



Graphene oxide nano-engineered recycled aggregate concrete for sustainable construction: A critical review

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ARTICLE INFO

Keywords:

Recycled aggregate concrete (RAC)

Graphene oxide (GO)

Nanotechnology

Carbon emission

Sustainable construction

ABSTRACT

Graphene oxide (GO) has been generally accepted can improve the microstructure of concrete because it can promote cement hydration, this nano-enhancement strategy is valuable for improving the weak interfacial transition zone in recycled aggregate concrete (RAC). This paper review aims to provide a comprehensive understanding and comparison of the impact of GO on the performance and microstructure of RAC through various modification methods. Initially, the characteristics of GO and its utilization in preparing RAC are introduced. Subsequently, the effects of admixing GO on the performance of RAC and its roles within the RAC system are analyzed and discussed. Furthermore, an economic, environmental evaluation, and research limitations of GO-modified RAC are analyzed. Finally, the conclusions and potential research prospects for future investigations are outlined. The findings of this review have the potential to expand the understanding of GO-modified RAC and can serve as a source of inspiration for future research endeavors.

1. Introduction

In recent years, there has been a significant increase in the demolition of large-scale old concrete infrastructures in China, including buildings, bridges, and dams (Shi et al., 2016), consequently, this demolition activity has led to a substantial generation of construction and demolition (C&D) waste (Tam et al., 2007). According to previous literature (Xiao et al., 2018), it is reported that approximately 1.8 billion tons of C&D waste is accumulated each year, and waste concrete accounts for up to 80% of it (Wang et al., 2024a), having a great burden and negative impact on the environment (Yoda and Shintani, 2014). Recycling C&D waste is an effective strategy for reducing environmental stress and developing sustainable cement concrete (Ismail and Ramli, 2013), becoming a focal point of research efforts (Kim et al., 2018). As such, reusing concrete waste as recycled concrete aggregates (RCA) to prepare new recycled aggregate concrete (RAC) is a promising strategy for solving the plight of natural aggregate (NA) resource shortage and relieving environmental pressure (Pepe et al., 2014).

The presence of a layer of porous mortar adhering to the surface of RCA particles enables it to display characteristics, such as high water

absorption, porosity, and crushing index (Tian et al., 2019). As such, the incorporation of RCA in concrete results in the formation of multiple types of interfacial transition zones (ITZs) within the RAC system (Zhao et al., 2023; Sojobi et al., 2021). The defects of RCA particles and the presence of old mortar adhered to their surfaces can increase the potential for energy dissipation through friction under external loads (Wang et al., 2022a). This, in turn, can enhance the damping performance of concrete structures, thereby improving their safety in extreme environmental conditions (Wang et al., 2022b). Unfortunately, these characteristics often have a detrimental impact on the mechanical and durability properties of the concrete (Thomas et al., 2013). Therefore, addressing the poor mechanical properties and durability of RAC is of utmost importance (Xia et al., 2024). According to the existing literature (Shi et al., 2016; Al-Bayati et al., 2016), supplementary cementitious materials (SCMs) are typically utilized as substitutes for cement to enhance the properties of RAC, however, RAC-containing SCMs may face challenges such as low early-age strength and significant shrinkage issues (Bravo et al., 2015; Dimitriou et al., 2018). Furthermore, the significant costs associated with pre-processing and transportation are worth considering (Kisku et al., 2017). Especially, in certain countries

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<https://doi.org/10.1016/j.dibe.2024.100444>

Received 21 January 2024; Received in revised form 21 April 2024; Accepted 25 April 2024

Available online 27 April 2024

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like China, the price of SCMs has already reached or even exceeded that of cement, these factors collectively limit the practical utilization of SCMs in practical applications (Mohajerani et al., 2017).

Recently, it has been proven that using graphene oxide (GO) can increase the early-age compressive strength of cementitious composites due to the admixed GO can promote cement hydration (Lu et al., 2022a). Given that the mechanical strengths and durability of RAC are generally lower than those of traditional concrete, GO holds significant potential to enhance the performance of RAC (Lu et al., 2022b). Indeed, some attempts have indicated that the admixed GO can enhance the mechanical strengths (Lu et al., 2023a), sulfate attack resistance (Chiranjakumari Devi and Ahmad Khan, 2020), carbonation resistance (Devi and Khan, 2020a), and penetration resistance of RAC (Zhao et al., 2018). Additionally, adding GO to the RAC can improve the mechanical strengths of the RAC and thus augment the RCA usage and lower CO₂ emissions (Zhan et al., 2022). As such, GO-modified RAC can promote the practical applications of RCA and it can be regarded as a promising approach to consuming RCA resources (Alvi et al., 2023; Bahraq et al., 2022). However, the following key knowledge gaps outlined below hinder the practical applications of GO-modified RAC: 1) The aggregation issue of GO in the RAC system has not been effectively resolved. The tendency of GO to form aggregates within the RAC system poses challenges to achieving a uniform dispersion and optimal performance of GO-modified RAC; 2) An efficient modification method for incorporating GO into the RAC system has not been proposed. The development of a reliable and efficient method for modifying GO and ensuring its effective integration into the RAC matrix is crucial for achieving desired properties and performance; and 3) The impact of admixing GO on the workability, mechanical properties, and durability of RAC has yielded inconsistent findings. The reasons behind these discrepancies remain unclear, necessitating further research to comprehensively understand the effects of GO on the performance of RAC.

To fill the knowledge gaps and promote the practical applications of RAC, this review work summarizes and compares the published studies on GO nano-engineered RAC, and examines its potential applications in civil engineering. To gain an in-depth understanding and comparison of the impact of introduced GO on the performance and microstructure of RAC, this paper aims to systematically review the performance of GO-modified RAC prepared by different modification methods. First, the characteristics of GO and its usage methods in preparing RAC are introduced. Next, the admixed GO on the performance of RAC and its roles in the RAC system is analyzed and discussed. Subsequently, the economic and environmental evaluation of RAC and GO-modified RAC are compared. Finally, the limitations of previous studies and potential research prospects in the future are provided. The findings presented in this review can serve as a source of inspiration for future research endeavors in this field and advance the practical applications of GO-modified RAC, as well as unlock its full potential as a sustainable and high-performance construction material.

2. Methodology

This review work provides a comprehensive literature review on the recent advancements in GO-modified RAC. The data collected underwent a systematic analysis comprising several steps, including data collection; classification of the data based on specific topics; organizing the data in the form of tables and figures; describing and discussing the data and each topic, and drawing conclusions for each item and pointing out the limitations of previous studies and potential research prospects in the future.

Specifically, the data were obtained from a thorough literature review, focusing on the preparation process, performance analysis, and potential applications of GO-modified RAC. An overview was conducted based on the keywords "GO, RCA, RAC, modification methods, flowability, workability, mechanical properties, durability, enhancement mechanism, economic analysis, carbon emissions, etc.". The selected

research works were sourced from reputable scientific literature, including indexed journals that are relevant to mortar and concrete. The review encompassed sources such as ScienceDirect, Google Scholar, Scopus, Mendeley, ResearchGate, Taylor and Francis, Springer Link, and others.

3. Properties of GO and the preparation of GO-modified RAC

3.1. Properties of GO and the potential for improving the performance of RAC

GO also referred to as graphitic oxide or graphitic acid, is a compound consisting of carbon, oxygen, and hydrogen in varying proportions (Brittain et al., 2023; Shang et al., 2019). It is obtained by subjecting graphite to treatment with strong oxidizers and acids to eliminate excess metals (Ghahremani et al., 2022; Li et al., 2017). The resulting fully oxidized bulk product manifests as a yellow solid with a carbon-to-oxygen (C:O) ratio ranging from 2.1 to 2.9 (Jeong et al., 2022). Despite retaining the layered structure of graphite, the spacing between its layers becomes significantly larger and irregular (Myapati et al., 2021). GO nanosheets have found widespread application in the development of robust paper-like materials, membranes, thin films, and composites (Pei and Cheng, 2012). As illustrated in Fig. 1, GO garnered considerable attention as a potential intermediate for graphene production. However, graphene obtained through the reduction of GO retains certain structural defects. While these defects may be disadvantageous for certain applications, they can be advantageous for others, particularly in enhancing the microstructure and performance of cement concrete.

GO is a two-dimensional nanomaterial, having oxygen-containing graphene sheets, which is produced by the exfoliation of GO, based on the electrochemical method and Hummers' method (see Fig. 2) (Zhou et al., 2022; Yoo and Park, 2019). As can be seen in Fig. 2c, GO has a hydroxyl (O-H) group at its base and carboxyl and carbonyl groups (COOH- and C=O) at its edges (Zhao et al., 2018; Zhou et al., 2022; Dharmasiri et al., 2022), enabling it to have great potential to promote cement hydration (Gong et al., 2015). GO exhibits higher structural stability compared to graphene (Zhao et al., 2018), primarily attributed to the presence of oxygen-containing functional groups on its surface (Xu et al., 2019). These functional groups enhance the reactivity of GO, enabling potential reactions with other molecules (Wang et al., 2015). Furthermore, the incorporation of these functional groups increases the electrostatic repulsion between GO nanosheets, facilitating its dispersion in aqueous solutions (Hu et al., 2019a; Zhao et al., 2020a), as such, GO is easily dispersed in aqueous solutions to prepare high-quality dispersions for developing high-performance cement composites (Yan et al., 2020a). As shown in Fig. 3a, GO nanosheets exhibit chemical reactivity in the presence of liquid water, resulting in a negative charge

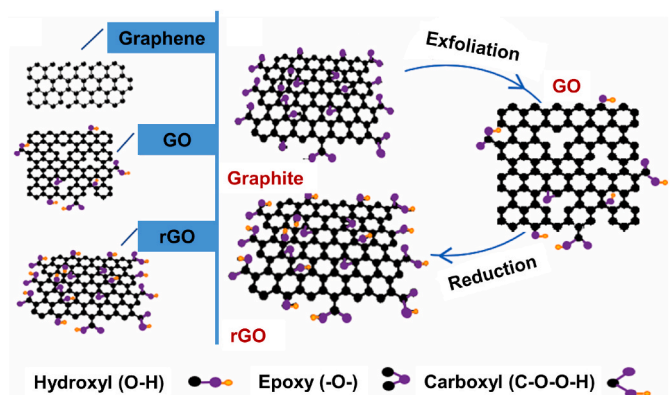


Fig. 1. Illustration of Graphene and its derivatives (Alvi et al., 2023). rGO is reduced graphene oxide.

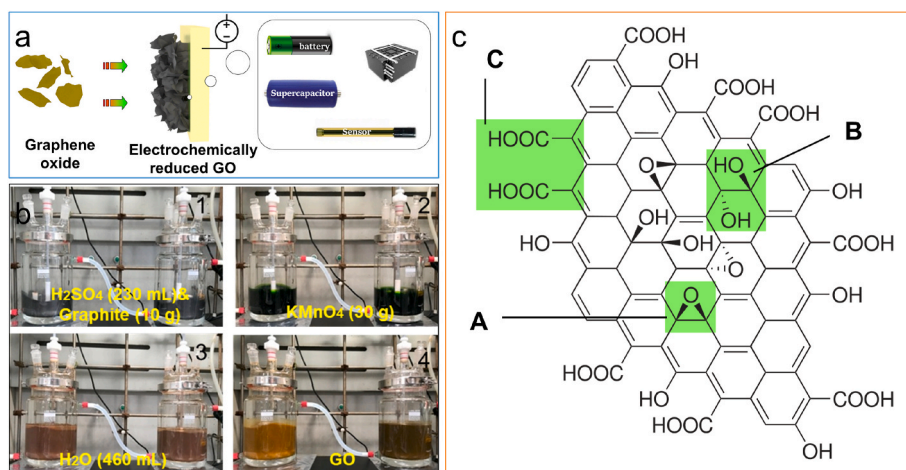


Fig. 2. (a) Electrochemically reduced GO (Zhou et al., 2022); (b) experimental procedure of GO synthesis (Yoo and Park, 2019); and (c) structure of GO. A: Epoxy bridges, B: Hydroxyl groups, C: Pairwise carboxyl groups.

