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Effect of Chemico-Mechanical Treatment of Recycled Concrete Aggregate on Concrete Performance: A Review

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Abstract: *The rapid growth of construction and demolition waste, together with the steady depletion of natural aggregate sources, has made recycled concrete aggregate (RCA) an attractive option for new concrete. Its use is held back, however, by the layer of old mortar that clings to the aggregate surface, which raises water absorption and porosity and makes properties vary from one source to another. This paper reviews peer-reviewed work on concrete made with non-treated RCA and with RCA treated by chemical, mechanical, and other methods. Attention is given to how the origin of the aggregate, the type and severity of treatment, and the replacement level influence workability, density, water absorption, strength and durability. The studies reviewed agree that a suitable treatment improves aggregate quality and brings recycled aggregate concrete closer to the behaviour of natural aggregate concrete, but the extent of the gain depends on the quality of the parent concrete, the treatment conditions and the mix design. Acid soaking followed by abrasion, accelerated carbonation and nano-silica modification emerge as the most frequently studied routes. Gaps remain in standardised treatment protocols, long-term durability data, life-cycle and cost assessment, and treatment strategies matched to specific aggregate sources. The review also outlines the experimental programme planned by the authors, in which concrete with natural, non-treated and chemico-mechanically treated aggregate will be compared.*

Keywords: *Recycled Concrete Aggregate, Non-Treated RCA, Chemico-Mechanical Treatment, Chemical Treatment, Mechanical Treatment, Concrete, Compressive Strength, Water Absorption, Sustainability.*

I. INTRODUCTION

Aggregates make up the largest share of concrete by volume, so where they come from matters as much as the cement. Quarrying natural stone and gravel is becoming more expensive and more contested, while cities produce growing quantities of demolition debris that mostly ends up in landfill or as low-grade fill. Crushing that debris into recycled concrete aggregate (RCA) and returning it to concrete is one way of dealing with both problems at once [1]. Recycled aggregate concrete (RAC) has already been used in a range of building and infrastructure projects. In a review of structural applications, Xiao et al. concluded that RAC structures performed safely in most of the scenarios examined and that substituting RAC for natural aggregate concrete can lower the overall cost of a project [2].

The difficulty lies in the particle itself. A piece of RCA is not clean rock; it is rock coated with the cement mortar of its previous life (Fig. 1 and Fig. 2). That mortar is porous and is often micro-cracked by crushing, so the aggregate absorbs more water and is weaker and lighter than natural aggregate [3, 4]. It also adds extra interfacial transition zones (ITZs) to the concrete: one between the original rock and the old mortar and another between the old mortar and the new paste. Weak ITZs and high absorption together account for much of the loss in workability, strength and durability reported for RAC [4, 5].

Two broad responses are available. The first is to use the aggregate as it comes, after basic crushing, sieving, washing and drying, and to compensate through the mix, for example by limiting the replacement level or adjusting the water content. The second is to improve the aggregate before it reaches the mixer. Treatments can remove the weak mortar, strengthen it, or do both [6, 7]. Mechanical processes such as ball milling or abrasion strip loose mortar from the surface, acid soaking weakens and partly dissolves it, and carbonation or nano-silica fills the pores of whatever remains. Routes that couple a chemical step with a mechanical one are usually called chemico-mechanical treatments.

Reviews of individual treatments are now plentiful. This paper instead sets non-treated and chemico-mechanically treated aggregate side by side and pays attention to where the aggregate came from.

It surveys work published since 2020, compares the two conditions and describes the experimental programme the authors intend to follow, in which concrete made with natural aggregate, non-treated RCA and RCA treated with 0.5 M hydrochloric acid followed by Los Angeles abrasion will be compared through slump, compressive strength and water absorption tests.

