

**To Cite:** Sadık, A. C., Karabudak, F. & Kula, M. E. (2026). Dynamic and Mechanical Properties of Nanoparticle Doped Aramid/Glass Fiber Reinforced Interply Hybrid Composite. *Journal of the Institute of Science and Technology*, 16(2), 715-728.

## Dynamic and Mechanical Properties of Nanoparticle Doped Aramid/Glass Fiber Reinforced Interply Hybrid Composites

Ayşegül Cansu SADIK<sup>1</sup>, Filiz KARABUDAK<sup>1\*</sup>, Muhammed Emin KULA<sup>2</sup>

### Highlights:

- Nanocomposite
- Mechanical properties
- Dynamic properties

### Keywords:

- Nanoparticles
- Nanocomposite
- Mechanical tests
- Modal analysis

### ABSTRACT:

In this study, the mechanical and dynamic properties of glass/aramid interply hybrid composites reinforced with four different nanoparticles were investigated. Firstly, matrix modification was performed and composite plates were manufactured by hand lay-up technique. Silicon dioxide (SiO<sub>2</sub>), graphene (GNP), silver (Ag) and cerium oxide (CeO<sub>2</sub>) nanoparticles were added to the epoxy matrix as reinforcement. With the addition of nanoparticles, the highest tensile (16%) and flexural (67.3%) strengths were observed in Ag reinforced composites. Tensile (16.8%) and flexural (14.4%) strengths decreased with the addition of graphene nanoparticles. Tensile and flexural tests revealed delamination, matrix and fibre rupture in all plate types. As a result of modal analysis, the highest natural frequency values and the lowest damping ratios were determined in the FFBC boundary condition. The addition of nanoparticles improved the mechanical properties of the composites in general.

<sup>1</sup>Ayşegül Cansu SADIK ([0009-0009-6582-0812](mailto:0009-0009-6582-0812)), Filiz KARABUDAK ([0000-0002-7365-0333](mailto:0000-0002-7365-0333)), Gümüşhane University, Faculty of Engineering, Department of Mechanical Engineering, Gümüşhane, Türkiye.

<sup>2</sup>Muhammed Emin KULA ([0009-0002-6718-031X](mailto:0009-0002-6718-031X)), Faculty of Engineering, Department of Mechanical Engineering, Erzurum, Türkiye.

\*Corresponding Author: Filiz KARABUDAK, e-mail: filizkarabudak@gumushane.edu.tr

This study is derived from Ayşegül Cansu Sadık's Master's thesis.

## INTRODUCTION

With the development of technology, new materials are used in engineering applications every day. Researchers emphasize that the material should be light, strong, and cost-effective according to the areas of use. In this context, composites are among the most widely used materials in engineering studies in line with the needs of many scientists. Composite materials, which are preferred in critical areas such as automotive, aerospace, and defense, also have an important place for the scientific community on a global scale.

Composite materials are produced by combining two or more components with different structural properties to create a new material with improved properties. Nanoparticles are added to the matrix to improve the mechanical properties of the materials further. As a result, materials called nanocomposites emerge (Selvan & Vedaraj, 2023). In addition, with the advancement of nanotechnology, nanoparticle-reinforced composite materials have become more widely used (Acar et al., 2017). The category of two-dimensional materials in which at least one component of the composite material is below 100 nm in size is called nanocomposite materials (El-Eskandarany et al., 2021). Thanks to their large surface area and perfect crystal arrangements at the nanoscale, nanocomposites are superior to micro and macro-scale materials in terms of mechanical, thermal, and electrical properties (Colorado et al., 2023). These composites have wide application areas in the aerospace, automotive, and electronics industries and are generally preferred in the form of nanowires, nanoparticles, graphene, carbon nanotubes, and nanofilms (Colorado et al., 2023).

In the literature, it has been observed that nanoparticles are added to polymeric systems to improve the mechanical properties of sandwich structures, enhancing characteristics such as strength and stiffness (Aydın et al., 2023). These nanoparticles are used to improve the properties of composite materials by filling weak micro-voids at the interfaces of epoxy fillers (Oner et al., 2023). The mechanical properties vary depending on the structural characteristics, particle size, and surface properties of the composite with nanoparticle reinforcement (Tabar et al., 2015; Pirayesh and Saadatnia, 2016). It has been observed that adding a small amount of nanoparticles to the structure significantly increases mechanical properties (Kiran et al., 2018).

Silicon dioxide ( $\text{SiO}_2$ ), a white material obtained by crushing oxide-rich rocks and used as a reinforcing material, has a low specific gravity and a high melting point (Kantarci et al., 2021). It has been observed that mechanical and thermal properties are significantly improved with nano-silicon dioxide reinforcement (Ates et al., 2020). However, it has been reported that silicon addition reduces the thermal expansion coefficient (Sprenger, 2013). It is also preferred in production studies because it increases the processability of polymer materials (Vidakis et al., 2021). Additionally, its low density, high transparency, low cost, and easy availability give it an advantage over other materials (Hao et al., 2021). Due to their superiority, they are widely used in many industries such as material applications, cosmetics, pharmaceuticals, and the construction industry (Di Credico et al., 2023; Karnati et al., 2020). In addition, due to its large surface area, high surface energy, and easy production process, it finds its place in many applications such as polishing solutions and electronic materials (Qin et al., 2015).

In the studies in the literature, it is seen that graphene is another reinforcing material widely used as nanoparticles. Graphene, is cheaper than carbon nanotubes (CN) because they are much easier to produce, has recently attracted much attention (Han et al., 2011). Graphene exhibits superior electrical conductivity, thermal conductivity, and elasticity due to its large specific surface area (Tang et al.,

2013). In addition, according to graphene-based composite studies, it was observed that important mechanical properties such as fracture toughness, impact resistance, flexural, and tensile strength of the composite increased with the addition of graphene nanoparticles to the structure (Acar et al., 2013). Graphene is cheaper than carbon nanotubes (CN) because graphene is much easier to produce (Shen et al., 2017). Widely preferred in studies, graphene is chosen as a reinforcing element in composite structures due to its low cost and high strength properties (Li et al., 2015a; Yang et al., 2017). The addition of nanographene increases the surface area, effectively improving the efficiency of the contact surface and thus increasing the strength value (Liao et al., 2023). Exhibiting high tensile strength and elastic modulus at the nanoscale, graphene is an effective reinforcing material in polymer matrix composites (Han et al., 2011; Tang et al., 2013). As a result, it is widely used in aerospace, automotive, medical, and other technical applications (Koppanati et al., 2023). When the studies were examined, it was determined that graphene alone is not sufficient, but derivatives of graphene can also be used. Graphene and functionalized graphene products have recently been recognized as ideal reinforcements in polymer matrices due to their high mechanical properties, stiffness and affordability (Feng et al., 2017; Wang et al., 2019). There are two main functionalized products of graphene, graphene oxide (GO) and reduced graphene oxide (rGO). While GO is obtained as a result of the oxidation of graphite, rGO is synthesized as a result of the reduction of GO. GO is mainly preferred in bio-applications. This is because GO has various functional groups (e.g. hydroxyl, carboxyl and epoxy groups) that allow it to bind to biomolecules (Tahriri et al., 2019). The significant difference between GO and rGO is the predominance of carboxyls and the lower amount of oxygen (Magne et al., 2021). The selection between GO and rGO is therefore application-dependent, as their surface chemistry and electrical properties influence dispersion behavior and interfacial bonding within polymer matrices (Feng et al., 2017; Wang et al., 2019).

