

COBEM2023-1631 THE EFFECTS OF CONTROLLED GRAPHENE ADDITION ON STEREOLITHOGRAPHY-PRODUCED MATERIALS

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Abstract. *The incorporation of graphene in polymer composites has garnered significant attention due to graphene's exceptional mechanical and electrical properties. This study investigates the effect of adding a low concentration of graphene on the mechanical properties of a photopolymerizable resin used for additive manufacturing by stereolithography. Tensile, flexural, and impact tests were performed on printed parts made with the graphene-reinforced composite and compared to parts printed solely with resin. The results obtained so far indicate a slight improvement in the Elastic Modulus due to the addition of graphene; however, it resulted in decreased tensile and flexural strength. Furthermore, the addition of graphene did not modify the impact toughness. This comprehensive methodology of this study incorporated standardized specimen design, controlled printing parameters, thorough curing, meticulous specimen selection, and rigorous mechanical testing, ensuring the accuracy and reliability of the obtained results. The findings from this study will contribute to a deeper understanding of the mechanical behavior of materials with different compositions, paving the way for potential applications in various industries, such as aerospace, automotive, and consumer electronics.*

Keywords: Stereolithography; graphene; Photopolymerizable resin; nanocomposites; mechanical properties

1. INTRODUCTION

Additive manufacturing, which is commonly known as 3D printing, has witnessed a substantial upsurge in popularity within the industrial sphere owing to its exceptional precision and remarkable adaptability. This highly innovative and cutting-edge method of manufacturing facilitates the production of intricate designs and complex geometries with unparalleled accuracy, thus bringing about a revolutionary transformation in traditional production processes. As the demand for additive manufacturing continues to escalate and gain momentum, there persists an unwavering and relentless pursuit of new materials and technological enhancements aimed at optimizing the final product and pushing the boundaries of its capabilities to unprecedented heights.

Photopolymerizable resins are widely used in additive manufacturing due to their unique ability to solidify and transform into a solid state when exposed to specific wavelengths of light (Pagac *et al.*, 2021).

As a result, this process creates robust and dimensionally accurate printed parts known for their precision. Incorporating graphene, a two-dimensional carbon nanomaterial known for its exceptional mechanical and electrical properties, presents an opportunity to enhance the performance and capabilities of resin-based additive manufacturing processes.

Conversely, the incorporation of graphene in composites offers an opportunity to enhance thermal conductivity (Prolongo *et al.*, 2013) (Chandrasekaran *et al.*, 2013). Graphene, with its exceptional thermal properties, can act as an efficient conductor, facilitating the transfer of heat within the material. This opens up new avenues for the exploration of additional intrinsic properties of the composite material. By capitalizing on the thermal conductivity enhancement provided by graphene, researchers can delve into applications that require efficient heat dissipation and thermal management, such as electronics, energy storage systems, and thermal interface materials.

The primary and foremost objective of this meticulously executed and meticulously planned research endeavor is to make groundbreaking and invaluable contributions to the advancement, progression, and evolution of additive manufacturing techniques by stereolithography. Moreover, it seeks to elucidate and shed light upon the vast and untapped potential of graphene as an incredibly potent and influential reinforcement material in the realm of resin-based printing. By undertaking an exhaustive and comprehensive investigation encompassing multifaceted dimensions, it aspires to unearth, discover, and unravel invaluable insights and knowledge that can be harnessed and utilized to drive and fuel the

development, creation, and realization of technologically superior and highly innovative composite materials. Ultimately, this would enable and empower the seamless and flawless production of high-quality, structurally robust, and impeccably precise components and parts within the additive manufacturing processes. The profoundly impactful findings and discoveries that emerge from this meticulously crafted and diligently conducted study possess and bear the tremendous and awe-inspiring potential to revolutionize, reshape, and transform the additive manufacturing industry at its very core. Consequently, this groundbreaking research endeavor has the capacity to open up new and unexplored frontiers, avenues, and horizons for relentless innovation and pioneering exploration, thus propelling and catapulting the additive manufacturing industry to unprecedented heights and dimensions of achievement that were once deemed inconceivable.

