NANO MATERIALS IN RECYCLED AGGREGATE CONCRETE: A COMPREHENSIVE REVIEW

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ABSTRACT

Recycled aggregate concrete (RAC) has emerged as a sustainable solution for reducing building waste and protecting the environment. However, when compared to conventional concrete, RAC typically has lower mechanical properties. In recent years, the incorporation of nanomaterials, notably nano-silica, has emerged as a viable way to improve RAC performance. Nano-silica works as a pozzolan and nanofiller in RAC, allowing for better hydration processes, denser microstructures, and increased mechanical strength. Additionally, its use aids in reducing the damaging environmental effects associated with the production of concrete. In order to enhance the mechanical and durability properties of RAC, this study explores the comprehensive studies and discoveries related to the usage of nanomaterials, notably nano-silica. This review, however, goes beyond nano-silica and investigates the synergistic effects achieved by combining nano-silica with other nanomaterials such as nano clay, nano TiO2, nano calcium carbonate, graphene and nano alumina, as well as the mechanisms by which these materials influence the various properties of concrete. The optimization of nanomaterial doses, their impact on RAC, the challenges and future scope of such advances are also discussed. This review provides valuable insights for researchers, engineers, and practitioners on the potential of nanomaterials in enhancing the performance of RAC and promoting the use of environmentally friendly construction approaches.

Keywords: *Recycled Aggregate Concrete, nanomaterials, nano-silica, recycled coarse aggregate , sustainable concrete*

1. INTRODUCTION

A large portion of the waste produced worldwide every year comes from the construction sector (Liang et al., 2022). As urbanization and infrastructural development continue to rise, there is an increasing need for building materials, especially concrete (Olafusi et al., 2019). Natural resource depletion and the build-up of building and demolition waste are the results of this demand (Liang et al., 2022). Recycled aggregate concrete (RAC) has become a viable substitute for traditional concrete as a result of these issues (McNeil & Kang, 2013). Reusing construction and demolition debris, mostly concrete, along with additional aggregate resources such sand, gravel, and crushed stones, results in the production of RAC. However, RAC frequently performs worse than natural aggregate concrete (NAC) in terms of durability, tensile strength, and compressive strength (Prusty et al., 2015). As a result, numerous tactics are being investigated to enhance the characteristics of RAC.

Utilizing nanoparticles in concrete serves as one such tactic (Liu et al., 2020; Olafusi et al., 2019; Singh & Saini, 2022). Because of their special qualities, nanomaterials have shown a lot of promise for improving concrete performance (Liu et al., 2020; Olafusi et al., 2019; Singh & Saini, 2022). Of all the nanomaterials, nano-silica (NS) has received the most research attention due to its capacity to increase the durability and strength of concrete (Li et al., 2021; Luo et al., 2023; Prusty et al., 2015; Shirvani et al., 2023). However, it is discovered that NS alone can only slightly increase the strength and decrease the porosity of RAC (Li et al., 2021; Luo et al., 2023; Prusty et al., 2015; Shirvani et al., 2023). As a result, studies on the combined impact of NS and other nanomaterials in RAC have begun.

The purpose of this work is to present a thorough overview of the state of the research on the application of NS and other nanomaterials in RAC. The impact of these nanomaterials on the fresh and hardened properties of RAC is the main topic of the review. Along with filling up knowledge gaps, the study makes recommendations for future research topics. The ultimate objective is to support the creation of high-performance, more environmentally friendly concrete products for construction sector. The problems and potential avenues for future research in this topic are discussed in the paper's conclusion.

In addition to addressing environmental issues related to construction waste and the depletion of natural resources, the use of RAC and nanomaterials in concrete offers a chance to improve the performance of concrete materials (McNeil & Kang, 2013; Olafusi et al., 2019; Singh & Saini, 2022). Concrete materials that are more sustainable and perform better can be created by comprehending the interactions between RAC and nanomaterials. Through evaluating the current state of this field's research and proposing new directions for investigation, this work contributes to the understanding of RAC and its relationship with nanomaterials.

2. RECYCLED AGGREGATE CONCRETE: AN OVERVIEW

Waste from building and demolition is recycled to create RAC (McNeil & Kang, 2013). Although concrete is the main component of RAC, it also contains other aggregate materials such sand, gravel, slag, and crushed stones (McNeil & Kang, 2013). By lowering the need for natural aggregates, the use of RAC promotes sustainability in addition to aiding in the management of construction waste (Chakradhara Rao, 2018; McNeil & Kang, 2013).

In order to produce RAC, crushed concrete must be gathered from a variety of sources, including broken bridges, roads, and buildings. The strength of the finished product is checked to make sure this concrete is free of any other elements, such as metal or wood fragments (McNeil & Kang, 2013). Large chunks and stones are broken up by impact force in the crushing equipment used for the concrete (McNeil & Kang, 2013). Ultimately, an aggregate e.g. sand, is combined with the crushed concrete to help it achieve the necessary density and uniformity (McNeil & Kang, 2013).