In various studies, it is aimed at improving structural properties by combining graphene derivatives with different nanomaterials. One of these nanomaterials is cerium oxide ( $\text{CeO}_2$ ). In composite systems, the contribution of  $\text{CeO}_2$  nanoparticles to mechanical performance is often attributed to improved particle dispersion and microstructural stabilization rather than direct load-bearing effects (Kang et al., 2021). Cerium oxide is a rare earth metal of the lanthanide series that can be easily dispersed in graphene oxide as a result of pi-pi bonding interactions and shows antibacterial and antioxidant properties (Panda et al., 2022). Cerium oxide with a crystal lattice structure provides greater redox capacity due to electron holes or oxygen defects in the nanoparticle matrix (Bailey et al., 2020). It also plays an important role in improving their mechanical properties cerium oxide alone significantly increased the pitting resistance of the base alloy (Hosseini et al., 2015). On the other hand, it also plays an important role in improving improving mechanical properties (Kang et al., 2021). In particular, cerium oxide dispersion has been found to improve corrosion resistance in aluminum matrices significantly (Ashraf et al., 2009). In addition, cerium oxide is added as nanoparticles into the epoxy matrix to improve its ultraviolet (UV) absorption properties. It has been reported that cerium oxide absorbs UV light significantly in studies and investigations. For this reason, cerium oxide is often preferred in various applications involving optical, magnetic, and electronic materials (Dao et al., 2011).

Silver (Ag) is one of the nanoparticles used in important applications such as optics and magnetics. In studies in the literature, it has been reported that as a result of the addition of silver nanoparticles to the matrix, electrical, chemical, mechanical, and optical properties are superior to many other metal nanostructures. In the studies, improvement in tensile strength and elongation at

break of the structure was observed due to the addition of silver nanoparticles (Su et al., 2020). However, it has been reported that structures containing as little as 1 wt% nano silver provide antibacterial performance while maintaining their mechanical properties (Aalaie et al., 2011). In addition, it is an important detail among the studies that the silver nanoparticle increases creep resistance and decreases the melting temperature (Li et al., 2015b). Finally, it was found that the stiffness value increased significantly with increasing mass fraction of nano-Ag particles. Compressive strength, tensile strength, elongation and wear resistance were reported to perform better compared to some alloy types (Gassour et al., 2023). Nevertheless, the mechanical response of Ag-reinforced nanocomposites may vary depending on particle size, distribution, and matrix compatibility, and therefore reported improvements are system-specific (Su et al., 2020).

In this study, the mechanical and modal properties of nanoparticle-reinforced polymer composites using glass and aramid fiber fabrics were investigated. For this purpose, four different nanoparticles with different particle sizes were used. Vibration, tensile, and three-point bending tests of the composites produced by adding silicon dioxide (SiO<sub>2</sub>), graphene, silver (Ag), and cerium oxide (CeO<sub>2</sub>) nanoparticles separately as reinforcements to the epoxy matrix were performed. The damping ratio and natural frequency value were determined by modal testing of the composite laminates manufactured with the hand lay-up technique. The tensile strength and Young's modulus of the specimens were then determined by tensile testing. Finally, flexural properties were examined by the three-point bending test. By comparing different nanoparticle types under identical manufacturing and testing conditions, this study aims to provide a clearer understanding of the individual effects of each nanofiller on the mechanical and modal behavior of fiber-reinforced polymer composites.

## MATERIALS AND METHODS

### Materials

Nanoparticle reinforced glass and aramid fibers used in the study were supplied by nanography company. Duratek DTE1200 epoxy and DTS 1151 hardener polymeric system was used as matrix material (Duratek A.Ş. Kocaeli/Turkey). Silicon dioxide (SiO<sub>2</sub>), graphene, silver (Ag) and cerium oxide (CeO<sub>2</sub>) nanoparticles supplied by Nanography company were used as nanoparticle reinforcements at a rate of 1 wt% in different size.

### Composite Plate Manufacturing

Composite plates were produced using the hand lay-up method. First, three layers of glass and aramid fiber fabrics were prepared for the production of plates consisting of six layers by cutting them in equal sizes with the help of a cutter. Then, to obtain the resin system, it was prepared by stirring for one minute with a ratio of 79/21 epoxy/hardener by weight with the help of a mechanical process at room temperature according to the resin system manufacturer's recommendation. Finally, nanoparticles (silicon dioxide, graphene, silver and cerium oxide) were added to the mixture and mixing was completed. Technical specifications of the nanoparticle materials used in the composite plate production study are shared in Table 1;

**Table 1.** Technical properties of the nanoparticles used (Nanografi A.Ş.)

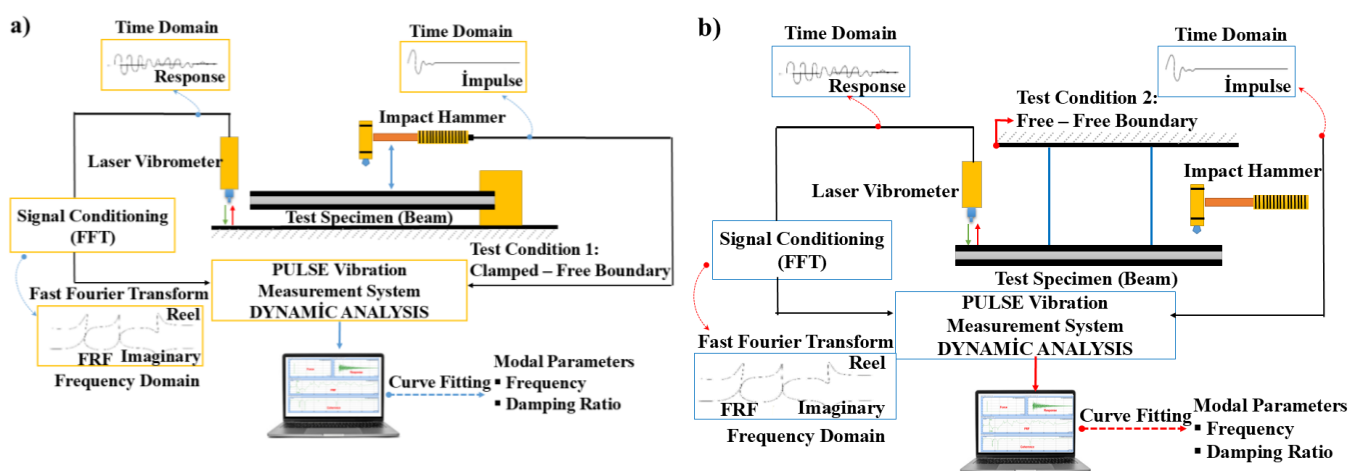
Additive Material	Grain Size (nm)	Purity (%)	Color
Graphene Powder	3 nm	99	Black
SiO <sub>2</sub> Powder	10-20 nm	99	White
Cerium Powder	<5 nm	99	White
Ag Powder	<100 nm	99	Black

