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Assessment of the Change in Hardness of Particulated Intraply Carbon/Aramid Reinforced Composites After UV Aging

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ABSTRACT
This work examines how the hardness characteristics of intraply carbon/aramid hybrid composites are affected by UV aging and nanoclay addition. After being produced with different weight percentages of nanoclay (0%, 0.5%, 1.0%, 1.5%, 2.0%, and 3.0%), the samples were exposed to UV aging for 0, 450, and 900 hours. In comparison to unreinforced samples, nanoclay reinforcement dramatically increased the surface hardness, as demonstrated by increases of 4.69%, 17.19%, 27.73%, 31.25%, and 32.81% for 0.5%, 1.0%, 1.5%, 2.0%, and 3.0% nanoclay content, respectively, according to hardness tests. In addition, it was determined that there was an increase in the hardness value of the samples at the end of UV aging. The increase in hardness values continued as the UV aging time increased. These results indicate that nanoclay reinforcement synergistically interacts with UV-induced molecular changes to enhance surface hardness, with diminishing returns observed at higher nanoclay contents.

UV Yaşlandırma Sonrası Parçacıklı Katman İçi Karbon/Aramid Takviyeli Kompozitlerin Sertlik Değişiminin Değerlendirilmesi

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ÖZ
Bu çalışmada, katman içi karbon/aramid hibrit kompozitlerin sertlik özelliklerinin UV yaşlanması ve nanokil ilavesiyle nasıl etkilendiği incelenmiştir. Farklı ağırlık yüzdelerinde nanokil ile üretildikten sonra (%0, %0,5, %1,0, %1,5, %2,0 ve %3,0), numuneler 0, 450 ve 900 saat UV yaşlanmasına maruz bırakılmıştır. Nanokil takviyesi, takviyesiz numunelere kıyasla yüzey sertliğini önemli ölçüde artırmıştır. Sertlik testlerine göre, sırasıyla %0,5, %1,0, %1,5, %2,0 ve %3,0 nanokil içeriği için %4,69, %17,19, %27,73, %31,25 ve %32,81'lik artışlar görülmüştür. Ayrıca, UV yaşlanması sonunda numunelerin sertlik değerlerinde bir artış olduğu belirlenmiştir. Sertlik değerlerindeki artış UV yaşlanma süresi arttıkça devam etmiştir. Bu sonuçlar nanokil takviyesinin yüzey sertliğini artırmak için UV kaynaklı moleküler değişikliklerle sinerjik olarak etkileşime girdiğini ve daha yüksek nanokil içeriklerinde azalan getiriler gözlemlendiğini göstermektedir.

1. INTRODUCTION

Composite materials are essential in modern engineering and manufacturing due to their unique ability to combine the strengths of different materials, resulting in superior mechanical, thermal, and chemical properties. They offer high strength-to-weight ratios, excellent corrosion resistance, and design flexibility, making them indispensable in industries such as aerospace, automotive, construction, and renewable energy. By tailoring the matrix and reinforcement components, composites can be engineered to meet specific performance requirements, enabling innovations in high-performance and sustainable applications. Their versatility and adaptability continue to drive advancements in technology and material science [1-3]. Composite materials are widely used in applications exposed to outdoor environments, such as aerospace, automotive, and construction, where ultraviolet (UV) radiation is a significant aging factor. Prolonged exposure to UV radiation can degrade the polymer matrix through photodegradation, leading to surface discoloration, microcracking, and loss of mechanical properties such as tensile strength and stiffness. Understanding the effects of UV aging is critical for predicting the long-term durability and reliability of composites in such conditions. By simulating UV exposure in controlled environments, researchers can evaluate material performance, identify failure mechanisms, and develop strategies to enhance UV resistance through optimized formulations, coatings, or stabilizers. This knowledge is essential for designing composite materials that maintain their structural integrity and aesthetic quality throughout their service life, ensuring safety and compliance with industry standards [4,5].

