engineering proceedings

Proceeding Paper

The Effect of Incorporating Graphene Nanoplatelets in the Engineering of Cementitious Composites on Compressive and Tensile Strengths for Potential Applications as a Repair Material †

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† Presented at the 4th International Electronic Conference on Applied Sciences, 27 October–10 November 2023; Available online: https://asec2023.sciforum.net/.

Abstract: Repair methods have been adopted to restore the integrity of structures and ensure their safety and longevity. Although jacketing is commonly adopted as a repair method, its implementation results in added loads and a reduction in dimensions and free spacing. In view of the challenges associated with the implementation of jacketing, the development of ultra-high-performance engineered cementitious composites (UHPECCs) are frequently discussed in research as this can enable jacketing to be performed using thin layers of repair material due to the higher strength-to-weight ratio of UHPECCs compared to conventional repair materials. Therefore, the adoption of UHPECCs for jacketing can reduce the overall weight and thickness of the repair material while ensuring the longevity of the repair. At the same time, graphene nanoplatelets (GnPs), which are carbon-derived nanoparticles, are well-known to be unique and advanced nanomaterials with superior properties. In light of the exceptional strength properties of GnPs, the effect of incorporating GnPs in engineered cementitious composites (ECCs) on strength was studied in an effort to further advance UHPECC research. Compressive and tensile strength tests were conducted on ECC samples that contain GnPs added in amounts ranging from 0.03 to 0.09% of the binder weight. The results reveal that the incorporation of GnPs improved strength: the strength of GnP-UHPECC increased as GnP content increased, and compressive and tensile strengths substantially increased by up to 32.9 and 64.6%, respectively.

Keywords: concrete repair; reinforced concrete jacketing; retrofit

Citation: Hisbani, N.; Shafiq, N.; Farhan, S.A. The Effect of Incorporating Graphene Nanoplatelets in the Engineering of Cementitious Composites on Compressive and Tensile Strengths for Potential Applications as a Repair Material. *Eng. Proc.* **2023**, *56*, 335. https://doi.org/10.3390/ASEC2023-16579

Academic Editor: Manoj Gupta

Published: 4 December 2023

1. Introduction

Structural deterioration is a serious issue that can lead to safety hazards and costly repairs. It can be caused by various factors, including weather, age, and poor maintenance. Early detection and rehabilitation can prevent further damage and ensure the longevity and safety of structures. Repair methods, such as reinforced concrete (RC) jacketing, externally bonded steel plates, and the use of fiber-reinforced polymers (FRPs), have been adopted to restore the integrity of structures and ensure their safety and longevity. Each of the techniques, along with its advantages, has disadvantages, particularly RC jacketing, which uses a layer with a minimum thickness of 60–70 mm, reducing interior spacing. In addition, there are also concerns about the fire resistivity of externally bonded steel plates or FRPs [1]. Traditional repair materials have not been considered since they have bonding issues with subtracting concrete. Therefore, nanomaterials, such as graphene nanoplatelets, have a tendency to enhance the bonding and durability of materials.

Engineered cementitious composites (ECCs) with high tensile hardening behavior [2,3] and high compressive strength [4], also known as ultra-high-performance engineered cementitious composites (UHPECCs), are frequently discussed in research. The addition of fibers in ECCs gives them a high tensile strain of 3–8% along with other advantages, such as high tensile strength and a high toughness and durability against cracking [5–7]. Structures repaired and strengthened with UHPECCs exhibit high corrosion resistance due to their protective layer [8–10]. This can enable jacketing to be performed using thin layers of repair material due to the higher strength-to-weight ratio of UHPECCs compared to conventional repair materials.

Nanoparticles are added to concrete to achieve additional environmental benefits and durability, such as improved mechanical properties and reduced permeability [11]. Graphene nanoplatelets (GnPs), which are carbon-derived nanoparticles, are well-known as unique and advanced nanomaterials used in the construction industry with high aspect ratios and surface areas [12]. Incorporating GnPs into a variety of materials, such as polymers, metals and concrete, is effective due to their superior mechanical, thermal, and electrical properties [7,13]. In addition to the improvement in mechanical and thermal properties of the cementitious material, GnPs are more environmentally friendly as they produce less carbon dioxide compared to normal concrete [14]. In light of the exceptional strength properties of GnPs, the effect of incorporating GnPs in ECCs in compressive and tensile strengths is studied in an effort to further advance UHPECC research and explore the potential of developing GnP-UHPECC as a repair material that can restore the integrity of structures.

2. Materials and Methods

The materials used for the preparation of UHPECCs in the present study are Type I ordinary Portland cement (OPC), Class-F low-calcium fly ash, polyvinyl alcohol (PVA) fibers, fine aggregates, GnPs, a superplasticizer, and water. GnPs were incorporated into the ECC mix at contents of 0.03, 0.06 and 0.09% according to the weight of the binder. The ECC mix that did not contain GnPs was also prepared for the casting of control samples. Mixes were designed with a 28-day target strength of 70 MPa.

Analyses of the compressive and tensile strengths of the UHPECC were conducted. Standard-size cube samples with dimensions of 100 × 100 × 100 mm, in accordance with BS EN 12390-1 [15], were adopted to determine compressive strengths after 28 days of curing (as shown in Figure 1a). Three samples for each GnP ratio were used. In accordance with ASTM D638-14 [16], dog-bone-shaped samples were prepared to evaluate the tensile strength. The samples used for tensile strength tests are shown in Figure 1b.

