origins. This approach entails initially subjecting the aggregates to mechanical treatment, followed by thermal treatment, aiming to enhance their properties. The thermal treatment involves heating the aggregates to a temperature of 210 degrees Celsius for a duration of 5 hours. Additionally, during the mechanical treatment, the drum undergoes 300 rotations with the

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inclusion of a single steel ball. The durability of material is tested by crushing and Los Angeles abrasion test. The RCA has higher for crushing and abrasion than natural aggregates due to adhered mortar present on the surface of RCA.

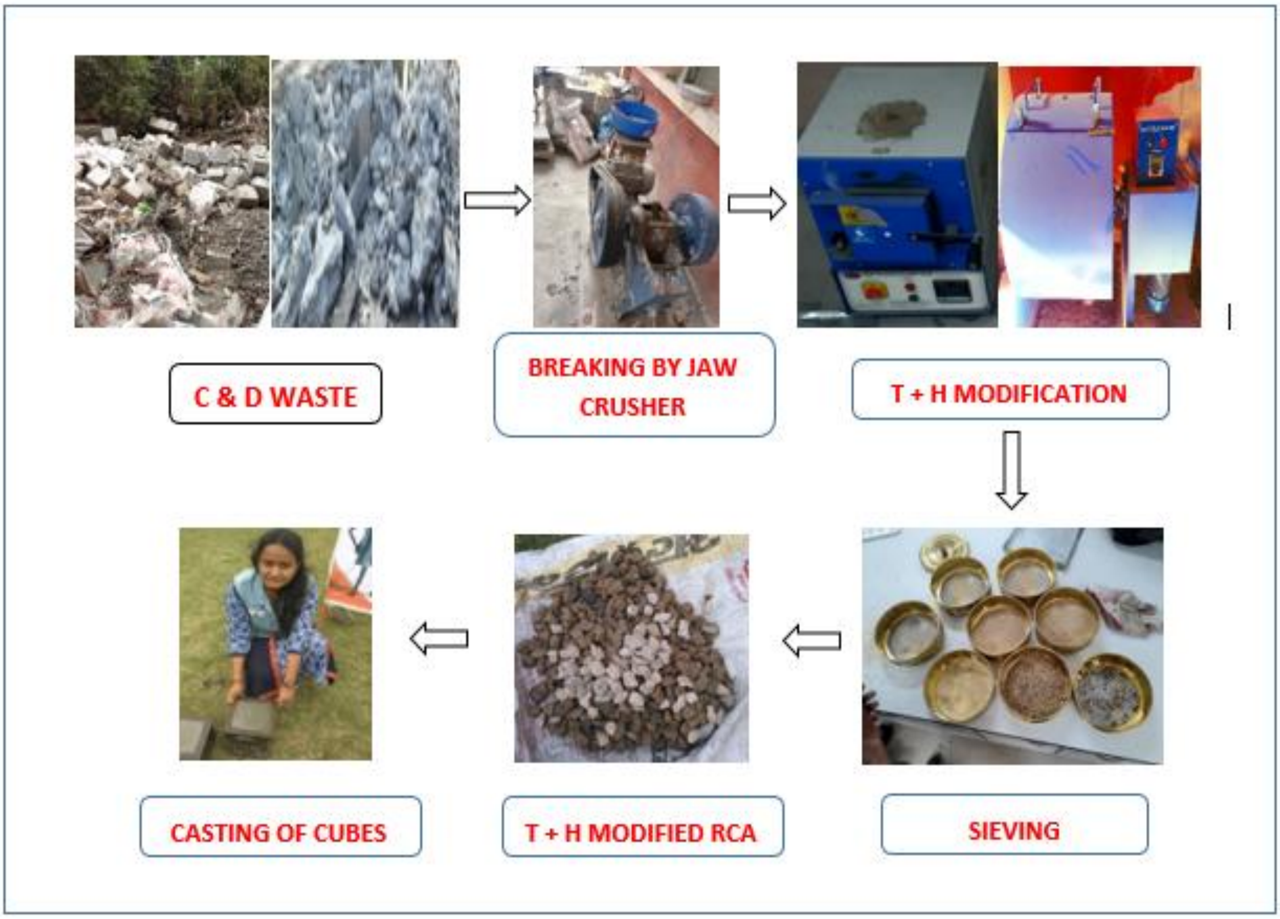

FIG 4: Flowchart for RCA recycling & modifications thermal plus mechanical

RESULTS AND DISCUSSION

EFFECT OF GRAPHENE AND THERMAL PLUS MECHANICAL MODIFIED RCA ON COMPRESSIVE STRENGTH OF CONCRETE