First, a transparent and heat-resistant release film was laid on the surface of the preheated production bench. Then, the epoxy system was uniformly distributed on the release film with a brush. During the lay-up process, layered composite plates consisting of six layers, one layer of glass and one layer of aramid fabric, were produced by applying resin treatment between them. Upon completion of the fabric lay-up process, the plates were covered with a high temperature resistant nylon to prevent air flow. In order to remove air bubbles and excess resin from the system, a hard object was placed on the plates and the plates were left to cure.

A total of 5 nanoparticle reinforced polymer composite plates were produced by repeating separately for the pure group and 4 nanoparticles (graphene, SiO<sub>2</sub>, silver and cerium oxide) materials at 1 wt%. The thickness of each specimen was approximately  $3 \pm 0.2$  mm.

### Vibration tests

Vibration test specimen size was determined as 15 x 150 mm in accordance with ASTM standards. ASTM E756-05 standard is taken as reference for vibration test. The experimental modal analysis was carried out using a vibrometer (Ometron Ltd. / UK) and PULSE® vibration measurement system and ME'scope VES® Modal Analysis Software. In this context, the natural frequencies and damping ratios of the specimens were determined. The natural frequency value was obtained using the half-power bandwidth method and the damping ratio was obtained in time domain with logarithmic decay. The experimental setup for the experimental modal analysis of nanoparticle reinforced composite samples is schematically shown in Figure 1.

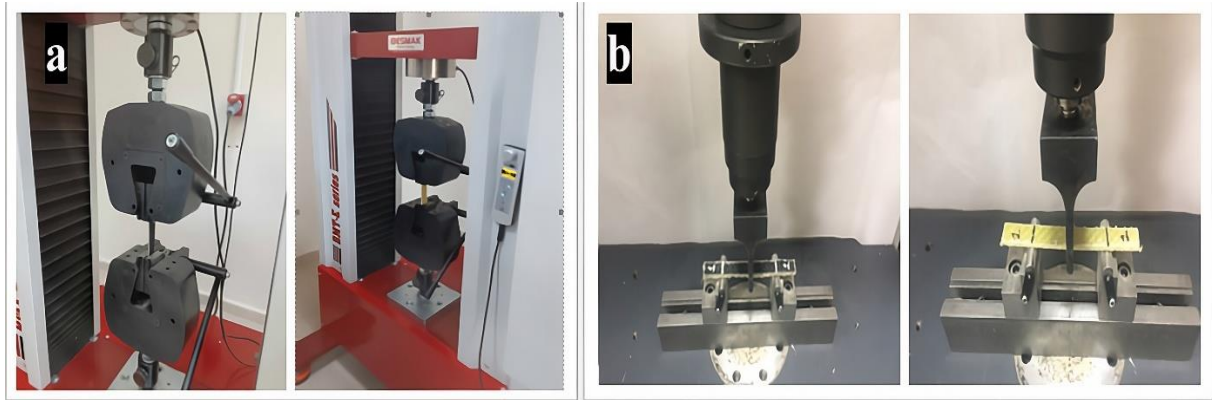


**Figure 1.** a) Specimen with one end anchored b) specimen with two ends freely connected

### Mechanical testing

Tensile test specimen size was determined as 15 x 150 mm and experimental studies were carried out. Tensile specimens were made at room temperature and at a tensile speed of 1 mm/min with a Besmak Bmt 200es model testing machine with a hydraulic pressure of 12-480 bar and a tensile capacity of  $\pm 20$  kN. As shown in Figure 2 (a), The specimen was aligned centrally and mounted in a straight configuration on the testing machine. During the tensile test, the tensile strength, yield strength and ductility of the specimens were investigated. At least 6 specimens were prepared for tensile test. The specimen size for the bending test was cut to 12.7x125 mm. ASTM D790 standard was taken as reference for the three-point bending test. As shown in Figure 2 (b), bending tests of nanoparticle reinforced polymer composites were carried out using Shimadzu AGS-X universal testing machine at room temperature and 1 mm/min bending speed. During the bending tests, the fracture of the surface

layers of the specimens and delaminations at the interface were investigated. At least 6 specimens were prepared for bending test.

