Review Article

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Reviewing the Role of Nano-alccofine and Superplasticizers in Enhancing Mechanical Properties of Recycled Concrete

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ABSTRACT

India has a population of 1.4 billion, raising the question of how to accommodate this growing number of people within the available land mass. Various construction projects are being carried out that contribute to the generation of significant amounts of demolition waste globally. Although the Bureau of Indian Standards allows the use of up to 25% recycled aggregates in concrete, research on the recycling and reuse of this debris has been limited. Recycling these materials to produce sustainable concrete is feasible. However, construction and demolition waste (CDW) often represents one of the most expensive types of waste to dispose of in landfills, a common practice in many countries. Moreover, there are very few regulations governing the reuse of this debris. Reusing CDW can significantly reduce the carbon footprint of the construction sector. This review paper summarizes the published literature of various researchers who have highlighted the importance of using CDW in concrete and examined various treatments that can enhance the fresh, mechanical, and durability properties of concrete. It also provides an overview of the use of nano Alccofine in concrete, explaining how it can be combined with supplementary cementitious materials (SCM) to improve the alkali activation of demolition waste. Furthermore, the paper discusses the impact of superplasticizers on recycled demolition waste. The paper outlines potential future research directions regarding the use of CDW and ultrafine SCM to produce sustainable concrete.

Keywords: Nano-Alccofine; Construction waste; Recycled aggregates; Sustainable concrete; Cementitious materials.

1. INTRODUCTION

Concrete is a vital material in construction, even for small residential buildings. However, achieving sustainability poses challenges as the industry works towardsthe Sustainable Development Goals (SDG). Concrete production releases significant carbon dioxide emissions, and demolition waste contributes to landfill pollution. Moreover, the energy-intensive process of cement production greatly impacts the environment due to its associated carbon emissions. The Construction and Demolition Wastes (CDW) are created due to waste building materials obtained from the construction, alterations, repairing, retrofitting, and demolishing operations of all infrastructure elements. The management of CDW waste in India is a significant concern due to the large volume of waste generated and the environmental harm caused by improper disposal. Addressing the challenges associated with CDW management is urgent and it is essential to foster collaboration among the government, the private sector, and the community to achieve sustainable solutions. (Tapkire and Ranjankumar, 2023). In India alone, there are approximately 530 tons of CDW waste produced according to the International Conference on Interdisciplinary Approaches in Civil Engineering for Sustainable Development. Concrete waste is the primary type of construction and demolition waste produced by the industry, frequently ending up in landfills. Recycling it into Recycled Concrete Aggregates (RCA) for use in concrete production can support environmental conservation (Ahmed *et al.* 2020). Construction and demolition waste constitutes more than 30% of the solid waste stream in India, is often neglected and loses its recycling potential (Devi *et al.* 2021). The shortage of usable aggregates in civil construction has made recycled aggregates from CDW a viable alternative. The CDW concrete offers lower densities and enhanced resistance to chloride penetration compared to conventional concrete, with minimal loss of mechanical strength. Given the high costs of raw materials and the need for sustainable development, recycled CDW aggregates are effective for use in mortars and concrete (Souza *et al.* 2021). The use of Recycled Aggregates (RA) and Recycled Concrete Powder (RCP) from CDW offers key benefits. It helps preserve natural aggregate sources, reduces landfill use, and supports a more sustainable built environment. Replacing some cement with RCP can reduce the carbon footprint of the construction industry, and RCP can also be used to create valuable construction materials (Ibrahim *et al.* 2023).

A practical solution for reducing global CO_2 emissions, land degradation, and water pollution from concrete production is to use recycled materials in construction. This strategy can significantly reduce the environmental impact of the industry. Key methods include utilizing waste materials, adopting green concretes to reduce energy consumption, and integrating recycled materials to foster eco-friendly practices. Reusing or recycling construction and demolition waste can significantly reduce its negative environmental impact. The reuse of recycled materials in construction is based on life cycle assessment for effective environmental management. The policy focuses on three key aspects: ensuring quality, reducing environmental impact, and managing costs (Xu *et al.* 2020). Cement manufacturing emissions can be reduced by replacing up to 15% of cement with Alccofine, a by-product derived from glass-based powder processed from iron and steel factories. This recycling of industrial waste provides various technical, economic, and environmental benefits while helping to reduce CO_2 emissions (Sachdeva and Sharma, 2020). Alccofine is a finely Ground Granulated Blast furnace Slag (GGBS) with particle sizes under 20 microns and a specific surface area of 3000 to 5000 m^2/kg. It improves workability and reduces the water content in concrete due to its ball-bearing effect. This material acts as a good pozzolanic material due to the 80% content of silica. Concrete cast with Alccofine is more durable due to the absence of bleeding and segregation in it (Singh and Lalotra, 2022). Ambuja Cement Ltd. and Alcon Group Goa have a joint venture that produces ultrafine slag under the brand name Alccofine. There are two main types: Alccofine 1101, which contains high calcium silicate and is used for rock anchoring and soil stabilization, and Alccofine 1203, a slag-based supplementary cementitious material known for its ultrafine nature and optimized particle size distribution. The Alccofine 1200 series includes Alccofine 1201, 1202, and 1203, which represent fine, microfine, and ultrafine particle sizes, respectively. Both Alccofine and metakaolin can replace up to 14% of cement in M40 grade concrete, providing good compressive strength. Alccofine 1203 has high reactivity due to the controlled granulation of slag with a high glass content. This low calcium silicate material improves workability and compressive strength, even with low water content. It is processed by Counto Micro Fine Products Pvt. Ltd. and meets the ASTM C989-99 standard.