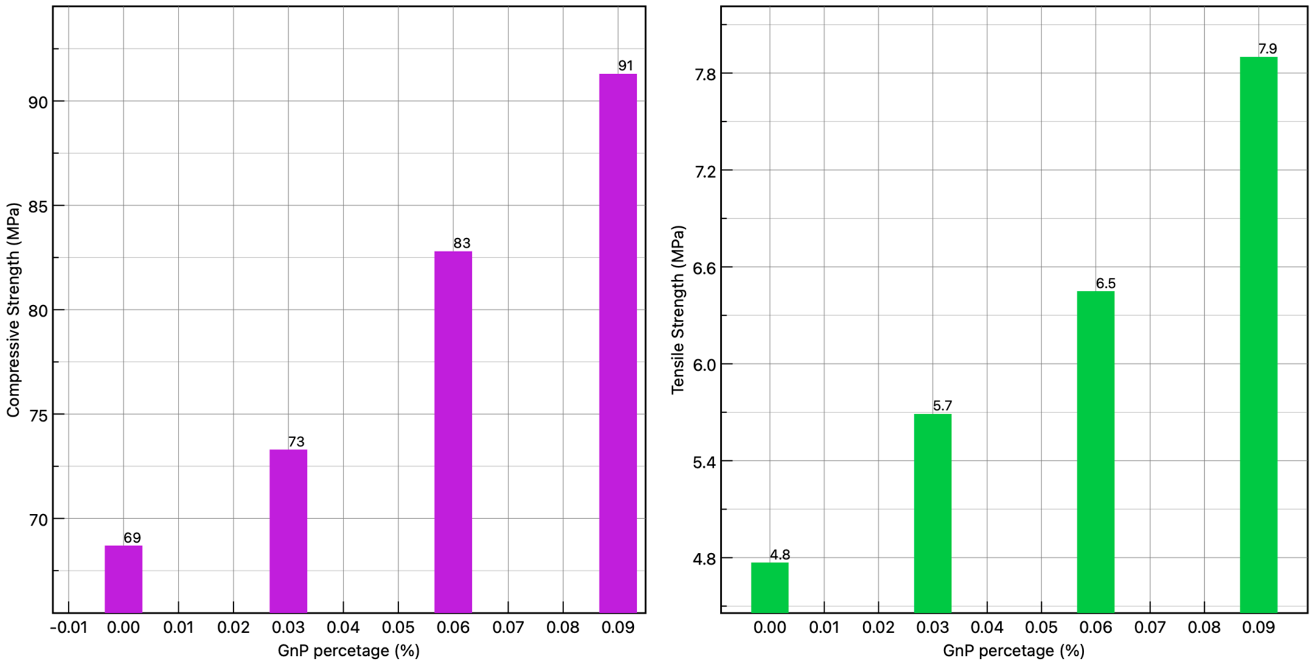
(**a**) (**b**)

Figure 1. Ultra-high-performance engineered cementitious material (UHPECC) samples for (**a**) compressive strength test and (**b**) tensile strength test.

3. Results and Discussion

The compressive and tensile strengths of the UHPECCs at varying GnP contents are presented in Figure 2a and 2b, respectively. The results reveal that the incorporation of GnP at all contents resulted in strength improvements. Furthermore, the strength increased as GnP content is increased. As shown in Figure 2a, the increase in the GnP content by up to 0.09% led to a 32.9% increase in the compressive strength from 68.7 to 91.3 MPa. At the same time, as shown in Figure 2b, the GnP content increase led to a 64.6% increase in the tensile strength from 4.8 to 7.9 MPa. The increase in compressive and tensile strengths of 32.9 and 64.6%, respectively, is substantial considering that the GnP content of 0.09% is relatively low.

The strong mechanical properties of the GnP act as reinforcing agents that effectively bridge cracks, and thus improve the mechanical properties of the UHPECC. Furthermore, the incorporation of GnP reduces the water-to-cement ratio without compromising workability, which ultimately results in the improved strength of the UHPECC.



(**a**) (**b**)

Figure 2. Strength of UHPECCs at varying graphene nanoplatelet (GnP) contents: (**a**) compressive strength and (**b**) tensile strength.

4. Conclusions

Compressive and tensile strength tests were performed on UHPECC samples with the addition of GnPs at contents of 0.03–0.09% according to the weight of the binder. Based on the findings of the study, the following conclusions can be drawn:

1. The incorporation of GnPs in UHPECCs resulted in strength improvements at all GnP contents; the strength of GnP-UHPECC increased with the GnP content.
2. Substantial increases were achieved in compressive and tensile strengths of up to 32.9 and 64.6%, respectively.

In view of the above conclusions, the development of GnP-UHPECC has great potential as a repair material that can restore the integrity of structures. Further research should be conducted on GnP-UHPECC to advance this idea and realize its potential.

Author Contributions: Conceptualization, N.S.; methodology, N.H.; investigation, N.H.; resources, S.A.F.; writing—original draft preparation, N.H.; writing—review and editing, N.S. and S.A.F.; supervision, N.S. and S.A.F.; project administration, S.A.F.; funding acquisition, N.S. All authors have read and agreed to the published version of the manuscript.

Funding: The study is funded by Yayasan Universiti Teknologi PETRONAS, Malaysia via project cost centre 015LC0-330, as administered by Technology Research Excellence Centre of Universiti Teknologi PETRONAS, Malaysia.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in the study are available on request from the corresponding author, S.A.F. The data are not publicly available as the study is part of an ongoing research project.

Acknowledgments: The authors are thankful to the technologists of Universiti Teknologi PETRONAS, Malaysia for the commitment and support to carry out various activities related to the experimental work in the laboratory.

Conflicts of Interest: The authors declare no conflict of interest.

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