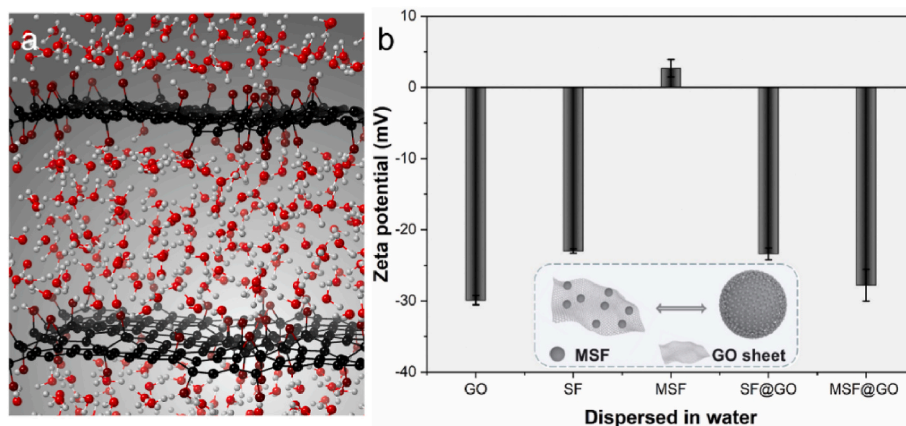


Fig. 3. (a) GO in water and (b) zeta potential of GO. SF is a silica fume, and MSF is a modified silica fume. The negatively charged GO can adsorb onto the MSF with a positive charge (Lu et al., 2022c).

on their surface (Lu et al., 2018a). This is reflected in the zeta potential of GO, which measures at -29.9 mV in deionized water (Fig. 3b) (Lu et al., 2022c), facilitating the interactions between the GO and cations generated during cement hydration.

Table 1 compares the physical properties of graphene and GO. As suggested in Table 1, GO exhibits a larger specific surface area of around 2600 m²/g and better surface chemical affinity than graphene (Shang et al., 2019; Pei and Cheng, 2012), this implies that GO can have more interactions with cement grains and have the potential to serve as nucleation sites for cement hydration, which gives GO the potential to promote cement hydration (Jing et al., 2020). Additionally, the presence of abundant oxygen-containing functional groups means that GO can react with cement hydration products (Lu et al., 2018b).

Table 1
Properties of graphene and GO.

Type	Thickness (nm)	Surface area (m ² /g)	Density (kg/m ³)	Tensile strength (GPa)	Aspect ratio	Refes.
Graphene	~0.08	700–1500	2200	~130	6000–600,000	Brittain et al. (2023), Jeong et al. (2022), Budde et al. (2016), Yan et al. (2020b), Guo et al. (2022)
GO	~0.67	2600	1800	~0.13	1500–45,000	Mypati et al. (2021), Li et al. (2022), Chuah et al. (2018)

3.2. Preparation of GO-modified RAC

3.2.1. Dispersion of GO in water and RAC

According to the existing literature (Zhao et al., 2018; Asadi et al., 2021; Balapour et al., 2018), the possible agglomeration of the admixed GO nanosheets within the cement matrix poses a significant challenge and can have detrimental effects on the properties of RAC. Specifically, the agglomeration of GO can impact the workability of fresh mixtures, resulting in increased viscosity and decreased slump (Lu et al., 2023b). Moreover, the presence of GO aggregation in cement composites can result in diminished mechanical properties and heightened transport properties (Hu et al., 2019a). Therefore, ensuring a high-quality dispersion of GO within the cement composites is essential for effectively enhancing their performance.

Table 2 presents a comprehensive overview of the dispersion methods employed for GO in water and the cement matrix. The widely adopted surfactant wrapping technique effectively mitigates the

Table 2
Dispersion of GO in water and cement matrix.

Dispersion approach	System	Description	Ref.
Ultrasonic dispersion	Water	Ultrasonic waves/energy can induce cavitation and exfoliation of GO sheets	Balapour et al. (2018)
Surface modification	Water/cement pore solution	The strong steric hindrance effects of GO can effectively separate it from charged ions.	Zhao et al. (2020a), Sharma and Kothiyal (2015)
Mechanical dispersion	Mechanical agitation	Applying a shearing force generated by mechanical friction, collision, and crushing can act on GO	Li et al. (2015), Pan et al. (2015)
	Ball milling		Kothiyal et al. (2016), Sharma and Kothiyal (2016)
Integrated dispersion approach	Cement matrix	–	Wang et al. (2015), Zhao et al. (2017a)

attractive forces between GO nanosheets, thereby enhancing the compatibility of GO with water (Zhao et al., 2018). This is achieved through charge repulsion or steric repulsion mechanisms, which depend on the molecular structure of the surfactants (Zhao et al., 2018, 2020b). Since GO is typically dispersed in water before its incorporation into cement, this section collects a detailed summary of its dispersion in water, cement pore solution, and the cement matrix, as shown in Table 2. To facilitate practical applications, surface active chemicals such as superplasticizers, shrinkage-reducing admixtures, and air-entraining surfactants are prepared in the form of aqueous solutions before being mixed with cement (Zhao et al., 2020b). In line with this concept, the preparation of a uniform aqueous dispersion of GO can greatly facilitate its utilization. However, it is crucial to acknowledge that achieving successful dispersion of GO in aqueous or pore solutions does not necessarily ensure its dispersion and stability within the cement

matrix (Lu et al., 2023c). The interactions and compatibility between GO and the cement matrix, as well as the processing methods employed, play a critical role in determining the uniform dispersion and stability of GO in the cementitious system (Chintalapudi and Pannem, 2020a). Further research is needed to investigate the strategies and techniques that can effectively promote dispersion and ensure the sustained stability of GO within the cement matrix.

3.2.2. Preparation of GO-modified RAC

Currently, the fabrication of GO-modified RAC includes two methods: directly mixing cement powder with GO suspension before mixing with aggregates and using GO suspension to pre-treating RCA particles (Lu et al., 2023a; Fan et al., 2017). Specifically, the direct mixing method is preparing GO suspension first and then adding GO suspension into cement during mixing and finally binding it with RCA particles (Hu et al., 2019a; Imanian Ghazanlou et al., 2020), as presented in Fig. 4. Based on the previous studies (Lu et al., 2023a; Chintalapudi and Pannem, 2020b; Kang et al., 2017), the combined usage of surfactant and mechanical stirring is the most used method in preparing GO suspension (Fig. 4c), and then mixing GO suspension with cement and RCA. In summary, the incorporation of GO in the cement matrix and then mixing with RCA to prepare the RAC mixture, method primarily aims to improve the cement matrix rather than effectively strengthen the ITZ region in the RAC system. Consequently, this approach proves to be inefficient. Furthermore, the complex pre-treatment procedures and associated additional costs, such as the use of surfactants and increased energy consumption, make this method unsuitable for practical applications.

Recently, our research group has proposed a novel method of nano-coating GO on the surface of RCA particles before their incorporation into new concrete production (Fig. 5) (Lu et al., 2023a). The primary objective of this approach is to enhance the ITZs of RAC with high efficiency, comparable to the improvements achieved through accelerated carbonation. Moreover, this method offers the advantages of simplicity and cost-effectiveness, with advancements in synthesis methods, the price of GO has fallen within the range of 50–60 \$/kg, and industrial-scale production has already been realized, greatly facilitating the practical implementation of this approach (Lu and Zhong, 2022).

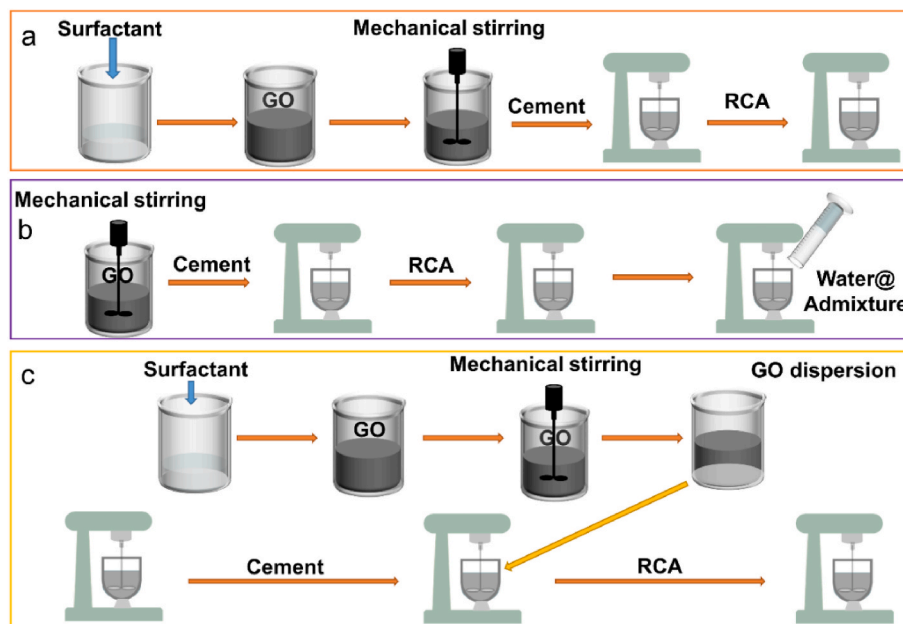


Fig. 4. Traditional methods of using GO in RAC production (Kang et al., 2017; Li et al., 2019): (a) GO suspension is mixed with cement and RCA; (b) CO is mixed with cement and then bound with RCA and surfactant solution, and (c) GO dispersion is mixed with the combined usage of surfactant and mechanical stirring and then mixing with cement and RCA.

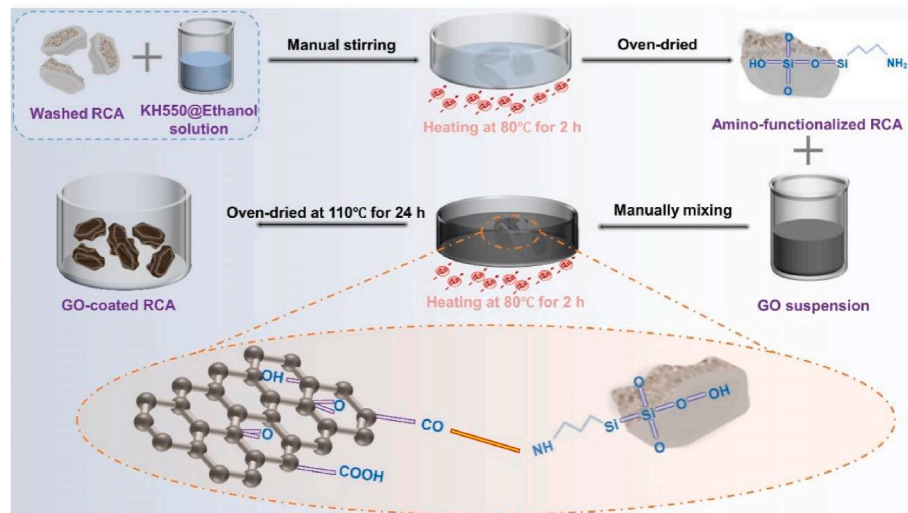


Fig. 5. Illustration of coating GO on RCA surface (Lu et al., 2023a).

While direct mixing of GO in RAC offers advantages such as ease of operation and scalability, its effectiveness in enhancing the performance of RAC is relatively low (Chintalapudi and Pannem, 2020a). In contrast, the application of GO pre-soaking or pre-wetting RCA particles represents a targeted approach to enhance the ITZ in RAC. This is because the admixed GO can generate more hydration products at the ITZ region and contribute to the densification of the microstructure (Lu et al., 2022a, 2023a). This targeted approach has shown promising results in improving the performance of RAC (Chintalapudi and Pannem, 2020b; Babak et al., 2014; Haeri et al., 2017). After nano-coating, GO is typically adsorbed to the RCA surface, aiming at targeting the enhanced ITZ region. However, the bonding strength between the RCA and GO is relatively weak. Therefore, it is crucial to enhance the bond between the RCA surface and the coated GO films to improve the performance of RAC. In this regard, a promising approach to achieve improved performance through nano-modification is the direct growth of GO nanosheets on the RCA surface.

4. The admixed of GO on the performance of RAC

4.1. The admixed GO on the workability of RAC

The slump test is a widely employed method for assessing the workability of RAC in its fresh state (de Brito and Kurda, 2021). Typically, the fluidity or slump decreases while the viscosity increases, as the amount of GO is added directly to the RAC mixture, mainly ascribed to the high water consumption of the admixed GO nanosheets (Zhao et al., 2018, 2020a; Yan et al., 2020a; Vallurupalli et al., 2020).

As summarized in Table 3, For instance, Luo et al. (2019a) suggested that directly mixing 0.25–0.50 wt% GO with cement can decrease the slump value of the RAC mixture by 12.6–35.5%, without any bleeding, as indicated in Fig. 6a and b. The combination of the two-dimensional nanosheet structure and high aspect ratio of GO (see Table 1), along with the high water absorption of RCA, contributes to the slump loss

Table 3
Effect of admixed GO on the workability of RAC.

