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Araştırma Makalesi / Research Article

Measurement of Charpy Impact Durability of Intraply Hybrid Composites Under Ultraviolet Light and Nanoparticle Reinforcement

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ABSTRACT: This study investigates the effects of nanoclay reinforcement and UV aging on the low-velocity impact resistance of polymer-based intraply carbon/aramid composites. Nanoclay particles, in concentrations ranging from 0% to 3% by weight, were incorporated into the composites. The impact resistance was examined experimentally, focusing on both the particle reinforcement and the impact of UV aging. Charpy impact tests were conducted on specimens subjected to 450 and 900 hours of UV exposure, alongside a control group. The results revealed that the composite reinforced with 2% by weight of nanoclay exhibited the highest impact resistance, with an improvement of 57.89% compared to the baseline. Although a reduction in impact resistance was observed after 450 hours of UV exposure, partial recovery occurred after 900 hours. Nonetheless, UV aging had an overall negative effect on the impact resistance of the materials. Additionally, scanning electron microscopy (SEM) was used to analyze the failure morphologies of the samples, providing insights into the damage mechanisms.

Keywords: Polymer, Intraply compsites, Nanoclay, Charpy impact test, UV aging

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1. INTRODUCTION

Composite materials are of critical importance due to their ability to combine the advantageous properties of different constituent materials, resulting in superior mechanical, thermal, and chemical performance compared to traditional materials. They offer a high strength-to-weight ratio, enhanced durability, and excellent resistance to environmental factors such as corrosion, fatigue, and wear. These properties make composites particularly valuable in applications where lightweight and high-performance materials are essential. Composite materials are widely used in a variety of industries, including aerospace, automotive, marine, and construction. In aerospace and automotive sectors, for instance, composites reduce vehicle weight, leading to improved fuel efficiency and lower emissions. In civil engineering, they are utilized in bridge reinforcement, building structures, and pipelines for their superior durability and resistance to harsh environmental conditions. Furthermore, composites are increasingly found in sporting goods, medical devices, and renewable energy systems, such as wind turbine blades, due to their versatile and customizable nature. This broad range of applications highlights the significance of composite materials in advancing modern technology and engineering solutions (Demircan et al., 2021).

Nanoparticle-reinforced composite materials are important due to their ability to significantly enhance the mechanical, thermal, and functional properties of conventional composites (Ekici et al., 2022). The incorporation of nanoparticles, such as nanoclay, carbon nanotubes, or graphene, into composite matrices can improve properties like strength, stiffness, toughness, and thermal stability without substantially increasing the material's weight. This is particularly advantageous in applications requiring high-performance materials with a low density. Additionally, nanoparticles contribute to enhanced resistance against environmental degradation factors, such as UV radiation, moisture, and chemical exposure, thus extending the lifespan of the composite materials in harsh conditions. Nanoparticles also facilitate better load transfer at the microscopic level due to their high surface area and interaction with the polymer matrix, resulting in superior damage tolerance and impact resistance. As a result, nanoparticle-reinforced composites are increasingly used in cutting-edge technologies, including advanced electronics, medical devices, and energy storage systems, where multifunctionality and superior performance are required.

The impact test is crucial for assessing the mechanical performance of composite materials and ensuring their reliability in various applications. Composite materials, known for their lightweight, high strength, and corrosion resistance, exhibit complex fracture behaviors when subjected to sudden impacts. Impact testing provides critical insights into their energy absorption capacity, fracture toughness, and damage propagation under dynamic loading conditions (Kösedağ et al., 2022) By evaluating the interaction between different layers of composite structures and identifying potential weak points, impact testing helps in optimizing material design and selection for enhanced durability and safety. Thus, the impact test plays a vital role in advancing the application of composites in high-performance environments.

Literature review has shown that composite materials are subjected to single or repeated impact tests (Zhou et al., 2020; Doğan et al., 2022; Kueh et al., 2023). Additionally, the impact properties of composites after hydrothermal aging conditioning was investigated by researchers (Ferreira et al., 2023; Oğuz et al., 2021a; Oğuz et al., 2021b).