A. Sources of recycled aggregate

RCA is made from whatever concrete waste is available locally: demolished buildings, old pavements, abandoned structures and the discarded test cubes that accumulate in laboratories and on construction sites. Ready-mix plants add another stream in the form of returned concrete, which can be allowed to harden, crushed and reused [8]. Aggregate taken from real demolition or plant sources is not the same as aggregate crushed in a laboratory from cast specimens, and several reviews treat the two separately [7]. The age, strength grade and service history of the parent concrete are likely to influence how much mortar stays attached to the aggregate and how sound that mortar is.



Fig. 1. Recycled concrete aggregate obtained from demolition waste

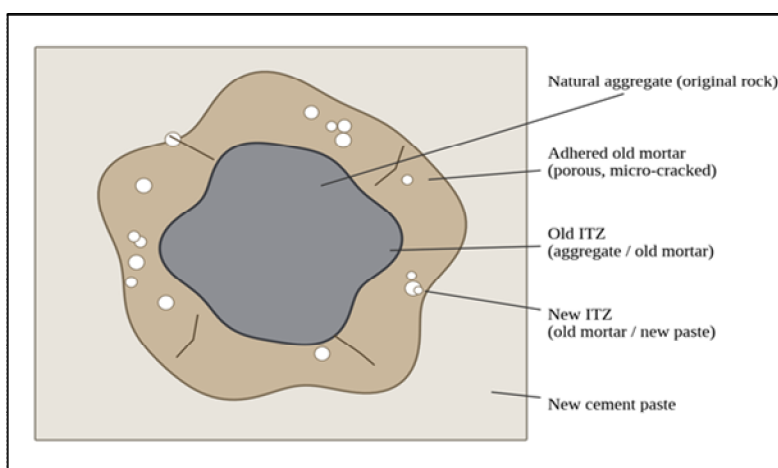


Fig. 2. Schematic of a recycled concrete aggregate particle in new concrete, showing the adhered old mortar and the two interfacial transition zones (ITZs). Not to scale.

II. OBJECTIVES

This review has been conducted for the following objectives:

- 1) To summarise the physical, mechanical and chemical characteristics of recycled aggregate obtained from construction and demolition waste, old concrete structures and other waste streams;

- 2) To describe how concrete made with non-treated recycled aggregate behaves in terms of workability, density, strength, durability and water absorption;
- 3) To examine how chemical, mechanical and combined chemico-mechanical treatments change the quality of recycled aggregate and of the concrete made from it;
- 4) To compare non-treated and treated aggregate with particular reference to adhered mortar, porosity, the interfacial transition zone and the resulting concrete properties; and
- 5) To identify research gaps and directions for developing durable, sustainable concrete from treated recycled aggregate.

III. SCOPE OF THE REVIEW

Earlier studies are acknowledged only through the later reviews that summarise them. The papers are grouped by theme rather than listed one after another: general overviews, non-treated aggregate, removal treatments, carbonation, nano-modification and combined routes, and the question of aggregate source. Where a finding is given as a number it belongs to the specific study and test conditions concerned, because values obtained on different aggregates and mixes cannot be compared directly.

IV. LITERATURE REVIEW

A. Recent overviews

Xiao et al. [1] give the broadest recent picture of RAC, running from aggregate production and enhancement through mix design to structural safety, durability and application. They note that RAC usually performs below comparable natural aggregate concrete but that careful design can narrow the gap, and they name standardised quality control and better aggregate processing as conditions for wider adoption. Alibeigibeni et al. [5] concentrate on structural concrete made with both fine and coarse RCA. Their conclusion is that pretreatment, optimised mixes and supplementary cementitious materials can each offset part of the penalty caused by adhered mortar, although variable aggregate quality remains a problem. Han et al. [9] compare pretreatment approaches by their effect on workability, strength and permeability, set them against cost and environmental impact, and add case studies of RCA in infrastructure. Earlier in the period, Le and Bui [4] followed RAC from microstructure up to structural and fire behaviour and stressed that aggregate treatment influences the outcome at every scale.