Hardness testing is a critical evaluation method for composite materials as it provides insights into their resistance to surface deformation, wear, and penetration under applied loads. This property is especially important for composites used in applications subjected to abrasive or high-contact conditions, such as aerospace, automotive, and protective equipment. By assessing hardness, researchers can predict the material's durability, optimize formulations, and ensure its suitability for demanding operational environments. The results from hardness tests also complement other mechanical evaluations, offering a comprehensive understanding of the composite's performance [6,7].

In the literature, some researches have investigated the impact of particle reinforcement on the surface hardness of composite materials. Moreover, some studies have investigated the effect of size on the hardness of the samples. Akaluzia et al. [1] studied the effect of wood charcoal particles (HWCP) on the hardness properties of polyester matrix composites. Samples were prepared with additive ratios varying between 5-30% by weight. In addition, the change in hardness values under the effect of particle size was investigated using 75, 150, 250, and 300 µm sizes for each ratio. According to the test results, hardness values increase inversely proportional to particle sizes; maximum hardness was obtained at 150 µm size and 20% weight percentage. In general, as the particle reinforcement ratio increased, the hardness value increased compared to the control group.

Raja et al. [2] assessed the effect of fly ash filler size on the mechanical properties of polymer matrix composites (PMC) reinforced with epoxy resin. Four different fly ash filler sizes (50 µm, 480 nm, 350 nm, and 300 nm) were incorporated at a 10% weight ratio, with particle size reduction achieved through ball milling. Mechanical tests, including hardness and Charpy impact strength, were conducted following ASTM standards. The results demonstrated that reducing the filler size enhanced the hardness and impact strength of the composites. The 300 nm filler size yielded the highest hardness (35 Hv) and impact energy (14 J), attributed to improved filler-matrix adhesion and reduced voids. The study highlights the potential of optimizing filler size to improve the performance of particulate-reinforced polymer composites, offering insights for applications in lightweight and durable materials.

Wachter et al. [3] evaluated the hardness properties of transparent wood composites after UV exposure. The samples were subjected to aging for 35 days and the hardness values were measured every 7 days. The hardness values showed a decreasing trend until the end of 28 days, but then increased again. However, the authors stated that this change was not significant.

Girimurugan et al. [4] investigated the hardness values of composite samples containing camellia sinensis particles varying between 2-6%. According to the results, the hardness values of 2, 4 and 6 wt% samples increased by 25, 87.5 and 182.5%, respectively, compared to samples without particle reinforcement.

Ramli et al. [5] searched the effects of UV curing exposure time on the mechanical and physical properties of epoxy and vinyl ester fiberglass laminate composites. Using two photoinitiators-Bisacyl Phosphine Oxide (BAPO) and Alpha Hydroxyl Ketone (AHK)-the laminates were cured under UV light for varying durations. Key tests, including density, tensile strength, hardness, and morphological analysis, were conducted to assess performance. The results revealed that epoxy composites cured faster and achieved superior mechanical properties compared to vinyl ester composites, which required additional curing time for full hardening. Increased UV exposure time improved density due to reduced voids but led to diminished tensile strength and hardness after optimal exposure due to material degradation.

The hardness of carbon fiber/epoxy (CFRP) samples that were exposed to ultraviolet light for 80 days was tested by Shi et al. [6]. It was found that ultraviolet (UV) light had little effect on the fibers' hardness, which remained comparatively constant during the course of aging. On the other hand, the matrix material exhibited a noticeable embrittlement impact and an enormous rise in hardness after UV aging. Following 40 days of UV exposure, the matrix phase showed a significant rise in hardness, increasing by as much as 35% as a result of embrittlement from UV-induced molecular modifications. Hardness started to decrease with further exposure after this peak.