In addition to composite materials subjected to impact testing without exposure to any environment or by exposure to hydrothermal/hygrothermal environments, the effect of UV aging on the impact resistance of various composite materials was also investigated. Doğan and Arman (2019) applied drop weight impact test to glass fiber reinforced composite materials after keeping them in different environments including UV aging. It was reported that aging affected the perforation threshold and absorbed energy values. Especially at low impact energies, delamination emerged as the main failure mode, while fiber fracture became more pronounced at higher energies. UV aging was found to reduce impact resistance by approximately 33% compared to the unaged group. Alsaadi and Erkliğ (2021) investigated the mode I fracture properties of glass/epoxy samples with micro particle reinforcement ranging from 0 to 20 wt% after 1000 hours of UV aging. It was found that the addition of 10% of micro particles improved the fracture toughness of aged samples by 14.3%, while the improvement in unaged samples was 1.7%. Ovalı and Sancak (2022) added various UV protective agents to jute fiber reinforced low density polyethylene materials and left the materials in the UV environment for 120 and 240 hours. Impact tests were applied to the samples at the end of two different aging periods. While the change in impact strength was seen as minor after short-term aging, dramatic decreases were observed in the impact strength of the samples after long-term aging. In addition, samples containing protective agents were less affected by UV aging than the group without. Nasri et al. (2022), evaluated the drop weight properties of natural fiber reinforced polypropylene after UV radiation. All samples were aged for 960 h. This study showed that flax fiber reinforced polypropylene (PP30-F) was more sensitive to UV radiation, with its impact strength decreasing by 33% after 960 hours of UV exposure. In addition, pine fiber reinforced polypropylene (PP30-P) showed a lower decrease, with the impact strength decreasing by around 10%.

In contrast to previous studies, this research focuses on the Charpy impact resistance of intraply carbon/aramid hybrid composites reinforced with six different weight percentages of nanoclay particles, both before and after UV aging. Specifically, the samples were subjected to UV exposure for 450 and 900 hours, without the use of UV stabilizers, in order to investigate the effect of varying nanoclay content on impact resistance over different aging periods. The absence of UV retardants and the exploration of the influence of nanoclay on UV-induced degradation marks a critical distinction from existing literature. This study aims to provide new insights into how nanoclay reinforcement alters the impact performance of hybrid composites under prolonged UV exposure, offering valuable data for outdoor and high-durability applications of such materials.

2. MATERIALS AND METHODS

2.1 Materials

The reinforcing material utilized in this study was a carbon/aramid twill woven fabric. To fabricate the composite laminates, epoxy resin MGS L 160 was mixed with hardener MGS H 160 in a stoichiometric ratio of 100:25 by weight. The fabric and chemical components used in the production of the composite plates were supplied by Dost Kimya (Turkey), while the nanoparticles were sourced from Grafen Kimya (Turkey). The physical properties of these materials are summarized in Table 1.

Table 1. Physical properties of materials

Material	Specifications	Dimensions
Carbon/aramid intraply fabric	Areal density	210 g/m^2
	Fiber thickness	0.12 mm
Epoxy Resin MGS L160	Density	1.13-1.17 g/m^3
	Viscosity	700-900 mPas
	Flexural Strength	110-140 (N/mm^2)
	Modulus of Elasticity	3.2-3.5 (kN/mm^2)
	Tensile Strength	70-80 (N/mm^2)
	Impact Strength	40-50 (kJ/m^2)
Nanoclay	Lateral width	0.5-2 µm
	Thickness	1-10 nm
	Bulk Density	200-500 kg/m^3

Composite samples were produced by vacuum-assisted hand lay-up method that include two primary steps. In the first step the MGS L 160 epoxy resin was mixed with varying weight percentages of nanoclay particles (0, 0.5, 1.0, 1.5, 2.0, and 3.0 wt.%) using an ultrasonic mixer. Then MGS H 160 hardener was added till a homogenous mixture was achieved. Epoxy resin and hardener were combined using a mechanical stirrer set at 8000 rpm for 10 minutes. After the first step was completed, the mixture prepared in the first step was applied to 12 layers of intraply carbon/aramid fabrics with 0°/90° stacking sequence by means of a roller. Attention was paid to the curing times of the resin system according to the manufacturer's recommendations and plate production was completed under 700 mm-Hg vacuum pressure. The sample thicknesses for each weight group are given in Table 2.

Table 2. Thickness of the composite groups

Thickness (mm)					
0 wt%	**0.5 wt%**	**1 wt%**	**1.5 wt%**	**2 wt%**	**3 wt%**
3.12±0.05	3.07±0.02	3.16±0.01	3.11±0.07	3.08±0.04	3.09±0.02

In this article, coding has been done for sample groups in the text or in their graphical representations. For example, in a name like CA0.5-450, CA represents carbon/aramid intraply fabric. The numerical expression immediately following CA (0.5, 1.0 etc.) refers to the reinforcement ratio. The number in the last part (0, 450 or 900) indicates the aging period.