B. Concrete made with non-treated aggregate

Non-treated RCA is the baseline against which every treatment is judged, and its main weakness is absorption. Gamielien et al. [10], reviewing untreated fine RCA, found that water absorption, gas permeability and chloride penetration of concrete rose as more fine RCA replaced natural sand, and that durability was closely tied to the water-binder ratio and to the porosity of the matrix. A replacement ceiling of around 30% was suggested for the durability properties they examined. Carbonation was an interesting exception: resistance increased with fine RCA content, which the authors attributed to the calcium hydroxide in the old mortar.

Bu et al. [11] reached a similar overall picture for recycled fine aggregate concrete. Durability falls as the replacement ratio and the water-cement ratio rise, and it depends on how much old mortar the aggregate carries and how good the parent concrete was. The same review reported that coating the aggregate with, or adding, pozzolanic materials such as fly ash, silica fume and metakaolin improves durability, as does optimising the moisture condition of the aggregate before mixing. Taken together, these studies show that non-treated RCA can still be used, particularly at moderate replacement levels, but that the limits are set largely by absorption and porosity.

C. Removal treatments: mechanical and chemical

Removal treatments try to take the weak mortar off the aggregate. Peiris et al. [7] reviewed the field and singled out ball milling and autogenous cleaning as the most effective mechanical removal methods. Mistri et al. [6] had earlier sorted treatments into mechanical, chemical, thermal and surface-strengthening techniques and compared removal with strengthening, suggesting that strengthening may be the more sustainable of the two. Wang et al. [3] traced the defects of RCA (pores, cracks and weak ITZs) mainly to attached mortar and to the crushing process, and reviewed mechanical removal, surface coating and chemical modification as ways of reducing porosity and improving bonding between aggregate and mortar.

Acid soaking is the usual chemical removal route. Its effect depends on the acid, its concentration, the exposure time and the aggregate itself. Trivedi et al. [12] reported that single-stage immersion in hydrochloric acid cut the water absorption of recycled aggregate by 78%.

Even so, they recommended a multi-stage sequence of jaw crushing, mechanical abrasion and sodium silicate treatment as the better overall option. In a related study, Trivedi et al. [13] found that concrete made with aggregate processed in this way had higher workability and density than concrete made with untreated RCA, and they used microstructural examination to explain the difference.

D. Strengthening by accelerated carbonation

Accelerated carbonation has become one of the most widely studied strengthening routes, partly because it stores CO₂ while it improves the aggregate. Shuvo et al. [14] compared four ways of carrying it out (standard, pressurised, flow-through and wet carbonation) and found that the effect on RCA could be positive or negative depending on the conditions. A systematic review of 124 studies by Ali et al. [15] identified a relative humidity of 50–70%, a temperature of 20–30 °C and a CO₂ concentration of 20–50% as the combination giving the best carbonation performance. The same review reported gains in compressive strength, water absorption and density, with smaller particles benefiting most because of their larger reactive surface. Using low-quality RCA from end-of-life buildings, Dündar et al. [16] showed that operating and material parameters all affected carbonation performance, and mortar tests confirmed the effect on workability and strength.

At the concrete level, Russo and Lollini [17] replaced about 30% of the natural aggregate with carbonated or untreated RCA and tested mechanical and durability properties at several ages. Carbonated RCA gave better hardened properties than untreated RCA, but the concrete still fell short of the natural aggregate reference. The result is a useful reminder that treatment narrows the gap rather than closing it. Wet carbonation has also been applied to a different waste stream, the crushed returned concrete from ready-mix plants, to improve the attached mortar [8].