1.1 Research Contributions

This study evaluates the feasibility and effectiveness of using CDW and ultrafine materials like Alccofine in producing sustainable concrete. Key contributions include:

- Demonstrating the enhanced performance of recycled concrete through pretreatment techniques such as grinding, alkali activation, and acid presoaking.
- Establishing the role of ultrafine Alccofine and other SCM in improving the microstructure and durability of concrete.
- Highlighting the positive effects of polycarboxylated superplasticizers in achieving improved workability and mechanical properties in CDW-based concrete.
- Exploring innovative techniques such as Alkali-Activated Materials (AAM) and geopolymers for high-Strength and eco-friendly concrete production.
- Providing evidence of reduced carbon footprints and improved circular economy practices through the recycling of CDW.

1.2 Research Gaps

Despite advancements, several gaps remain:

- Limited large-scale application and regulatory frameworks in countries like India.
- Inadequate research on the synergistic effects of combining ultrafine SCM, fibers, and recycled aggregates in different ratios.
- Lack of comprehensive studies on the long-term durability and structural performance of CDW-based concrete under various environmental conditions.
- Minimal investigation into advanced mechanical and chemical treatments to optimize ITZ quality in recycled aggregates.

2. REVIEW METHODOLOGIES

The integration of CDW into concrete demonstrates promising potential for sustainable construction. Effective pretreatment methods, including alkali activation, grinding, and acid presoaking, enhance the quality of Recycled Aggregates (RA) by improving their mechanical properties and reducing impurities. These treatments also refine the Interfacial Transition Zone (ITZ), a critical component affecting the durability of concrete. The use of Alccofine, an ultrafine supplementary cementitious material, complements CDW by refining the microstructure, increasing strength, and reducing porosity. For high-grade concrete mix designs, incorporating CDW requires optimized water-cement ratios and the use of tertiary blend cement compositions (OPC, fly ash, and Alccofine) to achieve desired mechanical and durability properties. In High-Performance Concrete (HPC), poly-carboxylated ether-

based super plasticizers ensure excellent workability and enhanced particle dispersion, countering the performance challenges of recycled materials. Innovative solutions like geopolymers and AAM provide eco-friendly alternatives, utilizing aluminosilicate-rich demolition waste to create dense, durable binders with superior resistance to chemical attacks. By addressing both mechanical and environmental concerns, these advanced methodologies enable the production of high-quality, sustainable concrete. Future research should focus on optimizing cost efficiency and scalability, making these technologies universally accessible.

3. OVERVIEW

3.1 Feasibility and Enhancements in Using Construction Demolition Waste in Concrete

The generation of waste is a significant issue in civil construction, along with the heavy consumption of aggregates, which are among the most widely used mineral inputs globally. Portland cement concrete, the main material in this industry, usually comprises about 42% coarse aggregate, 40% sand, 10% cement, 7% water, and 1% chemical additives per cubic meter. As the second most consumed material worldwide, the high usage of concrete leads to substantial environmental impacts from mineral extraction. The rise in population over the past decade has led to a trend in constructing multi-story buildings, such as apartments. This demand often results in the demolition of old structures, creating significant amounts of CDW. Unfortunately, this waste is frequently disposed of improperly, contributing to environmental degradation. Chennai, one of South India's most populous cities, generates substantial CDW, which poses risks to both the environment and public health (Haither-Ali and Anjali, 2024).