Dulebova et al. [7] investigated the hardness changes of polypropylene (PP) composites when exposed to UV rays and low temperatures. In the study, 10% to 50% talc and chalk were used as fillers, and 4% montmorillonite (MMT) was added. The hardness changes of the polymer composites were measured by Shore hardness test. It was observed that as the filler content increases, hardness, strength and other mechanical properties increase. UV exposure for 720 h did not cause any significant change in hardness. A slight increase in hardness was observed in PP/ chalk composites, while a slight decrease in hardness was observed in PP/talc composites. Minimal changes in hardness were also observed in tests performed at 20ºC.

Sahu et al. [8] studied the effects of UV exposure on mechanical properties of HDPE reinforced with carbon black. Carbon black acts as a UV stabilizer and was studied at three different loading rates (1%, 2% and 3%). All samples were exposed to UV light for 192 hours. At the end of aging, the surface hardness decreased by 3.28% for 1% reinforcement ratio, while it increased by 3.28% and 1.64% for 2% and 3% reinforcement ratios, respectively.

Oğuz et al. [9] evaluated the impact properties of particulated intaply hybrid carbon/aramid composites after UV aging. Samples were kept in a UV cabin for 0, 450, and 900 hours. The effects of aging time and hybridization effect on impact properties were evaluated experimentally. In this study, the extension of aging time caused an increase in hardness values. Although the toughness values decreased after 450 hours of UV aging for each reinforcement ratio, the extension of the UV aging period caused an increase in this value.

In this study, carbon/aramid intraply hybrid composite samples were reinforced with varying nanoclay contents of 0%, 0.5%, 1.0%, 1.5%, 2.0%, and 3.0% by weight, offering a systematic exploration of the effects of nanoclay on composite performance. Unlike previous studies that primarily focus on short-term UV exposure or single filler concentrations, this research subjected the samples to prolonged UV aging for 0, 450, and 900 hours, simulating extended environmental effect. The hardness values of the composites were measured post-UV exposure, providing critical insights into the role of nanoclay reinforcement in mitigating the effects of UV-induced material characterization. This approach not only bridges the gap in the existing literature but also establishes a comprehensive understanding of the durability and performance of hybrid composites under extended UV aging conditions.

2. MATERIALS AND METHOD

2.1. Composite Plate Production

Carbon/aramid twill fabric was used as the reinforcing material for this study. The epoxy resin MGS L 160 and the hardener MGS H 160 were mixed at a stoichiometric mass ratio of 100:25 to produce the composite samples. The fabric and chemicals required to create the laminates were supplied by Dost Kimya (Turkey), while the nanoparticles were supplied by Grafen Kimya (Turkey). The physical properties of these materials are listed 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

The approach of making specimens consists of two procedures. An MGS L 160-particle combination with different weight percentages of nano-clay (0, 0.5, 1.0, 1.5, 2.0, and 3.0 wt.%) was first mixed using an ultrasonic mixer adjusted at 8000 rpm. The combination was then mixed further until it was homogeneous following the addition of MGS H 160. The next step was to arrange Twelve hybrid carbon/aramid fabrics, each cut to 50 × 50 (cm^2) dimensions, on a flat surface with a layering angle of 0°/90°. The entire combination is then fed into the hybrid fabrics using a tiny hand roller. To make sure the epoxy-saturated laminated composites wouldn't deform at an appropriate pressure, the complete layout was kept at 700 mm-Hg vacuum pressure for 360 min. The laminates were then kept at 40°C for 120 minutes and cooled for a full day in order to finish the curing process. An operation diagram representation is shown in Figure 1. As per ASTM standards, the test pieces were CNC-cut to acquire specific sizes for hardness test after the laminates were produced.