2.2 UV Aging of Samples

For this study, an OSRAM brand UV lamp was used in a cabin according to ASTM G 154 standards. In addition, a fan was used for homogeneous heat distribution in the cabin. Two-thirds of the prepared samples were subjected to UV aging. Two different aging periods were determined for UV aging as 450 and 900 hours.

2.3 Charpy Impact Test

The impact strength of the samples was assessed using a Charpy impact testing machine (Köger 3/70) in compliance with the ISO 179/92 standard. The specimens, each with dimensions of 55 x 10 mm, were prepared for testing in a flatwise impact direction. An impact hammer with an energy capacity of 15 J was used for the tests. Fig. 1 illustrates the flatwise impact testing setup. The absorbed energy and impact strength values were calculated using Eqs. 1 and 2, based on the energy differences between the initial (E_1) and final (E_2) energy levels,

$$E = E_1 - E_2 \tag{1}$$

$$U = \frac{E}{bh} \tag{2}$$

Where E and U represent the absorbed energy and impact strength values. The width b and thickness h of the samples were used to calculate the impacted area.

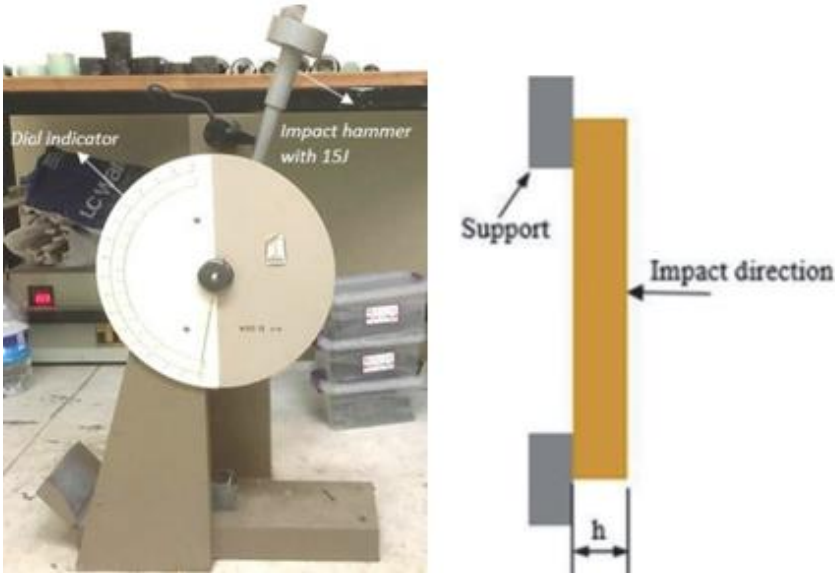

Figure 1. Illustration of Charpy impact test

After the Charpy impact test, the SEM images were taken to identify the damage character of samples.

3. RESULTS AND DISCUSSION

3.1 Charpy Impact Test Results

The Charpy impact test results of the samples are clearly shown in Figure 2. The Charpy impact test results for intraply carbon/aramid hybrid composites reinforced with varying weight percentages of nanoparticles (0, 0.5, 1.0, 1.5, 2.0, and 3.0 wt.%) showed a clear enhancement (45.95, 53.4, 56.74, 64.94, 72.55 and 72.04 kJ/m²) in impact strength with increasing nanoparticle content up to a certain threshold. The impact strength values for the composites ranged from 45.95 kJ/m² for the unreinforced (0 wt.%) sample to a peak value of 72.55 kJ/m² at 2.0 wt.% nanoparticle reinforcement. This represents a significant improvement in impact performance, particularly between 0 and 2.0 wt.% reinforcement, indicating that the inclusion of nanoparticles effectively increases energy absorption during impact. However, beyond 2.0 wt.%, a slight decrease to 72.04 kJ/m² was observed at 3.0 wt.%, suggesting a potential saturation point or agglomeration effect, where the addition of further nanoparticles may no longer contribute positively to the composite's impact strength. These findings highlight the optimal nanoparticle concentration for improving the mechanical properties of hybrid composites and emphasize the importance of controlling filler content to maximize performance.

