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RESEARCH ARTICLE / ARAŞTIRMA MAKALESİ

Effect of UV Aging on the Hardness Properties of Glass and Aramid Fiber-Reinforced Interply Hybrid Composites

UV Yaşlanmasının Cam ve Aramid Elyaf Takviyeli Interply Hibrit Kompozitlerin Sertlik Özellikleri Üzerindeki Etkisi

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Abstract

This study investigates the effect of UV aging on the hardness properties of hybrid composite materials configured with glass and aramid fibers in four designs: pure glass fiber (S1), pure aramid fiber (S4), and two hybrid structures (S2 and S3) with varied fiber layering. Samples were exposed to UV light for 0, 20, and 40 days, and hardness values were recorded to evaluate how UV exposure and fiber hybridization influence material durability. Initially, the pure aramid composite (S4) exhibited the highest hardness at 28 HV, a 26.13% increase over the pure glass configuration (S1) at 22.2 HV. The hybrid configurations demonstrated intermediate values (between pure glass and pure aramid), with S3 (aramid exterior) reaching 25.1 HV, indicating the influence of fiber hybridization. UV exposure further increased hardness in all configurations; after 20 days UV aging, values rose to 24.4 HV for S1, 27.3 HV for S2, 30.4 HV for S3, and 31.6 HV for S4. By 40 days UV aging, hardness reached 28.8 HV for S1, 30.1 HV for S2, 31.6 HV for S3, and 34.9 HV for S4, showing cumulative increases of 29.7% to 24.6% across the samples. These results demonstrate that UV aging enhances hardness, with hybrid models-particularly those with aramid fibers on the exterior-exhibiting improved UV resistance, suggesting their suitability for applications requiring both UV durability and hardness.

Keywords: Hardness, Glass Fiber, Aramid Fiber, Hybrid Composites, UV Aging

I. INTRODUCTION

Composite materials are essential in modern engineering and technology due to their unique ability to combine the best properties of different constituent materials, often resulting in superior performance compared to traditional materials. By blending fibers such as glass, carbon, aramid, or natural fibers with matrices like polymers, composites offer high strength-to-weight ratios, excellent durability, and enhanced resistance to environmental conditions. These attributes are particularly valuable in industries such as aerospace, automotive, and civil engineering, where reducing weight while maintaining strength is critical. Furthermore, the flexibility to tailor composites for specific applications through modifications in fiber orientation, layering, or hybridization allows engineers to meet diverse performance requirements [23], from enhanced load-bearing capabilities to improved mechanical properties. The development of composite materials continues to be a key area of research aimed at creating cost-effective, high-performance materials with reduced environmental impact [1,2,22]. Environmental aging tests are crucial for composite materials because these materials are often exposed to challenging environments that can change their mechanical, thermal, and chemical properties over time. Factors such as moisture, temperature fluctuations, UV radiation, and exposure to chemicals can cause irreversible changes in composite structures, leading to reduced strength, stiffness, and durability. Understanding the effects of environmental aging is essential for predicting the long-term performance of composites, especially in applications like aerospace, automotive, marine, and construction, where safety and reliability are paramount. By conducting environmental aging tests, researchers can identify vulnerabilities in the composite's design. Such tests also provide valuable data for life-cycle analysis and contribute to the development of industry standards, ensuring that composite materials maintain their performance and safety throughout their intended service lives [3,4].

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A crucial characteristic of composites is their hardness, which indicates how well they can withstand surface wear, penetration, and deformation when forces are applied. For composites used in structural, automotive, and aerospace industries that need durability and endurance, this property is especially crucial. A composite material's hardness is a crucial measure of its total mechanical integrity as it is impacted by its matrix, reinforcement, and the interfacial bonding between these phases. Increased hardness helps to the composite's load-bearing capacity and surface stability in addition to improving its resilience to abrasive conditions. Therefore, it is crucial to comprehend and maximize the hardness of composite materials to guarantee their dependability and functionality throughout demanding operating circumstances.