E. Nano-modification and combined chemical routes

Nano-silica and graphene oxide have been examined as modifiers that refine pores and strengthen the ITZ, and Zhan et al. [18] reviewed the materials, the dispersion problems and the mechanisms involved. Li et al. [19] compared five treatment approaches, among them pressurised, flow-through and wet carbonation and nano-silica spraying, and found that pressurised carbonation combined with nano-silica gave the largest improvement in both mechanical and durability properties. Kazmi et al. [20] tested five techniques, including acid soaking, mechanical rubbing, carbonation and combinations of these, and looked at the durability of the resulting concrete. Treated aggregate generally gave more durable concrete than untreated aggregate, and aggregate porosity turned out to be a useful predictor of concrete durability. That last finding matters for any chemico-mechanical programme, because porosity and water absorption are quick and cheap to measure on the aggregate before any concrete is cast.

F. Aggregate source and variability

The review literature repeatedly warns that RCA is not one material. Peiris et al. [7] considered both demolition-derived and laboratory-produced RCA, and Xiao et al. [1] list standardised quality control among the requirements for wider use. Bu et al. [11] link the durability of recycled fine aggregate concrete to the content of old mortar and the quality of the recycled concrete, and Alibeigibeni et al. [5] identify quality variability as a persistent obstacle in structural applications. A treatment tuned on aggregate from one source may therefore under-treat or over-treat aggregate from another. This is the main reason for the emphasis on source in the present review and for the plan to characterise each aggregate before it is treated.

G. Summary of treatment approaches

Table 1 condenses the preceding sections. It is qualitative on purpose: the studies use different aggregates, replacement levels and test ages, so their numerical results are not directly comparable.

Approach	Principle	Reported effects	Points to watch
Non-treated (crushing, sieving, washing, drying)	No modification of the adhered mortar	Usable at moderate replacement; durability falls as replacement and water-cement ratio rise [10, 11]	High absorption and porosity; quality varies with source [5, 10]

Approach	Principle	Reported effects	Points to watch
Mechanical removal (ball milling, autogenous cleaning, abrasion)	Strips weakly bound mortar from the surface	Among the most effective removal methods reviewed [7]	No chemicals needed, but mortar loss and energy use must be weighed [6]
Acid soaking (e.g. HCl)	Weakens and partly dissolves the old paste	Single-stage HCl immersion cut water absorption by 78% in one study [12]	Result depends on acid, concentration, time and aggregate [3, 12]; acidic effluent needs handling
Chemico-mechanical (acid + abrasion; abrasion + sodium silicate)	Chemical step loosens mortar, mechanical step removes it or the coating strengthens what is left	Higher workability and density than untreated RAC [13]; treated aggregate generally gave more durable concrete [20]	Number of stages and cost; treatment intensity must be tuned
Accelerated carbonation	CO ₂ reacts with the old mortar and fills its pores	Better strength, absorption and density [15]; better than untreated RCA but below natural aggregate in one concrete study [17]	Humidity, temperature and CO ₂ level control the outcome [14, 15]
Nano-silica or graphene oxide modification	Refines pores and strengthens the ITZ	Reviewed as a way to offset weaknesses of untreated RCA [18]	Dispersion and cost of nanomaterials [18]
Carbonation combined with nano-silica	Two strengthening steps applied in sequence	Largest improvement among five approaches compared [19]	Needs both CO ₂ treatment and nanomaterials

Table 1. Qualitative comparison of recycled aggregate treatment approaches.

V. NON-TREATED VERSUS CHEMICO-MECHANICALLY TREATED AGGREGATE

The studies above point the same way. Aggregate that has been cleaned of weak mortar, or whose mortar has been strengthened, produces concrete that is denser, absorbs less water and is more durable than concrete made with non-treated RCA [13, 19, 20]. Fig. 3 shows how the main treatments relate to each other.

A chemico-mechanical route is a logical answer to the limits of each step used alone. Acid can reach pores and cracks that abrasion cannot, but acid alone leaves partly dissolved paste on the surface. Abrasion removes loose material, but abrasion alone leaves mortar behind in the recesses of the particle. Combining them lets the acid soften the old paste and the abrasion clear it away, which is the idea behind the multi-stage processing reported by Trivedi et al. [12].