RA content (%)	GO dosage (%)	Variation of slump (%)	Ref.
100	0.25 and 0.50	–12.6 and –33.5	Luo et al. (2019b)
100	0.05 and 0.2	–7.5 and –18.8	Long et al. (2017)
60	0.02–0.08	–(0.9–14.0)%	Cheng et al. (2024)
100	0.04–0.10	–(7–54)	Esmaili et al. (2023)

observed in RAC (Tian et al., 2020), as suggested in Fig. 6c, the reduced fluidity of GO-modified composites, mainly due to the agglomerated GO entrapped a large content of water. Similarly, Devi et al. (Devi and Khan, 2020a) indicated that adding 0.224 wt% GO and 0.448 wt% GO into a RAC mixture can reduce 2% and 3%, respectively, as compared to concrete containing 100% RCA. Based on the data presented in Table 3, it is evident that the incorporation of GO in the RAC mixture can lead to a decrease in workability. The addition of high doses of water-reducing agents or superplasticizers can address this issue (Zajac et al., 2023). However, it is important to note that the use of high dosages of surfactants can increase the production cost of RAC, this is not conducive to the practical applications of GO-modified RAC. In addition, the bleeding of the RAC mixture can be mitigated, and the viscosity of the RAC mixture can be increased by introducing GO, this is attributed to the nano-sized GO particles that can act as fillers within the RAC mixture (Xu et al., 2019).

Using GO-coated RCA can offset the workability reduction in the RAC mixture, mainly because this nano-coating process can avoid GO agglomeration (Lu et al., 2023a). More importantly, the small specific surface area of the aggregates implies the utilization of very small dosages of GO for enhancing the performance of RAC. As a result, the nano-coating of RCA particles with GO shows promise in improving the workability of concrete, making it suitable for practical applications (Lu et al., 2023d,e). However, there is a significant research gap regarding the impact of GO-coated on the workability of RAC. In the future, there is potential to optimize the design of the GO coating on the surface of RCA. This optimization process would consider factors such as coating quality, including coverage rate and coating stability, as well as the refinement of the GO coating process itself. By doing so, any potential adverse effects of GO introduction on the workability of RAC can be mitigated, ensuring the overall quality of RAC during the mixing, transportation, and construction processes.

4.2. The admixed GO on the mechanical strengths of RAC

According to previously reported data (Marchi et al., 2023; Merino-Maldonado et al., 2024), it can be found that different mixture designs, RCA replacement ratios, and GO dosages for preparing concrete mixtures have been extensively studied.

Based on the findings presented in Table 4, the influence of admixing RCA and GO dosage on the performance of the RAC mixture is summarized and compared. It is evident from Table 4 that the performance of RAC is significantly influenced by the optimal content of GO.

The complete substitution of natural aggregate (NA) with 100%

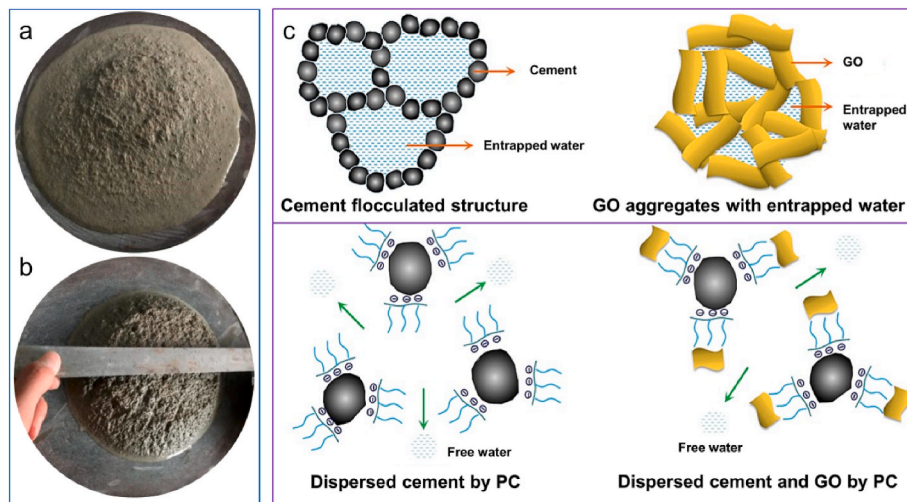


Fig. 6. Workability of cement composites: (a) RCA mortar (Luo et al., 2019a); (b) GO-modified RCA mortar (GONM) (Luo et al., 2019a); and (c) cement matrix containing GO (Zhao et al., 2018). PC is Portland cement.

Table 4
The influence of GO on the mechanical strengths of RAC.

GO wt%	Aggregate type	w/b ratio	Compressive strength (MPa)	Flexural strength (MPa)	Ref.
0.06	Fine RCA	0.30	159	185.3	Yu and Wu (2020)
0.05	Coarse RCA	0.50	16.64	25	Devi and Khan (2020b)
0.10	Coarse RCA	0.50	21.46	24	Devi and Khan (2020a)
0.2	Fine RCA	0.66	26.8	31	Long et al. (2018)
0.1	Coarse RCA	0.71	25	28	Alvi et al. (2023)

recycled concrete aggregate (RCA) in the production of Recycled Aggregate Concrete (RAC) typically leads to a reduction in compressive strength ranging from 10 to 30% (Lu et al., 2024a). The water-to-binder (w/b) ratio and the addition of supplementary cementitious materials are critical in enhancing the mechanical properties of RAC (Dimitriou et al., 2018; Bui et al., 2017; Dodds et al., 2017). Fig. 7a illustrates the enhancement in mechanical strengths of RAC containing 100% RCA at the optimal graphene oxide (GO) dosage (Kisku et al., 2017; Ismail et al., 2017; Koper et al., 2017). Studies indicate that adding 0.2–0.22 wt% GO

enhances the compressive and flexural strengths of RAC by approximately 15% and 20%, respectively (Alvi et al., 2023; Bahraq et al., 2022). This elucidates the impact of varying GO content on the mechanical properties of RAC, thus aiding in the material composition optimization for improved performance.

In addition, RAC with GO has been shown to have more hydration products and a denser microstructure, attributed to GO's facilitation of cement hydration (Jing et al., 2020; Imanian Ghazanlou et al., 2020; Chintalapudi and Rao Pannem, 2021; Hu et al., 2019b). For example, according to Devi et al. (Devi and Khan, 2020b), the compressive strength of RAC that was cured for 28 days reached a range of 18.6–24.6 MPa, as shown in Fig. 7b. This indicates the viability of using 100% RCA in lieu of NA for various construction applications. Similarly, Luo et al. (2019a) documented that incorporating 0.025 wt% and 0.050 wt% GO into RAC increased its compressive strength by 4.8% and 13.9%, respectively, in comparison to RAC without GO enhancement.

In general, the mechanical strengths of the RAC mixture can be enhanced when the GO is admixed, mainly attributed to the microstructure of concrete becoming more dense (Jing et al., 2019, 2020; Kang et al., 2017). The mechanical strengths enhancement in RAC by adding GO is ascribed to the following aspects: 1) GO can regulate cracks at the nanometer level due to its extraordinary flexibility (Zhao et al., 2017b, 2018); 2) there is a strong chemical bonding between GO with oxygen-rich functional groups on the surface and cementitious materials (Lv et al., 2013, 2014); and 3) the introduction of GO results in the generation of a more dense C–S–H, which prevents the ingress of

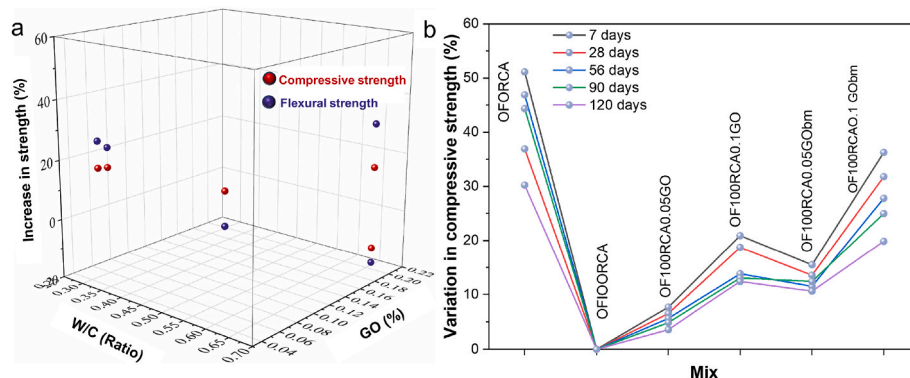


Fig. 7. Mechanical strengths of GO-modified RAC (Chiranjakumari Devi and Ahmad Khan, 2020; Devi and Khan, 2020a,b; Bahraq et al., 2022; Yu and Wu, 2020) and (b) percentage variation in compressive strength in GO-modified RAC (Devi and Khan, 2020b).

chemically aggressive agents (Muthu et al., 2021a,b). Based on the above advantages, GO can be considered the preferred nanocarbon material for developing high-performance RAC. Despite the excellent mechanical properties of GO, the performance of RAC highly depends on the GO dosage, the dispersion and distribution of GO, and the amount of RCA.

Similar to the influence of admixing GO on the workability of RAC, the effect of incorporating GO on the mechanical properties of RAC is also highly dependent on the dosage and dispersion quality of GO (Alvi et al., 2023). To improve the dispersion quality, surfactant pre-treatment of GO and the use of spherical particles such as nano-silica and fly ash as dispersing agents are commonly employed (Zhan et al., 2022). However, it is important to note that these processes do not guarantee efficient and stable dispersion of GO within the concrete matrix. Moreover, these processes come with additional costs and energy consumption, making them impractical for practical applications. Furthermore, directly mixing GO with cementitious materials has limited efficiency in enhancing the weakest (ITZ in RAC. Notably, pre-coating GO onto the surface of RCA particles can provide targeted enhancement of the ITZ in RAC. However, further extensive research is required to provide substantial evidence supporting this viewpoint.

4.3. The admixed GO on the durability of RAC

Table 5 provides a summary of data from previous literature on the influence of admixed GO on the durability of RAC, including both mortar and concrete specimens. Generally, the addition of GO has shown positive effects on the chloride penetration resistance, carbonation resistance, and moisture resistance of RAC (Zhan et al., 2022). However, there is a slight decrease in the freezing and thawing resistance of concrete when GO is incorporated. Importantly, the pre-wetting

Table 5
Effect of admixed GO on the durability of RAC.

Modification method	Durability	GO dosage (%)	Variation (%)	Ref.
Direct mixing	Chloride penetration resistance ($\times 10^{-13} \text{ m}^2/\text{s}$)	0.08	-22.6	Cheng et al. (2024)
	120 d-Carbonation depth (mm)	0.1	-50	Chiranjikumari Devi and Ahmad Khan (2020)
	120 d-Sorptivity ($\text{mm}/\text{s}^{1/2}$)	0.05	-8	Chiranjikumari Devi and Ahmad Khan (2020)
	Total charge passed (Coulombs)	0.01-0.05	-(9.9-15.2)	Wang et al. (2024b)
	Freezing and thawing resistance	0.02-0.08	+(0.55-2.7)	Yu and Wu (2020)
Pre-wetting	7 d-Water sorptivity ($\text{mm}/\text{s}^{1/2}$)	0.01	-30.3	Lu et al. (2023a)
	Total charge passed (Coulombs)	0.01	-58.7	Lu et al. (2023a)
Pre-coating	7 d-Water sorptivity ($\text{mm}/\text{s}^{1/2}$)	0.01	-32.9	Lu et al. (2023a)
	Total charge passed (Coulombs)	0.01	-63.4	Lu et al. (2023a)
Pre-coating	Chloride migration coefficient ($\times 10^{-12} \text{ m}^2/\text{s}$)	0.02-0.08	-(5.66-9.72)	Yu and Wu (2020)

or pre-coating of GO on the surface of RCA particles has been found to significantly enhance the durability of RAC. This approach can be considered an effective solution for improving the overall durability of RAC.

4.3.1. Permeability

Since concrete is exposed to corrosive environments during its service life, permeability is an important indicator in determining the durability of concrete (Alvi et al., 2023; Lu et al., 2024b,c). Based on this, this review work reviews the influence of GO on the permeability of RAC. Numerous studies have shown that the admixed GO has a positive effect on the water permeability of RAC. As presented in Fig. 8, Devi et al. (Devi and Khan, 2020b) suggested that adding GO can improve the water/ions resistance and enhance the microstructure of RAC. As indicated in Fig. 8b and c, the permeability of RAC with 0.1% GO can increase with the number of curing days, ranging from 17% to 48%. Overall, the admixed GO can improve the permeability resistance of RAC, mainly ascribed to the nucleation effect of GO in the cement matrix.