The compressive strength results reveal the influence of varying RCA replacement levels and the effectiveness of graphene oxide in enhancing concrete performance as shown in fig 5. As the percentage of untreated RCA increases, a gradual decline in compressive strength is observed due to the presence of adhered mortar and weak interfacial bonding. However, significant improvements are noted when RCA is subjected to thermal and mechanical treatment. The addition of graphene oxide further enhances strength by refining the concrete microstructure and improving the interfacial transition zone (ITZ). The following graph and data illustrate the variation in compressive strength across different mixes, highlighting the positive impact of both RCA modification and graphene incorporation.

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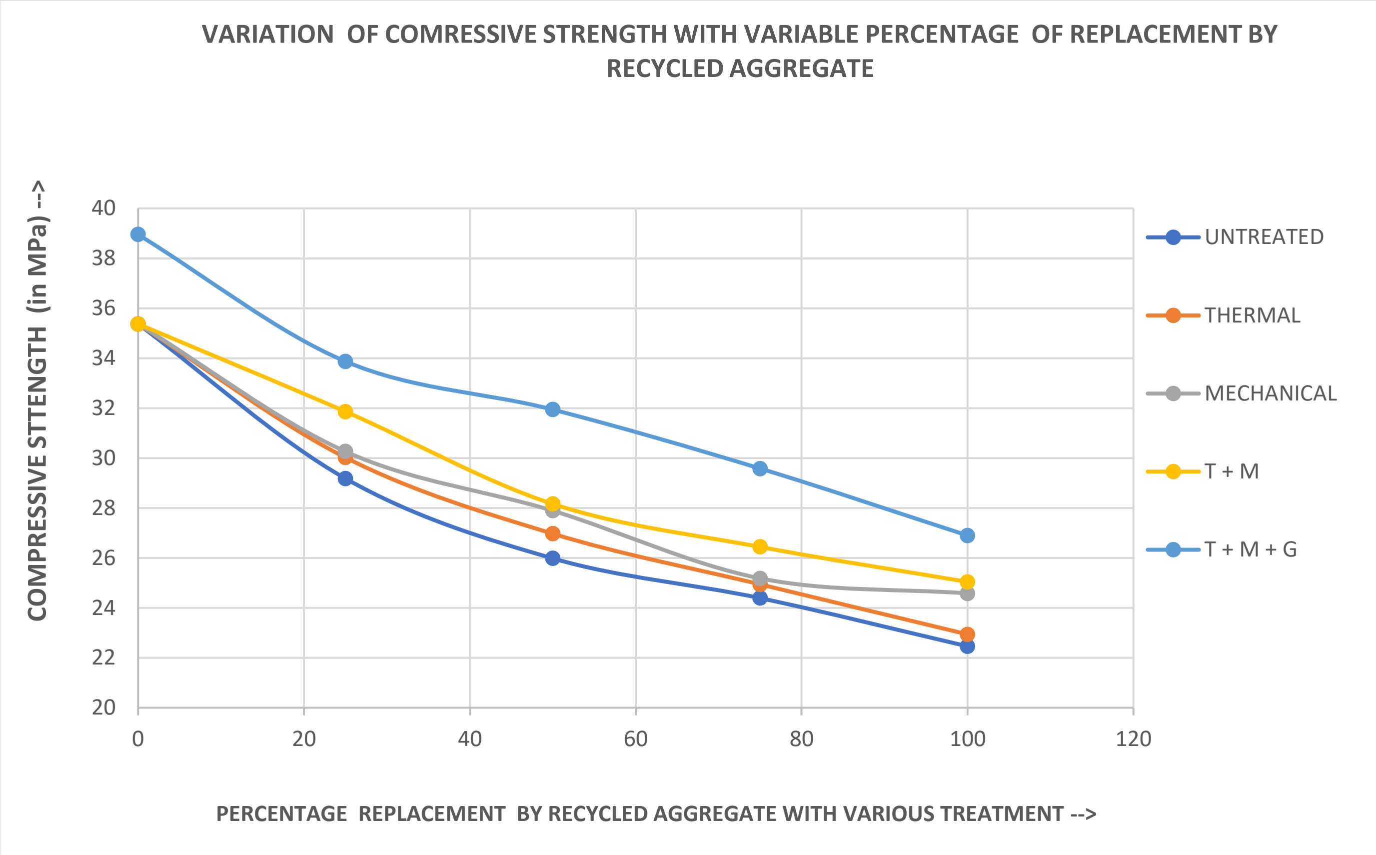

