Impact of Corona Treatment on Mechanical Properties and Morphology of Hemp Fiber Reinforced in Epoxy Matrix Composite

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Abstract: Corona treatment was applied to enhance the interfacial adhesion between hemp woven fibers and epoxy resin in fiber-reinforced composites. Using a cold pressing method with equal parts of resin and fiber (50 g each), samples were treated for 1–4 min. SEM analysis revealed that increased treatment time led to greater fiber surface roughness and reduced voids at the fiber–matrix interface, improving bonding. Tensile strength increased with treatment time, peaking at 48.68 MPa at 3 min before slightly decreasing at 4 min. The elastic modulus remained stable (304.67–312.52 MPa) up to 3 min, then dropped slightly to 302.86 MPa. Overall, corona-treated composites exhibited a 55% increase in tensile strength compared to untreated ones, confirming the treatment's effectiveness in enhancing mechanical performance.

Keywords: Corona treatment, Mechanical properties, Composite material, Hemp fibers.

1. INTRODUCTION

Fiber-reinforced epoxy composites are renowned for their exceptional mechanical performance, offering high strength and stiffness through the incorporation of reinforcing fibers such as carbon, glass, or natural fibers. Their combination of lightweight and robust properties makes them particularly suitable for applications in the aerospace, automotive, and construction sectors [1]. These composites also demonstrate excellent corrosion resistance, surpassing metals in harsh environments by withstanding moisture, chemicals, and UV radiation, thereby extending service life and reducing maintenance costs [2]. A key advantage of epoxy composites is their design flexibility, which enables the tailoring of mechanical properties and the fabrication of complex structures, thus enhancing industrial efficiency. In particular, natural fiber-reinforced epoxy composites—using fibers such as flax, hemp, and jute—offer a sustainable alternative to synthetic reinforcements [3-5]. These materials not only deliver impressive mechanical properties, including high strength, stiffness, and load-bearing capacity, but also contribute to environmental sustainability [6-9]. Natural fibers are renewable, biodegradable, and possess a lower carbon footprint compared to synthetic counterparts, requiring less energy during production [10]. Their lightweight nature improves fuel efficiency and reduces emissions, while their affordability supports broader adoption in cost-sensitive industries [11,12]. Overall, natural fiber-reinforced composites represent a promising, eco-friendly solution for high-performance engineering applications.

The weak adhesion between natural fibers and epoxy resin in composite materials poses a significant challenge, primarily due to their contrasting hydrophilic and hydrophobic properties. Natural fibers are inherently hydrophilic, readily absorbing moisture, whereas epoxy resin is hydrophobic and resists water absorption. This incompatibility at the fiber–matrix interface impairs interfacial bonding, ultimately reducing the mechanical performance and structural integrity of the composites [9,13]. A key factor contributing to poor adhesion is the moisture absorption capacity of natural fibers. When exposed to humidity, these fibers swell and degrade the fiber–matrix interface, weakening the bond and increasing the risk of delamination and mechanical failure. Moreover, the chemical composition of natural fibers—rich in lignin, hemicellulose, and other polar functional groups—further promotes water absorption, intensifying hydrophilicity and hindering effective bonding with the epoxy matrix [14-16]. To address these issues, various surface treatment techniques have been developed to reduce fiber hydrophilicity and improve compatibility with hydrophobic epoxy resins. Methods such as chemical modification, plasma treatment, and the use of silane coupling agents

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enhance fiber wettability and interfacial adhesion [17]. Additionally, hybrid composites combining natural and synthetic fibers can balance moisture resistance with sustainability and cost-effectiveness. The incorporation of bio-fillers like cellulose nanocrystals and nanoparticles such as graphene oxide has also shown promise in reducing moisture uptake, improving fiber dispersion, and reinforcing the matrix [9,18]. Furthermore, optimized processing techniques—such as vacuum-assisted resin transfer molding and hot pressing—enhance fiber impregnation and overall mechanical performance. Together, these strategies significantly improve the durability and functionality of natural fiber-reinforced epoxy composites [9].

Corona treatment is a highly effective surface modification technique employed to enhance the adhesion between natural fibers and epoxy resin in composite materials. This method introduces polar functional groups onto the fiber surface, thereby improving the wettability and compatibility of natural fibers with epoxy resins, which in turn enhances the overall performance of the composite [19]. The process involves the application of a high-voltage electrical discharge to the surface of natural fibers, generating reactive species, such as ozone, free radicals, and ions. These reactive species alter the surface chemistry of the fibers by introducing oxygen-containing functional groups, including carbonyls and hydroxyls, which increase the surface energy and hydrophilicity of the fibers. This modification effectively reduces the interfacial tension between the hydrophilic fibers and the hydrophobic epoxy resin, thereby facilitating improved adhesion and enhancing stress transfer across the fiber-matrix interface [20]. Numerous studies have demonstrated that corona-treated natural fibers exhibit significantly improved mechanical properties, such as enhanced tensile strength and flexural modulus, when incorporated into epoxy-based composites [21]. A key advantage of corona treatment is its ability to enhance fiber-matrix adhesion without significantly compromising the mechanical integrity of the fibers. The introduction of polar groups facilitates stronger chemical bonding with the epoxy matrix, resulting in improved interfacial adhesion and enhanced composite properties, including tensile strength, flexural strength, and impact resistance. Moreover, corona treatment is a relatively simple, cost-effective process that can be seamlessly integrated into existing manufacturing workflows. In addition to its effectiveness, corona treatment is an environmentally sustainable alternative to conventional chemical surface modifications. Unlike chemical treatments that may involve hazardous reagents, corona treatment relies solely on electrical energy and air, generating no harmful by-products or waste. Furthermore, its applicability across a wide range of natural fibers underscores its versatility for various composite applications [22]. While corona treatment proves highly effective, its application requires careful optimization to prevent over-treatment, which may result in fiber degradation and compromised mechanical performance. Key factors such as treatment duration, intensity, and environmental conditions play a critical role in determining the extent of surface modification. For example, prolonged exposure to corona discharge can lead to surface etching and chain scission in natural fibers, thereby diminishing their structural integrity [23]. Consequently, it is vital to strike a balance between achieving sufficient surface activation and maintaining the fibers' inherent properties. Recent advancements in corona treatment technologies, such as atmospheric pressure plasma treatment, have provided enhanced control over the modification process, yielding promising improvements in interfacial adhesion for natural fiber-reinforced composites [24].