UV aging is a significant factor affecting the hardness properties of composite materials, as prolonged exposure to ultraviolet radiation can lead to surface degradation, embrittlement, and a reduction in overall mechanical integrity [5,6]. The polymer matrices within composites are particularly susceptible to UV-induced chemical changes, such as chain scission and oxidation, which can result in change of mechanical properties. These changes not only diminish the hardness but also affect wear resistance and durability, especially in outdoor applications like automotive, marine, and aerospace structures where UV exposure is constant. Evaluating the impact of UV aging on hardness properties provides critical insights into the composite’s longevity and performance under real-world conditions, enabling the development of UV-resistant formulations or protective coatings that enhance durability [7].

Raajeshkrishna et al. [8] investigated the effect of reinforcement material and production method on the mechanical properties of glass and basalt laminate composites. Hardness tests were applied to glass/epoxy and basalt/epoxy samples prepared using production methods such as hand layup followed by compression moulding (HLC), vacuum bagging method (VBM) and vacuum assisted resin infusion method (VARIM). The hardness values of glass/epoxy samples produced by HLC, VBN and VARIM methods were 78, 75, 73 SD, respectively. The hardness values of basalt/epoxy samples were 99, 95, 90 SD for HLC, VBN and VARIM methods, respectively. As a result, it was found that the production method was effective on the hardness values of composite materials.

The hardness values of hybrid composite materials reinforced with carbon and flax fibers were examined by Ramesh et al. [9]. As a result of hardness measurements, the hardness value of the composites ranged from 62.33 to 77.66 (HRC), and the average hardness was determined as 70.85 (HRC).

Suryawan et al. [10] compared to the hardness values of nettle fibers and glass fibers. Both nettle and glass fibers were mixed with epoxy resin at 10, 15 and 20% by weight. The effect of weight ratios on the hardness values of the samples was investigated. The hardness values of the glass fiber reinforced composites were measured as 82.4, 84.5 and 86.5 Shore D, respectively. The hardness values of the nettle fiber reinforced composites were found as 81.6, 85.0 and 86.6 Shore D, and an increase in hardness was observed as the fiber weight fraction increased.

Rout et al. [11] researched the hybridization effect of the hardness values of Kevlar, carbon and glass samples. When the hardness values of pure Kevlar, carbon and glass samples produced for comparison with hybrid samples were evaluated among themselves, it was found that carbon samples had the highest hardness value and glass samples had the lowest hardness value. In addition, it was observed that the hardness values of the samples with carbon layers on the outer surface in hybrid composites were higher than other hybrids.

Markovičová et al. [12] studied the hardness values of 10, 20, 30% glass fiber amounts added to the polyamide 66 (PA 66) matrix under UV light. Hardness tests were performed after 500 hours of UV aging and compared with control group samples. Accordingly, the hardness value of 10% glass reinforced samples increased by 21.21% after 500 hours of aging. However, UV aging caused a decrease of 23.91% and 37.04% in the hardness values of 20% and 30% reinforced samples, respectively.

Shi et al. [13] conducted hardness tests of carbon fiber/epoxy (CFRP) composites subjected to UV aging for 80 days. It was observed that the hardness of the fibers was minimally affected by UV irradiation, maintaining relatively stable values throughout the aging period. In contrast, the matrix material showed a substantial increase in hardness under UV aging, reflecting a pronounced embrittlement effect. The matrix phase exhibited a substantial increase in hardness, rising by up to 35% after 40 days of UV exposure due to embrittlement from UV-induced molecular changes. Following this peak, hardness began to decline with continued exposure.

Ramli et al. [14] examined the hardness values of glass-reinforced composite samples prepared with vinyl ester and epoxy matrices exposed to UV light for different periods of time. In this study, it was stated that while an increase in the hardness values of the vinyl ester matrix composite samples was observed as the UV duration increased, UV aging caused a decrease in the hardness values in the epoxy matrix samples.