FIG 5: Variation of compressive strength with variable percentage replacement by recycled aggregate

UNTREATED COMPRESSIVE STRENGTH		
0 % RCA (Fresh Aggregtare)	0	35.37
25 % RCA UNTREATED	25	29.18
50 % RCA UNTREATED	50	25.98
75 % RCA UNTREATED	75	24.39
100 % RCA UNTREATED	100	22.46

THERMAL MODIFIED COMPRESSIVE STRENGTH		
0 % RCA (Fresh Aggregtare)	0	35.37
25% RCA Thermal	25	30.02
50 % RCA Thermal	50	26.97
75% RCA Thermal	75	24.94
100% RCA Thermal	100	22.94

MECHANICAL MODIFIED COMPRESSIVE STRENGTH		
0 % RCA (Fresh Aggregtare)	0	35.37
25% RCA Mechanical	25	30.26
50% RCA Mechanical	50	27.89
75% RCA Mechanical	75	25.18
100% RCA Mechanical	100	24.58

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THERMAL PLUS MECHANICAL MODIFIED COMPRESSIVE STRENGTH		
0 % RCA (Fresh Aggregtare)	0	35.37
25% RCA (Thermal + Mechanical Treated)	25	31.86
50% RCA + Graphene (Thermal + Mechanical Treated)	50	28.16
75% RCA + Graphene (Thermal + Mechanical Treated)	75	26.44
100% RCA + Graphene (Thermal + Mechanical Treated)	100	25.04

THERMAL PLUS MECHANICAL MODIFIED WITH GRAPHENE COMPRESSIVE STRENGTH		
0 % RCA (Fresh Aggregtare)	0	38.95
25% RCA (Thermal + Mechanical Treated)	25	33.87
50% RCA + Graphene (Thermal + Mechanical Treated)	50	31.94
75% RCA + Graphene (Thermal + Mechanical Treated)	75	29.58
100% RCA + Graphene (Thermal + Mechanical Treated)	100	26.92

INFLUENCE OF GRAPHENE AND THERMAL PLUS MECHANICAL MODIFIED RCA ON MOE OF CONCRETE

The modulus of elasticity (MOE) is a critical parameter that reflects the stiffness and deformation behavior of concrete under load. As with compressive strength, an increasing percentage of untreated RCA leads to a reduction in MOE due to the weaker and more porous nature of recycled aggregates as shown in fig 6. However, the application of thermal and mechanical treatment enhances the quality of RCA, resulting in improved stiffness. The addition of graphene oxide further contributes to this improvement by enhancing the microstructure and reducing internal voids. The following results illustrate the variation in MOE with different RCA replacement levels and clearly demonstrate the beneficial effect of combining RCA treatment with graphene incorporation.