However, several limitations must be carefully considered. The effectiveness of corona treatment is influenced by key parameters such as treatment duration, power intensity, and fiber type, requiring precise optimization to achieve consistent surface modification. Additionally, the long-term stability of treated fibers under varying environmental conditions necessitates further investigation to ensure the durability of composite materials. Ongoing research continues to advance corona treatment methodologies to enhance adhesion performance and improve the mechanical reliability of natural fiber-reinforced epoxy composites. This study specifically focuses on hemp fiber due to its increasing recognition as a sustainable and high-performance reinforcement material in epoxy matrix composites. Hemp fibers, derived from Cannabis sativa, are renewable, biodegradable, and have a lower environmental footprint than synthetic fibers. When combined with epoxy resin, a thermosetting polymer known for its strong adhesion and mechanical properties, they form lightweight, durable composites suited for automotive, construction, and aerospace applications, where demand for sustainable materials is increasing [25-27]. Their high specific strength and stiffness further enhance their reinforcement potential in epoxy composites [28].

These composites offer mechanical properties comparable to glass and carbon fiber-reinforced materials while being more eco-friendly. The high cellulose content of hemp fibers contributes to their tensile strength, while their low density ensures lightweight composites. Proper fiber treatment and alignment can further enhance their tensile strength and flexural modulus, making them viable for structural applications [29]. Additionally, the natural roughness and porosity of hemp fibers improve interfacial adhesion with the epoxy matrix, enhancing overall composite performance [30]. Beyond mechanical benefits, hemp fibers support environmental sustainability [31]. They require minimal pesticides and fertilizers, grow rapidly, and are biodegradable, unlike petroleum-based synthetic fibers. Their use aligns with circular economy principles, as they can be recycled or composted at the end of their lifecycle [32]. Additionally, their lower cost compared to synthetic alternatives makes them an attractive option for industrial applications [33].

Given these advantages, this study aims to improve the adhesion between hemp fiber and epoxy resin in hemp fiber-reinforced epoxy composites by mitigating their contrasting hydrophilic properties through corona treatment. Furthermore, this research investigates the tensile properties and analyzes the fracture surface morphology of the composite specimens to evaluate their mechanical behavior.

2. EXPERIMENTAL

2.1. Materials

The hemp woven material used in this study was sourced from a hemp fiber product community enterprise in Chiang Mai, Thailand. The hemp woven specimens are presented in Figure **1**. The matrix material employed was epoxy resin YD 582, a modified bisphenol-A-based epoxy resin known for its excellent mechanical properties. The curing agent, EPOTEC TH 7278, a modified amine, was provided by J.N. TRANSOS Company, Thailand.

2.2. Methodology

Figure 1: Hemp woven.

The hemp woven material was treated using a corona discharge system designed in-house, employing a dielectric barrier technique. The system comprises a horizontally oriented cylindrical glass reactor with a diameter of 15 cm and a length of 40 cm. It is equipped with three inlets and three outlets to facilitate the introduction of inert gases or the application of a vacuum pump. Inside the reactor, two planar rectangular electrodes (12 cm × 10 cm) are centrally positioned within the reaction chamber, maintaining an inter-electrode distance of 5.5 mm. The corona discharge is generated using a low-frequency high-voltage power supply (typically 20 kV, 50 Hz). To prevent arc discharge, two glass panels (40 cm × 30 cm) serve as dielectric barriers, as illustrated in Figure **2**.

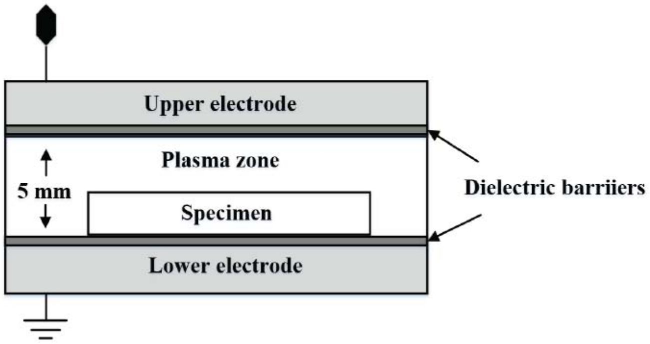

Figure 2: Corona discharge system.

The production of woven hemp fibers begins with the cultivation of Cannabis sativa L., followed by retting to facilitate the separation of bast fibers from the woody core. After drying, the stalks undergo mechanical decortication to extract the fibers, which are then scutched and hackled to remove impurities and align the fibers for subsequent processing. To achieve a uniform fiber diameter distribution, the fibers are manually sieved to a consistent size range of 0.6 to 1.0 mm. Woven hemp fabrics are subsequently produced using a manual laboratory-scale weaving machine. In this study, a plain weave pattern was selected for analysis of the hemp woven.