However, chemical effectiveness depends on the aggregate [12], so a fixed acid concentration and soaking period will not suit every source. Over-long exposure risks attacking the aggregate as well as the mortar, and the spent acid has to be neutralised and disposed of. Carbonation and nano-silica avoid some of these problems but need CO₂ handling equipment or relatively costly nanomaterials. Peiris et al. [7] therefore advise that the choice of treatment should weigh technical performance together with durability, cost and life-cycle impact, not strength alone.

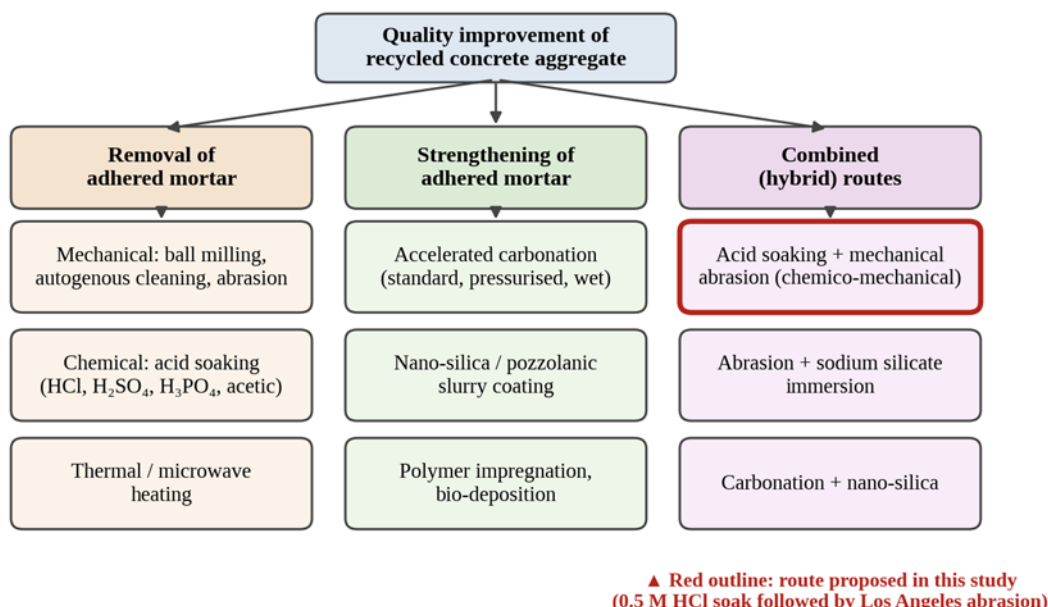


Fig. 3. Classification of recycled aggregate treatment methods [3, 6, 7]

A. Proposed experimental programme

Recycled aggregate will be collected, then crushed, sieved, cleaned and dried. One portion will be kept as the non-treated control. The other portion will be soaked in 0.5 M hydrochloric acid for 48 hours, washed and dried, and then abraded in a Los Angeles abrasion machine with abrasive charges. After aggregate characterisation, three concrete series will be prepared, using natural aggregate, non-treated RCA and treated RCA. Cubes will be cast and cured and tested for slump, compressive strength and water absorption (Fig. 4). The comparison should show how far the treatment improves the aggregate and whether the gain carries through to the concrete.