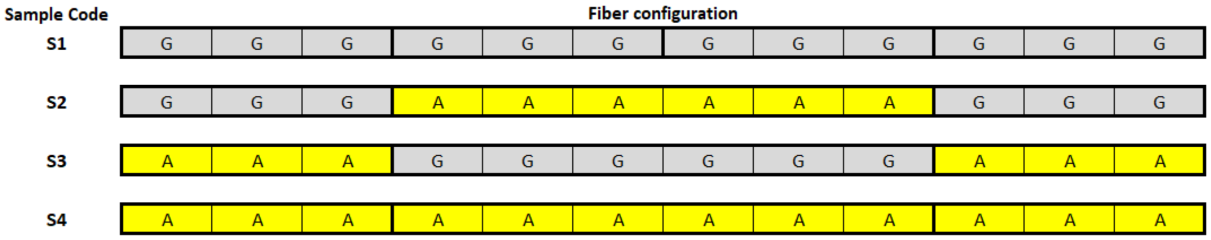
Compston et al. [15] studied the effect of UV curing on the hardness value of glass-fibre/vinylester samples. The control group samples were left to cure at room temperature and after 7 days, no change was observed in the hardness values and reached a hardness value of 60 HRM. However, it was determined that the curing process using UV light caused an increase in the hardness values of the samples (85 HRM).

In this study, the hardness properties of pure and interply hybrid specimens made from glass and aramid fabrics were evaluated after aging under UV light for different durations. While the effects of UV exposure on polymer-matrix composites have been widely investigated in the literature, research specifically examining the UV aging resistance of hybrid composites combining different fibers remains limited. This study distinguishes itself by providing a comparative analysis of pure and hybrid structures, revealing how varying fiber combinations influence UV resistance in terms of hardness retention. By focusing on the impact of UV aging on hybrid composites' hardness properties, this research aims to identify optimal configurations that enhance durability in structures containing both glass and aramid reinforcements. This novel approach contributes to the literature by shedding light on the UV durability differences between glass and aramid fiber combinations, offering insights for designing composites with improved resistance to environmental aging.

II. MATERIALS AND METHOD

2.1 Materials

For this study, woven glass and aramid fabrics with densities of 202 and 170 g/m^2 and fabric thicknesses of 0.15 mm and 0.27 mm, respectively, were used. Additionally, MGS 285 series epoxy and hardener were used as the resin system. Composite plates were fabricated using the hand lay-up technique at an ambient temperature of 25°C. All materials, including fabrics, hardener, and epoxy resin, were sourced from Dostkimya Company in Istanbul. The resin system used was Hexion MGS-L285 epoxy, mixed with Hexion MGS-H285 hardener in a 100:40 ratio. Four distinct composite plate configurations were produced: two pure and two hybrid using a sandwich structure. The configuration with 12 layers of glass fabric was designated as S1 (2.41±0.03 mm, thickness), while the configuration with 12 layers of aramid fabric was labeled S4 (2.91±0.07 mm, thickness). For the hybrid models, S2 (2.45±0.02 mm, thickness) was constructed with three layers of glass fabric on the exterior and six layers of aramid fabric in the core, whereas S3 (2.82±0.05 mm, thickness) featured three layers of aramid fabric on the exterior with six layers of glass fabric in the core.



Sample Code	Fiber configuration											
S1	G	G	G	G	G	G	G	G	G	G	G	G
S2	G	G	G	A	A	A	A	A	A	G	G	G
S3	A	A	A	G	G	G	G	G	G	A	A	A
S4	A	A	A	A	A	A	A	A	A	A	A	A

Figure 1. Fiber configuration and sample coding (G: Glass; A: Aramid)

The configuration of fiber layers and sample code are illustrated in Figure 1. The samples were cured for one hour at 80°C under 0.4 MPa pressure using a hot mold press equipped with flat molds. Following this, the laminates were allowed to cool to room temperature before being removed from the molds. A flowchart illustrating the production process and the hot mold machine are provided in Figure 2 (a) and (b), respectively.