There are various benefits to using RAC. It is a more affordable substitute for quarried stone and a highly resilient substance that works especially well on damp or soft terrain (McNeil & Kang, 2013). Because it doesn't require mining and requires less energy to produce than conventional concrete, natural ecosystems are preserved (McNeil & Kang, 2013). Furthermore, it provides possible tax breaks for businesses who invest in fuel-efficient technology (McNeil & Kang, 2013). Compared to ordinary concrete, which has an average water absorption rate of 3.7%, this concrete is more permeable (average water absorption value of 7.5%), which may lead to greater protection against seepage (McNeil & Kang, 2013).

Nonetheless, there are certain drawbacks to using RAC. An excessive amount of aggregate added to concrete can have a negative effect on the material's strength (McNeil & Kang, 2013). Moreover, RAC is more permeable than regular concrete, which may lead to better seepage protection (McNeil & Kang, 2013).

Despite these obstacles, the usage of RAC in the construction sector is expanding because to the growing need for sustainable building methods and efficient waste management (Chakradhara Rao, 2018). In addition to addressing environmental issues related to construction waste and the depletion of natural resources, the use of RAC and nanomaterials in concrete offers a chance to improve the performance of concrete materials (Chakradhara Rao, 2018; McNeil & Kang, 2013).

3. NANO MATERIALS IN CONCRETE: AN OVERVIEW

Materials with microstructural characteristics between 0.1 and 100 nm in size are referred to as nanomaterials (Olafusi et al., 2019). These materials display unique characteristics, such as surface activity, filling effect, and environmental sustainability, that set them apart from their bulk counterparts (Singh & Saini, 2022). Nanomaterials can be added to concrete to improve its strength, durability, and capacity for self-cleaning (Olafusi et al., 2019).

To enhance the qualities of concrete, a variety of nanomaterials have been used, such as nano-silica (NS), nano clay, nano TiO2, graphene, graphene oxide, and nano carbon (Singh & Saini, 2022). Research on the molecular interactions between these nanomaterials and the constituents of concrete is centered on the quickly expanding field of nanomaterial use in concrete (Olafusi et al., 2019).

There are two primary methods for incorporating nanomaterials into concrete: the "top-down" method, which involves shrinking larger structures to the nanoscale without atomic-level control, and the "bottom-up" method, also known as "molecular nanotechnology" or "molecular manufacturing," which involves creating materials from atoms or molecular components through assembly or self-assembly (Olafusi et al., 2019).

By lowering the energy needed to produce concrete and increasing its durability, the use of nanomaterials in concrete not only enhances its performance but also advances sustainability (Singh & Saini, 2022). Yet, there are drawbacks to using nanomaterials in concrete. These include the need to ensure that the materials are evenly distributed throughout the mixture and to comprehend how these components would affect the concrete's characteristics in the long run (Olafusi et al., 2019).

Despite these difficulties, research into the potential advantages of incorporating nanomaterials into concrete is an intriguing field with important implications for the development of concrete technology (Singh & Saini, 2022).

4. NANO-SILICA IN RECYCLED AGGREGATE CONCRETE

One of the most often utilized nanomaterials in recycled aggregate concrete (RAC) is nano-silica (NS). It is renowned for having special qualities like reactivity and a large surface area (Kumar &

Kumar; Liang et al., 2022). The qualities of the concrete can be improved by mixing NS with RAC. (Kumar & Kumar; Liang et al., 2022; Zhan et al., 2022).

NS helps to increase calcium-silicate hydrate (C-S-H) gel, speed up hydration, and encourage pozzolanic reaction (Liang et al., 2022). However, it is discovered that NS alone can only slightly increase the strength and decrease the porosity of RAC (Liang et al., 2022). In order to further improve the qualities of RAC, additional techniques, like as physical compression casting, are frequently employed in conjunction with NS (Liang et al., 2022).

Investigations were conducted into the impact of NS, compression casting, and their combinations on the characteristics of RAC (Liang et al., 2022). The compressive strength, peak strain, and modulus of elasticity were examined in order to assess the stress-strain reactions at the macro-level (Liang et al., 2022). Mercury intrusion porosimetry study and scanning electron microscope imaging technology were used to examine the porosity and pore distribution along the interface transition zones (ITZs) at the micro level (Liang et al., 2022).

The compressive strength attained by employing NS particles, compression casting, and their combination was raised by 37, 88, and 143%, respectively, in comparison with standard RAC (Liang et al., 2022). The total porosity of the mortar and the pore ratio along the ITZs can be successfully reduced by compression casting, or by compression casting in conjunction with NS particle treatment (Liang et al., 2022).