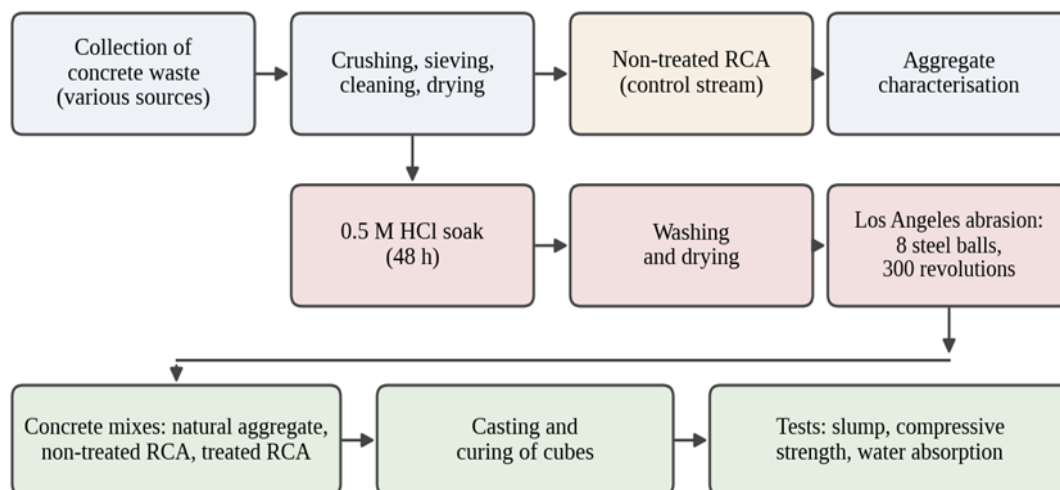


Fig. 4. Workflow of the proposed experimental programme

VI. RESEARCH GAPS AND EMERGING DIRECTIONS

Several directions stand out from the recent literature.

- **Standardisation:** Standardised quality control is important for the wider use of recycled concrete aggregates (RCA) [1]. However, the treatment methods and their intensity still vary from one study to another. For example, acid concentration, soaking time, abrasion cycles and carbonation conditions are not the same in all studies. This makes it difficult to compare the results and identify the most suitable treatment method.
- **Carbon utilisation:** Carbonation is receiving considerable attention because it improves the quality of aggregates while also storing CO₂ [14, 15]. Recent studies are focusing on finding the best carbonation conditions and exploring methods such as wet carbonation and pressurised carbonation.
- **Hybrid treatments:** Combining two or more treatment methods has shown promising results. For example, carbonation combined with nano-silica [19] and abrasion followed by chemical immersion [12] have produced better results in several studies. Therefore, combined treatment methods are likely to be explored further.
- **New aggregate sources:** Research on returned ready-mix concrete [8] shows that RCA can be obtained from sources other than demolished concrete. This highlights the need to select suitable treatment methods according to the source and condition of the aggregates.
- **Life-cycle and cost:** The cost and environmental impact of treatment methods are important factors when selecting a suitable treatment process [7, 9]. However, more work is needed to compare these factors along with the mechanical properties and durability of treated aggregates. Long-term durability data for concrete made with treated RCA are also limited. Therefore, further research is needed in both areas.
- **Structural use:** Research on structural safety, design guidelines and practical project applications of treated RCA is gradually increasing [1, 2]. Further evidence in these areas will help improve confidence in treated RCA and support its wider use in construction.

