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Research Article

A Comparison of Treated Recycled Aggregate Concrete, Natural Aggregate, and Recycled Aggregate Concrete Using Improved RCA Surface Treatment

Neha[1], Dr. S. Mishra[2], Dr. Rajeev Goel[3]
[1]*Research Scholar, Department of Civil Engineering, North Eastern Regional Institute of Science & Technology, Nirjuli, India,791109, erneha25@gmail.com*
[2]*Professor, Department of Civil Engineering, North Eastern Regional Institute of Science & Technology, Nirjuli, India, 791109, sudishtmishra@gmail.com*
[3]*Chief Scientist and Head, Bridge Engineering and Structures Division, CSIR-Central Road Research Institute, New Delhi, India-110025 India, rgoel.crri@nic.in*

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ABSTRACT

Reuse of demolition waste is get accelerated due to rising demand for sustainable construction. This study is based on an innovative fiber-coating method involving rice husk ash and styrene the concrete prepared with natural aggregate (NA), recycled concrete aggregate (RCA) and treated recycled concrete aggregate (TRCA) for investigation of their performance .an assessments made on physical, mechanical properties.

Keywords: Recycled Aggregate Concrete, Treated RCA, Natural Fiber Coating, Water Absorption, Mechanical Properties, Sustainability.

1. INTRODUCTION

Due to versatile durable and relative cost effectiveness property made concrete globally a most widely used construction material.natural aggregate such as gravel and crushed stones extracted from mining operations are heavily used in traditional concrete. Depletion of natural resources and severe environmental degradation are the result of increasing demand for concrete fueled by rapid urbanaization and infrastructure development. Climate change is also exacerbated by the substantial carbon dioxide emissions from the production of Portland cement, a crucial binder in concrete. Every year, a significant amount of garbage is produced by the construction and demolition (C&D) industry. By minimizing landfill disposal and preserving natural aggregate resources, recycling this trash to create recycled concrete aggregate (RCA) provides a sustainable option. In contrast to natural aggregates, RCA is made from crushed concrete debris that contains old cement paste and attached mortar, giving it a highly porous structure. As a result, RCA-made concrete usually has worse durability qualities, more water absorption, and lower mechanical strength than traditional concrete. A number of techniques, including the mechanical removal of connected mortar, acid treatments, thermal processing, and the addition of pozzolanic materials, have been used in previous studies to improve the qualities of RCA. Even though there have been some advancements, these techniques frequently come with extra expenses, difficult steps, or environmental issues related to the use of chemicals. A viable substitute in this regard is the surface treatment of RCA with natural fibers and polymeric coatings. Natural fibers with superior pozzolanic activity, such as rice husk ash (RHA), are economical and environment friendly. They can be mixed with polymeric binders such as styrene monomer to produce a composite slurry that covers RCA particles densely, closing pores and micro cracks and enhancing resistance to alkali attack and water intrusion. The current study expands on a patented technique for treating RCA by applying a mixture of styrene monomer, rice husk ash, and Ordinary Portland Cement (OPC) to its surface. Developing a Treated Recycled Concrete Aggregate (TRCA) that can produce concrete with much less water absorption while preserving or even improving mechanical performance is the goal of this treatment. The extensive experimental analysis presented in this paper compares conventional concrete constructed with

- natural aggregates (NA),

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- concrete that contains untreated RCA, and
- Treated RCA (TRCA)-produced concrete.

Indian Standards were used to analyze the essential aggregate properties, behavior of fresh concrete and the characteristics of hardened concrete. This comparative study illustrates the efficacy of the suggested treatment method and shows how it may be used in sustainable building.

2. LITERATURE REVIEW

2.1. Mechanical Cleaning: Mechanical cleaning methods, such as abrasion and water washing, have been employed to remove the attached mortar and reduce s the porosity of RCA.. These methods improves the physical properties, including water absorption, but they have limitations, such as high energy consumption, damage to aggregate size, and inconsistent results (Poon et al., 2004).

