# MECHANICAL PROPERTIES OF GRAPHENE NANOPLATELETS COMPOSITE RESIN FABRICATED BY 3D PRINTING TECHNIQUE

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## Abstract

**Vat photopolymerization 3D printing, including LCD 3D printing, is a versatile method for the fabrication of complex structures with numerous applications. The aim of this study was to investigate the potential of graphene nanoplatelets (GNP) as an additive for improving the mechanical properties of carbon-filled composite resin for LCD 3D printing. Tensile testing was conducted on the 3D printed samples using the ASTM D638 type V standard model. The results indicated that adding 0.1% w/w GNP with 20 sec of exposure time increased the elastic modulus of the specimen from 7.31±1.02 MPa to 9.38±0.37 MPa for x-orientation (horizontal) and from 7.62±0.93 MPa to 9.58±0.61 MPa for y-orientation (vertical). Furthermore, the maximum tensile strength increased from 3.87±1.13 MPa to 5.28±0.73 MPa for y-orientation and from 4.06±0.92 MPa to 5.49±0.49 MPa for x-orientation. These results demonstrate the efficacy of GNP as an effective additive for enhancing the mechanical properties of carbon-based composite resin in LCD 3D printing.**

**Keywords:** **Composite resin; graphene nanoplatelets; LCD 3D printing; mechanical properties; vat photopolymerization**

## Introduction

Three-dimensional (3D) printing, also known as additive manufacturing, has emerged as a transformative technology in the manufacturing industry due to its capability of producing complex geometries with high precision and accuracy (Abdollahi *et al*., 2018; Shahrubudin *et al*., 2019). Among the different 3D printing technologies, liquid crystal display (LCD) 3D printing, also known as mask stereolithography (MSLA), has gained significant attention due to its high resolution and accuracy (Lee *et al*., 2017; Malas *et al*., 2019). However, the mechanical properties of the printed objects using LCD 3D printing are often limited by the brittleness of the resins used. To address this challenge, researchers have been exploring the incorporation of various additives into the resins

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to improve the mechanical properties of the printed objects. In particular, the incorporation of carbon-based nanomaterials, such as graphene nanoplatelets (GNP), has shown great promise in enhancing the mechanical properties of various materials, including polymers, metals, and ceramics.

Graphene, a single layer of carbon atoms arranged in a hexagonal lattice, is known for its exceptional mechanical, thermal, and electrical properties (Lim *et al*., 2017; Hanon *et al*., 2021). GNP, a form of graphene produced by exfoliating graphene layers from graphite, possesses many advantages over other forms of graphene, such as high aspect ratio, low cost, and ease of production (Feng *et al*., 2019; Markandan *et al*., 2020). The incorporation of GNP into the resins used in LCD 3D printing has the potential to significantly enhance the mechanical properties of the printed objects.

In this study, we investigate the effectiveness of incorporating GNP into a UV-curable resin used in LCD 3D printing to enhance the mechanical properties of the printed objects. UV-curable resins are widely used in LCD 3D printing due to their fast-curing time, low shrinkage, and high resolution. However, the mechanical properties of the printed objects using UV-curable resins are often limited. Through a systematic characterization of the mechanical properties of the GNP-reinforced UV-curable resin, we aim to provide insights into the underlying mechanisms of the reinforcement effect and identify optimal processing conditions for the LCD 3D printing of high-performance objects. The study contributes to the field of vat photopolymerization by providing valuable insights into the enhancement of mechanical properties, specifically the elastic modulus and tensile strength, of 3D printed parts. Understanding the impact of GNPs on the resin matrix helps in the development of optimal printing parameters and conditions for composite materials, thereby advancing the application of vat photopolymerization 3D printing technology.

## Methodology

This section provides a detailed account of the materials and equipment used in this research, along with the sample preparation, experimental and testing methodologies.

### Material and Printer

The material used in this study was Pufferomer3D resin (Hard) as the base material and Graphene nanoplatelets (GNP) obtained from Graphene Technology Co. Ltd. (Thailand) as the reinforcing material. The resin was stored in a cool, dry place to prevent contamination. The 3D printer used in this study was the Elegoo Mars LCD 3D printer. The printer was calibrated and the build platform was leveled prior to printing.