The fibers were subsequently woven into sheets, which were then cut to dimensions of 15 cm × 15 cm. These hemp sheets were subjected to corona treatment for varying durations of 0, 1, 2, 3 and 4 min, with a power output 1,500 W.

The composite matrix was formulated using epoxy resin with a density of 1,200 kg/m³, combined with a hardener. The cured epoxy composites exhibited a hardness exceeding 85 Shore A. Composite panels were fabricated via compression molding, as depicted in Figure **3**. To prepare the matrix solution, epoxy resin and hardener were mixed in a 4:1 ratio to produce 50 g of the mixture, which was then degassed to eliminate air bubbles. An initial 10 g of this mixture was poured into the base of a mold (15 cm × 15 cm × 20 cm), followed by the uniform distribution of approximately 50 g of hemp woven material. The remaining resin was then added to ensure complete impregnation. The mold was sealed and subjected to a compressive force of 1.5 MN for 2 hours at 25°C. The resulting specimen was subsequently removed and allowed to cure at 25°C for 72 h, yielding fully developed composite panels, as depicted in Figure **4**.

Figure 3: Cold pressing process (1) Frame (2) Hydraulic press control lever (3) Pressure guage (4) Pressing tool (5) Metal mold and (6) Composite panel.

Figure 4: Composite panel.

Composite panels incorporating hemp woven sheets subjected to corona treatment for durations of 0, 1, 2, 3 and 4 min were developed. Each composite panel, consisting of 50 g of hemp woven material and 50 g of resin, underwent tensile testing to assess its mechanical properties. Additionally, scanning electron microscopy (SEM) was employed to analyze the fracture surfaces of the composite panels following tensile testing.

2.3. Characterization

Composite panels were fabricated and sectioned along two orthogonal directions (0° and 90°) to assess fiber distribution and material homogeneity. Tensile testing was conducted at a displacement rate of 5 mm/min until the specimen reached the load cutoff, in accordance with ASTM D638 standards [34]. The experiment was performed using Bluehill software, version 3 (INSTRON Co., Ltd., High Wycombe, Bucks, UK). The fracture mechanisms of the composite plate following the tensile test were analyzed using a JEOL JSM-5900LV SEM, operated at an acceleration voltage of 20 kV.

3. RESULTS AND DISCUSSION

3.1. Effect of Corona Treatment on Surface Hemp Woven

A key aspect of these composites is the influence of corona treatment on the surface characteristics of hemp woven. As the duration of corona treatment increases from 0 to 4 min, a substantial rise in surface roughness is observed, as illustrated in Figure **5**. This