2.2. Better Mechanical and Durability Properties: According to recent research, fiber coatings like carbon or polypropylene can greatly increases tensile strength, resistance to cracking, and thermal stability of RCA(Ghazali et al., 2023). These fibers improve the overall performance of concrete built with RCA by reducing water absorption and bridging micro cracks in the aggregate surface.

2.3. Sustainability Benefits: When compared to chemical treatments, fiber-coating processes are more eco-friendly. Vegetable fibers and waste plastic fibers are two examples of sustainable sources from which many of the fibers used are recycled. Additionally, fiber coating can be a closed-loop process to promotes the circular economy by lowering waste production (Zhao et al., 2024).

2.4. Fiber-Coating vs Conventional Techniques: In contrast to conventional techniques, fiber-coating offers a more consistent and long-lasting surface improvement for the RCA. Additionally, fibers strengthen the RCA-new mortar interfacial bond without adversely affecting aggregate size or shape (Amin et al., 2023). Fiber-coating is therefore a potentially revolutionary method for enhancing the performance and sustainability of recycled aggregates in concrete.

2.5. New Developments in Fiber-Coating Methods

A range of fibers, including carbon, glass, and polypropylene fibers, have been investigated recently for covering RCA.
For example, polypropylene fiber coatings have demonstrated significant potential in lowering shrinkage cracking, increasing concrete's workability, and boosting durability (Gonzalez-Fonteboa & Martínez-Abella, 2022). Furthermore, it has been noted that carbon fibers enhance RCA's thermal resistance and load-bearing ability, providing a possible remedy for high-performance concrete applications.

2.6. In conclusion

Fiber-coating techniques offer a straightforward, economical, and eco- friendly substitute for conventional approaches in enhancing the quality of recycled concrete aggregates. Fiber-coating is positioned as a viable treatment for boosting RCA and promoting the broad use of recycled aggregates in the construction sector due to its ease of application, as well as improvements in mechanical qualities and durability.

2.7. Surface Coating using Recycled Materials

Recycled concrete aggregates, or RCA, are becoming more and more popular as a sustainable building technique for fresh concrete. However, because of the adhered old mortar,provides poor qualitywith recspect in larger porosity, higher water absorption, and weaker interfacial zones, RCA has worse mechanical strength and durability as compared to natural aggregates (Silva et al., 2014; Tam et al., 2007).By improving the aggregate surface properties, surface coating treatments have become a viable method to solve these shortcomings and enhance RCA quality.
2.8. Cement-Based Surfaces
In order to strengthen the interfacial transition zone (ITZ) and densify the old mortar, one of the oldest techniques is to treat RCA with cement slurry to plug surface holes and fractures.
According to Kou et al. (2011), covering RCA with cement paste increases the compressive strength of concrete and

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decreased its water absorption. Although cementitious coatings enhance physical characteristics, they may also make the aggregate heavier and have a partial impact on workability.

2.9. Coatings of Pozzolanic Materials

To further polish the RCA surface, pozzolanic compounds such as fly ash, metakaolin, and silica fume have been used.By encouraging secondary pozzolanic reactions, Li et al. (2021) demonstrated that coating RCA with colloidal nano-silica or silica fume enhanced the ITZ while simultaneously decreases the porosity. The silica fume slurry was especially successful in enhancing durability characteristics like resistance to chloride ions as well as mechanical strength.
Furthermore, it has been discovered that adding fly ash to coating slurries improves their long-term strength while lowering drying shrinkage (Pedro et al., 2017).

2.10. Coatings made of polymers and nanomaterials

Nanomaterials and polymer coatings have been used in more recent methods. According to Wang et al. (2022), polymer-modified RCAperofms outstanding in account of untreated RCA in terms of impermeability and freeze-thaw resistance. Cost and possible incompatibility with cementitious matrices are still issues. Coatings made of nanomaterials, like nano-silica, show great promise for improving the surface microstructure. Nano-silica fills capillary pores, decreases micro cracking, and greatly strengthens the link between RCA and new mortar, according to studies (Zhang et al., 2020).