4.3.2. Resistance to physical/chemical attack

Typically, concrete develops cracks during long-term service due to the intrusion of corrosive media (Zhan et al., 2022; Lu et al., 2023c; Gong et al., 2024). The presence of acids is very harmful to the performance of RAC because of the chemical reaction between some corrosive media (e.g., acids) and cement hydration products that form soluble products (Devi and Khan, 2020a,b). As the acid concentration increases, the more severe the damage to RAC (Kim, 2022). The addition of GO leads to a more dense microstructure of RAC, which in turn inhibits the intrusion of corrosive media. Previous studies found that the chloride ion permeability of ultra-high performance concrete (UHPC) containing fine RCA can be optimized, mainly because the introduction of GO improved the microstructure of the concrete (Yu and Wu, 2020; Chu et al., 2020). According to the findings of Chu et al. (2020), the incorporation of GO in UHPC can enhance its resistance to chloride permeation and the optimal concentration of GO was determined to be 0.05 wt %. As suggested in Fig. 9b, the relatively high percentage increase in mass of concrete containing 100% RCA indicated that the introduction of GO promotes cement hydration, which can be also confirmed by XRD results. Another promising method is the utilization of GO-coated RCA, which has demonstrated superior resistance to chloride ion penetration in RAC compared to the direct mixing method. In fact, the chloride ion attack capacity of GO-coated RCA is even higher than that of ordinary concrete (Lu et al., 2023a).

4.3.3. Resistance to freeze-thaw cycles

Typically, subjecting RAC samples to an increased number of freeze-thaw cycles leads to higher weight loss (Xia et al., 2024). However, it has been observed that the weight loss of GO-modified RAC is generally lower than that of control RAC samples, indicating that GO can enhance the freeze-thaw resistance of RAC (Chiranjikumari Devi and Ahmad Khan, 2020). For instance, Yu et al. (Yu and Wu, 2020) found that RAC samples containing 0.06% GO exhibited the lowest weight loss after 300 freeze-thaw cycles, and this trend was also reflected in their dynamic modulus of elasticity. Chu et al. (2020) reported that the freeze-thaw resistance of RAC reached its minimum value with the addition of 0.075% GO, and the performance of the specimen deteriorated when the GO content exceeded 0.075 wt%. Furthermore, Devi et al. (Devi and Khan, 2020b) demonstrated that the addition of GO can improve the resistance of RAC to sulfate attack. However, there remains a significant research gap regarding the impact of GO addition on the freeze-thaw cycles of RAC. Therefore, it is crucial for future studies to conduct comprehensive research to investigate the influence of adding GO on the frost resistance of RAC.

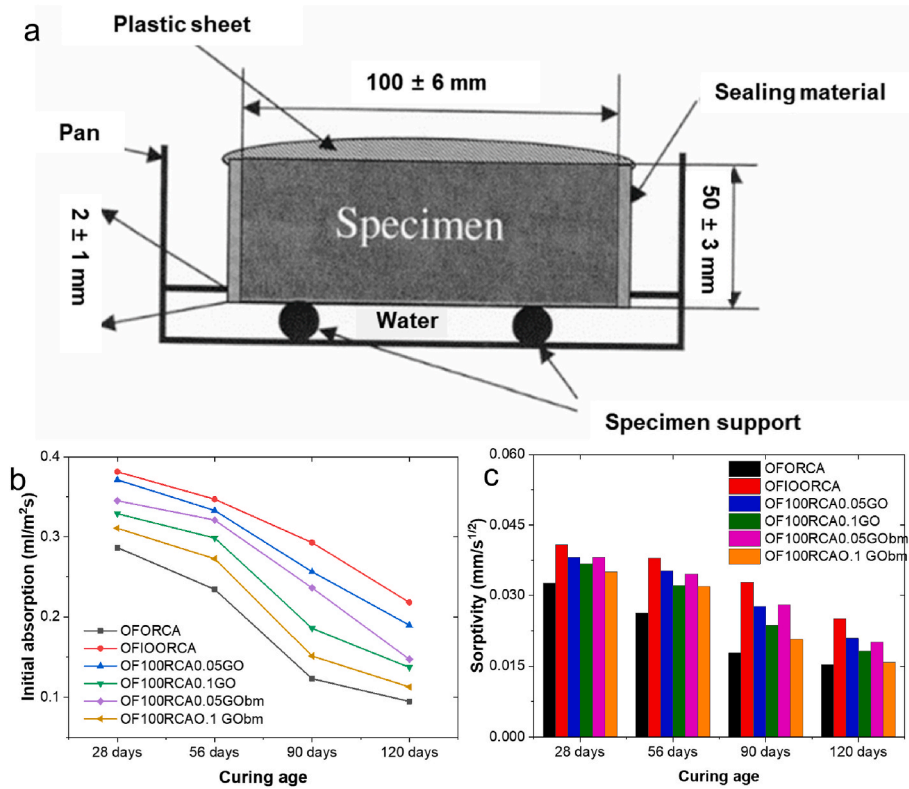


Fig. 8. (a) Sorptivity test of RAC samples (Devi and Khan, 2020b); (b) initial sorptivity (Devi and Khan, 2020b); and (c) sorptivity (Devi and Khan, 2020b).

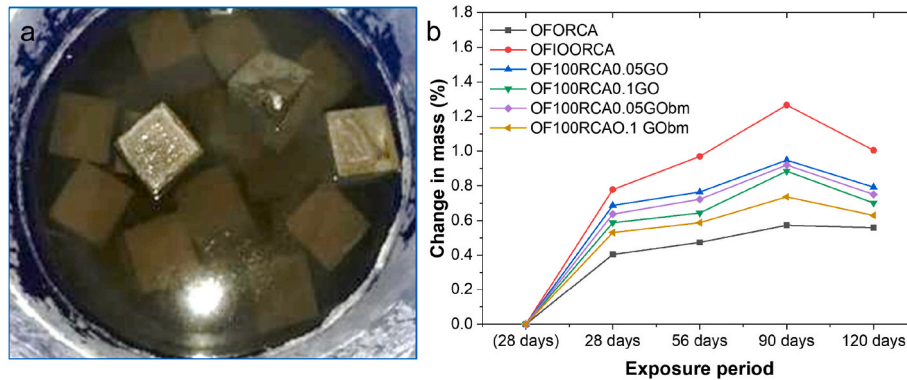


Fig. 9. (a) Preparation of specimens immersed in acid solution (Devi and Khan, 2020a); and (b) percentage change in mass for different exposure periods compared to mass before exposure to sulfate solution (Chiranjikumari Devi and Ahmad Khan, 2020).

4.3.4. Resistance to carbonation

Carbonation is the process of producing calcite by the reaction between the cement hydration product $\text{Ca}(\text{OH})_2$ (CH) and carbon dioxide (Xing et al., 2022). When the concrete was carbonated, it exhibited low alkalinity (Lu et al., 2023f). Moreover, the alkaline protective layer in reinforced concrete (RC) can become acidic, resulting in the corrosion of the reinforcing steel. This corrosion process significantly impacts the service life and durability of the structure (Liu et al., 2022). Temperature variations, relative humidity, pressure and carbon dioxide concentration play a crucial role in influencing the carbonation of RAC (Ouyang et al., 2020). The introduction of GO is reported to improve the microstructure and pore structure of RAC, which in turn increases the resistance to CO_2 intrusion (Yu and Wu, 2020). Typically, the carbonation depth of RAC is higher than that of ordinary concrete, simply because of the poorer RCA quality and the multiple poorer ITZs in RAC (Zheng et al., 2021). As such, the performance of RAC can be improved by employing

high-quality RCA or introducing some admixtures (Ouyang et al., 2020). Fig. 10b presents the impact of GO on the porosity and carbonation depth of RAC, and the introduction of GO can reduce the porosity of RAC by about 50%, and the carbonation depth decreases accordingly. Accordingly, the introduction of GO can potentially reduce the carbonation depth of RAC, especially for RAC samples containing 0.05% GO, which has the lowest carbonation depth (Fig. 10c). The surface chemistry of GO plays a critical role in the ionic cross-linking process within the cement matrix, as evidenced by studies (Luo et al., 2019a; Long et al., 2018; Chu et al., 2020). GO can promote the formation of calcium-silicate-hydrate (C-S-H) and enhance the microstructure of RAC (Devi and Khan, 2020a,b; Yu and Wu, 2020). Resisting carbonation is essential for sustainable cement-based materials, and incorporating GO in RAC presents a viable approach (Malazdrewicz et al., 2023). However, further investigation is necessary to fully understand the strengthening efficiency of GO, highlighting the need for future research

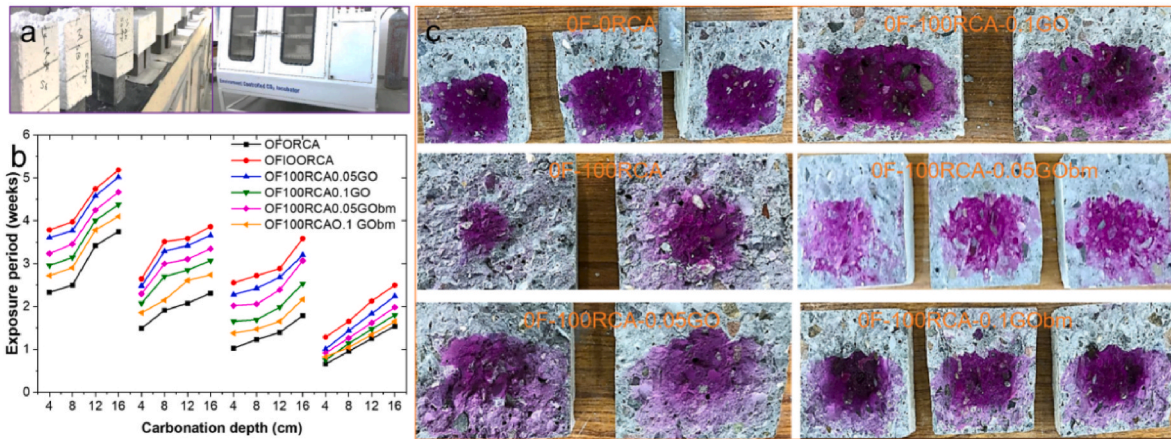


Fig. 10. Carbonation chamber used for experiment (Chiranjikumari Devi and Ahmad Khan, 2020); (b) carbonation depth of RAC samples at exposure to CO₂ (Devi and Khan, 2020a); and (c) visual images of carbonation depth of RAC samples (Chiranjikumari Devi and Ahmad Khan, 2020).

studies in this area.

In general, the current research on the durability of GO-modified RAC is very limited, particularly regarding its shrinkage performance.