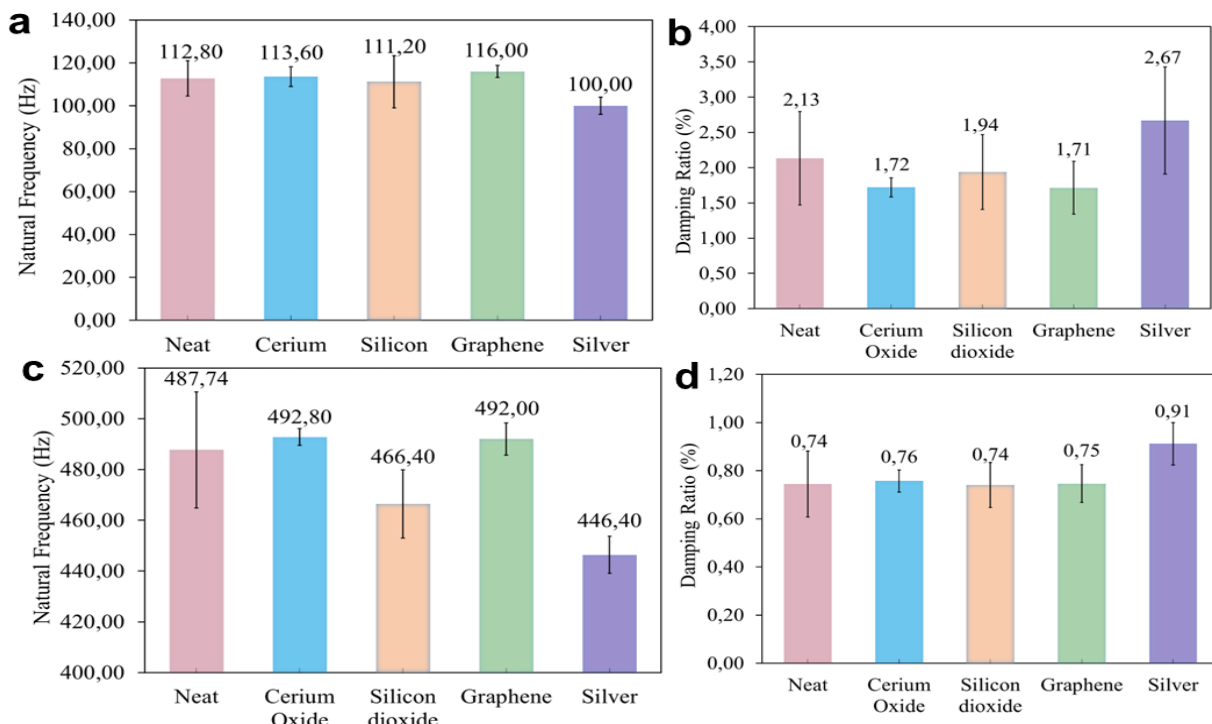


**Figure 2.** a) Tensile test b) three point bending test

**RESULTS AND DISCUSSION**

**Dynamic Analysis**

Dynamic analysis was performed to determine the dynamic properties of nanoparticle-doped composites. The natural frequencies and damping ratios of the specimens were determined with reference to clamped-free boundary condition (CFBC) and free-free boundary condition (FFBC) boundary conditions. Figure 3 presents a graphical summary of the modal analysis results, illustrating the average natural frequencies and damping ratios of all samples whose values fall below the CFBC and FFBC limits.



**Figure 3.** Modal analysis results of nanoparticle doped composites, a) 1<sup>st</sup> natural frequencies in CFBC b) 1<sup>st</sup> damping ratios in CFBC c) 1<sup>st</sup> natural frequencies in FFBC d) 1<sup>st</sup> damping ratios in FFBC

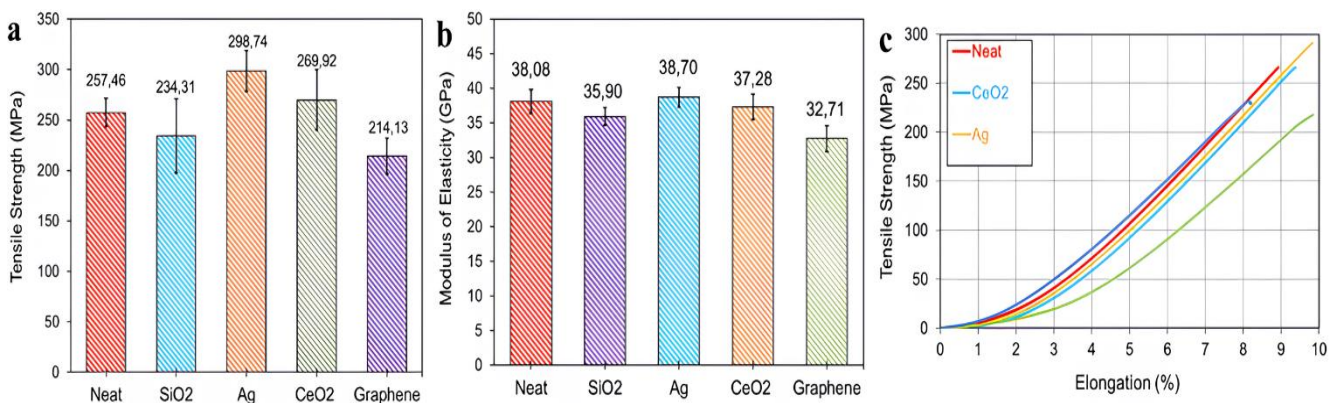
The average natural frequency and damping ratios of nanoparticle reinforced composites are given in Figure 3. First, the results under CFBC boundary condition and then under FFBC boundary condition are analyzed. Accordingly, the average natural frequencies of the neat, CeO<sub>2</sub> reinforced, SiO<sub>2</sub> reinforced, graphene reinforced and Ag reinforced composites with CFBC boundary condition were determined as 112.80, 113.60, 111.20, 116 and 100 Hz, respectively. The damping ratios of the same specimens were 2.13, 1.72, 1.94, 1.71 and 2.67, respectively. According to the FFBC boundary condition, the average natural frequencies of the neat, CeO<sub>2</sub> reinforced, SiO<sub>2</sub> reinforced, graphene reinforced and Ag reinforced composites were obtained as 487.74, 492.80, 466.40, 492 and 446.40 Hz, respectively. Damping ratios were obtained as 0.74, 0.76, 0.74, 0.75 and 0.91, respectively. When the results of the modal analysis performed under the CFBC boundary condition are examined, it is observed that the first natural frequency values show a similar trend. It was observed that the silver doped composite structure was lower than the other nanoparticle structures in the first natural frequency value of the specimens with FFBC boundary condition. However, the first natural frequency value of the graphene reinforced specimen was slightly higher than the other nanoparticle-doped structures at both boundary conditions. It is known that the orthotropic mechanical properties of the plates are improved with the addition of graphene to the structure. With the addition of graphene nanoparticles to the composite plates, the stiffness of the structure increases and as a result, the natural frequency value is also reported to increase (Koppanati et al., 2023). When the damping ratios of both boundary conditions are analyzed, it is found that they have a homogeneous dispersion error confidence interval.

Modal analysis results showed that the natural frequency is directly related to the rigidity of the structure. Specifically, the highest natural frequency values were observed under FFBC boundary conditions. This finding is consistent with the elastic modulus and vibration behavior reported in the literature (Tabar et al., 2015; Aydın et al., 2023). In conclusion, nanoparticle type, distribution, and interaction with the matrix play a decisive role in the modal performance of composites.