The RCA can weaken the matrix, but adding 30% ultrafine materials increases the number of nucleation sites in the ITZ, resulting in a denser structure. This allows up to 100% replacement of RCA, enhancing the mechanical properties and durability of Recycled Glass Polymer Concrete (RGPC) while reducing vulnerability to water and chloride attacks (Kumar and Mishra, 2022). Sustainable materials like fly ash, GGBS and demolition waste were used in M40grade concrete. The results indicated that using 50% demolition waste as a replacement for fine and coarse aggregates led to higher compression, split tensile, and flexural strengths compared to a 100% replacement. In self-compacting high-strength concrete, replacing up to 50% of the aggregate with Recycled Rubber Coarse Aggregate (RRCA) enhances mechanical and microstructural properties, resulting in reduced porosity compared to traditional RCA. When SCM is used with Recycled Aggregates (RA) in the production of HPC, resistance can be achieved in chloride ion penetration up to 47% (Bušić *et al.* 2018). Glass waste and alkali-rich cement fragments in recycled aggregates increase the risk of alkali-silica reaction expansions. Recycled aggregates with densities ranging from 860 to 2300 kg/m³ were tested in lean and rich concrete mixes. The lean mix had a Water-to-Cement (W/C) ratio of 0.5 with 300 kg/m³ of cement, while the rich mix had a W/C ratio of 0.3 with 500 kg/m³ of cement. The compressive strengths were 56 MPa for RCA1 and 26 MPa for RCA2, based on the quality of the mortar in the aggregates. The size of the coarse aggregate has a great impact on the mechanical properties of concrete (Liu *et al.* 2022).

Recycled aggregates combined with silica fume enhance the sulphate resistance and contribute to high-strength concrete. Cement mortar was tested with CDW as a sand replacement at levels of 25%, 50%, and 75%. The incorporation of the burnt clay brick waste showed only a slight reduction in strength against acid and alkaline chemicals, similar to the control mortar. The results indicate that CDW can enhance the stability of cement mortar (Tam *et al.* 2018). Crushed stone aggregates can be replaced with concrete aggregates recycled with compressive strengths of 45 MPa and 85 MPa at proportions of 50% and 100%. To achieve high-performance concrete, 2% steel fibers are added and some mixtures include granulated blast furnace slag (GGBS) as a cement substitute. Tests of electrical resistivity, drying shrinkage, and water absorption reveal that high-performance concrete can be made using these recycled aggregates. The addition of steel fibers and GGBS enhances the mechanical properties of RCA. Using 50% recycled aggregates led to a 141% increase in electrical resistivity at 28 days and 149% at 90 days. However, using 100% recycled concrete aggregate resulted in a 71% increase in drying shrinkage, a 54% increase in water absorption, and a 51% reduction in electrical resistivity (Akhtar and Sarmah, 2018).

3.2 Effect of Nano Alccofine in Concrete

Alccofine can serve as a third-party material that consumes calcium hydroxide during cement hydration, forming gel-like pozzolans similar to C-S-H (Mani *et al.* 2023). The replacement of 14% of the cement with Alccofine in the M20 and M30 concrete resulted in compressive strengths of 19.26 MPa and 41.11 MPa, respectively. Alccofine, made from iron oxide, sulfur trioxide, silica, magnesia, alumina and calcium oxide combined with fly ash, is a highly durable concrete composite. We use 15% Alccofine as a cement substitute in our mix to achieve the desired strength while also enhancing workability (Kumar *et al.* 2024). Alccofine can replace up to 8% of cement in concrete; beyond this, insufficient binder may occur due to a lower W/C ratio in high-strength concrete. Combining bagasse ash with Alccofine can increase compressive strength by 13% and reduce costs by 1.3% in M70 high-strength concrete. Seven binder proportions were developed to evaluate the Standard Consistency (SC), Initial Setting

Time (IST), and Final Setting timE (FST) of Alccofine-1203 binders, along with the mechanical properties of High-Strength Concrete (HSC) using 4% to 14% Alccofine as a cement replacement. While higher Alccofine levels slightly increased SC and decreased IST and FST, compressive and tensile strengths improved with 4% to 10% replacement but declined at 12% and 14%. Alccofine (1203) was used at varying percentages (0%, 5%, 10%, 15%, and 20%) with 30% Ground Granulated Blast-furnace Slag (GGBS) for M60grade concrete with a W/C ratio of 0.3. A superplasticizer was added for improved workability. Concrete with 30% GGBS and 15% Alccofine exhibited compressive, split tensile, and flexural strengths that were 12%, 19% and 25% higher than conventional concrete, demonstrating enhanced strength and durability (Shi *et al.* 2016). Alccofine can replace up to 15% of Ordinary Portland Cement (OPC) in high-grade concrete like M60 due to its silica and alumina content, which aids in forming Calcium Silicate Hydrate (CSH) gel and Calcium Aluminum Silicate Hydrate (CASH) gel. In Mix-3 for M80 grade concrete, with 22% fly ash and 8% Alccofine, a compressive strength of 93.52 MPa, a split tensile strength of 9.8 MPa, and a flexural strength of 7.9 MPa were achieved, along with resistance to sulfuric acid attack. The mechanical behavior of the concrete with Alccofine was consistent and its chemical resistance was satisfactory. Alccofine is a suitable substitute for silica fume due to its favorable composition. The replacement of 8% to 12% of cement with Alccofine is recommended. The enhanced workability of Alccofineover silica fume is attributed to the latter's high water demand, as indicated by its higher Loss On Ignition (LOI) value of 4.96, compared to the lower LOI of Alccofine at 1.76. Alccofine is effective in Ultra-High-Performance Concrete (UHPC), providing improved workability and mechanical strength.