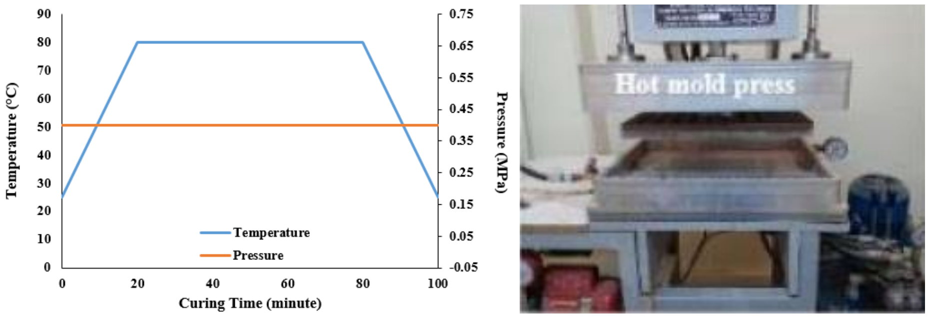

a) b)

Figure 2. a) Flowchart of sample production b) Hot mold press

2.2 UV Aging

In accordance with the applicable ASTM standard, accelerated UV testing was carried out in this investigation utilizing an OSRAM ultraviolet lamp [16]. Three sets of samples were made for each composite configuration: one control group, which was not exposed to UV aging; a second group, which was exposed to UV light for 20 days; and a third group, which was exposed for 40 days.

2.3 Hardness Test

The material used in the Vickers hardness test creates an indentation that affects the test sample. The force that is applied and the area formed by the puncture on the sample's test surface have a direct impact on the determined Vickers hardness measurement. The notch geometry employed in the Vickers hardness test is the geometric arrangement of a square pyramid formed of diamonds at an angle of 136° between opposing sides. The specimen exhibits an indentation zone with a somewhat typical diamond shape, as shown in Figure 3 a). The hardness test of samples is evaluated using a Qness brand hardness tester, as shown in Figure 3 b), in accordance with ASTM E92-17 (ASTM E92-17, 2017). The sample underwent at least fifteen Vickers hardness test measures for each composite combination; the findings are presented as the average of the fifteen examinations.