2.1.1.Mineral Coatings and Carbonation

Mineral slurry coatings and carbonation treatments are two more innovative techniques. In their investigation of slag-coated RCA followed by rapid carbonation, Shi et al. (2023) discovered notable enhancements in compressive strength, ITZ densification, and water absorption decrease (up to 40%). In a similar vein, Junak and Sicakova (2017) coated RCA with geopolymer slurry, which enhanced its chemical durability and compressive strength.

2.1.2. Combined Treatment Approaches

Combination Methods of TreatmentMulti-stage treatments, like mechanical abrasion and pozzolanic slurry surface coating can have synergistic effects, according to recent research.

In contrast to single-stage treatments, Panghal and Kumar (2024) demonstrated that RCA performance improves when combining chemical treatment (such as acid cleaning) with subsequent cementitious coating.

2.1.3.Summary
The mechanical, durability, and microstructural qualities of recycled aggregates have been demonstrated to be significantly enhanced by surface coating treatments of RCA utilizing cementitious, pozzolanic, polymeric, or nanomaterial slurries.
Because of their efficiency and suitability for conventional concrete matrices, pozzolanic and nano-silica coatings stand out among these as the most promising approaches. However, more study is still needed in the areas of improved coatings' scalability, environmental impact, and cost-effectiveness.

2**.1.5.Gaps in Current Techniques**

Despite the considerable progress in the development of surface treatments for RCA, several gaps persist in these methods, hindering their effectiveness and large-scale implementation: Complexity and manpower-Intensive Processes: Most surface treatment methods, such as chemical treatments or mechanical cleaning, involve multiple stages, requiring significant time, energy, and manpower, making them less viable for large-scale applications (Silva et al., 2014). **2.1.6.Cost and Environmental Concerns:**

Chemical treatments and additive coatings often involve the use of costly materials, such as silane, epoxy resins, and expensive pozzolanic substances. These treatments also tend to have environmental drawbacks due to the use of chemicals and the potential for chemical waste generation (Zhao et al., 2013).

2.1.7. Motivation for a Simple, Effective Fiber-Coating Technique:

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Given the limitations of traditional methods, there is a strong motivation to develop simpler, more effective alternatives. Fiber-coating techniques are emerging as a promising solution to overcome the gaps associated with current treatments. Inconsistent Effectiveness: The performance improvement observed through these methods can be inconsistent. For example, mechanical treatments can occasionally damage the aggregate, and chemical methods can result in unpredictable results depending on environmental conditions (Zhang et al., 2020). Simplicity and Cost-Effectiveness: Fiber-coating techniques involve applying thin coatings of natural or synthetic fibers onto the RCA surface. These fibers can be easily applied and can be sourced at a reasonable cost.

In general, the coating process can be completed in a single step and uses fewer resources, which lowers the manpower intensity and overall cost (Gonzalez-Fonteboa & Martínez-Abella, 2022).