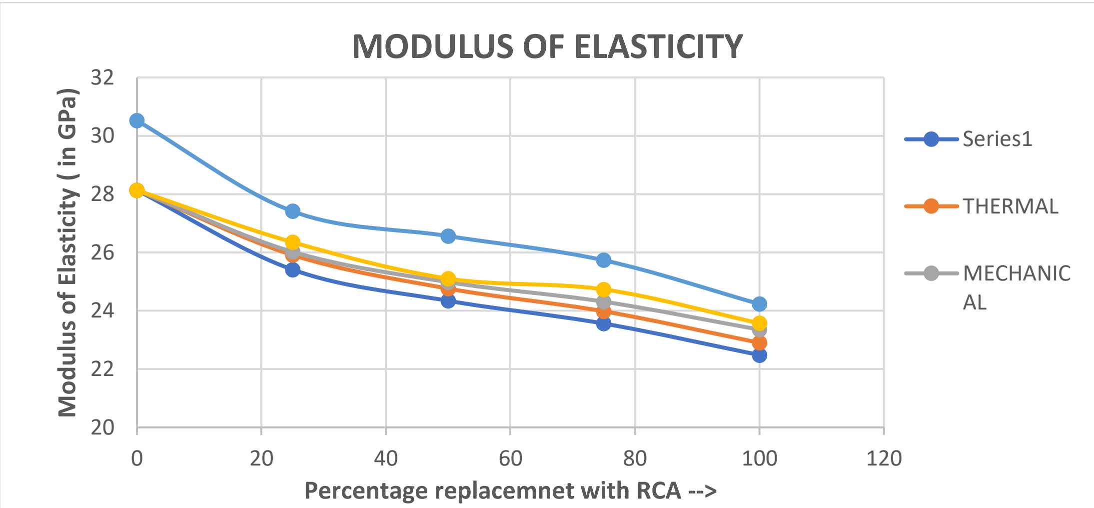

FIG 6: Variation of modulus of elasticity with variable percentage replacement by recycled aggregate

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UNTREATED MOE		
0 % RCA (Fresh Aggregtare)	0	28.13
25 % RCA UNTREATED	25	25.41
50 % RCA UNTREATED	50	24.34
75 % RCA UNTREATED	75	23.56
100 % RCA UNTREATED	100	22.48

THERMAL MODIFIED MOE		
0 % RCA (Fresh Aggregtare)	0	28.13
25% RCA Thermal	25	25.91
50 % RCA Thermal	50	24.76
75% RCA Thermal	75	23.98
100% RCA Thermal	100	22.9

MECHANICAL MODIFIED MOE		
0 % RCA (Fresh Aggregtare)	0	28.13
25% RCA Mechanical	25	26.02
50% RCA Mechanical	50	24.98
75% RCA Mechanical	75	24.31
100% RCA Mechanical	100	23.35

THERMAL PLUS MECHANICAL MODIFIED MOE		
0 % RCA (Fresh Aggregtare)	0	28.13
25% RCA (Thermal + Mechanical Treated)	25	26.35
50% RCA + Graphene (Thermal + Mechanical Treated)	50	25.1
75% RCA + Graphene (Thermal + Mechanical Treated)	75	24.73
100% RCA + Graphene (Thermal + Mechanical Treated)	100	23.57

THERMAL PLUS MECHANICAL MODIFIED WITH GRAPHENE MOE		
0 % RCA (Fresh Aggregtare)	0	30.52
25% RCA (Thermal + Mechanical Treated)	25	27.41
50% RCA + Graphene (Thermal + Mechanical Treated)	50	26.56
75% RCA + Graphene (Thermal + Mechanical Treated)	75	25.73
100% RCA + Graphene (Thermal + Mechanical Treated)	100	24.23

EFFECT OF GRAPHENE AND THERMAL PLUS MECHANICAL MODIFIED RCA ON POISONS RATIO OF CONCRETE

Poisson's ratio provides insight into the lateral deformation behavior of concrete under axial loading and is influenced by the internal structure and bond quality of the mix. As the percentage of untreated RCA increases, a gradual rise in Poisson's ratio is observed, indicating higher lateral strain and a less compact internal structure as shown in fig 7. Treatment of RCA through thermal and mechanical methods reduces this effect by improving aggregate quality and interfacial bonding. Furthermore, the incorporation of graphene oxide leads to a noticeable decrease in Poisson's ratio across all mixes, suggesting improved microstructural integrity and reduced deformability. The following results demonstrate the variation in Poisson's ratio with different RCA contents and confirm the positive impact of graphene and RCA treatment.