2. EXPERIMENTAL

In order to conduct a comparative analysis of the mechanical behavior in parts with different compositions, test specimens were designed and printed using Creality Standard resin and a Halot One printer. The specimens were standardized according to ABNT guidelines, with dimensions of 10 mm x 50 mm and a uniform thickness of 2 mm, following the recommended aspect ratio of five times the equivalent width for the tensile test.

Graphene was added to the resin at a concentration of 0.3 wt% prior to printing. The resin with graphene addition was mixed in a roller mixer for 180 minutes under 60 rpm to ensure the homogeneity of the mixture. For the tensile test six specimens were printed using purely resin composition, while another six specimens were printed using a composition of 99.7% resin and 0.3% graphene, 4 samples of each type were printed for the bending test and other 10 samples of each were printed for the impact test. The printer settings were optimized for the resin type, including layer height, print speed, and exposure time to achieve the best possible print quality.

All samples were printed with the same printing parameters. To ensure the reproducibility of the results, a controlled environment was maintained throughout the printing process, including temperature and humidity control.

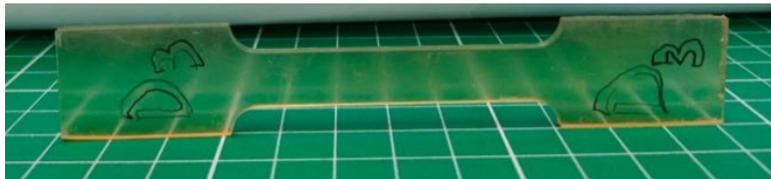


Figure 1. Pure resin sample for tensile test

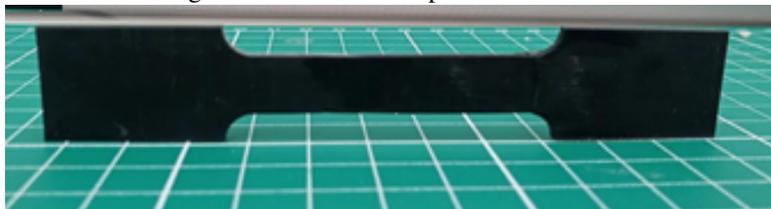


Figure 2. Sample with graphene addition



Figure 3. Pure resin sample for bending test



Figure 4. Sample with graphene addition

After the printing process, the specimens were carefully removed from the build platform, meticulously cleaned employing isopropyl alcohol in order to ensure that no remnants of wet resin persisted and to establish secure adherence to the grips of the testing machine, the samples underwent an additional exposure to UV light with 405 nm wavelength for 10 minutes, aiming to ensure the complete curing.

In addition to following a structured experimental protocol, it is important to note that certain aspects of our study also incorporated trial-and-error procedures. While we emphasized controlled printing parameters, standardized specimen design, and meticulous preparation to maintain a controlled environment, we recognize that the optimization of certain experimental conditions involved iterative testing and parameter adjustments. This trial-and-error approach was employed to fine-tune the printing process and achieve the best possible results. By systematically exploring variations and making adjustments, we aimed to optimize the performance of our graphene-reinforced composite materials. This iterative methodology allowed us to refine our experimental setup and, ultimately, enhance the accuracy and reliability of our findings, contributing to a more comprehensive understanding of the materials' mechanical behavior.

Afterwards, samples were inspected for any visible defects or irregularities. Any flawed specimens were discarded, ensuring that only high-quality samples were included in the subsequent mechanical testing.