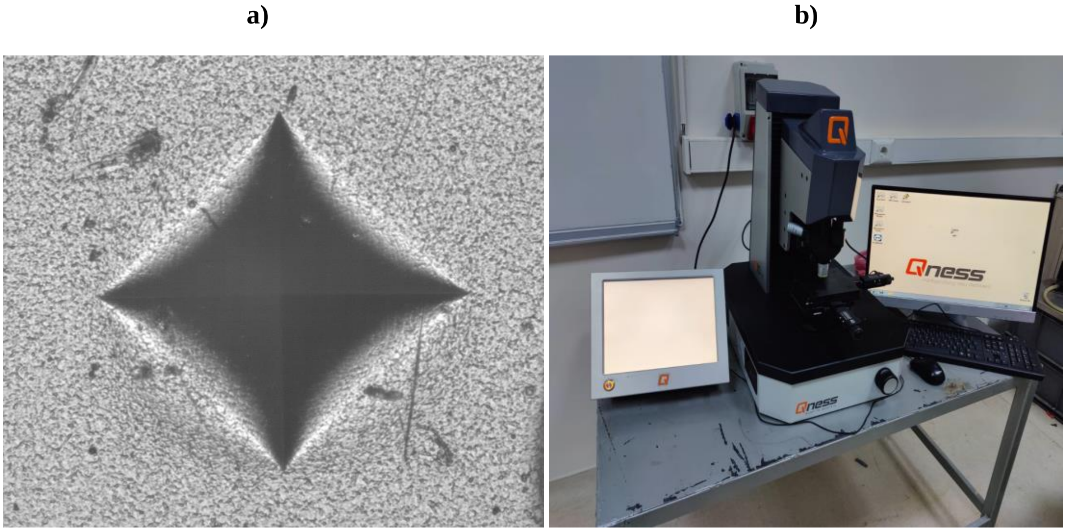


Figure 3. a) Regular diamond shape for hardness test b) Hardness test machine

III. RESULTS AND DISCUSSION

In this study, four distinct composite configurations (S1, S2, S3, and S4) were tested to evaluate the effects of hybridization, UV aging, and UV exposure duration on hardness. The hardness of each sample was measured at 0, 20, and 40 days of UV exposure. Hardness values of samples in different UV aging periods is shown in Figure 4. Further, change rate of hardness values of samples is shown in Figure 5 based on unaged samples. Each sample group (S1, S2, S3 and S4) was evaluated within itself in Figure 5. During the evaluation, the change rates after 450 and 900 hours of UV aging were compared with the unaged samples. The initial hardness values (0 days of UV exposure) indicate a clear impact of the fiber composition on hardness. Pure glass fiber composite (S1) had an initial hardness of 22.2 HV, while the pure aramid fiber composite (S4) had a higher hardness of 28 HV, showing that the aramid configuration offers a 26.1% increase in hardness over glass. For the hybrid configurations, S2 (glass on the outer layers, aramid in the core) and S3 (aramid on the outer layers, glass in the core) recorded initial hardness values of 23.4 HV and 25.1 HV, respectively. This suggests that both hybrid structures improve hardness compared to pure glass fiber (S1), with S2 showing a 5.4% increase and S3 a 13.1% increase. S3, with aramid on the outside, achieved higher hardness than S2, indicating that the position of aramid fibers in the laminate impacts hardness, with aramid on the exterior providing better surface resistance. Although the two hybrid composites include an identical amount of fabrics, it is important to note that the fiber order affects the hybrid composites' hardness characteristics. Because Aramid fiber has a higher modulus than glass fiber, exterior Aramid layers increase the composite's hardness, according to comparable findings published by Rout et al. [11] and Nayak et al. [17]. As anticipated, it is also noted that the hardness of all hybrid composites differs between glass fiber-reinforced polymer composites and plain Aramid. In addition, when hybrid composites are compared with pure configurations, it has been stated in different studies in the literature [18-20] that the mechanical properties of hybrid configurations have values between those of pure composites.