3.3 Alkali Activation, Grinding, and Acid Presoaking in CDW Treatments

Alkali-activated mortars and concretes have gained increased attention due to their potential to offer a more sustainable alternative to traditional ordinary Portland cement mixtures. Furthermore, incorporating high volumes of recycled materials into these conventional mortars and concretes presents specific challenges (Miraldo *et al.* 2022). Alkali-activated materials, when combined with recycled aggregates, can serve as environmentally friendly substitutes for traditional concrete. A mixture of sodium hydroxide and sodium silicate was used, and this was shown to produce high strengths, up to 70 MPa at 28 days; the optimal alkali modulus and dosage combinations have a maximum strength of 70 MPa around an alkali dosage of 12.5% and an alkali modulus of 1.25. Partial FA replacement with GGBS leads to increases in compressive strength (Abdollahnejad *et al.* 2019). To improve the quality of recycled concrete aggregates and remove the surrounding mortar layer, several techniques can be used, such as mechanical grinding, acid presoaking, polymer emulsions, activated carbonation, heat treatments, and coating with cement or fly ash paste. Economic factors should be considered when selecting pretreatment methods. Recycled concrete aggregates can replace natural coarse aggregates from 30% to 100%, but it is recommended to limit the replacement ratio to 25% to maintain concrete properties. Using 100% recycled aggregates can decrease mechanical properties by 10% to 30% and may double absorption capacity compared to standard concrete. Mechanical grinding, or autogenous cleaning, involves manually removing non-mineral fractions from aggregates, grinding the debris, and sieving to separate fine materials like sand from coarse ones. This process reduces aggregate porosity and water absorption. Alkali activation with 8% Na_2O and curing at 700 ℃ for 24 hours greatly enhances the compressive strength of recycled brick demolition waste concrete. The issues of reactivity and durability of RA in alkali-activated concrete are shown in Fig. 1 (Abdollahnejad *et al.* 2019; Makul *et al.* 2021).

Table 1. Proposed solutions to mitigate durability issues in alkali-activated concretes with RA (adopted from Abdollahnejad *et al.* 2019)

Durability Index	Proposed Solutions
Water absorption, porosity, sorptivity	The moisture state of RA should be approximately 80% or pre-saturated
	Staged mixing approach could be used
	Limit RA content
	Use small size RA
Chloride and sulfate diffusion	Use of 25-75 wt % of RA
	Increasing sodium silicate to sodium hydroxide ratio
Acid resistance	Using recycled bricks instead of crushed old OPC concretes as RA
	Use reactive additive to enhance binder properties
Freeze and thaw resistance	Using crushed old OPC concretes instead of recycled bricks as RA
Hardened state Properties	**Proposed solutions**
Mechanical strength	Using less than 50% RA (25 to 40 wt %)
	Adding slightly larger quantity of cement (-5%) in the cementitious compositions
	The improvement at the ITZ by focusing on the quality and strength of RA and the properties of alkaline solutions
	Adjustment of water demand of RA with using (1) pre-saturation and (2) the addition of more water during the mixing procedure
	Using thermal curing conditions with a temperature of 60-70°C
	Increasing the molarity of sodium hydroxide up to a certain point
	Using carbon dioxide sequestration as a treatment approach for RA
Shrinkage	The internal curing action using RA with a diameter less than 2mm
	Replacing RA up to 30% (wt%)

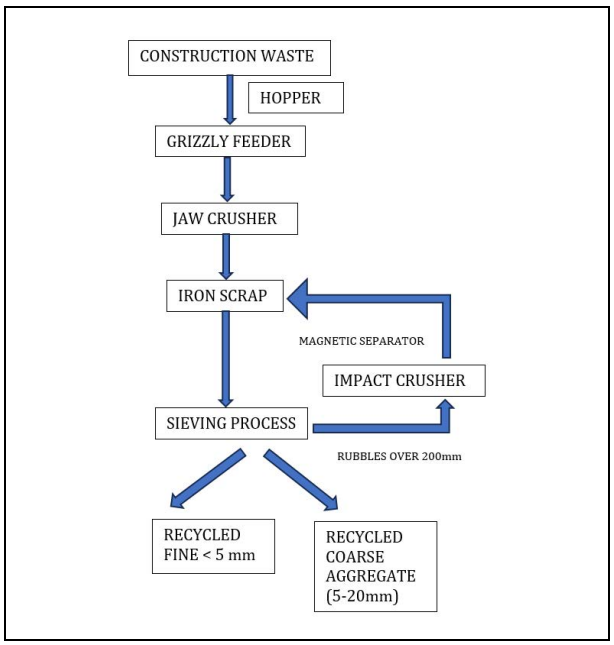


Fig. 1: Flowchart showing Mechanical recycling of CDW (Abdollahnejad *et al.* 2019)