VII. CONCLUSION

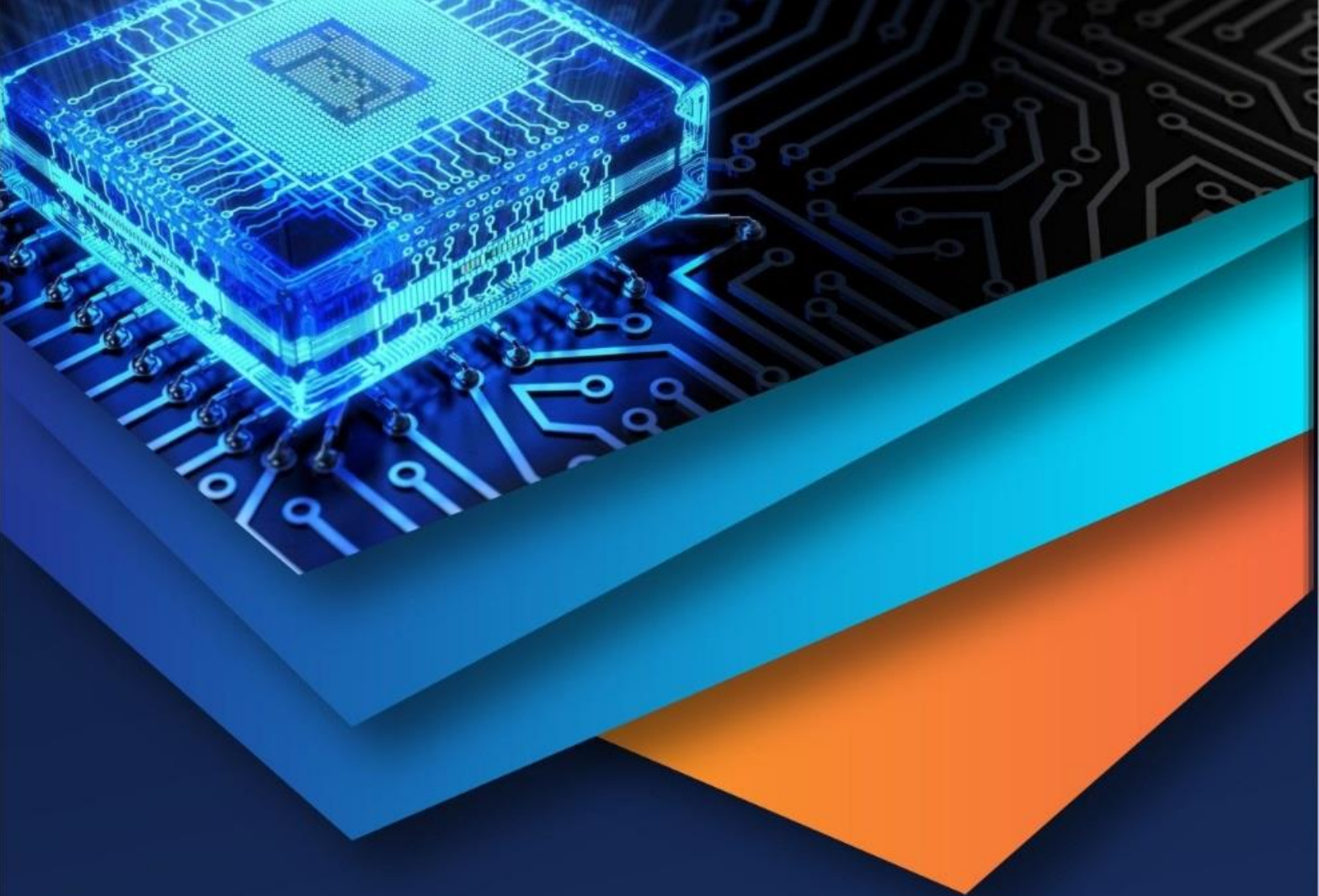
Recycled concrete aggregate can replace natural aggregate in concrete, but the old mortar attached to it increases absorption and porosity and brings weak interfaces into the concrete. The work reviewed here shows that non-treated RCA is workable at moderate replacement levels yet limited in durability, and that mechanical, chemical, carbonation, nano-modification and combined treatments can improve both the aggregate and the concrete made from it. The improvement is not uniform. It depends on the source and quality of the aggregate, on how intensely it is treated and on the mix design, and treated RCA concrete in the studies discussed still did not always match natural aggregate concrete.

From the study it is found evidential that soaking RCA in 0.5 M HCl for 48 hours, washing and drying it, and then abrading it in a Los Angeles machine with abrasion charges for specific rotation cycles, it will remove the adhered mortar considerably and we get cleaner RCA. Concrete made with this aggregate will be compared with natural aggregate concrete and non-treated RCA concrete using slump, compressive strength and water absorption tests, together with aggregate characterisation. The results will show how effective the treatment is and whether treated RCA is suitable for concrete production.

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