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Effect of Incorporating Graphene Nanoplatelets in Engineering Cementitious Composite on Compressive and Tensile Strengths for Potential Application as a Repair Material †

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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 the addition of 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 composite (UHPECC) is frequently discussed in research as it can enable jacketing to be performed using thin layers of repair material due to the higher strength-to-weight ratio of UHPECC as compared to conventional repair materials. Therefore, the adoption of UHPECC 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 (GnP), which are carbon-derived nanoparticles, are well-known as unique and advanced nanomaterials with superior properties. In light of the exceptional strength property of GnP, the effect of incorporating GnP in engineered cementitious composite (ECC) on strength is studied in an effort to further advance UHPECC research. Compressive and tensile strength tests were conducted on ECC samples that contain GnP added at contents in the range of 0.03–0.09% by weight of the binder. Results reveal that incorporation of GnP resulted in strength improvements, with increasing strength of GnP-UHPECC as GnP content is increased and substantial increases in compressive and tensile strengths of up to 32.9 and 64.6%, respectively.

Keywords: concrete repair; reinforced concrete jacketing; retrofit

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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 the structure. Repair methods, such as reinforced concrete (RC) jacketing, externally bonded steel plates, and fiber-reinforced polymer (FRP), 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 of a minimum thickness of 60–70 mm hence reducing the interior spacing. In addition, there are also concerns about the fire resistivity of externally bonded steel plates or FRP [1]. Traditional repair materials are not engineered, and they have bonding issues with subtracting concrete. Therefore, nanomaterials, such as graphene nanoplatelets, have a tendency to enhance the bond and durability of material.

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

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

2. Materials and Methods

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

Analyses of compressive and tensile strengths of the UHPECC were conducted. Standard-size cube samples with dimensions of 100 x 100 x 100 mm, in accordance with BS EN 12390-1 [15], as shown in Figure 1 (a) were adopted to determine the compressive strength after 28 days of curing. Three samples for each GnP ratio were cast. 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 1 (b).

(**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

Compressive and tensile strengths of the UHPECC at varying GnP content is presented in Figure 2 (a) and (b), respectively. Results reveal that incorporation of GnP at all GnP contents resulted in strength improvements. Furthermore, the strength increases as GnP content is increased. As shown in Figure 2 (a), increase in the GnP content 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 2 (b), 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 can be considered as substantial, considering that the GnP content of 0.09% is relatively low.

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

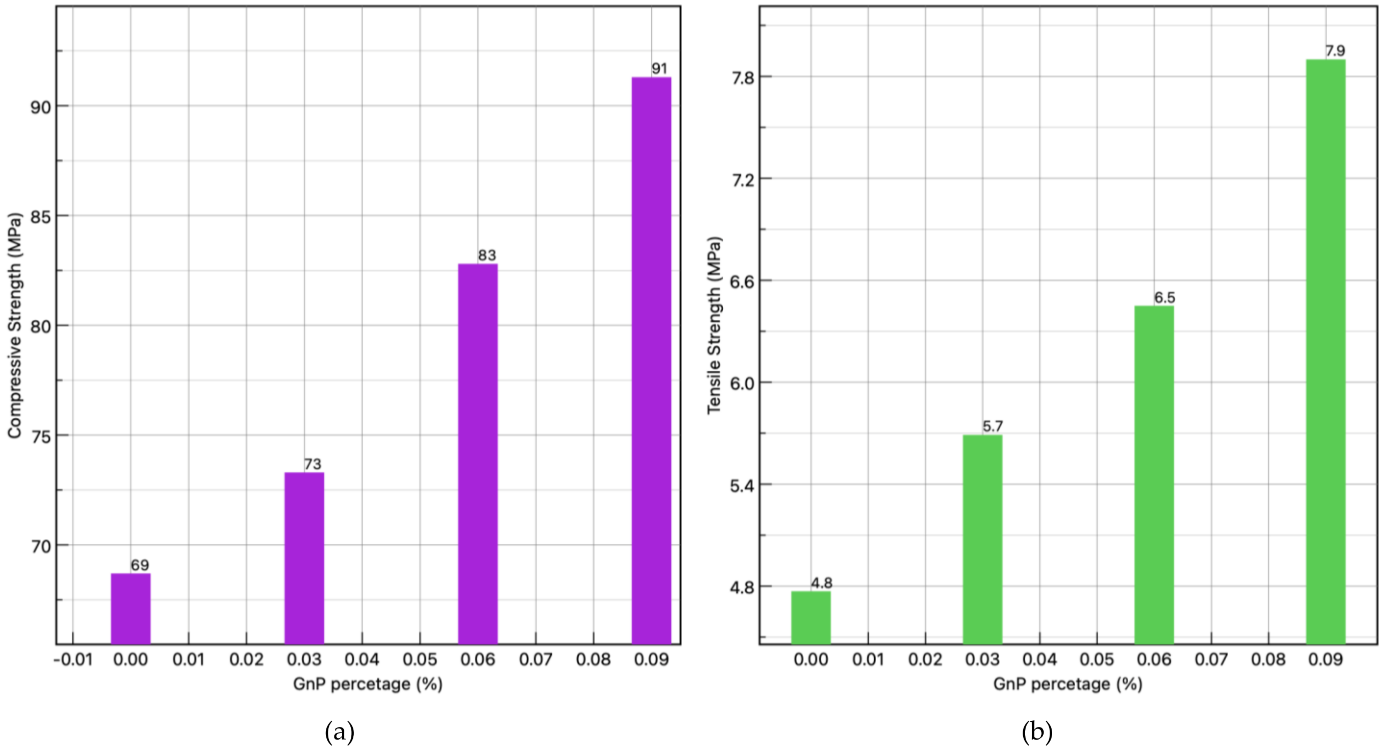

Figure 2. Strength of UHPECC at varying graphene nanoplatelets (GnP) content: (a) compressive strength; (b) tensile strength.

4. Conclusion

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

1. Incorporation of GnP in UHPECC resulted in strength improvements at all GnP contents, with increasing strength of the GnP-UHPECC with respect to increasing GnP content.
2. Substantial increases in compressive and tensile strengths of up to 32.9 and 64.6%, respectively, were achieved.

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

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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.

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