3.4 High-grade Concrete Mix design considerations along with CDW

The impact of the W/C ratio on the workability and mechanical properties of M70 high-strength self-compacting concrete is studied, with optimal results achieved at a W/C ratio of 0.23 using a mix of fly ash and micro silica (Falmata *et al.* 2020). The same grade of concrete with silica fume and superplasticizer showed a decrease in compressive strength at 28 days. Crushed Clay Brick Aggregate (CCBA) partially replaced natural sand at levels of 10%, 20%, 30%, 40% and 50%, using the same ratios of granite, water, and superplasticizer as the control mix. The compressive strength for the mixtures with 30%, 40%, and 50% CCBA and 10% calcined clay was 4.9%, 8.7% and 13% lower, respectively, than the control mix. To tackle porosity and density issues in recycled aggregate concrete, this study used RA with an 80 to 90% moisture content, soaking them for 5 hours before mixing (Raman *et al.* 2021). Alccofine can replace 12% to 16% of cement, enhancing slippage strength and increasing bond strength. In both M20 and M60 concretes, optimal bond strength is achieved at a 12% replacement of Alccofine (Zeng, 2022). The cement was replaced with 30% GGBS, and the Alccofine content ranged from 5% to 20%. The slump flow increased linearly with the Alccofine content, with the optimal results achieved at 30% GGBS and 10% Alccofine. To allow more optimum mix design, three tiers, including cement paste: cementitious materials + water + any superplasticizer added, mortar: cement paste + aggregate particles smaller than 1.2 mm, and concrete mix: mortar + aggregate particles larger than 1.2 mm. During the mixing and placement of concrete mixes, it is observed that even when the concrete mix shows serious signs of segregation, aggregate particles smaller than 11 mm tend to stay in the cement paste. The machine learning process used a dataset of concrete mixes designed for compressive strengths of 28days between 60 MPa and 82 MPa. It included cylinder strength measurements from the ACI and Aïtcin methods, as well as cube strength measurements from the modified Design of Experiments (DOE) method. Tree models and MATLAB were used to visualize the tests, with over 600 mix design models analyzed (Olofinnade and Ogara, 2021). According to this input, the artificial neural networks and fuzzy logic models predict the compressive and splitting tensile strength values from the mechanical properties of recycled aggregate concretes containing silica fume. The models of the training and testing results have shown that artificial neural networks and fuzzy logic systems have strong potential for predicting 3, 7, 14, 28, 56 and 90 days compressive and splitting tensile strength values of recycled aggregate concretes containing silica fume listed in Table 1 (Salimbahrami and Sakeri, 2021).

Table 2. Mix proportions with varying water-to-cement ratios and M70 concrete with CDW compressive strength at 28 days (Balamuralikrishnan and Saravanan, 2019)

Mix	Concrete Mixes Respect to W/C ratio (kg/m^3)					M70 Grade Mix
	0.23	0.24	0.25	0.26	0.27	0.27
C	574	574	574	574	574	
FH	41	34.3	27.6	20.9	14.2	584.19
MS	40.18	40.18	40.18	40.18	40.18	
FA	844.18	844.18	844.18	844.18	844.18	650.96
CA	805.32	805.32	805.32	805.32	805.32	1135.73
W	140.68	143.82	146.97	150.11	153.25	
SP	11.07	10.95	10.83	10.71	10.59	165.56
VMA	1.72	1.72	1.72	1.72	1.72	

C - Cement, FH - Flyash, MS - Micro Silica, FA - Fine Aggregate, CA - Coarse Aggregate, W - Water, SP - Super Plasticisers, VMA - Viscocity Modifying Admixtures

3.5 High-performance Concrete using Tertiary Blend Cement Composition

Three types of blended cement can enhance the workability of recycled aggregate concrete. A mix of 40% recycled fine and normal aggregates was used to produce M50, M60, and M70 grades. Bagasse ash was added, reducing theinitial strength, while nano silica (12 nm particle size)and superplasticizer (1.42 to 2.97 L/m³) resulted in a slump of 150-180 mm. FRC grade M70 concrete was produced by replacing cement with Alccofine (5%) and GGBS (25%). Using recycled aggregate for 20% of the coarse aggregate showed positive results when steel fibers were added at 1.2% of

the cement weight, along with Auramix at 1% (Azam *et al.* 2020). Sixteen mortar mixes were considered to finalize the optimal binder and sodium silicate/sodium hydroxide ratios for hardened High-Strength Geopolymer Concrete (HSGPC) using Ground Granulated Blast furnace Slag (GGBS), Fly Ash (FA), and Silica Fume (SF) as binders, along with Manufactured Sand (MS) as fine aggregate, to evaluate the performance of fresh and HSGPC. The maximum compressive strength achieved was 104 MPa. Microstructural analysis of the HSGPC indicated that the improvement in mechanical properties resulted in a dense microstructure featuring various gel formations such as CSH, CASH, and Sodium Alumino Silicate Hydrate (NASH) gels. Additionally, there was a remarkable 90% reduction in carbon footprint (Jagad *et al.* 2023)