### Tensile test results

The average tensile strengths of nanoparticle reinforced composites are given in Figure 4 (a). Accordingly, the average tensile strengths of neat, Ag reinforced, CeO<sub>2</sub> reinforced, graphene reinforced and SiO<sub>2</sub> reinforced composites were determined as 257.46, 298.74, 269.92, 214.13 and 234.31 MPa, respectively. The highest contribution of nanoparticle additives to tensile strength occurred in Ag reinforced composites with an increase of 16%. Similarly, an increase of 4.8% was observed in CeO<sub>2</sub> reinforced composites. On the other hand, graphene and SiO<sub>2</sub> reinforced composites showed reductions of 16.8% and 9%, respectively. The reason for these reductions is thought to be the possibility that the nanoparticles are heterogeneously dispersed in the epoxy resin or agglomerated among themselves, or that these two unfavorable conditions may occur simultaneously. The average moduli of elasticity of nanoparticle reinforced composites are given in Figure 4 (b). Accordingly, the average moduli of elasticity of neat, Ag reinforced, CeO<sub>2</sub> reinforced, graphene reinforced and SiO<sub>2</sub> reinforced composites were found to be 38.08, 38.70, 37.28, 32.71 and 35.90 GPa, respectively. It should be noted that nanoparticle reinforcement did not produce significant increases in the average modulus of elasticity of the composites, but a significant decrease of 14.1% was observed in graphene reinforced samples. Despite its high mechanical properties, graphene tends to agglomerate within the matrix due to strong van der Waals interactions (Papageorgiou et al., 2017). This agglomeration and weak interfacial interaction reduce load transfer efficiency, leading to stress concentrations and premature material failure (Hu et al., 2014). Consequently, graphene reinforcement can decrease rather

than improve mechanical performance if homogeneous dispersion is not achieved (Atif et al., 2016). Representative stress and displacement (%) curves of these specimens are presented in Figure 4 (c).



**Figure 4.** a) Average tensile strength of nanoparticle reinforced composites b) Average modulus of elasticity of nanoparticle reinforced composites c) Representative stress and displacement (%) curves of nanoparticle reinforced composites

Figure 5 shows the damage images of nanoparticle doped polymer composites under tensile load. The matrix and fiber fractures of all composite plates under tensile loading are shown in Figure 5. When the studies in the literature are carefully examined, it is estimated that fiber pull-out grooves occur with the separation of fiber and epoxy. As a result, fiber grooves indicate a sawtooth damage mechanism. The sawtooth damage mechanism occurs perpendicular to the fiber direction and is one of the most important fractographic features in composite materials.

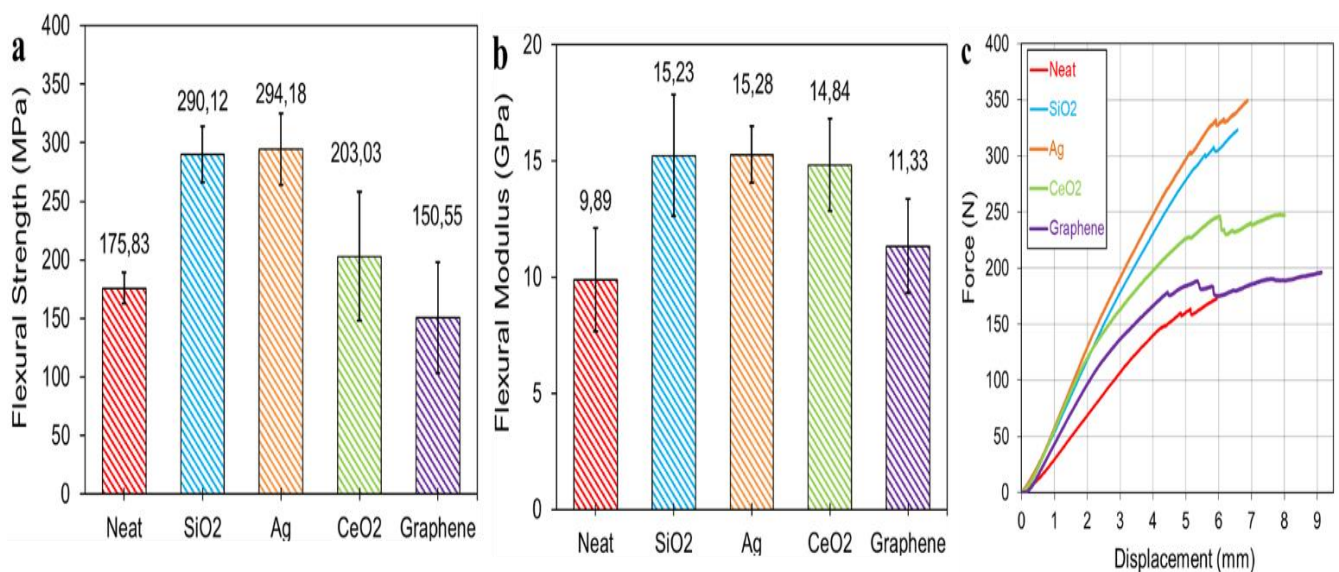
According to the tensile test results, a significant increase in tensile strength was observed in Ag nanoparticle-reinforced composites. This can be explained by the fact that Ag nanoparticles delay microcrack formation by providing effective load transfer in the polymer matrix (Su et al., 2020; Li et al., 2015b). In contrast, a decrease in tensile strength was observed in graphene-reinforced samples; in the literature, this is attributed to the increase in local stress concentrations as a result of the non-homogeneous distribution or agglomeration of graphene particles (Shen et al., 2017; Liao et al., 2023). The lack of a significant overall increase in the modulus of elasticity may be due to the limited effect of the nanoparticle ratios used on structural stiffness (Pirayesh & Saadatnia, 2016).