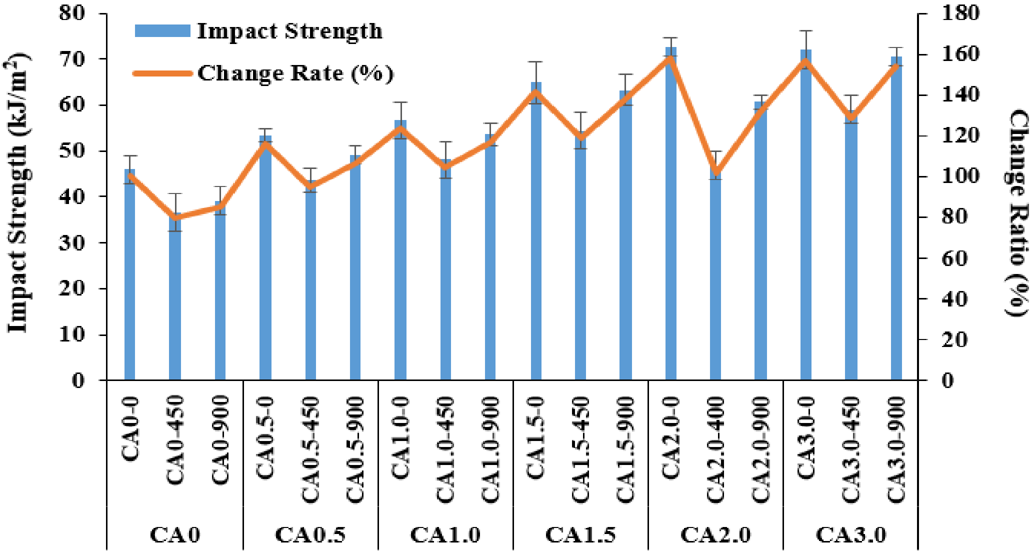

Figure 2. Impact strength results of samples

The Charpy impact test results for hybrid carbon/aramid intraply composites reinforced with varying weight percentages of nanoparticles (0, 0.5, 1.0, 1.5, 2.0, and 3.0 wt.%) demonstrated notable differences in impact performance after 450 and 900 hours of UV aging. For the 450-hour UV-aged samples, impact strengths were found as 36.6, 43.62, 48.09, 54.47, 46.78 ve 59.03 kJ/m^2 for 0, 0.5, 1.0, 1.5, 2.0, and 3.0 wt.%, respectively. It is clear that the impact strengths decreased across all nanoparticle concentrations compared to the unaged composites, with the maximum impact strength observed at 1.5 wt.% reinforcement (54.47 kJ/m²), followed by a significant drop at 2.0 wt.% (46.78 kJ/m²). This suggests that prolonged UV exposure up to 450 hours induces degradation that weakens the composite, particularly at higher nanoparticle concentrations, potentially due to UV-induced surface microcracking or material embrittlement. After 900 hours of UV aging, however, the impact strength values showed a recovery trend compared to the 450-hour aged samples, with a peak value of 70.61 kJ/m² at 3.0 wt.% reinforcement. For the 0, 0.5, 1.0, 1.5, 2.0, and 3.0 wt.% nanoparticle reinforced composite samples the impact strengths were found as 39.18, 49.04, 53.59, 63.35, 60.69 ve 70.61 kJ/m^2, respectively. This improvement after extended UV exposure might be attributed to the relaxation or reformation of the polymer matrix after prolonged aging, allowing better load distribution during impact. Although the 900-hour aged samples did not fully regain the initial impact strengths of the unaged composites, the results indicate that nanoparticle reinforcement helps mitigate UV degradation over time, particularly in higher concentrations.

These findings imply that the extended UV aging period increased the cross-linking and rigidity on the outermost layer of the samples by allowing the free radicals produced during radiation exposure to recombine. This durability improvement can be ascribed to a potential crosslinking among adjacent molecules from both resin and particles, which results in a stronger durability against UV aging after 900 hours of UV aging degradation (Silva et al., 2020; Azim, 2016).