When a tertiary blend was mixed with a combination of GGBS, cement and Alccofine in a proportion of 8%, 10%, 12% and 14%, keeping GGBS constant, its compressive strength values were found to be lower than those of the conventional concrete mix. This shows that the combination of GGBS and Alccofine as a replacement for cement would not be useful in the formation of Ternary Blended Concrete (TBC). Still, a similar blend produces good workability and good split tensile strength until 90 days under normal curing conditions. The DOE results indicated that a dose of 6% silica fume and 8% Alccofine achieved maximum compressive strength (Mohan and Mini, 2018). The mechanical properties of ultra-high-performance concrete (UHPC) were evaluated using quartz powder, ground granulated blast furnace slag, and Alccofine or silica fume, with coarse aggregates limited to 6 mm and 10 mm. The results showed that UHPC with Alccofine achieved a compressive strength of 136.67 MPa, a splitting tensile strength of 15.2 MPa, and a flexural strength of 31.88 MPa after 28 days of normal curing, outperforming mixtures with silica fume. The combination of fly ash and Alccofine significantly increases compressive and split tensile strength. When the fly ash content rises from 350 kg/m³ to 370 kg/m³, notable improvements are seen under both ambient and heat-cured conditions. Specifically, increasing fly ash from 350 kg/m³ to 400 kg/m³ results in a 56% increase in ambient conditions and a 71% increase in heat-cured conditions. These gains are particularly pronounced at 900°C with Alccofine. A concrete mix with 30% recycled aggregates, silica fume and a W/C ratio of 0.3 achieved compressive strengths of over 70 MPa at 28 days, aided by a superplasticizer. Finite element analysis indicated that recycled gravel reduces strength by no more than 17% for a target strength of 70 Mpa (Liu *et al.* 2022).

3.6 Geopolymers and Alkali Activation in Demolition Wastes

Geopolymers are alkali-activated materials formed by polymerizing aluminosilicates using highly alkaline liquids and soluble silicates. The geopolymerization mechanism greatly depends on the type of alkaline activator and the chemical composition of precursors (Guneyisi, 2020). Alkali activation results in a hardened binder formed from a combination of hydrous alkali-aluminosilicate phases. Ordinary Portland Cement (OPC) was mixed with RCBW and CW in proportions of up to 30% to create hybrid cement. The AAC obtained with the RCBW, the CW and the Glass Waste exhibited maximum compressive strengths (28 days) of 102, 33 and 57 MPa, respectively. Alkali-activated concretes are made from aluminosilicate precursors like fly ash and metakaolin, alkali activators such as sodium hydroxide and sodium silicate, and aggregates (Guo *et al.* 2023). High concentrations of sodium hydroxide (12 M and 16 M) outperformed the 8 M concentration in strength and durability. The sodium silicate had 12.5% Na_2O, 30.2% SiO_2, and 57.2% H_2O. In contrast, sodium hydroxidewas used at 8 M, 12 M, and 16 M. Geopolymer concrete with recycled concrete aggregate achieved a compressive strength of 30.6 to 38.4 MPa, which is about 76% to 93% of the strength of geopolymer concrete with crushed limestone (Casanova *et al.* 2021).

The feasibility of replacing ultrafine materials for fly ash @ 0, 15, and 30% along with recycled demolition waste was studied; activator solution 12M sodium hydroxide solution was mixed with sodium silicate yielded the best characteristics in geopolymer concrete. The study examined the impact of the Na_2SiO_3/NaOH ratios and NaOH molarity on the compressive strength of geopolymer concrete. It was found that a 16M NaOH solution achieves high compressive strength when the SiO_2/Na_2O ratio in Na_2SiO_3 is between 2.00 and 2.40 and the Na_2SiO_3/NaOH ratio is 2.5. Ground granulated blast furnace slag can be activated with Na_2SiO_3 and Na_2CO_3, but only for C33/43 grade cements. This combination reduces porosity and enhances resistance to chloride attack, although the strength gain is minimal (El-Inaty *et al*. 2024). The slump values increased by 15% when the molarity of sodium hydroxide and sodium silicate changed from 16M to 8M; this shows that workability decreases with an increase in the concentration of the alkaline solution. Geopolymer mortars have obtained a high 28-day compressive strength of 86.0 MPa when activated with NaOH and Na_2SiO_3. The results indicate that the setting time of the paste decreases with an increase in fly-ash fineness. NaOH and Na_2SiO_3 solutions are denser than water, making the GPC more cohesive and stickier than conventional concrete (Waqas *et al*. 2021).