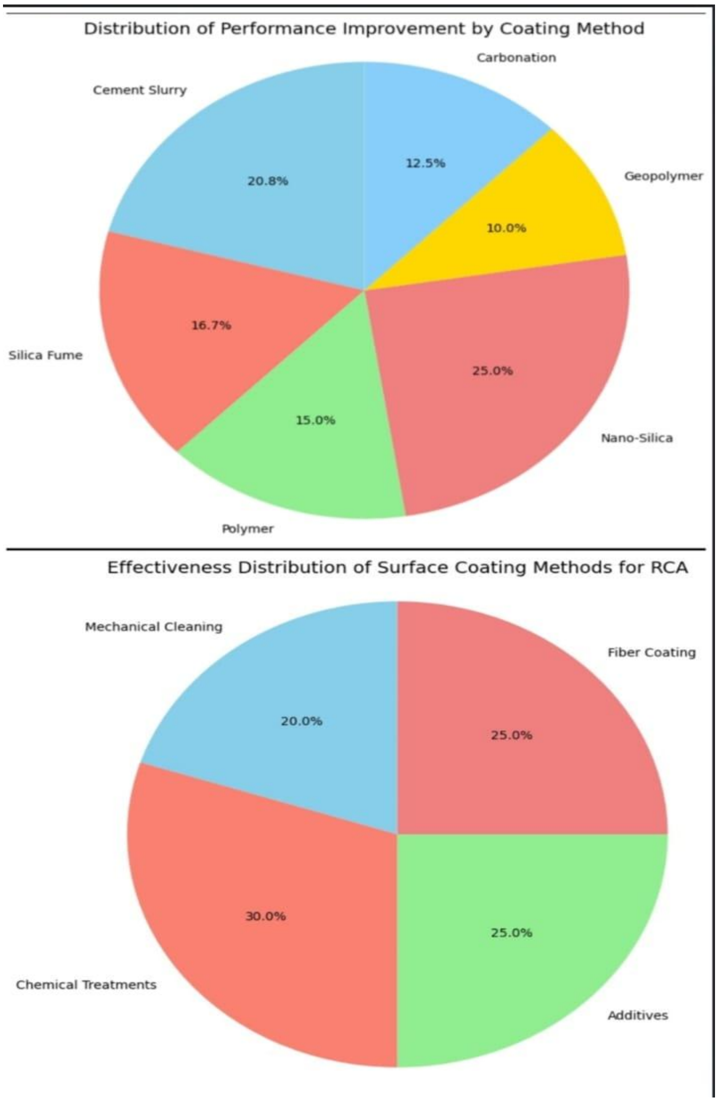

FIGURE 1

3. MATERIALS AND METHODS

3.1 Materials

3.1.1. Cement

Throughout the experimental research, Ordinary Portland Cement (OPC) of 43 Grade, which complies with IS 8112:1989, was utilized. The cement was lump-free, fresh, and kept in an airtight container to keep moisture from absorbing.

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3.1.2. Aggregates

There were three kind of coarse aggregates utilized:

• Natural Aggregate (NA): crushed granite stone that is readily available locally and has a nominal maximum size of 20 mm.

• Recycled Concrete Aggregate (RCA): Made by crushing leftover concrete fragments from buildings that have been demolished and sieved to a size of 20 mm.

• TRCA (Treated Recycled Concrete Aggregate): RCA is surface treated using a proprietary technique.

Clean river sand that complied with IS 383:2016's Zone II was utilized as the fine aggregate.

3.1.3. Rice Husk Ash (RHA)

The natural fiber component in the treatment procedure was rice husk ash, which was produced by carefully burning rice husk at 600°C. To guarantee consistency, it was passed through a 75-micron sieve and RHA had a specific gravity of 2.10 and a moisture content of 15%.

3.1.4. Styrene Monomer

The polymeric binding agent was industrial-grade styrene monomer very high (99.95%) styrene purity — satisfies premium grade requirements.

At 0.003%, aldehyde (benzaldehyde) is extremely low and well below the 2 ppm maximum.

Very low (<1 ppm and <1.0 ppm) peroxide and polymer content, indicating stability.

"Clear and Free" is the visual quality; no contaminants are visible.

A color score of 6 on the platinum-cobalt scale is considered satisfactory and denotes extremely clear material.

It was kept in airtight containers after being purchased from a licensed chemical supplier.

3.1.5. Water

Both mixing and curing were carried out using pure, fresh drinking water. . In order to determine its acceptability, a digital pH meter nd a TDS meter were used to measure the pH and TDS. The findings showed that the pH was 8.4 and the TDS was 148 mg/L, respectively.

3.1.6. Super plasticizer

MasterGlenium SKY B8777, a high-performance superplasticizer, was applied to concrete mixtures to increase their workability & the specific gravity was 1.10.