However, when the impact test results were examined in general, it was observed that UV aging reduced the impact strength of nanoclay reinforced intraply samples. UV aging negatively affects impact strength due to several key mechanisms that degrade the material’s structural integrity over time. Prolonged exposure to UV radiation leads to both physical and chemical changes in the polymer matrix of composite materials, resulting in a reduction in their ability to absorb and dissipate energy during impact events (Doğan and Arman, 2019). UV exposure induces photo-oxidation in the polymer matrix, breaking down polymer chains and leading to a loss of mechanical properties. This chemical degradation weakens the polymer structure, making the material more brittle. As a result, the material's ability to resist impact diminishes, as it becomes more prone to cracking and failure under stress (Alsaadi and Erkliğ, 2021; Ovalı and Sancak, 2022). In addition, UV aging typically causes the polymer matrix to stiffen, reducing its ductility and flexibility. As the material becomes more brittle, its capacity to deform and absorb energy during an impact event decreases. Instead of absorbing the impact energy through plastic deformation, UV-aged materials are more likely to fracture suddenly, leading to lower impact strength (Nicholas et al., 2016; Doğan and Arman, 2019). In fiber-reinforced composites, UV radiation can deteriorate the fiber-matrix interface. This weakening reduces the efficiency of load transfer between the fibers and the matrix, a critical factor in the composite's overall impact performance. The compromised interface leads to poor bonding and reduced ability to withstand impact forces, resulting in lower impact strength (Nasri et al., 2022; Silva et al., 2020).

The amount of energy absorbed by the samples during the flatwise Charpy impact test is shown in Figure 3. When the absorbed energy amounts are taken into consideration, it is clearly seen that the results are parallel to the impact strength results. An increase in the absorbed energy amounts was detected with particle reinforcement. The increasing trend continued up to 2.0 wt.%. Although a slight decrease was observed for the 3.0 wt.% samples, the amount of absorbed energy was still high for this ratio compared to the unreinforced samples. Also, similar to the impact strength results, the absorbed energy amounts decreased after 450 hours of UV aging. Although the absorbed energy amounts after 900 hours of UV aging improved compared to 450 hours, they were still lower than the unaged samples.

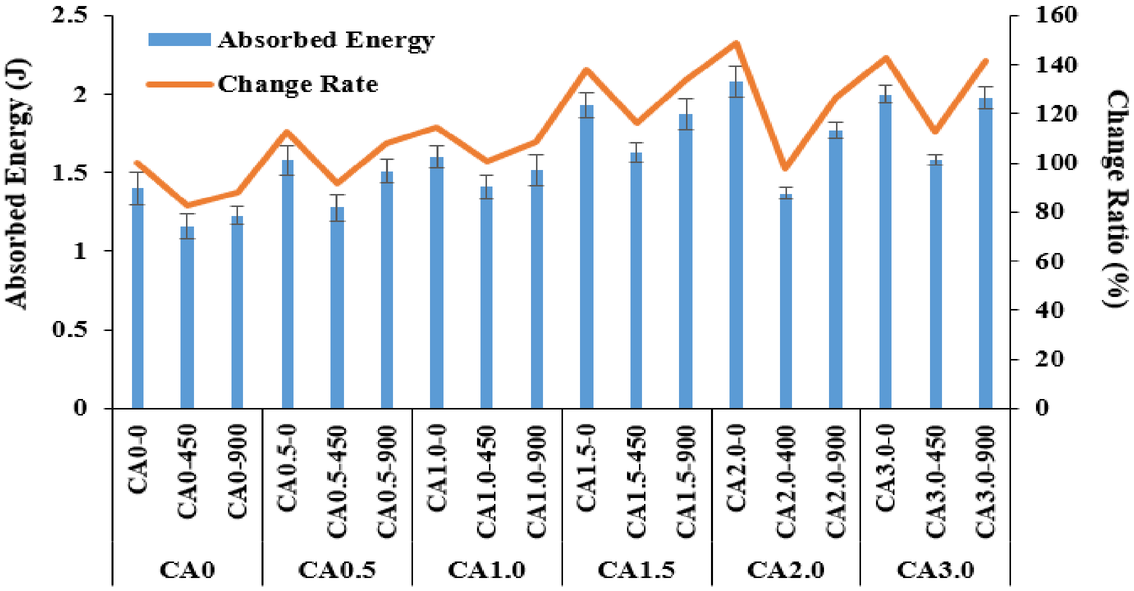

Figure 3. Absorbed energy values of samples

For the unaged samples, absorbed energies were found as 1.4, 1.58, 1.6, 1.93, 2.08 and 2.0 J for 0, 0.5, 1.0, 1.5, 2.0, and 3.0 wt.%, respectively. In addition, the absorbed energy amounts after 450-900 h of UV aging were 1.16-1.23, 1.28-1.51, 1.41-1.52, 1.63-1.87, 1.37-1.77 and 1.58-1.98 J for 0, 0.5, 1.0, 1.5, 2.0, and 3.0 wt.%, respectively.