### Preparation and Printing Conditions

The printing conditions were varied to investigate their effects on the mechanical properties of the printed samples. The layer height was set to 0.05 mm, which is the highest resolution available on the Elegoo Mars LCD 3D printer. The exposure time was varied between 10, 20, and 30 sec for both the normal and GNP added resins. The concentration of GNP in the resin was 0.1% w/w. As shown in Figure 1, the printing orientation was varied between horizontal (x) and vertical (y) for each exposure time. After printing, the samples were post-exposed for 90 sec to ensure complete curing.

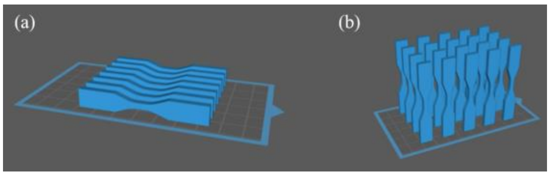


**Figure 1. Printing orientation of specimens in horizontal (x) and vertical (y) axes, as shown in (a) and (b), respectively**

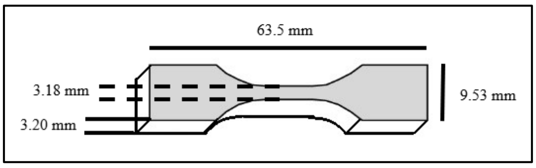


**Figure 2. Demonstration of the dimensional schematic of the ASTM D638 Type V model utilized for tensile testing**

### Tensile Testing

Tensile testing was performed on an UTM Instron 5565 machine, which is capable of applying forces up to 100 kN. ASTM D638 type V standard model was used for the tensile testing, as in Figure 2. ASTM D638 is a standardized test method that outlines the procedures for evaluating the tensile properties of plastics and other resin materials (Kumar and Narayan, 2018). The test method provides guidelines for the preparation of the specimens, including their shape and size, as well as the testing apparatus and conditions. Specifically, the test involves using a dumbbell-shaped specimen. The test procedure involves subjecting the specimen to a tensile force until it fractures, while monitoring the load and displacement. The test measures a range of mechanical properties including ultimate tensile strength, yield strength, elongation at break, and elastic modulus. These properties can be used to assess the strength, stiffness, and ductility of the material, and can be useful for material selection, design, and quality control purposes (Harding and Welsh, 1983). The accuracy requirements for the test frames and accessories used are also outlined in the standard, ensuring that the results obtained from different laboratories are comparable. In this work, the samples were placed in the UTM Instron 5565 machine and tested at the speed of 1 mm/min. The tensile testing was conducted until the sample broke, and the maximum load and elongation at break were recorded.

## Result and Discussion

The obtained results revealed that the elastic modulus of the resin composite increased with exposure time, as illustrated in Figure 3(a). The solid and stripe plots in Figure 3(b) represent the printing orientation of the specimens in the x and y axes, respectively. Interestingly, no significant difference was observed in the elastic modulus between the two printing orientations. These findings suggest that exposure time is a more critical factor than printing orientation in enhancing the elastic modulus of the resin composite. Furthermore, the data from this study provides valuable insights for the development of optimal printing parameters and conditions for the fabrication of composite materials using 3D printing technologies. Additional experiments can be conducted to further validate these findings and optimize the printing parameters for different composite materials.

Moreover, the effect of adding 0.1% w/w graphene mixed resin on the mechanical properties of 3D printed specimens was investigated. The results, as shown in Figures 4(a) and 4(b), indicate that there was a significant increase in elastic modulus and maximum tensile strength for specimens printed in the x-axis with 20 sec of exposure time.

The elastic modulus of the specimens increased by 28.3% while the maximum tensile

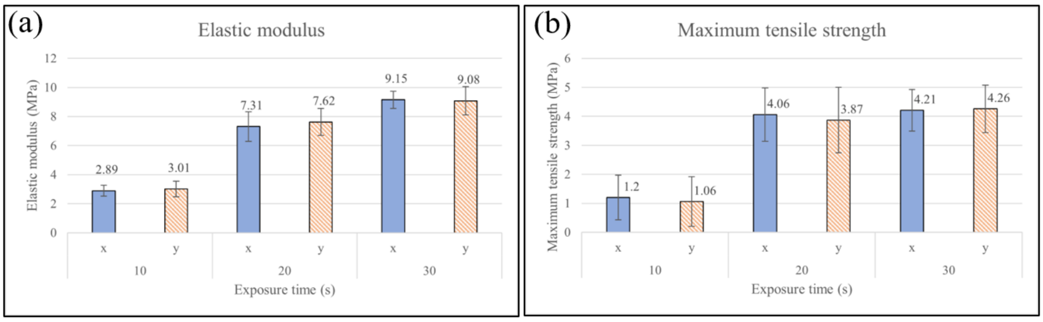


**Figure 3. Plot of (a) elastic modulus and (b) maximum tensile strength over exposure time for both horizontal (x) and vertical (y) printing orientation**