3.2 Preparation of Treated Recycled Coarse Aggregate (TRCA)

The following steps were part of the therapy process:

1. RCA Collection and Processing: To exclude impurities including metals, plastics, and wood, demolition trash was physically sorted. To obtain RCA of size 20 mm, the waste was crushed with a jaw crusher and sieved.
2. Slurry Preparation: OPC (9.99% w/w), rice husk ash (9.99% w/w), and styrene monomer (0.0135% w/w) were combined with water to create a slurry. Styrene was added after the binder and RHA were mixed in a 1:1 weight ratio.
3. Coating Process: To guarantee full surface covering, the RCA was well combined with the prepared slurry. To ensure homogeneity, manual stirring was used. .
4. Drying: For 24 to 48 hours, the slurry-coated RCA was allowed to air dry in a shaded area. To guarantee that the polymeric coating cured naturally, care was taken to prevent direct exposure to sunlight or artificial heating.
5. Storage: Until they were used again, the treated aggregates were kept dry.

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FIGURE2

3.3 Mix Proportion and Concrete Preparation

3. Concrete Preparation and Mix Proportion

In accordance with IS 10262:2019, concrete was designed for an M35 grade with a water-to-cement ratio of 0.40. Three mixtures were made:

• Mix 1: 100% NA concrete

• Mix 2: 100% RCA concrete

• Mix 3: 100% TRCA concrete

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All three concretes had the same mix proportions (by weight), with the exception of the coarse aggregate type. Content Quantity of concrete per square meter 375 kg of cement, 691 kg/m^3 of fine aggregate, 1243 kg/m^3 of coarse aggregate, andnwater 150 Kg/m^3 admixture **admixture3.75Kg/m^3.**

3.1 Resources

Crushed stone is a natural aggregate; cement is OPC 43 Grade.

Crushed concrete that has been demolished is recycled aggregate.

Rice Husk Ash (RHA) is a natural fiber; industrial-grade styrene monomer

• Drinkable water

4. EXPERIMENTAL PROGRAM

4.1 Testing of Aggregates

Various experimental processes by specified in IS 2386 (Part I-III)-1963:

- Specific Gravity measures the density of aggregate relative to water. More durable and strong aggregate for higher specific gravity.
- Water Absorption measures the retained amount of water in aggregate.requirement of more cement paste for higher absorption more absorption indicates porosity and poor durability.
- Aggregate Crushing Value crushing under compression evaluating the resistance of aggregate.suitability of high load caring structure for lower aggregate crushing value.
- Aggregate Impact Value during sudden impact it measures the toughness and resistance.
- Abrasion Value (Los Angeles test) measures the resistance during grindig forces. Higher crushing resistance requires for highways.

Various experimental processes by specified in IS code (IS 1199:1959), has done for finding the performance of fresh properties of all mix series. Slump ,Compaction Factor , Vee-Bee Consistency, Air Content & Density.

- Slump: For field test measuring of consistency and workability for fresh concrete slump is widely used. Identify the ease by which concrete flows and for specific condition for suitability of placing.
- Compaction Factor: Especially used for low workable concrete mixes where slump test is not suitable. for under a standard effort compaction factor provides more precise workability for for desired degree of compaction.

4.1.2.Hardened Concrete Tests

- Following test are covered for functioning and strengthen quality of mix series as governing the provision of IS Code. Compressive Strength (7, 28 days – IS 516) , Split Tensile Strength (IS 5816) ,Flexural Strength (IS 516) ,Rebound Hammer (with and without 10 KN load – IS 13311 Part2) ,Ultrasonic Pulse Velocity (UPV – IS 13311 Part 1).
- Compressive Strength: Basic and most common test for load bearing capacity of harden concrete for compressive strength it identifies the axial load without resistance of failure. it seems to be necessary for axial design and overall quality control by visual identification. for axial design and quality control it is very crucial without failure resisting the axial load which can be identified by the compressive strength and indicates the overall qualities. 140 no of cubes of size (15mmX150mmX150mm) are casted for obtaining the compressive strength of concrete . Method of tests for compressive strength of Concrete is strictly followed as per (IS 516:1959).
- Split Tensile Strength: it is an indirect method for access the direct tensile strength of concrete as per IS516 (Part1/sec1)2021140 no of cubes of size(15mmX150mmX150mm)are casted for obtaining the split tensile strength. Due to weak in tension its very crucial to find the accuracy in direct tension. This test is widely used for identifying the tensile behaviour of concrete.