3.2 SEM Results

SEM images were taken from the broken samples after the Flatwise Charpy impact test. Figure 4 displays the typical configuration of the impact damage and distributions across a laminate. In most cases, low-velocity impacts result from things like fallen tools and collision damage. The laminate displays a quasi-static behavior in these circumstances, with bending of the laminate being the predominant stress state (Bibo and Hogg, 1996). As a result, ply cracking and delamination are frequently the most common damage types. The SEM images of samples are shown in Figure 5. As clearly observed from the images, impact-induced fiber breakage, matrix breakage or crack, delamination between fiber-matrix and fiber-fiber were identified as the main types of failures.

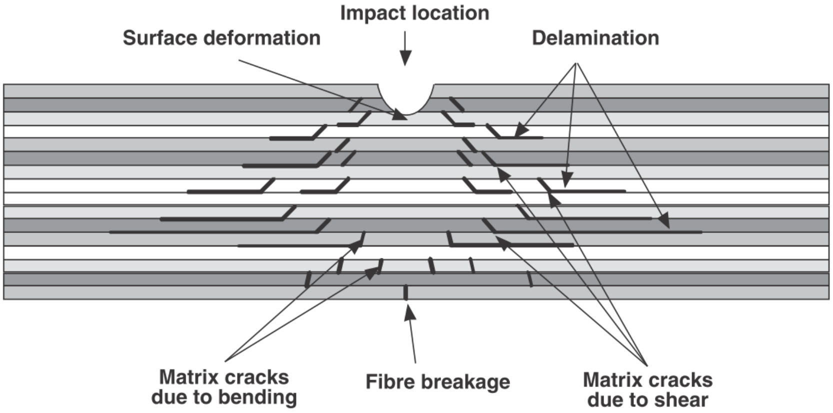

Figure 4. Schematic designation of a general low impact failure of a composite (Shyr and Pan, 2003)