It is well-known that shrinkage is a significant issue in RAC that has yet to be effectively addressed (Esmaeili et al., 2023; Makul, 2020). The incorporation of SCMs in RAC often exacerbates early-age shrinkage

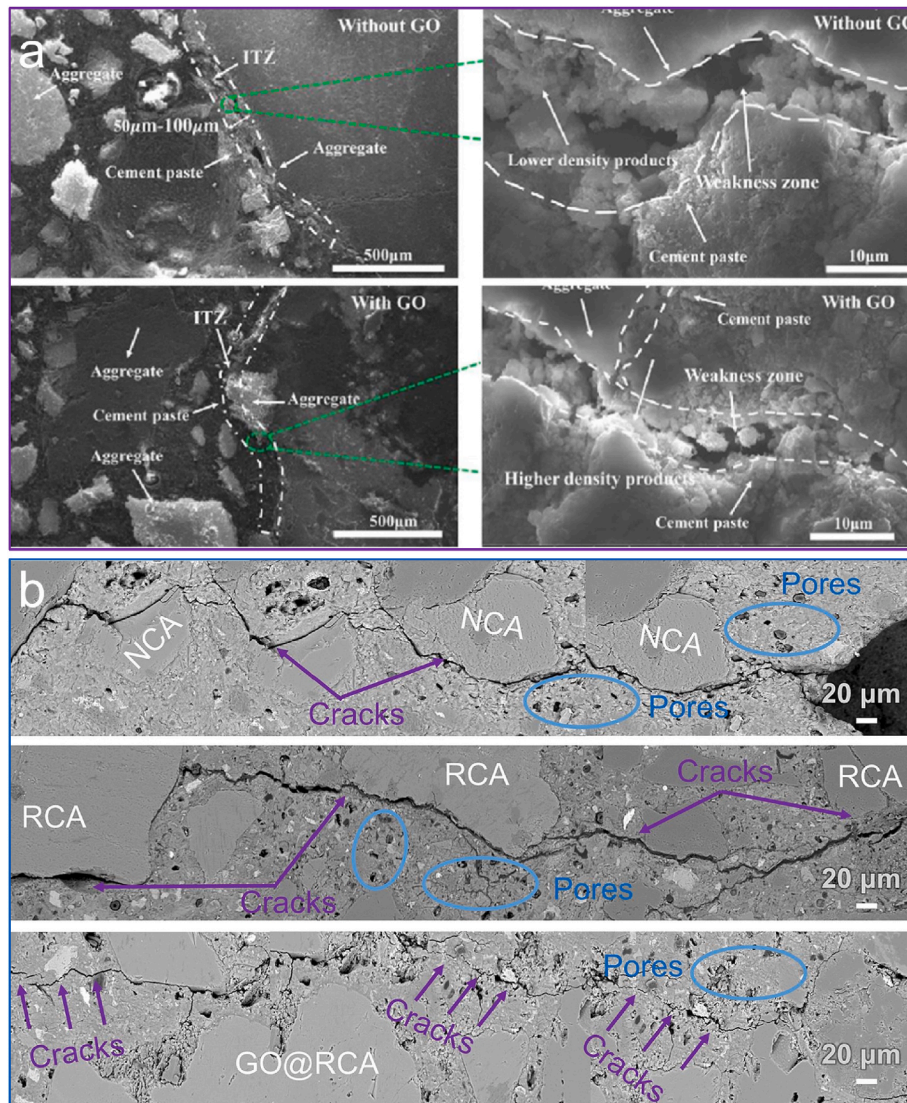


Fig. 11. (a) SEM images of crystal morphology in RAC samples (Long et al., 2018); and (b) typical microcracks in concrete samples (Lu et al., 2023a).

(Makul, 2020; Steiner et al., 2015). However, GO shows potential in promoting early hydration of cement, which can lead to densification of the microstructure and potentially reduce early-age shrinkage in RAC (Zeng et al., 2023). Considering that GO is a two-dimensional nanomaterial, its scale is far different from that of the concrete system (e.g., macro-scale materials such as fine and coarse aggregates), which is a fundamental reason for the limited research on GO-modified RAC. Fortunately, the surface area of the aggregate phase is relatively small compared to cement, suggesting that coating RCA with a very low dosage of GO could target the enhancement of the ITZ in RAC, thereby significantly improving its permeability resistance. However, favorable evidence supporting this concept is currently limited, necessitating further research for validation.

5. Roles of admixed GO in the RAC system

This section discusses the mechanisms underlying the influence of GO admixture on the properties of RAC. Based on previous studies (Devi and Khan, 2020a; Zhao et al., 2018; Alvi et al., 2023; Malazdrewicz et al., 2023), in RAC, pores with diameters larger than 50 nm are widely recognized as crucial factors affecting its mechanical and durability performance, whereas pores smaller than 50 nm are linked to the dimensional stability of concrete (Xiao et al., 2018; Yoda and Shintani, 2014; Wu et al., 2018). The typical particle size of GO ranges from 5 to 50 nm, which is significantly smaller than that of cement particles (~20 μm) (Lu and Zhong, 2022; Wang et al., 2020). Previous studies (Devi and Khan, 2020a,b; Alvi et al., 2023) have reported that the incorporation of GO can fill voids, refine the microstructure of concrete, and facilitate the formation of low-density C-S-H. Notably, GO has demonstrated the ability to reduce porosity in RAC, particularly in the range of 0.02–0.1 μm (Chu et al., 2020). Overall, adding GO has a refining effect on the pore structure of RAC. Consequently, it is important to establish a correlation between the pore structure and the durability of GO-modified RAC in future research studies.

GO, owing to its unique two-dimensional lamellar structure, can act as a bridging agent, effectively inhibiting the propagation and expansion

of microcracks in RAC (Alvi et al., 2023; Chiranjeevi et al., 2023). Fig. 11a presents evidence of the bridging effect of GO in RAC, demonstrating its ability to impede crack expansion (Chiranjikumar Devi and Ahmad Khan, 2020; Bahraq et al., 2022). In a study by Long et al. (2018), it was observed that the addition of GO effectively suppressed the extension of microcracks by deflecting or forcing cracks to tilt and twist around the GO sheets. Similarly, in the C-GO@RCA samples, a significant portion of microcracks propagated through the substrate, as indicated by the purple arrows in Fig. 11b.

The addition of GO can initiate heterogeneous nucleation by reducing the critical ion concentration. This effect is primarily attributed to the creation of additional nucleation sites through the crystal growth of hydrates. The microhardness of the GO-modified recycled mortar (GORM) samples containing 0.05 wt% GO is almost equal to that of GO-modified normal mortar (GONM) (Luo et al., 2019a). According to Fig. 12d, the microhardness of the concrete incorporating GO-coated recycled aggregate concrete (GO@RAC) was higher compared to that of the traditional RAC. Specifically, the microhardness of the GO@RAC sample was approximately 52 HV, whereas the RAC sample had a microhardness of around 43 HV. Additionally, the thickness of the ITZ was reduced by 44.4% in the GO@RAC sample, indicating the beneficial impact of GO coating on the ITZ (Lu et al., 2023a). Based on the published reports, it can be indicated that the conventional method of mixing GO-modified cement with RCA has a relatively low efficiency in enhancing the ITZ of RAC (Zhan et al., 2022; Devi and Khan, 2020b). In contrast, the process of using GO-coated RCA can efficiently enhance the microstructure and microhardness of the ITZ (Lu et al., 2023a). In the future, it is necessary to utilize tools such as nanoindentation and backscattered electron microscopy (BSE) to further investigate the impact of introducing GO on the porosity and micro-mechanical properties of multiple ITZs in RAC. Additionally, efforts should be made to establish the relationship between the micro-mechanical characteristics of RAC and its macroscopic performance, aiming to predict the performance evolution of RAC in long-term service.

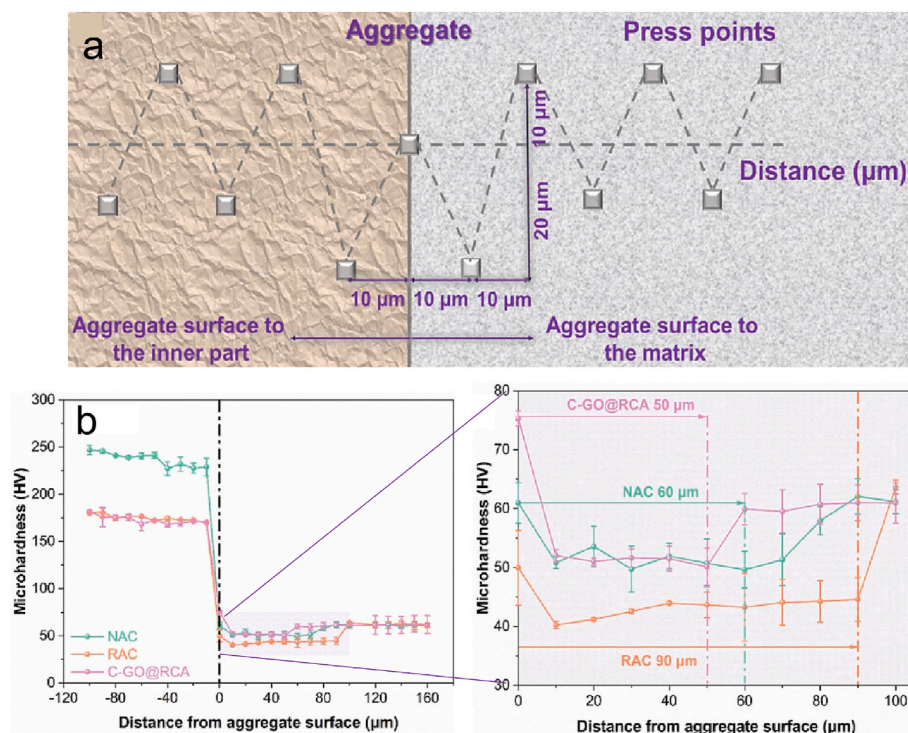


Fig. 12. Microhardness of cementitious composites: (a) Indentation points for testing (Lu et al., 2023a); and (b) microhardness of RAC (Lu et al., 2023a).

6. The potential applications, benefits, and limitations of GO-modified RAC

6.1. The potential applications

In most developing countries, RCA is often underutilized. Generally, RCA is primarily used in lower-grade applications such as sidewalks, direct landfills, and road subbases (Wu et al., 2018). Based on previous experimental results and engineering cases (Shi et al., 2016; Ouyang et al., 2020; Xu et al., 2022), it is feasible to incorporate approximately 40% or higher proportions of RCA in new concrete construction, especially with the implementation of GO-modified RAC, this can further increase the utilization of RCA ratio in RAC preparation, leading to savings in limited natural aggregate resources, reduced energy consumption, and decreased CO₂ emissions, thus providing significant economic and environmental benefits, as presented in Fig. 13.

For instance, GO-modified RAC can be directly applied to various pavements, including rigid and flexible pavements, as well as concrete infrastructures such as buildings, bridges, dams, and tunnels. GO-modified RAC can also be used in building construction, for example, in lightweight structures for upper-level buildings. Due to its high porosity and the presence of voids in RCA, it can also be used as a sound-absorbing material, where materials with numerous internal voids can effectively absorb sound energy.

Considering the substantial reduction in landfill waste and the significant economic and environmental advantages of applying GO-modified RAC, extensive foundational research should be conducted to understand the mechanisms and long-term performance evolution of GO-modified RAC, this will promote the practical applications of GO-modified RAC and realize low-carbon and sustainable construction.

6.2. Economic and environmental evaluation

The cost of implementing GO-modified RAC presents a challenge for their practical applications in the construction industry (Ma et al., 2022). Typically, the price of GO is approximately \$100/kg and assuming the amount of GO in RAC production is assumed to be 0.05 wt % of the cement, namely, the additional cost of GO-modified RAC is 5.6% of that of concrete, according to the local price of C35 concrete (<https://price.cement.com>). However, the usage of GO can significantly enhance the performance and prolong the service life of RAC structures (Liu et al., 2023; Velardo et al., 2022). Therefore, the cost of

GO-modified RACs is deemed acceptable over the entire life cycle of the structure. Moreover, the utilization of RCA in place of NA offers substantial benefits in terms of natural resource conservation and social sustainability. The recycling of RCA has been reported to conserve approximately 60% of NA resources and reduce CO₂ emissions by 15–20% (Shi et al., 2016). Recognizing that the economic and environmental impacts of RACs cannot be adequately represented by CO₂ emissions or costs alone, two indices, namely C_p (cost index) and CI (CO₂ emission index), have been employed to assess the overall performance of GO-modified RAC.

$$C_p = \text{Cost}/f_c \tag{1}$$

$$CI = C_{\text{weight}}/f_c \tag{2}$$

where Cost is the total cost of RAC, \$/m³; C_{weight} is the total mass of CO₂, kg/m³; f_c is the compressive strength of RAC at 28 days, MPa. The replacement of NA with RCA can reduce the C_p by 2–15%.

Concrete production is reported to consume about 5 billion tons of cement per year and accounts for 6% of the world's CO₂ emissions (Ismail and Ramli, 2013; Kim et al., 2018; Gupta et al., 2021). By using GO, the CO₂ emissions of RACs can be reduced by enhancing the strength and durability performance of RACs (Cui and Chang, 2022; Cui et al., 2021). Currently, there is a trend to add GO to buildings; however, there is still a lack of understanding of its production and environmental impact on concrete. For LCA of GO-modified RACs, raw materials, GO fabrication, superplasticizers, adhesives and RCAs can be used as the main inputs to the model (see Fig. 14). In conclusion, the use of

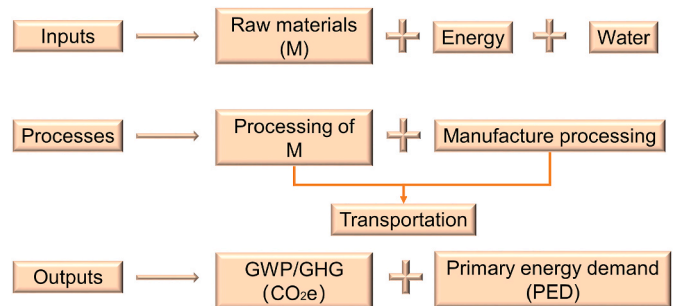


Fig. 14. Life Cycle Assessment (LCA) calculation of RAC.