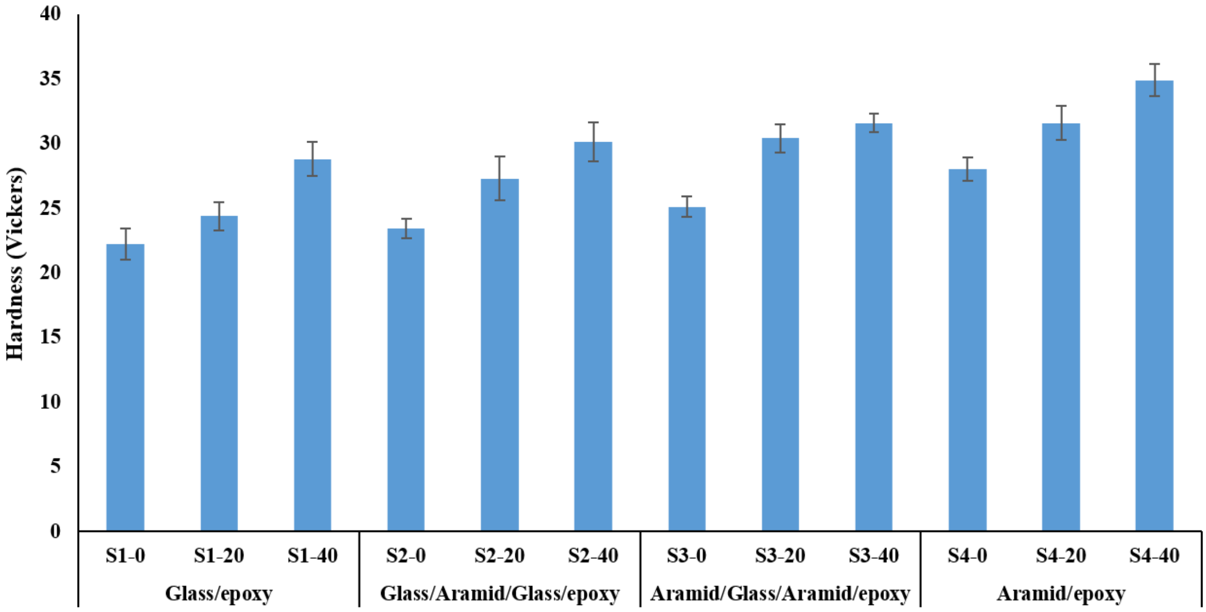


Figure 4. Hardness values of samples in different UV aging periods

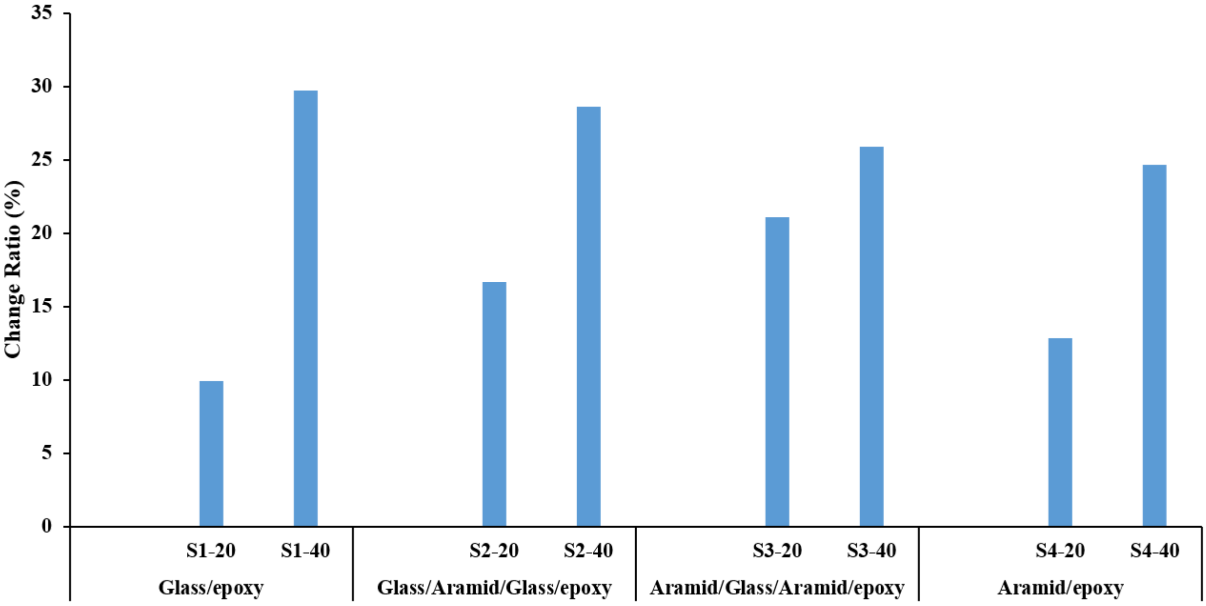


Figure 5. Change rates of hardness values of samples based on UV aging periods

UV exposure had a significant effect on the hardness of all samples, with increased hardness observed after both 20 and 40 days. After 20 days of UV exposure, the hardness values for S1, S2, S3, and S4 increased to 24.4 HV, 27.3 HV, 30.4 HV, and 31.6 HV, respectively. This represents an increase of 9.91% for S1, 16.67% for S2, 21.12% for S3, 12.86% for S4. After 40 days of UV exposure, further increases were noted, with hardness values reaching 28.8 HV for S1, 30.1 HV for S2, 31.6 HV for S3, and 34.9 HV for S4. This marks a cumulative increase of 29.73% for S1, 28.63% for S2, 25.9% for S3, 24.64% for S4. These results indicate that UV exposure enhances the hardness of all samples, likely due to surface embrittlement effects from prolonged UV-induced polymer degradation. Notably, the pure glass fiber sample (S1) experienced the highest percentage increase over 40 days, possibly because the glass fiber matrix is more susceptible to UV-related hardening than the aramid fiber [11,21]. The effect of UV aging duration (from 0 to 20 to 40 days) on hardness was evident across all configurations. Between 0 and 20 days, the hardness of S1, S2, S3, and S4 increased by 9.9%, 16.67%, 21.12%, and 12.86%, respectively. Between 20 and 40 days, the hardness values continued to rise by 18.0% for S1, 10.3% for S2, 3.9% for S3, and 10.4% for S4. The results show that while all samples exhibited increased hardness with extended UV exposure, the rate of increase was highest in the initial 20 days, especially for S3, which incorporates aramid fibers on the outer layers. After 20 days, the rate of hardness increase slowed, indicating a potential plateau in UV-induced hardening effects as the surface reaches a saturation point in embrittlement. In this study, UV aging caused an increase in the hardness values of the samples primarily due to photochemical changes in the polymer matrix, leading to surface hardening and embrittlement. When exposed to ultraviolet (UV) light, the polymer matrix undergoes chemical reactions, such as chain scission (breakage of polymer chains) and oxidation. These reactions result in the formation of free radicals, which can lead to cross-linking of the polymer chains at the surface. As a result, the material becomes more rigid and less flexible, contributing to an increase in surface hardness [5,6]. UV radiation accelerates the curing process on the surface of the composite materials, causing a hardening effect. This is because UV light promotes polymerization, where the free radicals initiate a process of bonding between polymer chains, creating a more tightly cross-linked structure on the surface [6,11,13]. This enhanced cross-linking reduces the material's ability to deform, thus increasing the material's surface hardness. Additionally, the