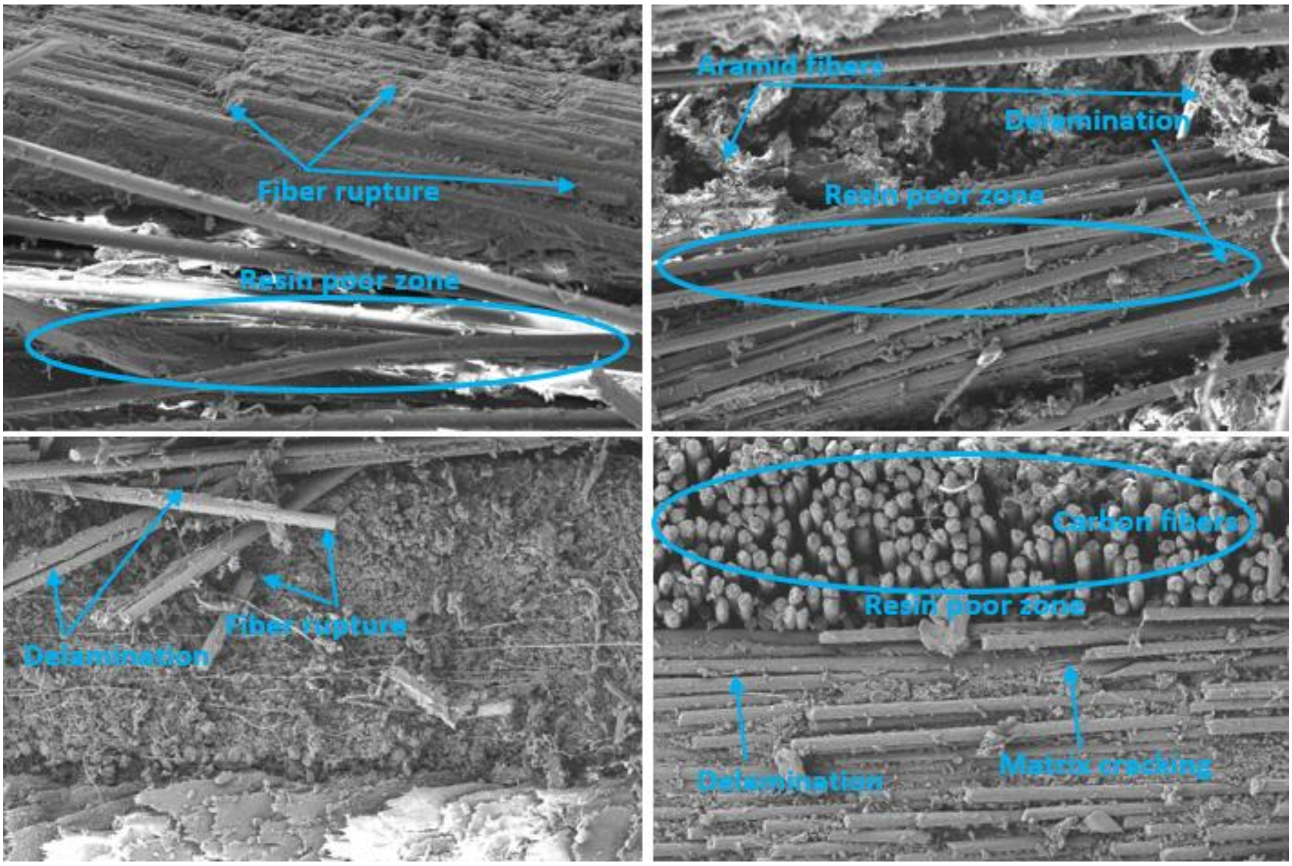

Figure 5. SEM images of samples

4. CONCLUSION

This study investigated the impact strength of nanoparticle-reinforced carbon/aramid hybrid composites subjected to various UV aging periods (450 and 900 hours) to assess the effect of UV exposure on mechanical performance. Charpy impact tests were performed on composites with different weight percentages of nanoclay reinforcement (0, 0.5, 1.0, 1.5, 2.0, and 3.0 wt.%).

The results for unaged samples showed a steady increase in impact strength as the nanoclay content increased, reaching a peak value of 72.55 kJ/m² at 2.0 wt.% reinforcement. Beyond this concentration, a slight decrease in impact strength was observed, with the 3.0 wt.% sample registering 72.04 kJ/m². This suggests that nanoparticle addition improves the energy absorption capacity of the composites up to an optimal threshold, after which further reinforcement does not provide additional benefits.

However, UV aging significantly impacted the composite's performance. After 450 hours of UV exposure, a notable decline in impact strength was observed across all samples. The impact strength of the 0 wt.% sample dropped from 45.95 kJ/m² to 36.6 kJ/m², indicating the material's sensitivity to UV degradation. The highest impact strength after 450 hours was recorded at 1.5 wt.% reinforcement (54.47 kJ/m²), but a significant drop occurred for the 2.0 wt.% sample (46.78 kJ/m²). This suggests that while nanoclay reinforcement initially improves UV resistance, higher concentrations may lead to diminished benefits under prolonged UV exposure due to potential agglomeration or interface weakening.

After 900 hours of UV aging, the impact strength of all samples recovered to some extent compared to their 450-hour values. The 3.0 wt.% sample exhibited the highest impact strength after 900 hours (70.61 kJ/m²), demonstrating a significant improvement over the 2.0 wt.% sample, which had the highest unaged performance. This recovery indicates that extended UV exposure may lead to matrix reorganization or relaxation, allowing for better load distribution during impact. Nonetheless, even after 900 hours of aging, the composites did not fully regain their unaged impact strength levels, reflecting the persistent effects of UV-induced degradation.

In conclusion, the addition of nanoclay particles significantly enhances the impact strength of carbon/aramid hybrid composites, particularly at concentrations up to 2.0 wt.%. However, UV aging introduces degradation mechanisms that reduce impact performance, particularly after shorter exposure periods. Despite some recovery in impact strength with prolonged aging, the results underscore the importance of optimizing nanoparticle content and UV stabilization strategies to improve the long-term durability of hybrid composites in outdoor applications.

5. ACKNOWLEDGEMENTS

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6. CONFLICT OF INTEREST

Author approves that to the best of their knowledge, there is not any conflict of interest or common interest with an institution/organization or a person that may affect the review process of the paper.

7. AUTHOR CONTRIBUTION

Zeynal Abidin OĞUZ has the full responsibility of the paper about determining the concept of the research, data collection, data analysis and interpretation of the results, preparation of the manuscript and critical analysis of the intellectual content with the final approval.

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