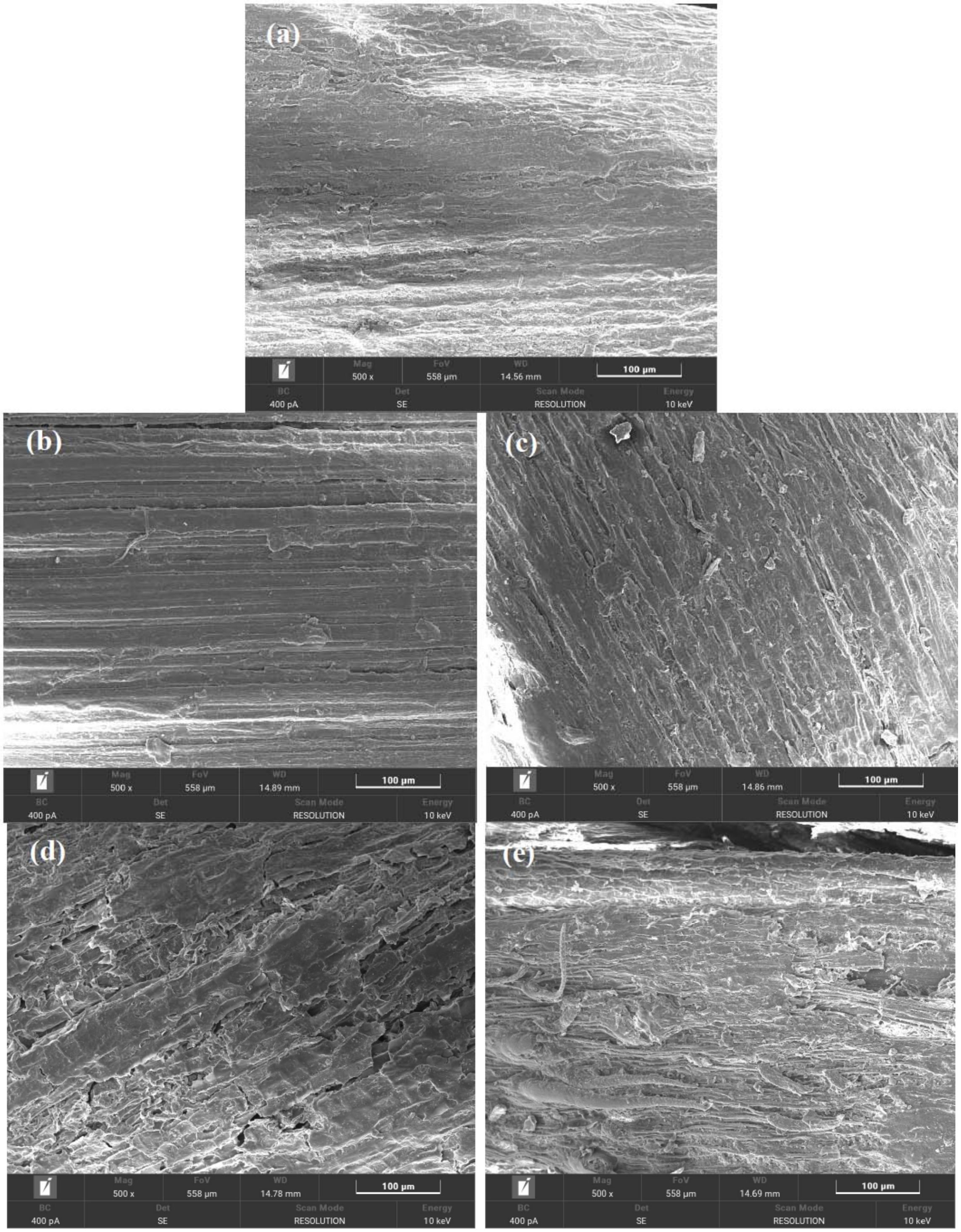

Figure 5: SEM images of hemp woven fiber surfaces subjected to different corona treatment durations: (**a**) untreated (0-min) hemp; (**b**) hemp treated for 1 min; (**c**) 2 min; (**d**) 3 min; and (**e**) 4 min.

phenomenon is primarily attributed to the formation of micro-pits and cavities on the fabric surface, which facilitate mechanical interlocking between the hemp fibers and the epoxy resin matrix [35]. The bombardment of oxygen plasma species induces an ablation effect on the fabric surface [36], thereby contributing to these surface modifications. Furthermore, corona discharge generates numerous activated sites along the polymeric chains, which subsequently react with oxygen, leading to an etching effect [37,38].

The increase in surface roughness due to corona treatment has significant implications for the performance of hemp-epoxy resin composites. Enhanced surface roughness improves the wettability of hemp fibers, thereby promoting superior adhesion with the epoxy resin. This improvement in adhesion is critical for augmenting the mechanical strength and durability of the composite material. Empirical studies have demonstrated that the presence of micro-pits and cavities on the fiber surface substantially enhances interfacial bonding, resulting in composites with superior mechanical properties [39].

Moreover, the duration of corona treatment plays a crucial role in optimizing the surface characteristics of hemp woven fiber. Inadequate treatment may fail to produce sufficient surface roughness, while excessive treatment could compromise fiber integrity. Therefore, a balanced approach is required to achieve the desired surface modifications without adversely affecting the structural stability of the fibers [40]. Research findings suggest that a treatment duration of approximately 3-4 minutes provides an optimal balance between surface roughness and fiber integrity.

3.2. Evaluation of Homogeneity in Composites

The analysis of fiber dispersion and the efficiency of the manufacturing process in hemp woven composites is essential for understanding their mechanical behavior and ensuring material homogeneity. In this study, tensile tests were performed on hemp woven composite materials along two principal directions, α = 0° and α = 90°. The resulting stress-strain curves exhibited an initial linear elastic region, followed by plastic deformation leading to failure in both orientations, as shown in Figure **6**. This mechanical response suggests that the material possesses a capacity for substantial deformation prior to fracture, a characteristic that is particularly advantageous for applications demanding high toughness and durability [41].

The tensile test results demonstrated a slight variation in Young's modulus depending on the loading direction. Specifically, Young's modulus was marginally higher in the α = 90° direction compared to the α = 0° direction. Moreover, the strength at break exhibited more pronounced differences, with the α = 90° orientation displaying superior strength. These variations can be attributed to the inherent anisotropy of the woven fabric structure, wherein the fiber alignment significantly influences the mechanical response [42].

Despite these directional differences, it is important to acknowledge that complete anisotropy in composite materials is unlikely. The observed variations in mechanical properties were relatively minor, indicating that fiber dispersion within the composite matrix does not exhibit a strong preferential orientation. This finding suggests that the employed manufacturing process effectively promotes a homogeneous fiber distribution, which is critical for ensuring consistent mechanical performance across various loading conditions.

3.3. Tensile Test

The weight and thickness of all composite samples were precisely measured using digital scales and calipers. The recorded values for thickness, weight, and density were 4.8 ± 0.32 mm, 100.8 ± 1.25 g, and 1.14 ± 0.12 g/cm³, respectively.

The mechanical properties of hemp woven composites subjected to varying durations of corona

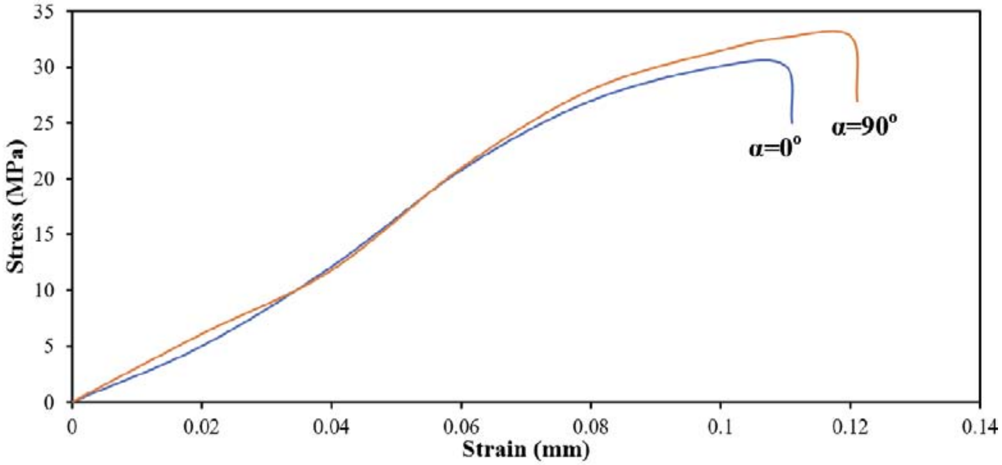

Figure 6: Tensile curve obtained from testing the homogeneity of composites.