To improve the workability of the fresh geopolymer mix,a naphthalene sulphonate-based water-reducing superplasticizer of IS 9103:1999 can be used (Gupta and Rathore, 2024). A mixture of concrete,

ceramics, masonry, and CDW, was geopolymerized with NaOH and Na_2SiO_3. The mortars with the highest compressive strengths were recorded for the AA 0.4 RFA 1:1 mixture, showing 13.9 MPa, 30.9 MPa, and 40.5 MPa at 7, 28, and 90 days, respectively. The modulus of rupture at 28 days for the various polypropylene contents was 2.3 MPa, 2.7 MPa, and 3.3 MPa, respectively. Life cycle analysis indicated that the carbon footprint for the 450, 550, and 650 kg/m³ concrete was 215.2, 261.0, and 306.8 kg CO_2 equivalent per cubic meter of concrete, respectively (Robayo-Salazar *et al.* 2022). Alkali-activated CDW mortars using a mixture of NaOH and sodium silicate as an activator produced 18 MPa after 3 days of curing at 65°C. When BFS was added as part of the precursor, improvements in mechanical strength occurred, with values above 55 MPa after 7 days of curing at 65°C (Borrachero *et al.* 2022).

3.7 ITZ of RA Aggregates

The Inter-Transition Zone (ITZ) of the Recycled Dewatered Waste (RDW) matrix is influenced by the strength of the aggregates and the bonding properties of both the old mortar and the new mortar. Prewetting and saturating the RDW aggregates in a solution of activated sodium silicate and sodium hydroxide can enhance the microstructure of ITZ. A formula for ITZ thickness was simulated using concrete models and ABAQUS finite element analysis. The findings reveal that thicker ITZ significantly reduces the cracking strength of recycled concrete. Specifically, an ITZ thickness of up to 2 mm and a 30% replacement rate of recycled aggregates showed notable strength. The mechanical properties of RCA and RCBA in ITZ were found to have 22-49% higher tensile strength than normal aggregates. Microhardness and Scanning Electron Microscope Back-Scattered Electron (SEM-BSE) techniques show 15%, 8%, and 30% 7-day strength reductions for RCA, RBCA and RBA concrete, respectively (Auliya *et al.* 2025).

Treated recycled aggregates, when soaked in mild acetic acid, result in the removal of adhesive mortar. Along with mineral admixture like PPC and silica fume improves the ITZ of the microstructure and also shows better results than untreated recycled aggregates. Prewetting recycled aggregates increases the intensity of workability by 50-60 % and also produces strength up to 82.7 Mpa. The ITZ was the weakened when the W/C ratio increased, leading to macrospores and porosity. The study examined the compressive and flexural strengths of RCA with different dosages of nano-silica and nano-calcium carbonate. The addition of NS improved the microstructure and reduced porosity in the ITZ. In contrast, NC-modified RCA had larger pores, negatively affecting its mechanical properties. Moreover, incorporating Mineral Aggregate Replacement (MRA) increased the porosity of ITZ by 190%. However, adding silica fume mitigated this effect, reducing porosity by 32% compared to MRA alone, as it fills pores in the ITZ when used with polycarboxylate superplasticizers (Vázquez-Rodríguez *et al.* 2020).

3.8 Effect of CDW and Nano-alccofineon Concrete

Various proportions of M40grade concrete were tested using fly ash and Alccofine as cement replacements and recycled demolition waste as aggregates. The slump of the concrete decreased with increasing Alccofine due to its high-water absorption. Compressive and flexural strength improved with up to 10% Alccofine but dropped when recycled aggregates exceeded 25%, attributed to weaker bonding. The split tensile strength was optimal with 50% recycled aggregates and 10% Alccofine. A total of 12 M40 grade concrete mixes were prepared using glass fibers at 0.25%, 0.50%, and 0.75%, with 10% Alccofine and Recycled Concrete Aggregate (RCA) replacements of 25%, 50%, 75%, and 100%. The addition of 10% Alccofine improved the compressive strength of the RCA by 11%. The mixture with 100% RCA, 10% Alccofine, and 0.50% glass fiber achieved a compressive strength of 51.38 MPa, exceeding the target strength. Recycled Coarse Concrete Aggregates (RCCA), carbonation treatment, and Alccofine effectively improved the workability, ITZ, density, and water absorption of the concrete mix CRCCA100. At 28 and 90 days, the compressive strength of concrete with carbonated RCCA was similar to that of natural aggregate concrete. Furthermore, using RCCA can reduce production-related CO_2-equivalent greenhouse gas emissions by up to 21 kg. Alccofine (AF) increases compressive strength and improves the mechanical and durability properties of recycled aggregates (Vivek *et al.* 2023). The cracking moment of beams made with 100% RCA is enhanced by mineral admixtures and a two-stage mixing approach, which strengthens the bond between the ITZ and the concrete. Consequently, the loadcarrying capacity and deflection of Alccofine and RCA beams improve with the addition of mineral admixture (Ababneh *et al.* 2020).