UV-induced surface embrittlement creates a stiffer, more brittle outer layer, further raising the measured hardness values. While UV aging typically leads to degradation over time, the initial stages of UV exposure can result in surface hardening due to the increased degree of cross-linking and chemical changes in the polymer matrix [5,10]. Therefore, the observed increase in hardness in this study can be attributed to these photochemical processes that make the surface layers of the composites more rigid and less prone to deformation under stress.

IV. CONCLUSION

This study examined the effect of UV aging on the hardness properties of composite samples with four configurations: pure glass fiber (S1), pure aramid fiber (S4), and two hybrid configurations (S2 and S3) combining both fiber types in different arrangements. The samples were subjected to UV exposure for 0, 20, and 40 days, and their hardness values were assessed to evaluate the impact of hybridization, UV exposure, and aging duration on material performance. The results showed that UV aging significantly increased the hardness of all samples. Initially, at 0 days of UV exposure, the pure glass fiber sample (S1) had a hardness of 22.2 HV, whereas the pure aramid sample (S4) exhibited a hardness of 28 HV, marking a 26.1% higher hardness for aramid. Hybrid configurations, S2 and S3, demonstrated intermediate initial hardness values of 23.4 HV and 25.1 HV, respectively, with S3 achieving a 13.1% improvement over the pure glass sample due to the outer positioning of aramid fibers. After 20 days of UV exposure, the hardness of all samples increased further. S1, S2, S3, and S4 reached hardness values of 24.4 HV, 27.3 HV, 30.4 HV, and 31.6 HV, respectively, representing increases of 9.9% for S1, 16.7% for S2, 21.1% for S3, and 12.9% for S4 compared to their initial values. After 40 days of exposure, the hardness values continued to rise, with S1 reaching 28.8 HV, S2 reaching 30.1 HV, S3 reaching 31.6 HV, and S4 reaching 34.9 HV. This resulted in cumulative hardness increases of 29.7% for S1, 28.6% for S2, 25.9% for S3, and 24.6% for S4. The data suggests that while UV exposure generally increases hardness across all configurations due to surface embrittlement and photochemical changes in the polymer matrix, the rate of increase tends to diminish over time as the materials reach a saturation point in hardening effects. Hybrid configurations, especially those with aramid fibers on the exterior (S3), consistently exhibited higher hardness, emphasizing the role of fiber positioning in optimizing UV resistance. These findings indicate that hybrid composites, with proper configuration, can offer enhanced durability under UV exposure, making them suitable for applications requiring high hardness and UV stability. Further studies could investigate longer UV exposure periods and additional mechanical properties to fully understand the long-term durability of these materials.

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