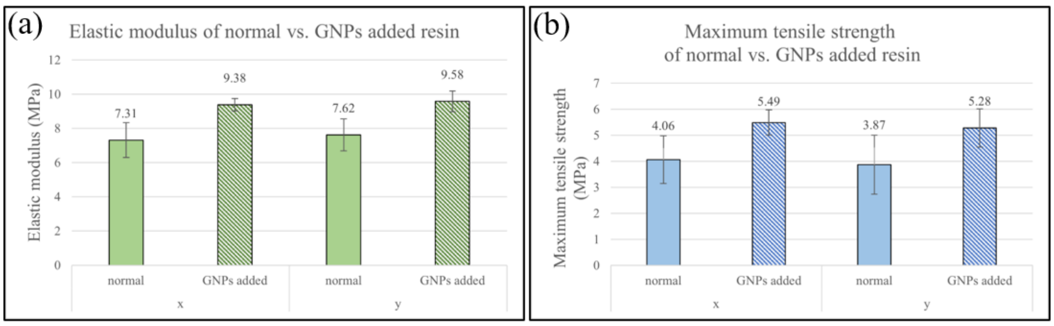


**Figure 4. (a) Comparison of elastic modulus between normal resin and resin with added GNPs, with 20 sec of exposure time, for horizontal (x) and vertical (y) printing orientations. (b) Comparison of maximum tensile strength between normal resin and resin with added GNPs, with 20 sec of exposure time, for horizontal (x) and vertical (y) printing orientations**

strength increased by 36.4%. This suggests that graphene nanoplatelets have a reinforcing effect on the composite material, resulting in improved mechanical properties.

The results also showed that there was no significant difference in mechanical properties observed between the x-axis and y-axis printing orientations. However, some studies have reported that printing orientation can indeed have an impact on the mechanical properties of 3D printed parts. The observed increase in load-bearing capacity before ultimate failure can be attributed to the angled arrangement of the print layers relative to the applied load. This structural configuration enhances the ability of the printed parts to withstand higher loads, resulting in improved mechanical performance (Saini *et al*., 2020). While our study did not observe a significant difference in mechanical properties between the x-axis and y-axis printing orientations, it is worth noting that printing orientation can play a role in certain cases. The effect of printing orientation on mechanical properties can be influenced by factors such as the part geometry, layer adhesion, and anisotropic material behavior. It is possible that the specific resin matrix and GNPs used in our study mitigated the influence of printing orientation on the elastic modulus of the composite material. However, further investigations and specific experimental conditions may be required to fully understand the interplay between printing orientation and the mechanical properties of 3D printed parts in the context of resin composites with GNPs.

Overall, the addition of graphene nanoplatelets to the resin can be an effective method for improving the mechanical properties of 3D printed parts, which can be useful in various applications including aerospace, automotive, and biomedical industries. For instance, in the aerospace industry, these improved characteristics can contribute to the development of lightweight and durable components, leading to increased fuel efficiency and overall performance of aircraft systems. In the automotive sector, the augmented mechanical properties enable the production of stronger and more reliable parts, enhancing the safety and longevity of vehicles. Similarly, in the biomedical field, the heightened mechanical properties offer opportunities for fabricating patient-specific implants with superior strength and durability, thereby improving the success rates and longevity of medical interventions. The enhanced performance of these 3D printed parts holds great promise for advancing technological innovations and meeting the stringent requirements of these industries.

## Conclusions

In conclusion, this study investigated the effect of adding graphene nanoplatelets (GNPs) to the resin for 3D printing of carbon-based composite materials using vat photopolymerization. The results showed that the addition of GNPs led to an increase in both elastic modulus and maximum tensile strength of the printed specimens. Specifically, the specimens printed in the x-axis with 0.1% w/w graphene mixed resin and 20 sec of exposure time showed the highest increase in both elastic modulus and maximum tensile strength. These findings demonstrate the potential of vat photopolymerization 3D printing for the production of graphene nanoplatelets composite materials with improved mechanical properties.

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