3.9 Effect of Polycarboxylated Ethers in HPC

Polycarboxylate ether (PCE) improves the quality and workability of high-performance concrete when combined with Alccofine. It adheres to cement particles, preventing aggregation and enhancing dispersion, which reduces the water needed for workability. This results in a more compact and dense mix with better strength, durability, and lower permeability. In Alccofine concrete, the optimal PCE dosages are 0.3% for compressive and rupture strength and 0.4% for split tensile strength. Exceeding these amounts may reduce concrete strength. Workability and strength tests were performed according to NP EN 12350-2, NP EN 12390-3, and NP EN 12390-6 to evaluate additives of lignosulphonate and polycarboxylic polymers. Wear resistance to abrasion was assessed using

the German standard DIN 52108. The 0.5% polycarboxylic polymer superplasticizer proved more effective than lignosulfonate, and the use of rounder particles enhanced concrete performance (Dikshit *et al.* 2022). The mechanical and durability properties of 20 % AF and 40 % GGBS showed better results when 12.5mm normal coarse aggregates were used with polycarboxylic ether in UHPC mixture. Similarly, compared to binary blended UHPC, there was an improvement of about 73% in split tensile strength. The addition of mineral admixture also gave improved results for RCPT. It tends to fill all the voids present in the concrete mix, hence increasing the resisting power of the mix against chloride ions (Kumari and Kumar, 2024).

Replacing RCA with 10% micro-silica, fly ash, and natural zeolite reduced pore sizes and improved the ITZ. The mixtures had a W/C ratio of 0.36 and a cement content of 420 kg/m³, with PCE as a superplasticizer. Up to 30% zeolite replacement led to good mechanical properties but increased water absorption (Xuan and Jun, 2019). Alccofine concrete with various polycarboxylate SP, the strength increases by 9.37%, 17.91%, 15.25% at 7 days and 7.27%, 14.61%, 18.39% at 28 days when the PCE dosage was 0.2%, 0.3% and 0.4%, respectively. The flexural strength of concrete initially decreases as the PCE dose is maintained at 1.5%, and then increases when the dose reaches the optimal amount. Also, PCE allows for a 30% or more reduction in water content (Kumar *et al.* 2022). Polycarboxylate ether superplasticizers are carboxylic groups with comb-like molecular structures that can contain a high content of carboxylic groups and expect to adsorb strongly on CSH sheets (Fang *et al.* 2023).

4. CONCLUSION

The feasibility of using recycled aggregates to produce high-performance concrete is reviewed.The recycling of concrete debris can support environmental conservation and offers circular economy by preserving natural aggregate sources, reducing landfill use, and supporting a more sustainable built environment. Replacement of cement with Alccofine can lower the carbon footprint of the construction industry and can also be used to create valuable construction materials. Construction Demolition Waste (CDW) can replace 50% of cement, 19% of fine aggregates and up to 100% natural coarse aggregates with a little drawback of reduced workability and longer set time caused by the absorption of liquid phases in the concrete in CDW which can be activated through both mechanical and chemical methods. The simple processing, includes crushing, sieving, mechanical grinding, acid presoaking, polymer emulsions, activated carbonation, heat treatments, and coating with cement or fly ash paste, eliminating transportation costs from the RMC plant. Adding alkali-activated concretes decreases flowability and speeds up setting time for several reasons. High concentrations of sodium hydroxide (12 M and 16 M) outperformed the 8 M concentration in strength and durability. The NaOH solution of 16M achieves high compressive strength when the SiO_2/Na_2O ratio in Na_2SiO_3 is between 2.00 and 2.40, and the Na_2SiO_3/NaOH ratio is 2.5. Prewetting and saturating the RDW aggregates in a solution of activated sodium silicate and sodium hydroxide can enhance the microstructure of ITZ .The weak matrix at the nucleation sites of RCA, particularly in the ITZ, can be made denser by adding up to 30% ultrafine materials. These SCM helps in producing Self-Compacting Concrete (SCC), sulfate, and high-performance chloride-resistant concretes. The durability of concrete decreased slightly with 100% coarse fraction use and significantly with both fine and coarse fractions at 100%. Alkali-activated materials, when combined with recycled aggregates, can produce higher strengths of up to 70 Mpa.Ternary combination of GGBS, cement, and Alccofine produced less compressive strength, while the dosage of 6% silica fume and 8% Alccofine along with 30% RCDW achieved maximum compressive strength. Similarly, the combination of flyash and Alccofine also produced a good result. Recycled Coarse Concrete Aggregates (RCCA) and Mineral admixtures, when used along with polycarboxylate superplasticizers, fill pores in the ITZ, improves the workability and reduces the porosity of the concrete. There is limited research regarding the recycling and reuse of concrete debris in new concrete, and the various possible combinations mentioned above may facilitate producing new generation green concrete in achieving SDG 9,11, and 12.

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CONFLICT OF INTEREST

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