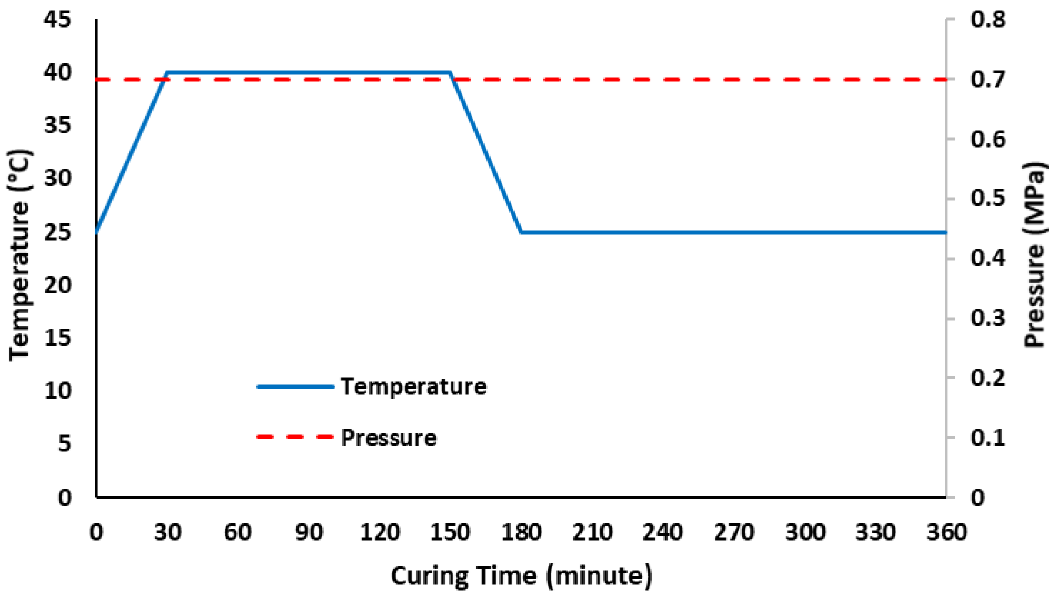


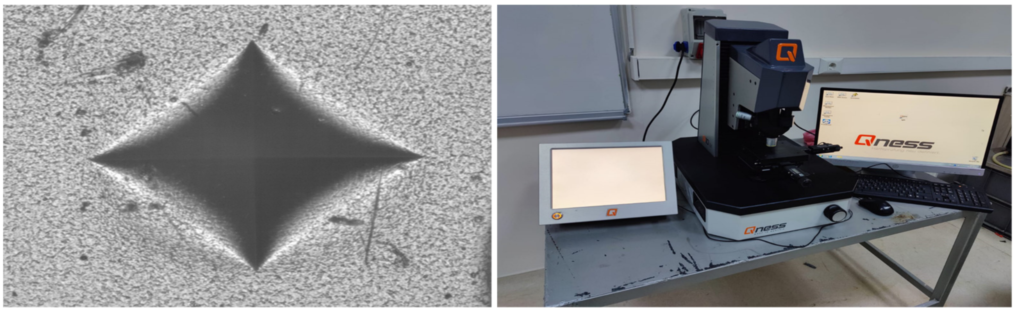
Figure 1. Composite plate production condition

2.2. UV Aging

The test samples were exposed to UV light in a QUV test chamber, which produces a radiation spectrum centered in the ultraviolet wavelengths, in accordance with standard ASTM G154 [10]. Test specimens were kept in chamber for 0, 450, and 900 hours at 50± 2°C.

2.3. Evaluation of Hardness Test

In order to determine the hardness of nanoclay filled intraply carbon/aramid composite material, a little load is applied first, after which is a significant load, and the level of penetration is then noted. Vickers hardness's primary benefit is its immediate presentation of hardness values, which eliminates the need for laborious computations that are a part of other hardness measuring methods. Usually, it is employed in metallurgy and engineering. Its tiny area of indentation, resolution, toughness, quickly, and dependability are the reasons behind its commercial prominence. The test piece's thickness must be at least ten times the indentation's depth in order to obtain a trustworthy result. Additionally, since convex surfaces provide lower measurements, tests should be made from a level, perpendicular surface. The Vickers hardness test, which followed ASTM E92-17, was used to assess the surface hardness of the composite samples. It was carried out using a standard Vickers hardness testing equipment that had a diamond pyramid-shaped indenter. For a duration of 10 seconds, the load was delivered to the sample surface using the indenter. After the load was removed, the diagonals of the resulting indentation were measured using an optical microscope integrated with the testing apparatus. Each specimen had fifteen measurements made at various points to guarantee accuracy, and a median result was given. The impact of UV aging and nanoclay reinforcement on the surface hardness of the composites could be evaluated thanks to the accurate and dependable hardness values this approach produced. The regular diamond shape for hardness test and hardness test device are shown in Figure 2 a) and b), respectively.