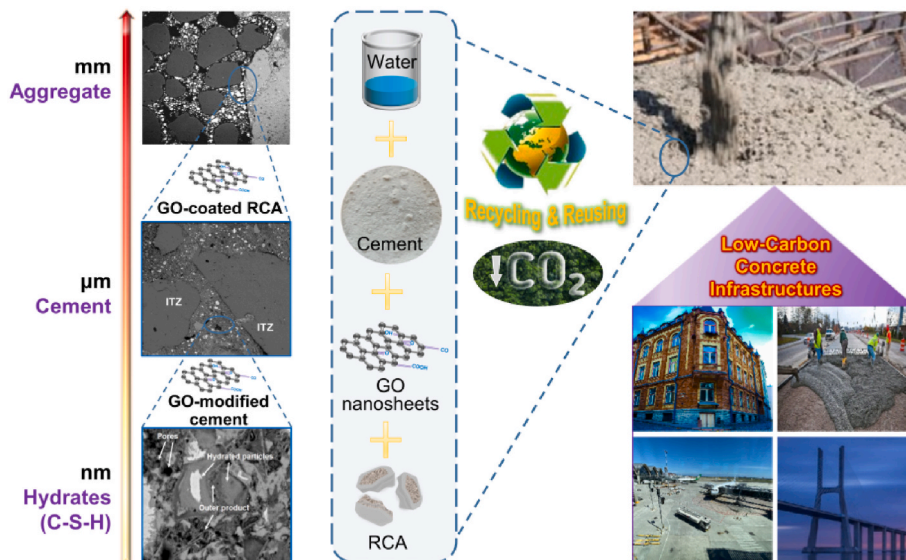


Fig. 13. GO can be directly mixed with cement and then bound with RCA. Also, GO can coat the RCA surface and then be mixed with cement (Lu et al., 2022a,d). The application of GO-modified RAC can reuse RCA and reduce carbon footprint.

GO-modified RAC produces lower CO₂ emissions, making it an ideal choice for the construction industry. Replacing NA with RCA for preparing concrete has great environmental benefits such as carbon emission reduction (Wu et al., 2018; Kou et al., 2014; Liang et al., 2022). The use of RCA also provides other benefits such as mitigation of natural resource depletion and negative impact on the environment (Xiao et al., 2018; Yoda and Shintani, 2014; Xu et al., 2022). Overall, this review work proposes to concentrate on the environmental performance of GO-modified RAC in specific applications, such as coastal environments and extremely cold regions.

6.3. The limitations of previous studies and potential research prospects

The existing research primarily focuses on enhancing the properties of mortar containing recycled fine aggregates through the use of GO, while the product used in practical engineering is concrete (containing RCA), therefore, the studies on the durability of GO-modified RAC are very limited. The optimal dosage and reinforcement mechanism for enhancing the durability of GO-modified RAC remains unclear. Further investigations in this area are necessary to promote the practical applications of GO-modified RAC.

The relationship between the dosage of GO and the mechanical/durability performance of GO-modified RAC is unclear, especially since there is a lack of well-established methods for determining the optimal dosage of GO to enhance the performance of RAC. Developing machine learning models for predicting the strength and durability performance of GO-modified RAC would be the next step, to develop and understand the relationship between the GO dosage and the strength and durability performance indicators of RAC.

Currently, there is a limited amount of research on the LCA assessment and cost analysis of GO-modified RAC, particularly with a lack of data from actual engineering projects. The next step should involve studying the LCA assessment of GO-modified RAC, emphasizing its environmental impact for practical applications. Detailed cost analysis can further demonstrate the feasibility of its practical applications.

7. Conclusions and prospectives

This review work has systematically reviewed and compared the impact of introduced GO on the performance and microstructure of RAC prepared by different modification methods. First, the characteristics of GO and its usage methods in preparing RAC are introduced. Next, the admixed GO on the performance of RAC and its roles in the RAC system is analyzed and discussed. Subsequently, the economic and environmental evaluation of RAC and GO-modified RAC are compared. Finally, the limitations of previous studies and potential research prospects in the future are provided. Based on this, the following findings and prospectives can be made:

- (1) The mechanical and durability performance of GO-modified RAC is primarily influenced by certain parameters, including the dosage of GO, the quality of dispersion, and the distribution of GO within the concrete matrix. By optimizing these parameters, GO can effectively improve the mechanical and durability properties of RAC, enabling its application in various scenarios such as underground construction, corrosion protection, and other concrete structures subjected to harsh environmental conditions.
- (2) The utilization of RCA as a substitute for NA offers significant benefits, including the reduction of CO₂ emissions and mitigation of environmental issues. Moreover, incorporating GO in the development of RAC can substantially enhance its mechanical and durability properties, thereby amplifying the environmental and economic advantages of RAC. Nevertheless, due to the higher cost associated with GO, it is advisable to focus future research efforts on assessing the environmental performance of GO-

modified RAC in specific applications, such as coastal environments and extremely cold regions.

- (3) When applying a nanocoating of GO onto the surface of RCA particles, GO tends to distribute itself on the RCA surface, targeting the improvement of RAC properties. However, the bonding strength between the RCA and GO is relatively weak. Therefore, it is crucial to enhance the bonding between the RCA surface and the coated GO film to enhance the overall performance of RAC. The direct growth of GO on the RCA surface presents a promising approach for nano-modification, which holds the potential for enhancing the performance of RAC.
- (4) The use of GO-coated RCA can counterbalance the reduction in workability observed in RAC production. This is primarily due to the nano-coating process that can prevent GO agglomeration. Additionally, the relatively small specific surface area of the aggregates implies that minimal amounts of GO are required for nano-coating, allowing for using very small dosages of GO to enhance RAC performance. Consequently, in terms of workability and mechanical properties of nano-modified RAC, priority should be given to coating RCA with GO suspensions, as they can be easily employed in practical applications.

CRediT authorship contribution statement

Dong Lu: Writing – review & editing, Writing – original draft, Data curation. **Fulin Qu:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Data curation. **Piyush Punetha:** Writing – review & editing, Data curation. **Xiaohui Zeng:** Writing – review & editing, Data curation. **Zhiyu Luo:** Writing – review & editing, Data curation. **Wengui Li:** Writing – review & editing, Supervision, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgment

The authors appreciate the support from the Australian Research Council (ARC), Australia (FT220100177; LP230100288; DP220101051; IH180100010; DP220100036).

References

- Al-Bayati, H.K.A., Das, P.K., Tighe, S.L., Baaj, H., 2016. Evaluation of various treatment methods for enhancing the physical and morphological properties of coarse recycled concrete aggregate. *Construct. Build. Mater.* 112, 284–298.
- Alvi, I.H., Li, Q., Hou, Y., Onyekwena, C.C., Zhang, M., Ghaffar, A., 2023. A critical review of cement composites containing recycled aggregates with graphene oxide nanomaterials. *J. Build. Eng.* 69.
- Asadi, I., Shafiq, P., Hashemi, M., Akhiani, A.R., Maghfouri, M., Sajadi, B., Mahyuddin, N., Esfandiari, M., Rezaei Talebi, H., Metselaar, H.S.C., 2021. Thermophysical properties of sustainable cement mortar containing oil palm boiler clinker (OPBC) as a fine aggregate. *Construct. Build. Mater.* 268.
- Babak, F., Abolfazl, H., Alimorad, R., Parviz, G., 2014. Preparation and mechanical properties of graphene oxide: cement nanocomposites. *Sci. World J.* 2014, 276323.
- Bahraq, A.A., Jose, J., Shameem, M., Maslehuudin, M., 2022. A review on treatment techniques to improve the durability of recycled aggregate concrete: enhancement mechanisms, performance and cost analysis. *J. Build. Eng.* 55.
- Balapur, M., Joshaghani, A., Althoey, F., 2018. Nano-SiO₂ contribution to mechanical, durability, fresh and microstructural characteristics of concrete: a review. *Construct. Build. Mater.* 181, 27–41.
- Bravo, M., de Brito, J., Pontes, J., Evangelista, L., 2015. Durability performance of concrete with recycled aggregates from construction and demolition waste plants. *Construct. Build. Mater.* 77, 357–369.