**Figure 5.** Damage images of tensile test specimens of nanoparticle doped composites

### Flexural test results

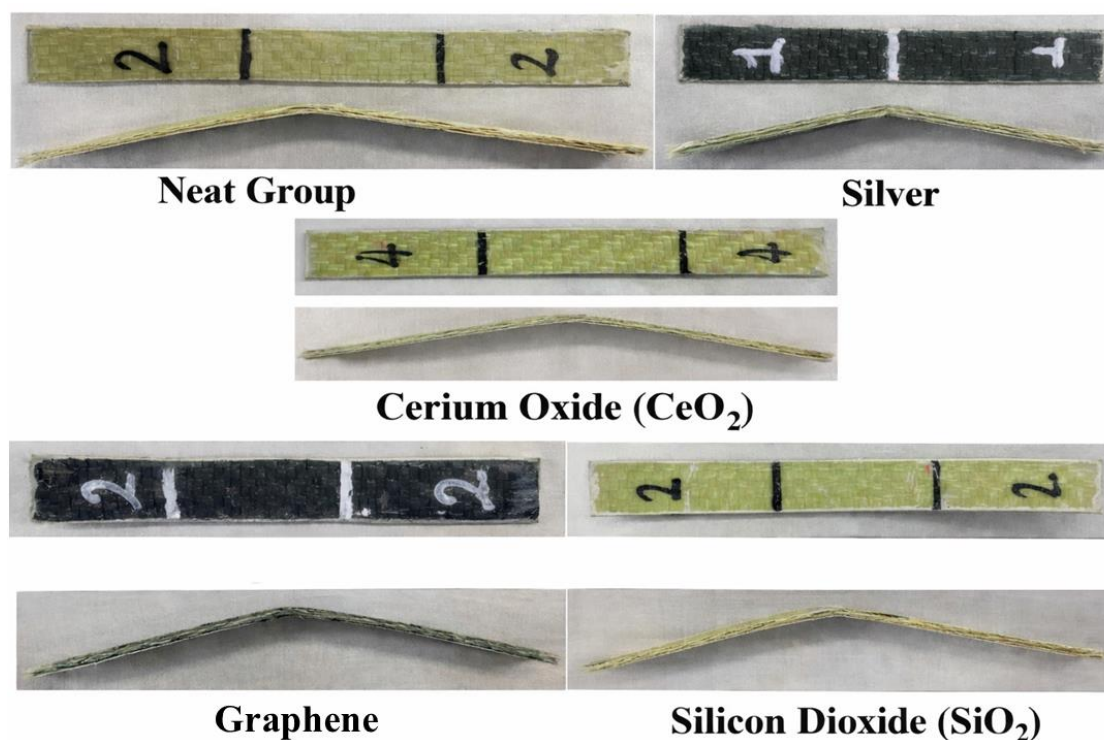
The average flexural strengths of nanoparticle reinforced composites are given in Figure 6 (a). Accordingly, the average flexural strengths of neat, Ag reinforced, CeO<sub>2</sub> reinforced, graphene reinforced and SiO<sub>2</sub> reinforced composites were determined as 175.83, 294.18, 203.03, 150.55 and 190.12 MPa, respectively. The highest contribution of nanoparticle additives to flexural strength occurred in Ag reinforced composites with an increase of 67.3%. Similarly, increases of 65% and 15.5% were observed in SiO<sub>2</sub> and CeO<sub>2</sub> reinforced composites, respectively. On the other hand, graphene reinforced composites showed a 14.4% reduction. The decrease with graphene reinforcement is thought to be due to the negative dispersion of the nanoparticles in the epoxy resin, as previously mentioned. The average flexural moduli of nanoparticle reinforced composites are given in Figure 6 (b). Accordingly, the average bending moduli of neat, Ag reinforced, SiO<sub>2</sub> reinforced, CeO<sub>2</sub> reinforced and graphene reinforced composites were found to be 9.89, 15.28, 15.23, 14.84 and 11.33 GPa, respectively. It should be noted that nanoparticle reinforcement significantly increases the average modulus of elasticity of the composites. In this context, the average flexural moduli of Ag-reinforced, SiO<sub>2</sub>-reinforced, CeO<sub>2</sub>-reinforced and graphene-reinforced composites increased by 54.5, 53.9, 50.1 and 14.6%, respectively, and it was determined that nanoparticle reinforcement showed very positive results on composite structures in flexural modulus behaviors. Representative force and displacement curves of these specimens are presented in Figure 6 (c).



**Figure 6.** a) Average flexural strength of nanoparticle reinforced composites b) Average flexural moduli of nanoparticle reinforced composites c) Representative force (N) and displacement (mm) curves of nanoparticle reinforced composites

Figure 7 shows the damage images of nanoparticle doped polymer composites under flexural load. In all plates produced, matrix fracture occurred at the middle interface as a result of flexural load. However, the plates suddenly broke and lost their integrity after carrying the load for some more time. During the test, all plates fractured first the top layer and then the bottom layer under stresses.

The bending test results showed that the flexural strength of Ag nanoparticle-reinforced composites also increased significantly. In graphene-reinforced samples, a decrease in flexural strength was observed; this result supports the literature on how nanoparticle distribution and agglomeration effects alter material behavior (Shen et al., 2017; Liao et al., 2023).



**Figure 7.** Front and side damage image of bending test specimens of nanoparticle doped composites

## CONCLUSION

In this study, tensile, flexural and vibration behaviors of polymer composite produced by adding nanoparticle powder to glass and aramid fiber fabrics using hand lay-up method were investigated. During the production study, 4 different nanoparticles with different particle sizes were used. The results of the composites produced by adding silicon dioxide ( $\text{SiO}_2$ ), graphene (GNP), silver (Ag) and cerium oxide ( $\text{CeO}_2$ ) nanoparticles separately as reinforcements to the epoxy matrix are summarized below.

- With the addition of nanoparticles, the highest tensile strength was observed in Ag (16%) reinforced composites. As a result of the addition of graphene nanoparticles, a 16.8% decrease in tensile strength was observed.

- The average modulus of elasticity of nanoparticle reinforced composites did not increase significantly. However, a significant decrease of 14.1% was observed in graphene reinforced samples.

- Upon completion of the tensile tests of the specimens, delamination, matrix and fiber fractures were observed in all plate types.

- When the flexural strength results were analyzed, the highest value was seen in Ag (67.3% increase rate) reinforced composites as in the tensile test. On the other hand, in graphene reinforced composites, reductions of 14.4% were determined.

- As a result of the modal analysis performed under CFBC and FFBC boundary conditions, the highest natural frequency values and the lowest damping ratios belong to the FFBC boundary condition.

- It was observed that the natural frequency value increased with increasing the stiffness of the structure.

## ACKNOWLEDGEMENTS

We would like to thank Dr. Volkan ACAR for her valuable contributions and support to our study.

## Conflict of Interest

The article authors declare that there is no conflict of interest between them.

## Author's Contributions

The authors declare that they have contributed equally to the article.