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- Flexural Tensile Strength: very commonly known as modulus of rupture and access the ability of concrete to resist failure during bending. due to bending tensile stress dominates in slab & pavement. the method of testing is strictly followed as per IS516 (Part1/sec1)2021 15 no of beams size (100mmX500mmX100mm) used to determine the flexural strength of mixes. Rebound Hammer
- Indian Standard Code IS 13311(part2):1992 impart for Non destructive Testing of Concrete and it is needed to cor-relate the rebound values with compressive strength . It is used to evaluate the concrete surface hardness and compressive strength. The rebound value measured against the surface of concrete by the help of hammer loaded with spring. For the variation of quality and uniformity Rebound hammer is very effective and easy for user. Two types of rebound values are illustrated on the sample of 140 cubes before placing for compression testing machine.because of rebound values obtain from different level without load and under load of dipper level.In realistic the concrete faces both surface stress as well as dipper core stress .Different rebound value can provide the real scenario of void cracks or weaker bonding with aggregate.Rebound value without load provides curing quality and hardness of surface level.Rebound value with 10 KN load illustrate the condition of dipper core strength and structural stress.

FIGURE 3

- UPV The Indian Standard IS 13311(part1):1992 recommended the concrete characteristics based on pulse velocity illustrated the uniformity, integrity and quality of concrete by travelling time of ultrasonic wave velocity throughout the material.UPV testing done on the same 140 cubes before compression testing and rebound hammer testing.r esult are corelated with compressive strength for estimating the strength ,cracks ,internal defects and homogeneity.

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5. RESULTS AND DISCUSSION

5.1 Aggregate Properties

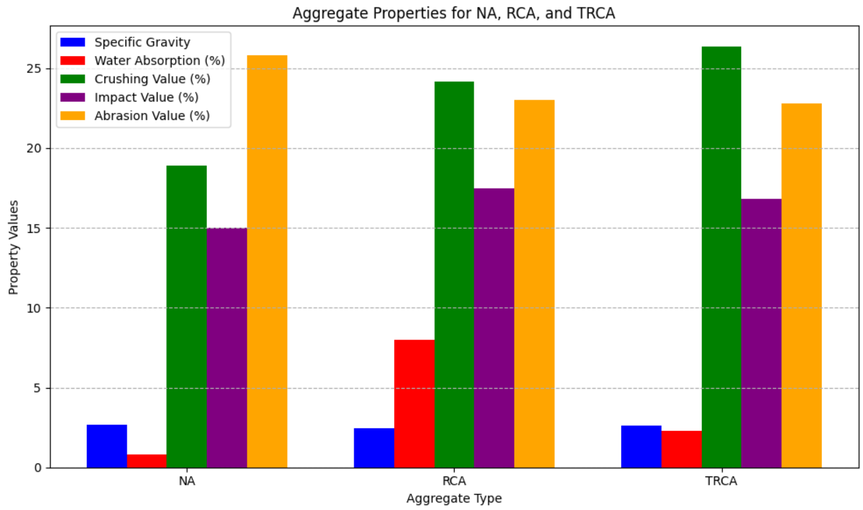

FIGURE 4

Observation

Figure 1 shows a comparison among the physical and mechanical properties of **Natural Aggregate (NA)**, **Recycled Concrete Aggregate (RCA)**, and **Treated Recycled Concrete Aggregate (TRCA)**. in density, strength, and durability point of view RCA is inferior to NA. the region behind this is presence of adhered mortar and higher porosity. While after treatment TRCA shows an improvement in specific gravity, water absorption, impact resistance, and abrasion resistance compared to RCA.