Table 1: Mechanical Properties of Composites Materials at Different Treatment Durations

Treatment time (min)	Tensile strength (MPa)	Elastic modulus (MPa)
0	31.24 ± 1.23	304.67± 1.96
1	35.34 ± 1.12	312.52± 1.63
2	38.64 ± 1.19	306.14± 1.02
3	48.68 ± 1.98	310.92 ± 0.98
4	46.31 ± 0.99	302.86 ± 1.27

treatment within an epoxy resin matrix are summarized in Table **1**. The results indicate a consistent increase in tensile strength with increasing treatment duration from 0 to 3 min, reaching a peak tensile strength of 48.68 MPa at 3 min. This improvement in mechanical performance can be attributed to the enhanced surface roughness and fiber-matrix adhesion induced by corona treatment. The treatment process promotes the formation of micro-pits and cavities on the hemp fiber surface, thereby improving mechanical interlocking with the epoxy resin matrix [41]. However, a subsequent reduction in tensile strength to 46.31 MPa was observed at a treatment duration of 4 min, while the elastic modulus remained relatively stable within the range of 304.67–312.52 MPa from 0 to 3 min before decreasing slightly to approximately 302.86 MPa at 4 min. This decline suggests that prolonged exposure to corona treatment may induce fiber degradation or excessive surface roughening, adversely affecting the overall mechanical performance of the composites. Extended treatment durations could compromise the fiber structure, diminishing its capacity to effectively transfer stress and maintain structural integrity within the composite matrix [43].

The observed variations in mechanical properties highlight the critical need to optimize corona treatment durations to achieve an optimal balance between surface modification and fiber integrity. Shorter treatment times (up to 3 min) have been found to enhance the mechanical properties of hemp woven composites, whereas prolonged treatment (4 min or more) may lead to performance deterioration. This underscores the importance of carefully regulating and monitoring the treatment process to ensure desirable outcomes. Notably, the composites fabricated from corona-treated hemp woven exhibited a 55% increase in tensile strength compared to those produced from untreated hemp woven, demonstrating the effectiveness of corona treatment in enhancing mechanical performance [44].

Table **2** presents the p-values obtained from the one-way Analysis of Variance (ANOVA). A significance level of 5% ($\alpha = 0.05$) was employed. If the p-value exceeds 0.05, it indicates that there is no statistically significant difference among the groups for the various durations of corona treatment. Conversely, a p-value below 0.05 suggests that the differences observed are statistically significant.

According to the ANOVA results, the incorporation of hemp fiber reinforcement in the epoxy matrix composite yields statistically significant differences in

Table 2: The ANOVA Results, Indicating the Statistical Decisions Based on the Corresponding p-Values

Source of Variation	SS	df	MS	F	P-value	F crit
Tensile strength (MPa)						
Between Groups	646.46429	4	161.6161	2032.907	1.67×10^{-14}	3.47805
Within Groups	0.795	10	0.0795			
Total	647.25929	14				
Are the different?					Yes	
Elastic Modulus (MPa)						
Between Groups	205.36449	4	51.34112	2473.079	6.29×10^{-15}	3.47805
Within Groups	0.2076	10	0.02076			
Total	205.57209	14				
Are the different?					Yes	

both tensile strength and elastic modulus, as shown in Table **2**. This implies that the null hypothesis, stating that the group means are equal, can be rejected with 95% confidence. These findings are further supported by the data presented in Table **1**.

3.4. Surface Failure Analysis

SEM was utilized to examine the fracture surfaces of the composite samples, providing insights into the effects of corona treatment on fiber-matrix adhesion. Figure **7** presents the fracture morphology of composites subjected to different treatment durations. As depicted in Figure **7a**, the untreated hemp composite exhibits clear evidence of resin matrix failure, delamination, and fiber pull-out. The occurrence of delamination is likely attributed to the inherent differences in the hydrophilic properties of the epoxy resin and natural fibers [45].

Delamination is a predominant failure mechanism in untreated natural fiber composites, primarily resulting from the inherent polarity mismatch between hydrophilic natural fibers and hydrophobic epoxy resin. Hemp fibers, which contain hydroxyl groups, readily absorb moisture, while epoxy resins resist water uptake. This incompatibility leads to poor interfacial adhesion, generating interfacial tension and microvoids during curing and under mechanical stress. These microstructural defects act as initiation points for cracks, promoting the onset and propagation of delamination. Studies by Çoban *et al*. [46] and Palumbo and De Finis [47] confirm that delamination often originates at the fiber–matrix interface and spreads along the laminate layers, significantly reducing the composite's load-bearing capacity and structural integrity. Furthermore, the presence of voids and interfacial gaps between the fibers and matrix indicates inadequate bonding, which contributes to failure through debonding and matrix tensile fracture. The weak interfacial interaction observed in untreated composites is largely attributed to the hydrophilic nature of natural fibers and the hydrophobic characteristics of epoxy resin, which collectively hinder the development of strong interfacial adhesion. Addressing this mismatch is therefore critical to improving the mechanical performance and durability of natural fiber-reinforced epoxy composites.