## REFERENCES

- Aalaie, J., Mirali, M., Motamedi, P., & Khanli, H. H. (2011). On the Effect of Nanosilver Reinforcement on the Mechanical, Physical, and Antimicrobial Properties of Polyethylene Blown Films. *Journal of Macromolecular Science. Physics*, 50(10), 1873–1881. <https://doi.org/10.1080/00222348.2011.553174>
- Acar, V., Cakir, F., Uysal, H., Seydibeyoglu, M. O., Akbulut, H., & Mosalam, K. M. (2017). Strengthening of concrete beams by monolayer prepreg composites with and without graphene reinforcement. *Construction & Building Materials*, 151, 866–880. <https://doi.org/10.1016/j.conbuildmat.2017.06.150>
- Acar, V., Erden, S., Sarikanat, M., Seki, Y., Akbulut, H., & Seydibeyoglu, M. (2020). Graphene oxide modified carbon fiber prepreps: A mechanical comparison of the effects of oxidation methods. *Express Polymer Letters*, 14(12), 1106–1115. <https://doi.org/10.3144/expresspolymlett.2020.90>
- Ashraf, P. M., & Shibli, S. (2009). Development of cerium oxide and nickel oxide-incorporated aluminium matrix for marine applications. *Journal of Alloys and Compounds*, 484(1–2), 477–482. <https://doi.org/10.1016/j.jallcom.2009.04.134>
- ASTM D3528–96, “Standard Test Method for Strength Properties of Double Lap Shear Adhesive Joints by Tension Loading”, ASTM International.
- ASTM D790-17, Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials, ASTM International, West Conshohocken, PA, USA, 2017.
- ASTM E756–05 standard test method for measuring vibration-damping properties of materials. West Conshohocken, PA: American Society for Testing and Materials (ASTM) Standard, 2017.
- Ates, B., Koytepe, S., Ulu, A., Gurses, C., & Thakur, V. K. (2020). Chemistry, Structures, and Advanced Applications of Nanocomposites from Biorenewable Resources. *Chemical Reviews*, 120(17), 9304–9362. <https://doi.org/10.1021/acs.chemrev.9b00553>
- Atif, R., Shyha, I., & Inam, F. (2016). Mechanical, thermal, and electrical properties of graphene-epoxy nanocomposites-A review. *Polymers*, 8(8), 281. doi: 10.3390/polym8080281
- Aydın, O. A., Acar, V., Aydın, M. R., Hülagü, B., Khan, T., Ünal, H. Y., Teke, E., Seydibeyoğlu, M. Ö., & Akbulut, H. (2023). Recycled Ti6Al4V alloy powder reinforced polyurethane core based sandwich structures: Mechanical and modal properties. *Journal of Reinforced Plastics and Composites*. <https://doi.org/10.1177/07316844231201008>

- Bailey, Z. S., Nilson, E., Bates, J. A., Oyalowo, A., Hockey, K. S., Sajja, V. S. S. S., Thorpe, C., Rogers, H., Dunn, B., Frey, A. S., Billings, M. J., Sholar, C. A., Hermundstad, A., Kumar, C., VandeVord, P. J., & Rzigalinski, B. A. (2020). Cerium oxide nanoparticles improve outcome after In Vitro and In Vivo Mild traumatic brain injury. *Journal of Neurotrauma*, 37(12), 1452–1462. <https://doi.org/10.1089/neu.2016.4644>
- Colorado, H. A., Gutierrez-Velasquez, E. I., Gil, L. D., & De Camargo, I. L. (2023). Exploring the advantages and applications of nanocomposites produced via vat photopolymerization in additive manufacturing: A review. *Advanced Composites and Hybrid Materials/Advanced Composites and Hybrid Materials*, 7(1). <https://doi.org/10.1007/s42114-023-00808-z>
- Dao, N. N., Luu, M. D., Nguyen, Q. K., & Kim, B. S. (2011). UV absorption by cerium oxide nanoparticles/epoxy composite thin films. *Advances in Natural Sciences Nanoscience and Nanotechnology*, 2(4), 045013. <https://doi.org/10.1088/2043-6262/2/4/045013>
- Di Credico, B., Manzini, E., Viganò, L., Canevali, C., D'Arienzo, M., Mostoni, S., Nisticò, R., & Scotti, R. (2023). Silica nanoparticles self-assembly process in polymer composites: Towards advanced materials. *Ceramics International*, 49(16), 26165–26181. <https://doi.org/10.1016/j.ceramint.2023.05.125>
- El-Eskandarany, M. S., Al-Hazza, A., Al-Hajji, L. A., Ali, N., Al-Duweesh, A. A., Banyan, M., & Al-Ajmi, F. (2021). Mechanical Milling: a superior nanotechnological tool for fabrication of nanocrystalline and nanocomposite materials. *Nanomaterials*, 11(10), 2484. <https://doi.org/10.3390/nano11102484>
- Feng, C., Kitipornchai, S., & Yang, J. (2017). Nonlinear free vibration of functionally graded polymer composite beams reinforced with graphene nanoplatelets (GPLs). *Engineering Structures/Engineering Structures (Online)*, 140, 110–119. <https://doi.org/10.1016/j.engstruct.2017.02.052>
- Gassour, H., El-Magd, G. E. a. A., Mazen, A., & Ibrahim, A. M. M. (2023). Characterization of aluminum composite reinforced by silver nanoparticles. *Scientific Reports*, 13(1). <https://doi.org/10.1038/s41598-023-45059-6>
- Han, D., Yan, L., Chen, W., & Li, W. (2011). Preparation of chitosan/graphene oxide composite film with enhanced mechanical strength in the wet state. *Carbohydrate Polymers*, 83(2), 653–658. <https://doi.org/10.1016/j.carbpol.2010.08.038>
- Hao, T., Wang, Y., Liu, Z., Li, J., Shan, L., Wang, W., Liu, J., & Tang, J. (2021). Emerging applications of silica nanoparticles as multifunctional modifiers for high performance polyester composites. *Nanomaterials*, 11(11), 2810. <https://doi.org/10.3390/nano11112810>
- Hosseini, S., Ranjbar, K., Dehmlaei, R., & Amirani, A. (2015). Fabrication of Al5083 surface composites reinforced by CNTs and cerium oxide nano particles via friction stir processing. *Journal of Alloys and Compounds*, 622, 725–733. <https://doi.org/10.1016/j.jallcom.2014.10.158>
- Hu, K., Kulkarni, D. D., Choi, I., & Tsukruk, V. V. (2014). Graphene-polymer nanocomposites for structural and functional applications. *Progress in Polymer Science*, 39(11), 1934–1972. doi: 10.1016/j.progpolymsci.2014.03.001
- Kang, Q., Li, A., Zhang, X., Xu, Z., Wang, J., & He, Q. (2021b). Study on mechanical and tribological properties of cerium oxide/fluorine rubber composites. *Materials Today Communications*, 28, 102596. <https://doi.org/10.1016/j.mtcomm.2021.102596>