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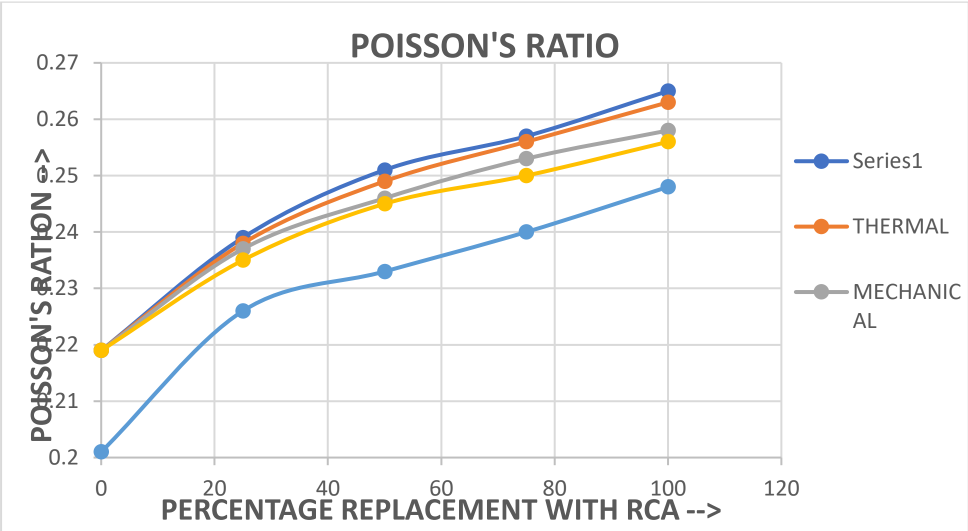

FIG 7: Variation of Poisson's Ratio with variable percentage replacement by recycled aggregate

UNTREATED POISSON'S RATIO		
0 % RCA (Fresh Aggregtare)	0	0.219
25 % RCA UNTREATED	25	0.239
50 % RCA UNTREATED	50	0.251
75 % RCA UNTREATED	75	0.257
100 % RCA UNTREATED	100	0.265

THERMAL MODIFIED POISSON'S RATIO		
0 % RCA (Fresh Aggregtare)	0	0.219
25% RCA Thermal	25	0.238
50 % RCA Thermal	50	0.249
75% RCA Thermal	75	0.256
100% RCA Thermal	100	0.263

MECHANICAL MODIFIED POISSON'S RATIO		
0 % RCA (Fresh Aggregtare)	0	0.219
25% RCA Mechanical	25	0.237
50% RCA Mechanical	50	0.246
75% RCA Mechanical	75	0.253
100% RCA Mechanical	100	0.258

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THERMAL PLUS MECHANICAL MODIFIED POISSON'S RATIO		
0 % RCA (Fresh Aggregtare)	0	0.219
25% RCA (Thermal + Mechanical Treated)	25	0.235
50% RCA + Graphene (Thermal + Mechanical Treated)	50	0.245
75% RCA + Graphene (Thermal + Mechanical Treated)	75	0.25
100% RCA + Graphene (Thermal + Mechanical Treated)	100	0.256

THERMAL PLUS MECHANICAL MODIFIED WITH GRAPHENE POISSON'S RATIO		
0 % RCA (Fresh Aggregtare)	0	0.201
25% RCA (Thermal + Mechanical Treated)	25	0.226
50% RCA + Graphene (Thermal + Mechanical Treated)	50	0.233
75% RCA + Graphene (Thermal + Mechanical Treated)	75	0.24
100% RCA + Graphene (Thermal + Mechanical Treated)	100	0.248

CONCLUSION

1. A significant increase in compressive strength was observed with 50% replacement level of RCA with thermal and mechanical treatment combined with graphene. It shows the positive effect of graphene, to increase the mechanical properties of concrete with sustainability.

2. Modification of recycled coarse aggregates by thermal plus mechanical process under a temperature of 210 degrees Celsius for a duration of 5 hours, with 300 roations by 1 steel ball, gives promising aggregates as per natural aggregates by reducing old adhered mortar from RCA.

3. Workability maintained at all replacement values, shows effectiveness of using graphene with RCA.

4. The modulus of elasticity of concrete increased with the inclusion of graphene oxide and thermally plus mechanically modified RCA, with the highest MOE recorded at 0% RCA with graphene. However, even at 50% replacement, the MOE remained significantly higher than that of untreated RCA mixes, indicating improved behavior of the concrete.

5. The addition of graphene oxide reduced the Poisson's ratio across all replacement levels, with the lowest value recorded at 0% RCA with graphene. This reduction signifies enhanced resistance to lateral deformation, suggesting a denser and more stable microstructure in graphene-modified concrete.

In conclusion, the use of graphene oxide in conjunction with thermally and mechanically treated recycled aggregates not only enhances the mechanical performance of concrete but also promotes sustainable construction practices by effectively utilizing construction and demolition waste. This makes the developed concrete mix a promising alternative for structural applications, especially in regions with high demand for eco-friendly building materials like Agra, Uttar Pradesh.

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