In contrast, composites reinforced with surface-treated fibers by corona discharge exhibit markedly improved fracture morphology. These treatments enhance the fiber–matrix interface, resulting in reduced fiber pull-out and more cohesive failure patterns, both of which are indicative of stronger interfacial bonding. SEM analyses reveal fewer interfacial voids and improved resin wetting, facilitating more efficient load transfer and delaying the initiation and propagation of cracks. These enhancements are primarily attributed to the increased surface roughness and the incorporation of functional groups that improve chemical compatibility between the natural fibers and the epoxy matrix [48].

The mechanical properties of hemp woven composites are highly dependent on the duration of corona treatment, particularly concerning the adhesion between fibers and the epoxy resin matrix. As the treatment duration increases, the presence of voids between the hemp fibers and the matrix progressively decreases, indicating improved interfacial bonding. This reduction in voids is a critical factor in enhancing the mechanical performance of the composites, as voids serve as stress concentrators that can compromise structural integrity. The observed decrease in void content suggests that corona treatment effectively modifies the fiber surface, facilitating stronger adhesion at the fiber-matrix interface [49]. At a treatment duration of 3 minutes, the fractured surface of the hemp composite exhibits a rough texture with minimal voids, as illustrated in Figure **7d**. This surface roughness signifies enhanced fiber-matrix bonding, which is attributed to the formation of micro-pits and cavities on the fiber surface due to corona treatment. These surface modifications increase the available bonding area, thereby promoting mechanical interlocking between the fibers and the epoxy resin matrix. The improved interfacial adhesion is reflected in the increased tensile strength and elastic modulus of the treated composites [50]. The enhancements in mechanical properties observed at a 3-minute treatment duration underscore the necessity of optimizing the corona treatment process. While shorter treatment durations may be insufficient to achieve the required surface modifications, excessively prolonged treatments can lead to fiber degradation, ultimately reducing the mechanical performance of the composite. Thus, a balanced approach is essential to achieve the desired surface modifications without compromising fiber integrity. Research suggests that a treatment duration of approximately 3 minutes provides the optimal balance between surface roughness and fiber stability, ensuring enhanced mechanical properties [51].

SEM analysis of the fracture surface confirms that corona treatment significantly enhances the interfacial