a) **b)**

Figure 2. a) Regular diamond shape for hardness test b) Hardness test device

The samples utilized in this investigation were coded. For example, for the code S0.5-450, S is abbreviation for specimen, 0.5 represents the nanoclay reinforcement ratio and 450 represents UV aging time (450 hours).

3. RESULTS AND DISCUSSION

The impact of nanoparticle adding on the hardness of intraply carbon/aramid hybrid samples was systematically evaluated. The hardness values and change rates of the samples for each case are clearly seen in Figure 3. The composites were prepared with nanoclay weight fractions of 0%, 0.5%, 1.0%, 1.5%, 2.0%, and 3.0%, and their hardness values were measured. The results demonstrated a significant improvement in hardness with the addition of nanoclay compared to the unreinforced samples. Specifically, the hardness values for the composites with 0.5%, 1.0%, 1.5%, 2.0%, and 3.0% nanoclay content exhibited increases of 4.69%, 17.19%, 27.73%, 31.25%, and 32.81%, respectively, relative to the unreinforced samples. This trend indicates that the incorporation of nanoclay enhances the resistance of the composite matrix to surface deformation, which can be attributed to the improved dispersion of nanoclay particles and their interaction with the polymer matrix [7,21]. The most substantial increase in hardness was observed at 3.0% nanoclay content, suggesting that the reinforcement was effective in enhancing the load-bearing capacity of the matrix [18,19]. Further, due to the nanoclay strengthens the polymer's ability to resist plastic deformation, it boosts the samples' hardness [9]. However, the diminishing rate of improvement beyond 2.0% indicates that the material may be approaching a saturation point, where further addition of nanoclay provides minimal incremental benefits. These findings underscore the critical role of nanoclay content in optimizing the mechanical properties of hybrid composites and provide valuable insights for their application in environments demanding high surface hardness.