- Brittain, R., Liskiewicz, T., Morina, A., Neville, A., Yang, L., 2023. Diamond-like carbon graphene nanoplatelet nanocomposites for lubricated environments. *Carbon* 205, 485–498.
- Budde, H., Coca-Lopez, N., Shi, X., Ciesielski, R., Lombardo, A., Yoon, D., Ferrari, A.C., Hartschuh, A., 2016. Raman radiation patterns of graphene. *ACS Nano* 10 (2), 1756–1763.
- Bui, N.K., Satomi, T., Takahashi, H., 2017. Improvement of mechanical properties of recycled aggregate concrete basing on a new combination method between recycled aggregate and natural aggregate. *Construct. Build. Mater.* 148, 376–385.
- Cheng, S., Chen, K., Wu, Q., Chen, X., Zhao, C., Wu, Z., 2024. Influence of industrial-grade graphene oxide on macro and micro properties of ultra-high performance concrete incorporating recycled fine aggregate. *Construct. Build. Mater.* 417.
- Chintalapudi, K., Pannem, R.M.R., 2020a. An intense review on the performance of Graphene Oxide and reduced Graphene Oxide in an admixed cement system. *Construct. Build. Mater.* 259.
- Chintalapudi, K., Pannem, R.M.R., 2020b. The effects of Graphene Oxide addition on hydration process, crystal shapes, and microstructural transformation of Ordinary Portland Cement. *J. Build. Eng.* 32.
- Chintalapudi, K., Rao Pannem, R.M., 2021. Strength properties of graphene oxide cement composites. *Mater. Today: Proc.* 45, 3971–3975.
- Chiranjeevi, K., Hemanth Kumar, D., Yathish, R.G., Ravi Shankar, A.U., 2023. Laboratory investigation on cement-treated recycled concrete aggregate bases for flexible pavements. *Mater. Today: Proc.*
- Chiranjiakumari Devi, S., Ahmad Khan, R., 2020. Influence of graphene oxide on sulfate attack and carbonation of concrete containing recycled concrete aggregate. *Construct. Build. Mater.* 250.
- Chu, H., Zhang, Y., Wang, F., Feng, T., Wang, L., Wang, D., 2020. Effect of graphene oxide on mechanical properties and durability of ultra-high-performance concrete prepared from recycled sand. *Nanomaterials* 10 (9).
- Chuah, S., Li, W., Chen, S.J., Sanjayan, J.G., Duan, W.H., 2018. Investigation on dispersion of graphene oxide in cement composite using different surfactant treatments. *Construct. Build. Mater.* 161, 519–527.
- Cui, K., Chang, J., 2022. Hydration, reinforcing mechanism, and macro performance of multi-layer graphene-modified cement composites. *J. Build. Eng.* 57.
- Cui, K., Lau, D., Zhang, Y., Chang, J., 2021. Mechanical properties and mechanism of nano-CaCO₃ enhanced sulphoaluminate cement-based reactive powder concrete. *Construct. Build. Mater.* 309.
- de Brito, J., Kurda, R., 2021. The past and future of sustainable concrete: a critical review and new strategies on cement-based materials. *J. Clean. Prod.* 281.
- Devi, S.C., Khan, R.A., 2020a. Effect of sulfate attack and carbonation in graphene oxide-reinforced concrete containing recycled concrete aggregate. *J. Mater. Civ. Eng.* 32 (11).
- Devi, S.C., Khan, R.A., 2020b. Compressive strength and durability behavior of graphene oxide reinforced concrete composites containing recycled concrete aggregate. *J. Build. Eng.* 32.
- Dharmasiri, B., Randall, J.D., Stanfield, M.K., Ying, Y., Andersson, G.G., Nepal, D., Hayne, D.J., Henderson, L.C., 2022. Using surface grafted poly(acrylamide) to simultaneously enhance the tensile strength, tensile modulus, and interfacial adhesion of carbon fibres in epoxy composites. *Carbon* 186, 367–379.
- Dimitriou, G., Savva, P., Petrou, M.F., 2018. Enhancing mechanical and durability properties of recycled aggregate concrete. *Construct. Build. Mater.* 158, 228–235.
- Dodds, W., Christodoulou, C., Goodier, C., Austin, S., Dunne, D., 2017. Durability performance of sustainable structural concrete: effect of coarse crushed concrete aggregate on rapid chloride migration and accelerated corrosion. *Construct. Build. Mater.* 155, 511–521.
- Esmaeili, J., Romouzi, V., Kasaei, J., Andalibi, K., 2023. An investigation of durability and the mechanical properties of ultra-high performance concrete (UHPC) modified with economical graphene oxide nano-sheets. *J. Build. Eng.* 80.
- Fan, D., Lue, L., Yang, S., 2017. Molecular dynamics study of interfacial stress transfer in graphene-oxide cementitious composites. *Comput. Mater. Sci.* 139, 56–64.
- Ghahremani, P., Mostafatabar, A.H., Bahlakeh, G., Ramezanzadeh, B., 2022. Rational design of a novel multi-functional carbon-based nano-carrier based on multi-walled-CNT-oxide/polydopamine/chitosan for epoxy composite with robust pH-sensitive active anti-corrosion properties. *Carbon* 189, 113–141.
- Gong, K., Pan, Z., Korayem, A.H., Qiu, L., Li, D., Collins, F., Wang, C.M., Duan, W.H., 2015. Reinforcing effects of graphene oxide on Portland cement paste. *J. Mater. Civ. Eng.* 27 (2).
- Gong, M., Sun, Y., Chen, J., 2024. Analysis of coupled thermo-mechanical response and damage behaviour of curved ramp bridge deck pavement using a 3D multiscale method. *Road Mater. Pavement Des.* 1–23.
- Guo, S., Zhang, X., Shi, C., Zhao, D., He, C., Zhao, N., 2022. Simultaneously enhanced mechanical properties and electrical property of Cu-2 wt% Ag alloy matrix composites with analogy-bicontinuous structures constructed via in-situ synthesized graphene nanoplatelets. *Carbon* 198, 207–218.
- Gupta, S., Lin, Y.-A., Lee, H.-J., Buscheck, J., Wu, R., Lynch, J.P., Garg, N., Loh, K.J., 2021. In situ crack mapping of large-scale self-sensing concrete pavements using electrical resistance tomography. *Cement Concr. Compos.* 122.
- Haeri, S.Z., Ramezanzadeh, B., Asghari, M., 2017. A novel fabrication of a high performance SiO₂-graphene oxide (GO) nanohybrids: characterization of thermal properties of epoxy nanocomposites filled with SiO₂-GO nanohybrids. *J. Colloid Interface Sci.* 493, 111–122.
- Hu, M., Guo, J., Fan, J., Li, P., Chen, D., 2019a. Dispersion of triethanolamine-functionalized graphene oxide (TEA-GO) in pore solution and its influence on hydration, mechanical behavior of cement composite. *Construct. Build. Mater.* 216, 128–136.
- Hu, M., Guo, J., Li, P., Chen, D., Xu, Y., Feng, Y., Yu, Y., Zhang, H., 2019b. Effect of characteristics of chemical combined of graphene oxide-nanosilica nanocomposite fillers on properties of cement-based materials. *Construct. Build. Mater.* 225, 745–753.
- Imanian Ghazanlou, S., Jalaly, M., Sadeghzadeh, S., Habibnejad Korayem, A., 2020. High-performance cement containing nanosized Fe₃O₄-decorated graphene oxide. *Construct. Build. Mater.* 260.
- Ismail, S., Ramli, M., 2013. Engineering properties of treated recycled concrete aggregate (RCA) for structural applications. *Construct. Build. Mater.* 44, 464–476.
- Ismail, S., Kwan, W.H., Ramli, M., 2017. Mechanical strength and durability properties of concrete containing treated recycled concrete aggregates under different curing conditions. *Construct. Build. Mater.* 155, 296–306.
- Jeong, D.W., Kim, K., Lee, G., Kang, M., Chang, H., Jang, A.R., Lee, J.O., 2022. Electrochemical transparency of graphene. *ACS Nano* 16 (6), 9278–9286.
- Jing, G.-j., Ye, Z.-m., Li, C., Cui, J., Wang, S.-x., Cheng, X., 2019. A ball milling strategy to disperse graphene oxide in cement composites. *N. Carbon Mater.* 34 (6), 569–577.
- Jing, G.-j., Ye, Z.-m., Li, C., Cui, J., Wang, S.-x., Cheng, X., 2020. A ball milling strategy to disperse graphene oxide in cement composites. *Carbon* 159.
- Kang, D., Seo, K.S., Lee, H., Chung, W., 2017. Experimental study on mechanical strength of GO-cement composites. *Construct. Build. Mater.* 131, 303–308.
- Kim, J., 2022. Influence of quality of recycled aggregates on the mechanical properties of recycled aggregate concretes: an overview. *Construct. Build. Mater.* 328.
- Kim, Y., Hanif, A., Kazmi, S.M.S., Munir, M.J., Park, C., 2018. Properties enhancement of recycled aggregate concrete through pretreatment of coarse aggregates – comparative assessment of assorted techniques. *J. Clean. Prod.* 191, 339–349.
- Kiskun, N., Joshi, H., Ansari, M., Panda, S.K., Nayak, S., Dutta, S.C., 2017. A critical review and assessment for usage of recycled aggregate as sustainable construction material. *Construct. Build. Mater.* 131, 721–740.
- Koper, A., Koper, W., Koper, M., 2017. Influence of raw concrete material quality on selected properties of recycled concrete aggregates. *Procedia Eng.* 172, 536–543.
- Kothiyal, N.C., Sharma, S., Mahajan, S., Sethi, S., 2016. Characterization of reactive graphene oxide synthesized from ball – milled graphite: its enhanced reinforcing effects on cement nanocomposites. *J. Adhes. Sci. Technol.* 30 (9), 915–933.
- Kou, S.-C., Zhan, B.-j., Poon, C.-S., 2014. Use of a CO₂ curing step to improve the properties of concrete prepared with recycled aggregates. *Cement Concr. Compos.* 45, 22–28.
- Li, X., Wei, W., Qin, H., Hang Hu, Y., 2015. Co-effects of graphene oxide sheets and single wall carbon nanotubes on mechanical properties of cement. *J. Phys. Chem. Solid.* 85, 39–43.
- Li, W., Li, X., Chen, S.J., Liu, Y.M., Duan, W.H., Shah, S.P., 2017. Effects of graphene oxide on early-age hydration and electrical resistivity of Portland cement paste. *Construct. Build. Mater.* 136, 506–514.
- Li, C.Y., Chen, S.J., Li, W.G., Li, X.Y., Ruan, D., Duan, W.H., 2019. Dynamic increased reinforcing effect of graphene oxide on cementitious nanocomposite. *Construct. Build. Mater.* 206, 694–702.
- Li, W., Qu, F., Dong, W., Mishra, G., Shah, S.P., 2022. A comprehensive review on self-sensing graphene/cementitious composites: a pathway toward next-generation smart concrete. *Construct. Build. Mater.* 331.
- Liang, C., You, J., Gu, F., Gao, Y., Yang, G., He, Z., Hou, S., Duan, Z., 2022. Enhancing the elastic modulus of concrete prepared with recycled coarse aggregates of different quality by chemical modifications. *Construct. Build. Mater.* 360.
- Liu, Z., Yuan, X., Zhao, Y., Chew, J.W., Wang, H., 2022. Concrete waste-derived aggregate for concrete manufacture. *J. Clean. Prod.* 338.
- Liu, X., Xie, X., Liu, R., Lyu, K., Zuo, J., Li, S., Liu, L., Shah, S.P., 2023. Research on the durability of nano-SiO₂ and sodium silicate co-modified recycled coarse aggregate (RCA) concrete. *Construct. Build. Mater.* 378.
- Long, W.J., Wei, J.J., Ma, H., Xing, F., 2017. Dynamic mechanical properties and microstructure of graphene oxide nanosheets reinforced cement composites. *Nanomaterials* 7 (12).
- Long, W.-J., Zheng, D., Duan, H.-b., Han, N., Xing, F., 2018. Performance enhancement and environmental impact of cement composites containing graphene oxide with recycled fine aggregates. *J. Clean. Prod.* 194, 193–202.
- Lu, D., Zhong, J., 2022. Carbon-based nanomaterials engineered cement composites: a review. *Journal of Infrastructure Preservation and Resilience* 3 (1).
- Lu, Z., Hanif, A., Sun, G., Liang, R., Parthasarathy, P., Li, Z., 2018a. Highly dispersed graphene oxide electrodeposited carbon fiber reinforced cement-based materials with enhanced mechanical properties. *Cement Concr. Compos.* 87, 220–228.
- Lu, Z., Hou, D., Hanif, A., Hao, W., Li, Z., Sun, G., 2018b. Comparative evaluation on the dispersion and stability of graphene oxide in water and cement pore solution by incorporating silica fume. *Cement Concr. Compos.* 94, 33–42.
- Lu, D., Shi, X., Zhong, J., 2022a. Nano-engineering the interfacial transition zone in cement composites with graphene oxide. *Construct. Build. Mater.* 356.
- Lu, D., Shi, X., Zhong, J., 2022b. Interfacial bonding between graphene oxide coated carbon nanotube fiber and cement paste matrix. *Cement Concr. Compos.* 134.
- Lu, D., Shi, X., Zhong, J., 2022c. Interfacial nano-engineering by graphene oxide to enable better utilization of silica fume in cementitious composite. *J. Clean. Prod.* 354.
- Lu, D., Shi, X., Wong, H.S., Jiang, Z., Zhong, J., 2022d. Graphene coated sand for smart cement composites. *Construct. Build. Mater.* 346.
- Lu, D., Wang, D., Wang, Y., Zhong, J., 2023a. Nano-engineering the interfacial transition zone between recycled concrete aggregates and fresh paste with graphene oxide. *Construct. Build. Mater.* 384.
- Lu, D., Sheng, Z., Yan, B., Jiang, Z., Wang, D., Zhong, J., 2023b. Rheological behavior of fresh cement composites with graphene oxide-coated silica fume. *J. Mater. Civ. Eng.* 35 (10).