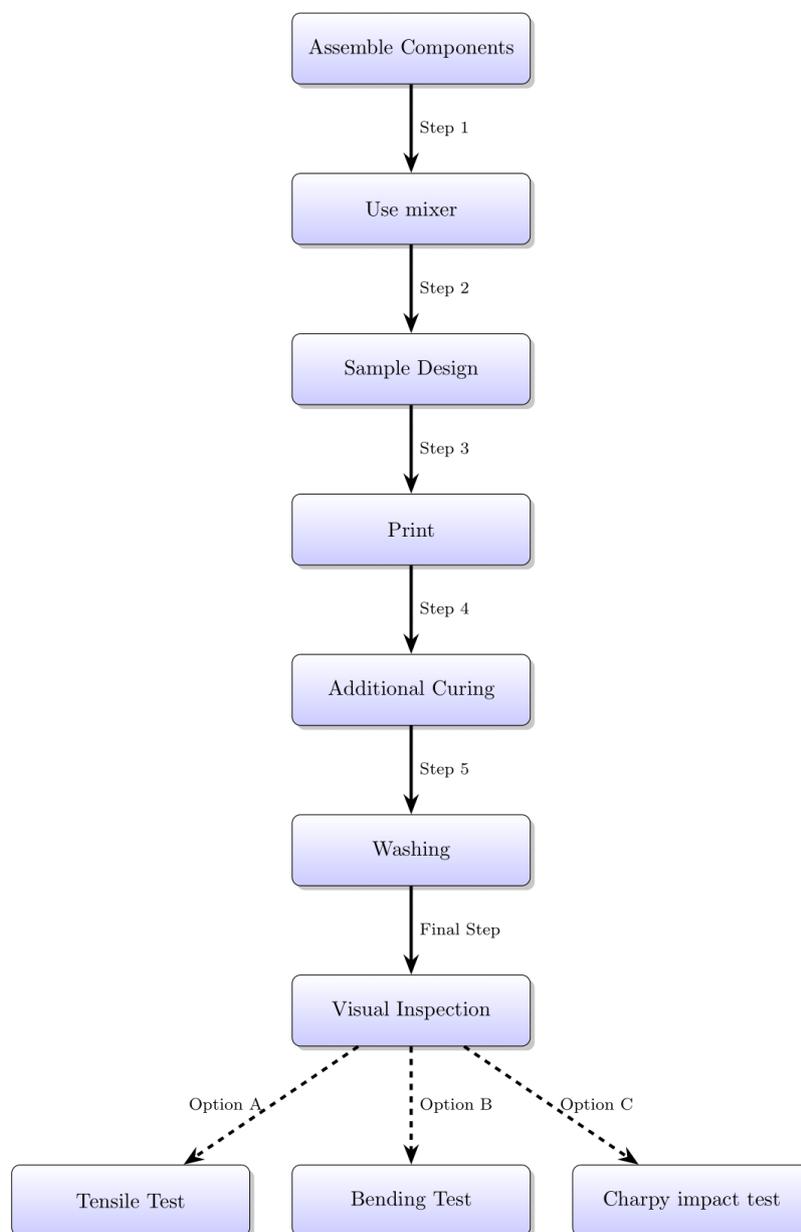


Figure 5. Process flow diagram

To assess the mechanical behavior, tensile and bending tests were performed on the printed specimens using a universal

testing machine(EMIC-2000) and a CEAST Resil 25 for the testing impact. The tests included tensile strength, flexural strength and impact test. The specimens were placed in the testing machine according to standardized procedures.

Throughout the entire experimental procedure, strict adherence to safety protocols and guidelines was followed to ensure the well-being of the researchers and prevent any potential hazards.

The obtained data from the mechanical tests were analyzed using statistical software. Statistical analysis involved the calculation of mean values, standard deviations, and the application of appropriate hypothesis tests.

3. RESULTS

Figure 1 depicts the 3D components post-SLA printing. Incorporating graphene changes the resin’s color from transparent to black. Moreover, upon curing, the printed part assumes an opaque appearance. Successful printing was achieved for both components: one without graphene nanoplatelets (GNP) addition, and the other with a GNP content of 0.3 wt %.