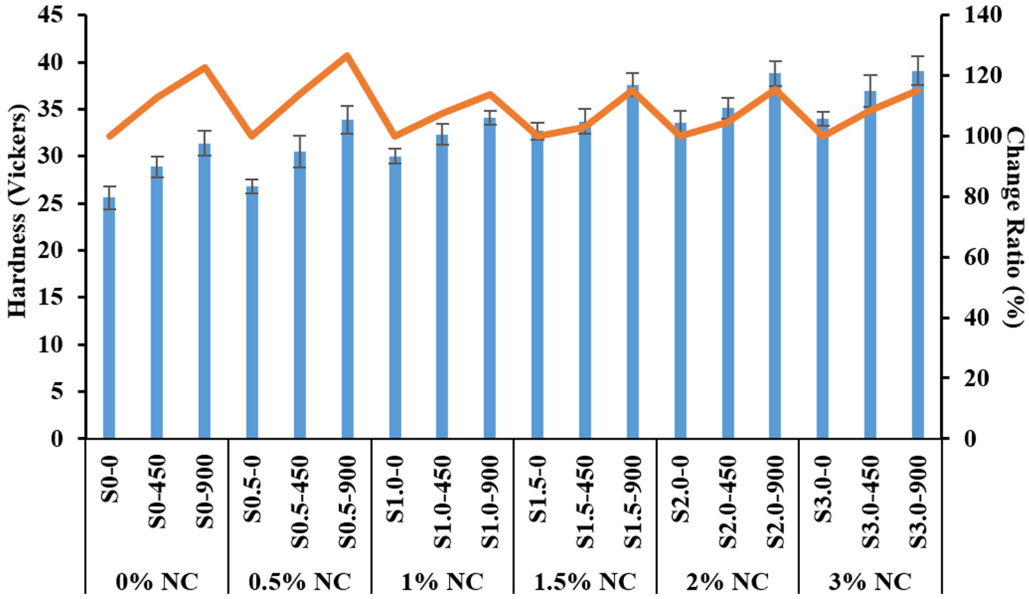


Figure 3. Hardness values and change ratios of samples

The influence of UV aging on the hardness of intraply carbon/aramid hybrid composites with varying nanoclay content (0%, 0.5%, 1.0%, 1.5%, 2.0%, and 3.0%) was systematically examined over 450 and 900 hours of exposure. The results reveal a notable increase in hardness values after UV aging, indicating the embrittlement effect induced by prolonged UV exposure [12,16,20]. At 450 hours of UV aging, all samples exhibited increased hardness compared to the control group. The hardness values for S0, S0.5, S1.0, S1.5, S2.0, and S3.0 samples increased by 12.89%, 13.81%, 7.67%, 3.06%, 4.46%, and 8.83%, respectively. This trend suggests that UV aging enhances the surface hardness due to the crosslinking and densification effects in the matrix caused by UV-induced molecular changes [15,20]. However, the lower increase observed for higher nanoclay contents (e.g., S1.5 and S2.0) may indicate that the reinforcement already contributes significantly to hardness, leaving less room for further enhancement through UV aging. At 900 hours of UV exposure, hardness values continued to rise compared to both the control group and the 450-hour results. The hardness values for S0, S0.5, S1.0, S1.5, S2.0, and S3.0 increased by 22.66%, 26.49%, 13.67%, 14.98%, 15.48%, and 15.0%, respectively. The progressive increase in hardness with prolonged UV exposure highlights the cumulative embrittlement effect, with the matrix becoming increasingly rigid over time. Notably, samples with higher nanoclay content (S2.0 and S3.0) showed relatively stable but significant improvements, indicating that nanoclay reinforcement synergistically interacts with UV-induced changes to enhance surface hardness. [12,20] These findings demonstrate that UV aging not only enhances the surface hardness of hybrid composites but also highlights the critical role of nanoclay content and aging duration in influencing the mechanical properties of these materials. The results provide valuable insights for designing composites for long-term outdoor applications where UV exposure is a critical factor.

4. CONCLUSION

This work examined how the hardness characteristics of intraply carbon/aramid hybrid composites were affected by UV aging and nanoclay reinforcement. In comparison to unreinforced samples, the addition of nanoclay at weight fractions of 0.5%, 1.0%, 1.5%, 2.0%, and 3.0% considerably increased surface hardness, with increases of 4.69%, 17.19%, 27.73%, 31.25%, and 32.81%, respectively. These results demonstrate how well nanoclay works to increase the composite matrix's load-bearing capability. All samples' hardness levels were further increased by UV aging. Hardness increases for S0, S0.5, S1.0, S1.5, S2.0, and S3.0 were 12.89%, 13.81%, 7.67%, 3.06%, 4.46%, and 8.83%, respectively, following 450 hours of UV exposure. More significant increases occurred after 900 hours of exposure, reaching 22.66%, 26.49%, 13.67%, 14.98%, 15.48%, and 15.0% for the same specimens, respectively. These findings show a substantial relationship between surface hardness and UV aging duration, which is explained by UV-induced embrittlement effects and molecular crosslinking in the polymer matrix. The results imply that UV aging and nanoclay reinforcement work in concert to improve the mechanical performance of hybrid composites. Intermediate nanoclay concentrations and extended UV exposure produced the best combination of endurance and reinforcing, whereas greater nanoclay levels shown declining returns in hardness enhancement. These findings serve as a basis for creating hybrid composites that are appropriate for long-term outdoor applications and have improved hardness and UV resistance. To increase the range of applications for these materials, further research might examine other mechanical characteristics including fatigue behavior and impact resistance.

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