☐ Treatment makes TRCA a great viable alternate source for NA in the application of concrete works.

5.2 Fresh Concrete Properties

Various experimental processes by specified in IS code (IS 1199:1959), has done for finding the performance of fresh properties of all mix series. Slump ,Compaction Factor , Vee-Bee Consistency, Air Content & Density.

Slump:For field test measuring of consistency and workability for fresh concrete slump is widely used. identify the ease by which concrete flows and for specific condition for suitability of placing.

Compaction Factor: Especially used for low workable concrete mixes where slump test is not suitable. for under a standard effort compaction factor provides more precise workability for desired degree of compaction.

Vee-Bee Consistency: Especially used for very stiff concrete where slump test cannot access accurate workability.

Air content: measures the volume of air voids in fresh mix concrete. Excess air entrainment effects the strength but in international aspects improves durability in cold climate under freeze and thaw condition. In this work Pressure method which is best suitable for normal weight concrete used for finding the air content values as per(IS 1199 Part 2:2018 – Section4).

Density: It is a necessary property of concrete for quality control.

calculation of mix proportion, air content cement factor can accesses by the help and also able to identify the segregation or improper batching. Expressed in kg/m^3 of mass per unit volume.

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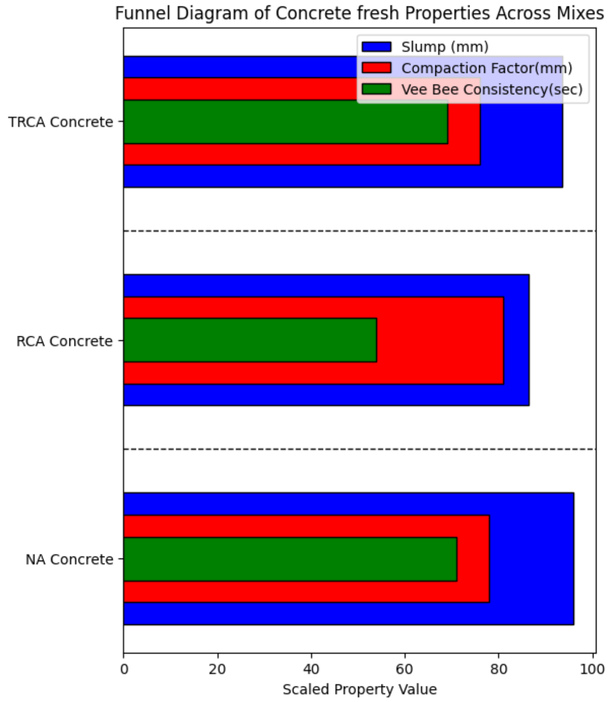

FIGURE 5

Observation:

Figure 4 shows that the workability of three different mixes NA,RCA and TRCA.each mixes having three important properties blue bar is denoted the slum properties of each mixes and measures the consistency and flowability of mix higher slump higher slump gives higher workability of mixes.RCA concrete consist lower and a partial recovery shows in TRCA mixes.red bar is for compaction factor of mixes indicating the ease of compaction under the vibration.better densification with higher compaction factor. RCA mix shows better densification among them. TRCA values lies between NA and RCA .the green bar denoted the vee bee consistency TRCA values lies between NA and TRCA concrete.Highest slump value and veebee time is higher makes NA the most workable concrete but taking mor time for densification.RCA shows better densification due to higher compaction factorbut less workable.TRCA shows a balanced performance in both properties but the compaction factor is slightly low.