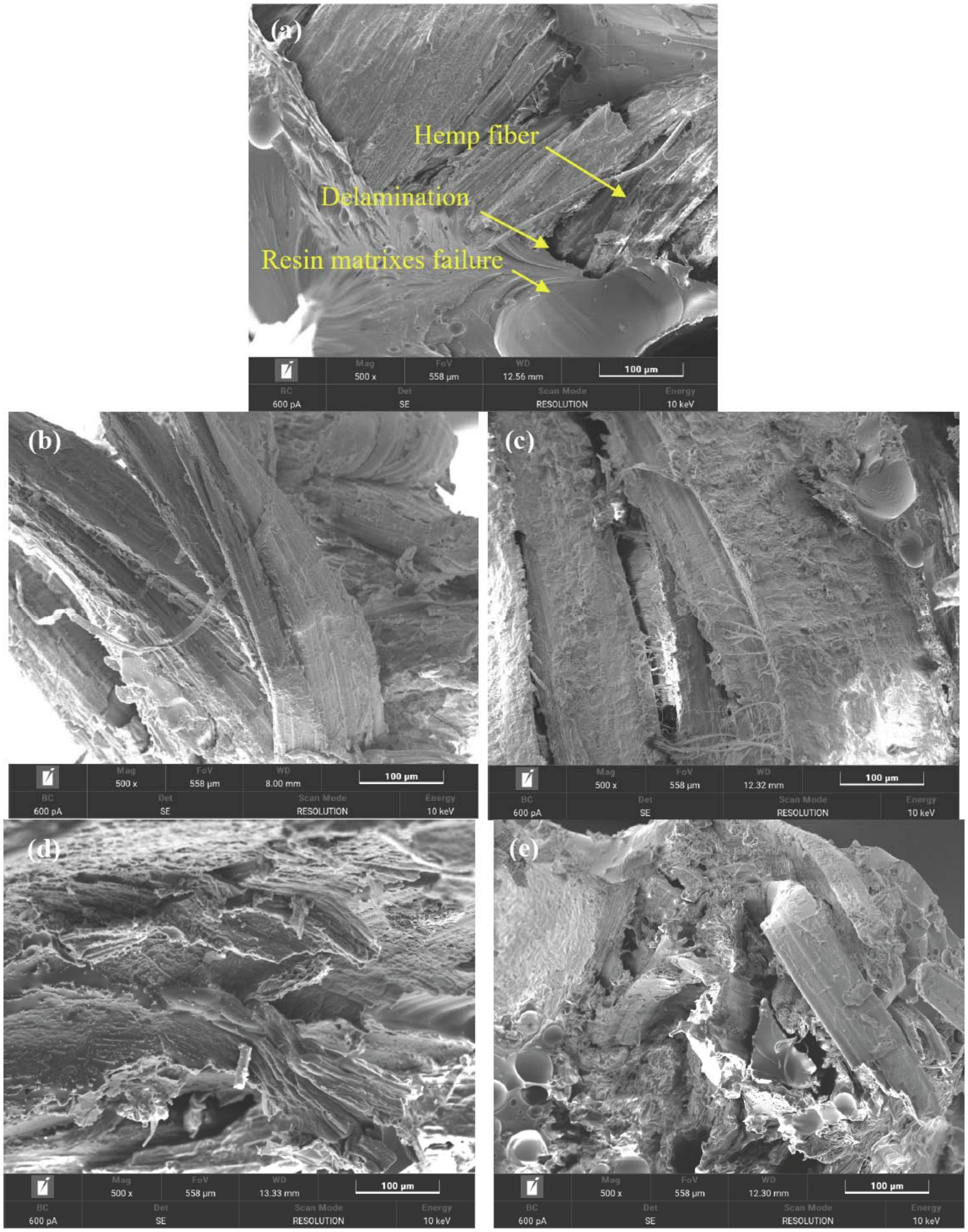

Figure 7: SEM of the fracture surface of composites at different corona treatment durations: (**a**) untreated (0-min) hemp; (**b**) hemp treated for 1 min; (**c**) 2 min; (**d**) 3 min; and (**e**) 4 min.

adhesion between the hemp fiber and the epoxy resin matrix.

4. CONCLUSIONS

Corona treatment was applied to enhance the adhesion between hemp woven fibers and epoxy resin in composite panels. The composites, fabricated via cold pressing using equal parts hemp fiber and resin, underwent corona treatment for 0 to 4 minutes. SEM and tensile testing revealed improved interfacial bonding and mechanical properties with increased treatment duration. Tensile strength peaked at 48.68 MPa after 3 minutes, before slightly decreasing at 4 minutes, while the elastic modulus remained relatively stable. SEM analysis confirmed reduced voids and improved fiber–matrix adhesion. Overall, corona treatment led to a 55% increase in tensile strength compared to untreated composites, demonstrating its effectiveness in enhancing composite performance. Corona-treated hemp woven fibers serve as value-added reinforcements in composites, providing a renewable and eco-friendly alternative material.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the author(s).

REFERENCES

[1] Yu Z, Li R, Peng Z, Tang Y. Carbon Fiber Reinforced Epoxy Resin Matrix Composites. Materials Science: Advanced Composite Materials 2017; 1: 1-6.

[2] Chowdary MS, Raghavendra G, Ojha S, Kumar MSRN. Morphology and Mechanical Properties of Epoxy/Natural Fiber Composites. Handbook of Epoxy/Fiber Composites 2022; 745-766. https://doi.org/10.1007/978-981-19-3603-6_27

[3] Al Mahmud MZ, Rabbi SMF, Islam MD, Hossain N. Synthesis and applications of natural fiber-reinforced epoxy composites: A comprehensive review. SPE Polymers 2024. https://doi.org/10.1002/PLS2.10161

[4] Raju A, Shanmugaraja M. Recent researches in fiber reinforced composite materials: A review. Mater Today Proc 2021; 46: 9291-9296. https://doi.org/10.1016/J.MATPR.2020.02.141

[5] Fairclough PA, Silva T, Golpour A, Patel RV, Yadav A, Winczek J. Physical, Mechanical, and Thermal Properties of Natural Fiber-Reinforced Epoxy Composites for Construction and Automotive Applications. Applied Sciences 2023; 13: 5126. https://doi.org/10.3390/APP13085126

[6] Parbin S, Waghmare NK, Singh SK, Khan S. Mechanical properties of natural fiber reinforced epoxy composites: A review. Procedia Comput Sci 2019; 152: 375-379. https://doi.org/10.1016/J.PROCS.2019.05.003

[7] Jarupong J, Artnaseaw A, Sasrimuang S. Cocoon waste reinforced in epoxy matrix composite: Investigation on tensile properties and surface morphology. Engineering and Applied Science Research 2023; 50: 597-604. https://doi.org/10.14456/EASR.2023.61

[8] Jarupong J, Sasrimuang S, Artnaseaw A. Characteristics of bulletproof plate made from silkworm cocoon waste: Hybrid silkworm cocoon waste-reinforced epoxy/UHMWPE composite. Science and Engineering of Composite Materials 2024; 31. https://doi.org/10.1515/SECM-2024-0006/MACHINEREADABLECITATION/RIS

[9] Khan FM, Shah AH, Wang S, Mehmood S, Wang J, Liu W, Xu X. A Comprehensive Review on Epoxy Biocomposites Based on Natural Fibers and Bio-fillers: Challenges, Recent Developments and Applications. Advanced Fiber Materials 2022; 4(4): 683-704. https://doi.org/10.1007/S42765-022-00143-W

[10] Tasgin Y, Demircan G, Kandemir S, Acikgoz A. Mechanical, wear and thermal properties of natural fiber-reinforced epoxy composite: cotton, sisal, coir and wool fibers. J Mater Sci 2024; 59: 10844-10857. https://doi.org/10.1007/S10853-024-09810-2/FIGURES/8

[11] Loidueanchai S, Seithtanabutara V, Artnaseaw A. Sustainable ballistic solutions for recycling silkworm cocoon waste into high-performance bulletproof materials. Green Chem Lett Rev 2024; 17. https://doi.org/10.1080/17518253.2024.2385929

[12] Jarupong J, Artnaseaw A. Facile armour production from cocoon waste by a cold-pressing process 2024. https://doi.org/10.1680/JGRMA.24.00013