The obtained data has been analyzed and tabulated along with their respective means and standard deviations. Firstly, the data from the tensile test are as follows:

Table 1. Tensile Test

	% Graphene	Tensile Strength(MPa)	Yield Strength(MPa)	Young’s Modulus(GPa)	Strain(%)
Resin	0	54.1 ±10	21 ±8	1.25±0.2	0.9 ±0.2
0.3 GNP	0.3%	35.5 ±7	21.6 ±4	1.4 ±0.1	0.52 ±0.1

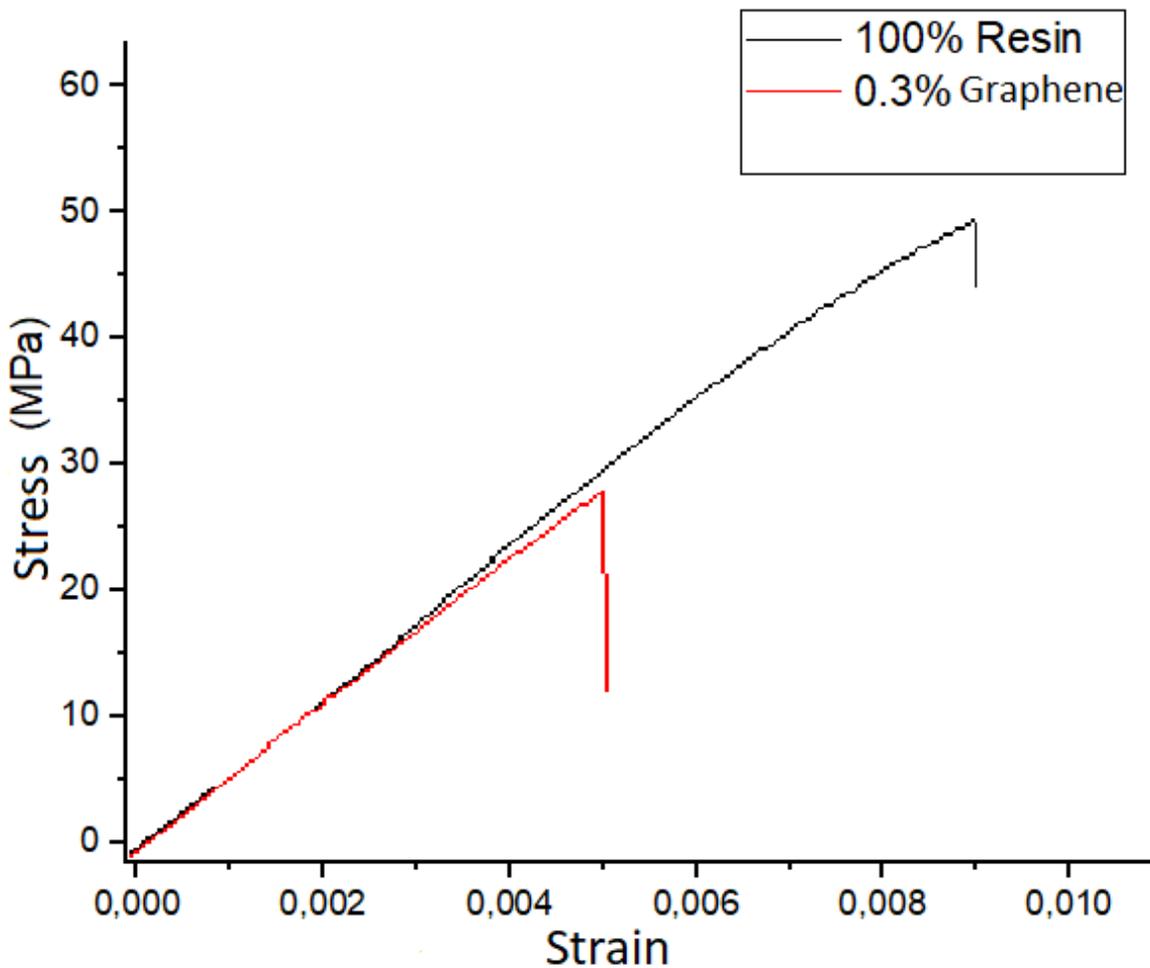


Figure 6. Example of results for tensile test

The tensile tests indicate an incremental rise in Young’s Modulus, accompanied by a decrease in ultimate tensile strength. Consequently, the introduction of graphene led to a decline in strength. These results are in accordance with the results reported by Prolongo *et al.* (2014), which also observed that graphene addition results in an increase in the stiffness, and reduction in strength and elongation.

The test results have generated findings that are in accordance with those documented in the current body of literature for this particular type of addition. It has been observed that the composites have demonstrated inferior mechanical properties overall when compared to samples fabricated solely from resin, primarily due to the substandard interface between the graphene particles and the polymer matrix. This inherent issue contributes to the formation of microcracks and microfissures, consequently leading to a decline in mechanical properties. The hypothesis posits that in the vicinity of the carbon particles, the resin may not have undergone a uniform and complete curing process. It is plausible that these particles could potentially obstruct the transmission of ultraviolet rays within the infinitesimal region encompassing them. This realization holds substantial significance in terms of modifying production methodologies to effectively harness the mechanical properties of graphene within such composite materials. Furthermore, it is imperative to conduct further research in order to refine these methodologies and explore the properties obtained through diverse manufacturing techniques.

Similarly, in the bending test, the addition of graphene led to a decrease in flexural strength

Table 2. Bending Test

	% Graphene	Flexural Strength(MPa)	Young’s Flexural Modulus(GPa)
Resin	0	69.51 ±14	2.2 ±0.9
0.3 GNP	0.3	28 ±3	0.5 ±0.2

The impact tests showed that the addition of graphene did not result in significant changes in the toughness of the samples. Such outcome was anticipated, given that in this type of composite, toughness is dictated by the properties of the matrix.