5.3 Hardened Concrete Properties

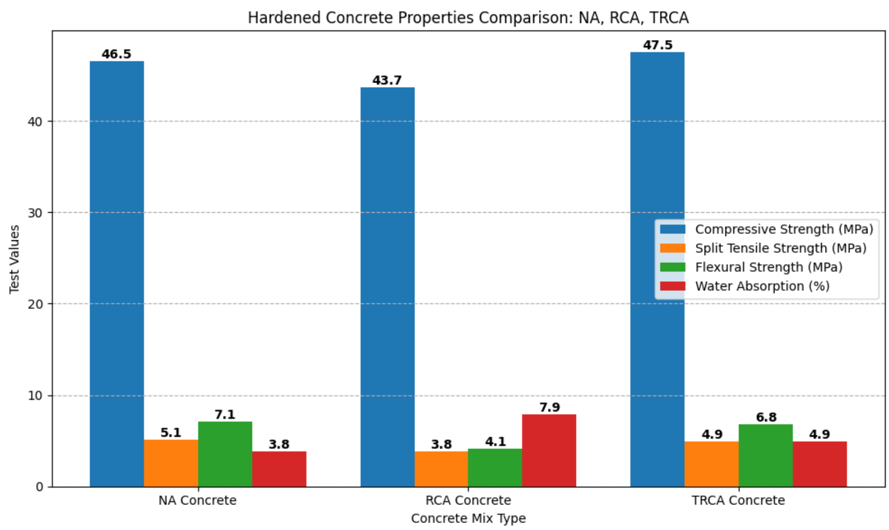

FIGURE 6

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Observation:

Figure 5 bar chart format graph represents mechanical and durability properties of the tree mixes NA,RCA and TRCA.Xaxis shows concrete mixes and Yaxis shows the test values. NA concrete still best in overall strength and RCA concrete poor performs in both strength and water absorption less cohesion and highly porous nature due to adhered mortar makes it less effective without any modification. test values are in favor of TRCA and proves that the treatment improves both strength and water absorption.95% compressive strength archived by TRCA as compared to NA concrete and 40% less water absorption compared to RCA concrete.

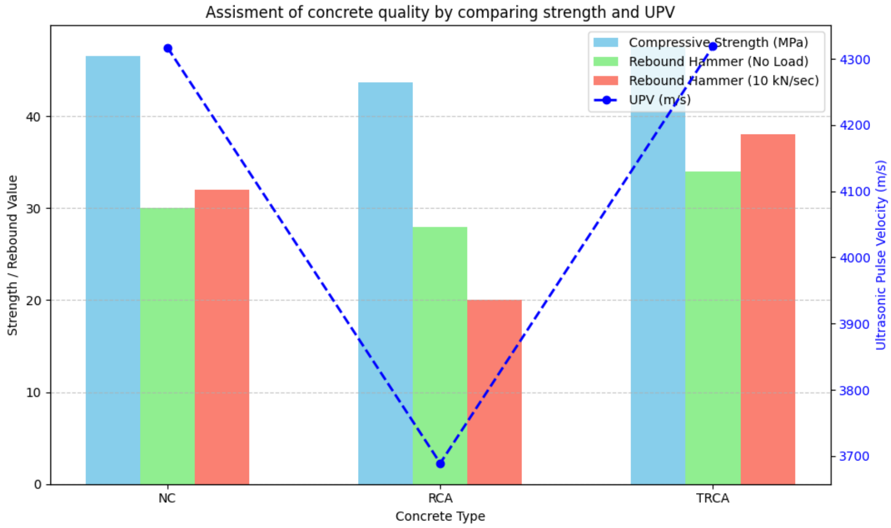

FIGURE 7

Figure 6 shows a bar and line graph for three types of mixes NC,RCA and TRCAfor a comparative evaluation of mechanical properties and ultrasonic pulse velocity

The compressive strength, rebound hammer values (measured with and without a 10 kN/sec load), and UPV were evaluated .for making easy visualization for both strength and UPV trends simultaneously.TRCA provides superior mechanical properties and quality even its use is better than conventional NC.

6. CONCLUSION

- Due to higher porosity RCA decreases the quality of concrete.
- RHA-styrene coating for surface treatment significantly improves the quality of RCA.
- TRCA concrete provides a similar approach in strength and durability those of NA concrete.
- Eco friendly and viable alternative is achieved by Treating RCA in modern construction.

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