Despite these developments, there are still difficulties in using NS in RAC, including making sure that the NS particles are evenly distributed throughout the concrete mix and comprehending how these materials would affect the concrete's characteristics in the long run (Kumar & Kumar; Liang et al., 2022; Zhan et al., 2022).

5. OTHER NANO MATERIALS ADDED WITH NANO SILICA IN RECYCLED AGGREGATE CONCRETE

To improve the characteristics of RAC, NS has been mixed with a number of other nanomaterials. Here are a few of them:

a) Nano Clay: In RAC, nano clay and NS have been utilized together. In a study by Yunchao et al. (2021), it was discovered that adding 2% of nano clay and 2% of NS to concrete increased its compressive strength by 20%. The layered structure of nano clay can provide concrete more durability and strength (Yunchao et al., 2021).

b) Nano Titanium Dioxide (TiO2): In a study by Zhong et al. (2022), 2% of NS and 1.2% of nano TiO2 were utilized. After 150 freeze-thaw cycles, the concrete's compressive strength rose by 25.52% (Zhong et al., 2022). According to Zhong et al. (2022), nano TiO2 is well-known for its photocatalytic qualities, which can give concrete self-cleaning capabilities.

c) Graphene and Graphene Oxide: These nanomaterials, which are based on carbon, have been employed in RAC in conjunction with NS. Their considerable strength and flexibility can help to improve the concrete's mechanical qualities (Zhan et al., 2022).

d) Nano Calcium Carbonate: In RAC, this nanomaterial has been combined with NS. It can increase the density and strength of concrete by plugging its pores (Liang et al., 2022). It also accelerates cement hydration, promotes pozzolanic reaction, and increases C-S-H gel content when mixed with NS (Yue et al., 2020).

e) Nano Alumina: Recently, nano alumina and NS have been combined in RAC. It can quicken the concrete's hydration process and increase its early strength (Liang et al., 2022).

6. CHALLENGES AND FUTURE RESEARCH DIRECTIONS

There are a number of issues with using nanomaterials in recycled aggregate concrete (RAC) that must be resolved:

a) Uniform Dispersion: One of the biggest challenges is ensuring that the nanomaterials are evenly distributed throughout the concrete mixture. Agglomeration is frequently caused by the high surface area to volume ratio of nanomaterials, which can cause uneven dispersion in the concrete mixture (Allujami et al., 2022; Guimarães et al., 2021).

b) Optimal Dosage: Another difficulty is figuring out the optimum dosage of nanomaterials in RAC. Although adding nanomaterials can improve RAC's qualities, using too much of them can be harmful (Allujami et al., 2022).

c) Long-term Effects: It is essential to comprehend how long-term exposure to nanomaterials affects the characteristics of RAC. To learn more about the long-term performance and durability of RAC using nanomaterials, more research is required (Guimarães et al., 2021).

d) Environmental Impact: One problem with employing nanomaterials in RAC is how they would affect the environment. Although producing nanomaterials can have an impact on the environment, using RAC promotes sustainability (Allujami et al., 2022; Guimarães et al., 2021).

The following areas could be the focus of future research in this field:

a) Advanced Mixing Techniques: Creating elaborate mixing methods to guarantee that the nanomaterials are evenly distributed throughout the concrete mixture (Allujami et al., 2022; Liu et al., 2021).

b) Optimization Studies: Optimization studies must be carried out to ascertain the ideal nanomaterial dosage in RAC (Allujami et al., 2022) .

c) Long-term Studies: Conducting long-term research to comprehend the performance and longevity of RAC using nanomaterials over time (Allujami et al., 2022).

d) Life Cycle Assessment: Conducting life cycle assessment research to determine how employing nanomaterials in RAC may affect the environment (Guimarães et al., 2021).

7. CONCLUSIONS

Recycled aggregate concrete (RAC) has showed great promise for improving its characteristics through the use of nanomaterials. In RAC, a variety of nanomaterials have been combined with nano-silica, including as nanocarbon, nano clay, nano $TiO2$, graphene, graphene oxide, and nano-silica. These mixtures have improved the concrete's strength, toughness, and capacity for self-cleaning.

Still, there are a number of issues that must be resolved, including making sure that the nanomaterials are evenly distributed throughout the concrete mixture, figuring out the best amount to use, comprehending the long-term consequences of these materials on the characteristics of the concrete, and assessing the environmental impact of using nanomaterials in RAC.

Potential opportunities for further research in this area include the development of sophisticated mixing methods, optimization studies, long-term investigations, and life cycle assessment studies. We may further improve the qualities of RAC and aid in the creation of more high-performing and sustainable concrete materials by tackling these issues and concentrating on these future research directions.

To sum up, research on the application of nanomaterials in RAC is exciting and could have a big impact on concrete technology in the future. It offers a chance to improve the performance of concrete materials in addition to addressing environmental issues related to construction waste and the depletion of natural resources. Future concrete materials will likely be more high-performing and sustainable with ongoing research and development.

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