Table 3. Impact Test

	%Graphene	Toughness (J)
0.3 GNP	0.3	0.39 ±0.11
Resin	0	0.39 ±0.19

4. CONCLUSION

The mechanical properties of reinforced composites have been limited by the weak interface formed during the manufacturing process. To fully exploit its potential, it is imperative to explore variations in manufacturing processes and test new types of resin that can strengthen the bonding at the composite interface, thus enhancing the mechanical properties. By addressing this challenge, the performance and durability of graphene-based composites can be significantly improved.

The addition of graphene increased Young’s modulus in the tensile test but reduced both tensile and flexural strength, with no significant impact on toughness.

The optimization of the mechanical properties of graphene-based composites through improved interface bonding exciting prospects for the development of advanced materials. By exploring variations in manufacturing processes, testing new resin types, and leveraging graphene’s exceptional properties, researchers can unlock the full potential of these composites, enabling their utilization in a diverse array of cutting-edge applications. The continued exploration of the intrinsic properties of composite materials holds the key to unlocking their transformative impact across industries and driving innovation forward.

The conclusion of this study provides a summary of our findings regarding the mechanical properties of graphene-reinforced composites and highlights the limitations of the current research. While our experiments have shed light on the impact of graphene addition on mechanical properties, we acknowledge that further investigations are warranted to explore the full scope of possibilities. Additional experimental results, such as a more extensive range of graphene concentrations or variations in the manufacturing process, could bolster the support for our conclusions. Moreover, the primary challenges that lie ahead include refining manufacturing methodologies to strengthen the interface between graphene particles and the polymer matrix, ultimately enhancing the mechanical properties of these composites. Overcoming this challenge is essential to unlock the transformative potential of graphene-based composite materials across various industries, fostering innovation and enabling the development of materials with superior performance.

5. REFERENCES

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6. RESPONSIBILITY NOTICE

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