- Kantarci, F., Türkmen, İ., ve Ekinçi, E. (2021). Improving elevated temperature performance of geopolymer concrete utilizing nano-silica, micro-silica and styrene-butadiene latex. *Construction and Building Materials*, 286, 122980.
- Karnati, S. R., Agbo, P., & Zhang, L. (2020). Applications of silica nanoparticles in glass/carbon fiber-reinforced epoxy nanocomposite. *Composites Communications*, 17, 32–41. <https://doi.org/10.1016/j.coco.2019.11.003>
- Kiran, M., Govindaraju, H., & Jayaraju, T. (2018). Evaluation of Mechanical Properties of Glass Fiber Reinforced Epoxy Polymer Composites with Alumina, Titanium dioxide and Silicon Carbide Fillers. *Materials Today: Proceedings*, 5(10), 22355–22361. <https://doi.org/10.1016/j.matpr.2018.06.602>
- Koppanati, M. S., Naga Rani, M., & Krishna Bhaskar, K. (2023). Free Vibration Analysis of Graphene Reinforced Laminated Composite Plates using Experimental Modal Testing. *Mechanics of Advanced Composite Structures*, 10(2), 363-374. doi: 10.22075/mac.2023.28869.1448
- Koppanati, M. S., Rani, M.N., Bhaskar, K.K., Free Vibration Analysis of Graphene Reinforced Laminated Composite Plates using Experimental Modal Testing, *Mechanics of Advanced Composite Structures*, 10.22075/mac.2023.28869.1448
- Li, Y., & Chan, Y. (2015b). Effect of silver (Ag) nanoparticle size on the microstructure and mechanical properties of Sn58Bi–Ag composite solders. *Journal of Alloys and Compounds*, 645, 566–576. <https://doi.org/10.1016/j.jallcom.2015.05.023>
- Li, Z., Guo, Q., Li, Z., Fan, G., Xiong, D., Su, Y., Zhang, J., & Zhang, D. (2015a). Enhanced Mechanical Properties of Graphene (Reduced Graphene Oxide)/Aluminum Composites with a Bioinspired Nanolaminated Structure. *Nano Letters*, 15(12), 8077–8083. <https://doi.org/10.1021/acs.nanolett.5b03492>
- Liao, X., Manapaya, A., George, M., & Selvaraj, R. (2023). Characterization of material, mechanical, static bending and vibration properties of glass fiber composite panels reinforced with graphene nanofillers. *Journal of Manufacturing Processes*, 99, 392–404. <https://doi.org/10.1016/j.jmapro.2023.05.028>
- Magne, T. M., De Oliveira Vieira, T., Alencar, L. M. R., Maia, F. F., Junior, Gemini-Piperni, S., Carneiro, S. V., Fechine, L. M. U. D., Freire, R. M., Golokhvast, K., Metrangolo, P., Fechine, P. B. A., & Santos-Oliveira, R. (2021). Graphene and its derivatives: understanding the main chemical and medicinal chemistry roles for biomedical applications. *Journal of Nanostructure in Chemistry*, 12(5), 693–727. <https://doi.org/10.1007/s40097-021-00444-3>
- Oner, G. A., Nadaroglu, H., Acar, V., & Gok, S. (2023). Flexural and thermal characterization of epoxy composites reinforced with nanoparticles synthesized from waste walnut husk with green synthesis method. *Biomass Conversion and Biorefinery*. <https://doi.org/10.1007/s13399-023-04364-w>
- Panda, P. K., Dash, P., Yang, J., & Chang, Y. (2022). Development of chitosan, graphene oxide, and cerium oxide composite blended films: structural, physical, and functional properties. *Cellulose*, 29(4), 2399–2411. <https://doi.org/10.1007/s10570-021-04348-x>
- Papageorgiou, D. G., Kinloch, I. A., & Young, R. J. (2017). Mechanical properties of graphene and graphene-based nanocomposites. *Progress in Materials Science*, 90, 75-127. doi: 10.1016/j.pmatsci.2017.07.004

- Pirayesh, H., Saadatnia, M.A. (2016). Effects of accelerating agent and SiO<sub>2</sub> nano-powder on the mechanical and physical characteristics of nut shell–cement based composites. *Materials and Structures*, 49, 3435–3443. <https://doi.org/10.1617/s11527-015-0730-3>
- Qin, W., Vautard, F., Askeland, P., Yu, J., & Drzal, L. T. (2015). Incorporation of silicon dioxide nanoparticles at the carbon fiber-epoxy matrix interphase and its effect on composite mechanical properties. *Polymer Composites*, 38(7), 1474–1482. <https://doi.org/10.1002/pc.23715>
- Selvan, S. S., & Vedaraj, I. R. (2023). Effects of nanoparticles on the mechanical and thermal behavior of fiber reinforced polymer composites – A review. *Materials Today: Proceedings*. <https://doi.org/10.1016/j.matpr.2023.07.008>
- Shen, H., Xiang, Y., & Lin, F. (2017). Nonlinear bending of functionally graded graphene-reinforced composite laminated plates resting on elastic foundations in thermal environments. *Composite Structures*, 170, 80–90. <https://doi.org/10.1016/j.compstruct.2017.03.001>
- Sprenger, S. (2013). Epoxy resin composites with surface-modified silicon dioxide nanoparticles: A review. *Journal of Applied Polymer Science*, 130(3), 1421–1428. <https://doi.org/10.1002/app.39208>
- Su, C., Chen, H., Ju, S., Chen, H., Shih, C., Pan, C., & You, T. (2020). The Mechanical Behaviors of Polyethylene/Silver Nanoparticle Composites: an Insight from Molecular Dynamics study. *Scientific Reports*, 10(1). <https://doi.org/10.1038/s41598-020-64566-4>
- Tabar, M. M., Tabarsa, T., Mashkour, M., & Khazaeian, A. (2015). Using silicon dioxide (SiO<sub>2</sub>) nano-powder as reinforcement for walnut shell flour/HDPE composite materials. *Journal of the Indian Academy of Wood Science*, 12(1), 15–21. <https://doi.org/10.1007/s13196-015-0139-1>
- Tahriri, M., Del Monico, M., Moghanian, A., Yarak, M. T., Torres, R., Yadegari, A., & Tayebi, L. (2019). Graphene and its derivatives: Opportunities and challenges in dentistry. *Materials Science & Engineering. C, Biomimetic Materials, Sensors and Systems*, 102, 171–185. <https://doi.org/10.1016/j.msec.2019.04.051>
- Tang, L., Wan, Y., Yan, D., Pei, Y., Zhao, L., Li, Y., Wu, L., Jiang, J., & Lai, G. (2013). The effect of graphene dispersion on the mechanical properties of graphene/epoxy composites. *Carbon*, 60, 16–27. <https://doi.org/10.1016/j.carbon.2013.03.050>
- Vidakis, N., Petousis, M., Velidakis, E., Tzounis, L., Mountakis, N., Korlos, A., Fischer-Griffiths, P. E., & Grammatikos, S. (2021). On the Mechanical Response of Silicon Dioxide Nanofiller Concentration on Fused Filament Fabrication 3D Printed Isotactic Polypropylene Nanocomposites. *Polymers*, 13(12), 2029. <https://doi.org/10.3390/polym13122029>
- Wang, Y., Xie, K., Fu, T., & Shi, C. (2019). Bending and elastic vibration of a novel functionally graded polymer nanocomposite beam reinforced by graphene nanoplatelets. *Nanomaterials*, 9(12), 1690. <https://doi.org/10.3390/nano9121690>
- Yang, J., Wu, H., & Kitipornchai, S. (2017). Buckling and postbuckling of functionally graded multilayer graphene platelet-reinforced composite beams. *Composite Structures*, 161, 111–118. <https://doi.org/10.1016/j.compstruct.2016.11.048>