- Lu, D., Leng, Z., Lu, G., Wang, D., Huo, Y., 2023c. A critical review of carbon materials engineered electrically conductive cement concrete and its potential applications. *Int. J. Soc. Netw. Min.* 1–27.
- Lu, D., Huo, Y., Jiang, Z., Zhong, J., 2023d. Carbon nanotube polymer nanocomposites coated aggregate enabled highly conductive concrete for structural health monitoring. *Carbon* 206, 340–350.
- Lu, D., Ma, L.P., Zhong, J., Tong, J., Liu, Z., Ren, W., Cheng, H.M., 2023e. Growing nanocrystalline graphene on aggregates for conductive and strong smart cement composites. *ACS Nano* 17 (4), 3587–3597.
- Lu, J., Cai, Z., Gao, Y., Yin, Y., Ma, Z., Liang, C., 2023f. Effects of pretreatment methods on the properties of recycled aggregates and prepared concrete under CO₂-curing. *Case Stud. Constr. Mater.* 18.
- Lu, D., Jiang, X., Qu, F., Huo, Y., 2024a. Mitigating sulfate ions migration in concrete: a targeted approach to address recycled concrete aggregate's impact. *J. Clean. Prod.* 442.
- Lu, D., Fu, C., Jiang, X., Chen, Z., Qu, F., Huo, Y., Leng, Z., Zhong, J., 2024b. Sustainable microwave-heating healing asphalt concrete incorporating functional aggregates and waste ferrite. *Transport. Res. Transport Environ.* 129.
- Lu, D., Jiang, X., Leng, Z., 2024c. Sustainable microwave-heating healing asphalt concrete fabricated with waste microwave-sensitive fillers. *J. Clean. Prod.* 434.
- Luo, J., Chen, S., Li, Q., Liu, C., Gao, S., Zhang, J., Guo, J., 2019a. Influence of graphene oxide on the mechanical properties, fracture toughness, and microhardness of recycled concrete. *Nanomaterials* 9 (3).
- Luo, J., Chen, S., Li, Q., Liu, C., Gao, S., Zhang, J., Guo, J., 2019b. Influence of graphene oxide on the mechanical properties, fracture toughness, and microhardness of recycled concrete. *Nanomaterials* 9 (3).
- Lv, S., Ma, Y., Qiu, C., Sun, T., Liu, J., Zhou, Q., 2013. Effect of graphene oxide nanosheets of microstructure and mechanical properties of cement composites. *Construct. Build. Mater.* 49, 121–127.
- Lv, S., Liu, J., Sun, T., Ma, Y., Zhou, Q., 2014. Effect of GO nanosheets on shapes of cement hydration crystals and their formation process. *Construct. Build. Mater.* 64, 231–239.
- Ma, M., Tam, V.W.Y., Le, K.N., Osei-Kyei, R., 2022. Factors affecting the price of recycled concrete: a critical review. *J. Build. Eng.* 46.
- Makul, N., 2020. Modern sustainable cement and concrete composites: review of current status, challenges and guidelines. *Sustain. Mater. Technol.* 25.
- Malazdrewicz, S., Adam Ostrowski, K., Sadowski, Ł., 2023. Self-compacting concrete with recycled coarse aggregates from concrete construction and demolition waste – current state-of-the-art and perspectives. *Construct. Build. Mater.* 370.
- Marchi, T., Garcia Diaz, E., Salgues, M., Souche, J.C., Devillers, P., 2023. Internal curing capacity of recycled coarse aggregates incorporated in concretes with low water/cement ratios. *Construct. Build. Mater.* 409.
- Merino-Maldonado, D., Antolín-Rodríguez, A., Blanco, S., Morán-del Pozo, J.M., García-González, J., Juan-Valdés, A., 2024. Surface protection of recycled concrete from different biogenic silica bio-deposition techniques: a sustainable approach. *J. Build. Eng.* 84.
- Mohajerani, A., Vajna, J., Cheung, T.H.H., Kurmus, H., Arulrajah, A., Horpibulsuk, S., 2017. Practical recycling applications of crushed waste glass in construction materials: a review. *Construct. Build. Mater.* 156, 443–467.
- Muthu, M., Yang, E.-H., Unluer, C., 2021a. Effect of graphene oxide on the deterioration of cement pastes exposed to citric and sulfuric acids. *Cement Concr. Compos.* 124.
- Muthu, M., Ukrainczyk, N., Koenders, E., 2021b. Effect of graphene oxide dosage on the deterioration properties of cement pastes exposed to an intense nitric acid environment. *Construct. Build. Mater.* 269.
- Mypati, S., Sellathurai, A., Kontopoulou, M., Dococsis, A., Barz, D.P.J., 2021. High concentration graphene nanoplatelet dispersions in water stabilized by graphene oxide. *Carbon* 174, 581–593.
- Ouyang, K., Shi, C., Chu, H., Guo, H., Song, B., Ding, Y., Guan, X., Zhu, J., Zhang, H., Wang, Y., Zheng, J., 2020. An overview on the efficiency of different pretreatment techniques for recycled concrete aggregate. *J. Clean. Prod.* 263.
- Pan, Z., He, L., Qiu, L., Korayem, A.H., Li, G., Zhu, J.W., Collins, F., Li, D., Duan, W.H., Wang, M.C., 2015. Mechanical properties and microstructure of a graphene oxide-cement composite. *Cement Concr. Compos.* 58, 140–147.
- Pei, S., Cheng, H.-M., 2012. The reduction of graphene oxide. *Carbon* 50 (9), 3210–3228.
- Pepe, M., Toledo Filho, R.D., Koenders, E.A.B., Martinelli, E., 2014. Alternative processing procedures for recycled aggregates in structural concrete. *Construct. Build. Mater.* 69, 124–132.
- Shang, H., Li, Y., Zhang, Y., Wei, X., Qi, Y., Zhao, D., 2019. Influence of adding nano-graphite powders on the microstructure and gas hydrogen storage properties of ball-milled Mg90Al10 alloys. *Carbon* 149, 93–104.
- Sharma, S., Kothiyal, N.C., 2015. Influence of graphene oxide as dispersed phase in cement mortar matrix in defining the crystal patterns of cement hydrates and its effect on mechanical, microstructural and crystallization properties. *RSC Adv.* 5 (65), 52642–52657.
- Sharma, S., Kothiyal, N.C., 2016. Comparative effects of pristine and ball-milled graphene oxide on physico-chemical characteristics of cement mortar nanocomposites. *Construct. Build. Mater.* 115, 256–268.
- Shi, C., Li, Y., Zhang, J., Li, W., Chong, L., Xie, Z., 2016. Performance enhancement of recycled concrete aggregate – a review. *J. Clean. Prod.* 112, 466–472.
- Sojobi, A.O., Xuan, D., Li, L., Liu, S., Poon, C.S., 2021. Optimization of gas-solid carbonation conditions of recycled aggregates using a linear weighted sum method. *Dev. Built Environ.* 7.
- Steiner, L.R., Bernardin, A.M., Pelisser, F., 2015. Effectiveness of ceramic tile polishing residues as supplementary cementitious materials for cement mortars. *Sustain. Mater. Technol.* 4, 30–35.
- Tam, V.W.Y., Tam, C.M., Le, K.N., 2007. Removal of cement mortar remains from recycled aggregate using pre-soaking approaches. *Resour. Conserv. Recycl.* 50 (1), 82–101.
- Thomas, C., Setién, J., Polanco, J.A., Alaejos, P., Sánchez de Juan, M., 2013. Durability of recycled aggregate concrete. *Construct. Build. Mater.* 40, 1054–1065.
- Tian, Z., Li, Y., Zheng, J., Wang, S., 2019. A state-of-the-art on self-sensing concrete: materials, fabrication and properties. *Compos. B Eng.* 177.
- Tian, Y., Yan, X., Zhang, M., Lu, D., Yang, T., Wang, Z., Li, W., 2020. Internal transport and corrosion behaviors of sulfate corrosion media carried by recycled aggregate in concrete. *Construct. Build. Mater.* 260.
- Vallurupalli, K., Meng, W., Liu, J., Khayat, K.H., 2020. Effect of graphene oxide on rheology, hydration and strength development of cement paste. *Construct. Build. Mater.* 265.
- Velardo, P., Sáez del Bosque, I.F., Sánchez de Rojas, M.I., De Belie, N., Medina, C., 2022. Durability of concrete bearing polymer-treated mixed recycled aggregate. *Construct. Build. Mater.* 315.
- Wang, Q., Wang, J., Lu, C.-x., Liu, B.-w., Zhang, K., Li, C.-z., 2015. Influence of graphene oxide additions on the microstructure and mechanical strength of cement. *Carbon* 95, 1083–1084.
- Wang, Y., Lu, D., Wang, F., Zhang, D., Zhong, J., Liang, B., Gui, X., Sun, L., 2020. A new strategy to prepare carbon nanotube thin film by the combination of top-down and bottom-up approaches. *Carbon* 161, 563–569.
- Wang, C., Xiao, J., Liu, W., Ma, Z., 2022a. Unloading and reloading stress-strain relationship of recycled aggregate concrete reinforced with steel/polypropylene fibers under uniaxial low-cycle loadings. *Cement Concr. Compos.* 131.
- Wang, C., Wu, H., Li, C., 2022b. Hysteresis and damping properties of steel and polypropylene fiber reinforced recycled aggregate concrete under uniaxial low-cycle loadings. *Construct. Build. Mater.* 319.
- Wang, C.-q., Cheng, L.-x., Ying, Y., Yang, F.-h., 2024a. Utilization of all components of waste concrete: recycled aggregate strengthening, recycled fine powder activity, composite recycled concrete and life cycle assessment. *J. Build. Eng.* 82.
- Wang, Q., Zhao, H., Luo, Z., Liu, S., Zhou, C., Liu, H., 2024b. Properties evaluation of concrete made with recycled coarse aggregate modified by graphene oxide. *J. Build. Eng.* 84.
- Wu, C.-R., Zhu, Y.-G., Zhang, X.-T., Kou, S.-C., 2018. Improving the properties of recycled concrete aggregate with bio-deposition approach. *Cement Concr. Compos.* 94, 248–254.
- Xia, P., Wang, S., Chen, K., Meng, T., Chen, X., Gong, F., 2024. A recycling approach of natural stone from crushed concrete based on freeze-thaw modification and usage of spalling mortar as recycled fine aggregate. *Construct. Build. Mater.* 416.
- Xiao, J., Wang, C., Ding, T., Akbarnezhad, A., 2018. A recycled aggregate concrete high-rise building: structural performance and embodied carbon footprint. *J. Clean. Prod.* 199, 868–881.
- Xing, W., Tam, V.W.Y., Le, K.N., Butera, A., Hao, J.L., Wang, J., 2022. Effects of mix design and functional unit on life cycle assessment of recycled aggregate concrete: evidence from CO₂ concrete. *Construct. Build. Mater.* 348.
- Xu, G., Du, S., He, J., Shi, X., 2019. The role of admixed graphene oxide in a cement hydration system. *Carbon* 148, 141–150.
- Xu, X., Luo, Y., Sreeram, A., Wu, Q., Chen, G., Cheng, S., Chen, Z., Chen, X., 2022. Potential use of recycled concrete aggregate (RCA) for sustainable asphalt pavements of the future: a state-of-the-art review. *J. Clean. Prod.* 344.
- Yan, X., Zheng, D., Yang, H., Cui, H., Monasterio, M., Lo, Y., 2020a. Study of optimizing graphene oxide dispersion and properties of the resulting cement mortars. *Construct. Build. Mater.* 257.
- Yan, Y., Zhai, D., Liu, Y., Gong, J., Chen, J., Zan, P., Zeng, Z., Li, S., Huang, W., Chen, P., 2020b. van der Waals Heterojunction between a Bottom-Up Grown Doped Graphene Quantum Dot and Graphene for Photoelectrochemical Water Splitting. *ACS Nano* 14 (1), 1185–1195.
- Yoda, K., Shintani, A., 2014. Building application of recycled aggregate concrete for upper-structural elements. *Construct. Build. Mater.* 67, 379–385.
- Yoo, M.-J., Park, H.B., 2019. Effect of hydrogen peroxide on properties of graphene oxide in Hummers method. *Carbon* 141, 515–522.
- Yu, L., Wu, R., 2020. Using graphene oxide to improve the properties of ultra-high-performance concrete with fine recycled aggregate. *Construct. Build. Mater.* 259.
- Zajac, M., Skocek, J., Golek, Ł., Deja, J., 2023. Supplementary cementitious materials based on recycled concrete paste. *J. Clean. Prod.* 387.
- Zeng, H., Qu, S., Tian, Y., Hu, Y., Li, Y., 2023. Recent progress on graphene oxide for next-generation concrete: characterizations, applications and challenges. *J. Build. Eng.* 69.
- Zhan, P., Xu, J., Wang, J., Zuo, J., He, Z., 2022. A review of recycled aggregate concrete modified by nanosilica and graphene oxide: materials, performances and mechanism. *J. Clean. Prod.* 375.
- Zhao, L., Guo, X., Liu, Y., Ge, C., Guo, L., Shu, X., Liu, J., 2017a. Synergistic effects of silica nanoparticles/polycarboxylate superplasticizer modified graphene oxide on mechanical behavior and hydration process of cement composites. *RSC Adv.* 7 (27), 16688–16702.
- Zhao, L., Guo, X., Ge, C., Li, Q., Guo, L., Shu, X., Liu, J., 2017b. Mechanical behavior and toughening mechanism of polycarboxylate superplasticizer modified graphene oxide reinforced cement composites. *Compos. B Eng.* 113, 308–316.
- Zhao, L., Guo, X., Liu, Y., Ge, C., Chen, Z., Guo, L., Shu, X., Liu, J., 2018. Investigation of dispersion behavior of GO modified by different water reducing agents in cement pore solution. *Carbon* 127, 255–269.
- Zhao, L., Zhu, S., Wu, H., Zhang, X., Tao, Q., Song, L., Song, Y., Guo, X., 2020a. Deep research about the mechanisms of graphene oxide (GO) aggregation in alkaline cement pore solution. *Construct. Build. Mater.* 247.

- Zhao, L., Guo, X., Song, L., Song, Y., Dai, G., Liu, J., 2020b. An intensive review on the role of graphene oxide in cement-based materials. *Construct. Build. Mater.* 241.
- Zhao, H., Li, W., Gan, Y., Wang, K., Luo, Z., 2023. Nano/microcharacterization and image analysis on bonding behaviour of ITZs in recycled concrete enhanced with waste glass powder. *Construct. Build. Mater.* 392.
- Zheng, Y., Zhang, Y., Zhang, P., 2021. Methods for improving the durability of recycled aggregate concrete: a review. *J. Mater. Res. Technol.* 15, 6367–6386.
- Zhou, A.a., Bai, J., Hong, W., Bai, H., 2022. Electrochemically reduced graphene oxide: preparation, composites, and applications. *Carbon* 191, 301–332.