[13] Bayliss N, Schmidt BVKJ. Hydrophilic polymers: Current trends and visions for the future. Prog Polym Sci 2023; 147. https://doi.org/10.1016/J.PROGPOLYMSCI.2023.101753

[14] Palanisamy A, Salim NV, Parameswaranpillai J, Hameed N. Water Sorption and Solvent Sorption of Epoxy/Block-Copolymer and Epoxy/Thermoplastic Blends. Handbook of Epoxy Blends 2017; 1097-1111. https://doi.org/10.1007/978-3-319-40043-3_40

[15] Nakamura S, Tsuji Y, Yoshizawa K. Role of Hydrogen-Bonding and OH−π Interactions in the Adhesion of Epoxy Resin on Hydrophilic Surfaces 2020. https://doi.org/10.1021/acsomega.0c03798

[16] Ibe KA, Otanocha B.O. Composites of hydrophilic and hydrophobic polymers as wicking agents. European Journal of Engineering and Technology 2017; 5. www.idpublications.org (accessed March 11, 2025).

[17] Gholampour A, Ozbakkaloglu T. A review of natural fiber composites: properties, modification and processing techniques, characterization, applications. J Mater Sci 2020; 55: 829-892. https://doi.org/10.1007/S10853-019-03990-Y/TABLES/23

[18] Alsuwait RB, Souiyah M, Momohjimoh I, Ganiyu SA, Bakare AO. Recent Development in the Processing, Properties, and Applications of Epoxy-Based Natural Fiber Polymer Biocomposites. Polymers 2023; 15: 145. https://doi.org/10.3390/POLYM15010145

[19] Kabir MM, Wang H, Lau KT, Cardona F. Chemical treatments on plant-based natural fibre reinforced polymer composites: An overview, Compos B Eng 2012; 43: 2883-2892. https://doi.org/10.1016/J.COMPOSITESB.2012.04.053

[20] Bledzki AK, Gassan J. Composites reinforced with cellulose based fibres. Prog Polym Sci 1999; 24: 221-274. https://doi.org/10.1016/S0079-6700(98)00018-5

[21] George J, Sreekala MS, Thomas S. A review on interface modification and characterization of natural fiber reinforced plastic composites. Polym Eng Sci 2001; 41: 1471-1485. https://doi.org/10.1002/PEN.10846

[22] Yang Y, Wang Z, Wang Y, Zhang J, Peng X, Fang P. EIS study on corona discharge degradation of epoxy resin: microstructure evaluation and water diffusion. Journal of Materials Science: Materials in Electronics 2024; 35: 1-15. https://doi.org/10.1007/S10854-023-11755-2/FIGURES/11

[23] Kalia S, Kaith BS, Kaur I. Pretreatments of natural fibers and their application as reinforcing material in polymer composites—A review. Polym Eng Sci 2009; 49: 1253-1272. https://doi.org/10.1002/PEN.21328

[24] Tserki V, Zafeiropoulos NE, Simon F, Panayiotou C. A study of the effect of acetylation and propionylation surface treatments on natural fibres. Compos Part A Appl Sci Manuf 2005; 36: 1110-1118. https://doi.org/10.1016/J.COMPOSITESA.2005.01.004

[25] Faruk O, Bledzki AK, Fink HP, Sain M. Biocomposites reinforced with natural fibers: 2000-2010. Prog Polym Sci 2012; 37: 1552-1596. https://doi.org/10.1016/J.PROGPOLYMSCI.2012.04.003

[26] Deshmukh GS. Advancement in hemp fibre polymer composites: A comprehensive review. Journal of Polymer Engineering 2022; 42: 575-598. https://doi.org/10.1515/POLYENG-2022-0033/ASSET/GRAPHIC/J_POLYENG-2022-0033_FIG_002.JPG

[27] Xiang C, Hu S, Zhang S, Gupta N. Compressive Characterization of Hemp Fiber-Epoxy Matrix Composite for Lightweight Structures JOM 2020; 72: 2324-2331. https://doi.org/10.1007/S11837-020-04024-8/FIGURES/8

[28] Pickering KL, Efendy MGA, Le TM. A review of recent developments in natural fibre composites and their mechanical performance. Compos Part A Appl Sci Manuf 2016; 83: 98-112. https://doi.org/10.1016/J.COMPOSITESA.2015.08.038

[29] Sood M, Dwivedi G. Effect of fiber treatment on flexural properties of natural fiber reinforced composites: A review. Egyptian Journal of Petroleum 2018; 27: 775-783. https://doi.org/10.1016/J.EJPE.2017.11.005

[30] Li X, Tabil LG, Panigrahi S. Chemical treatments of natural fiber for use in natural fiber-reinforced composites: A review, J Polym Environ 2007; 15: 25-33. https://doi.org/10.1007/S10924-006-0042-3/FIGURES/3

[31] Kiruthika AV, Khan A. Properties of Hemp Fibre Reinforced Polymer Composites 2021; 255-274. https://doi.org/10.1007/978-981-16-1854-3_11

[32] La Mantia FP, Morreale M. Green composites: A brief review. Compos Part A Appl Sci Manuf 2011; 42: 579-588. https://doi.org/10.1016/J.COMPOSITESA.2011.01.017

[33] Mohanty AK, Misra M, Drzal LT. Natural Fibers, Biopolymers, and Biocomposites, 1st ed., CRC Press, 2005. https://doi.org/10.1201/9780203508206

[34] ASTM D638-14, Standard Test Method for Tensile Properties of Plastics, ASTM International, West Conshohocken, PA, United States, 2014. https://doi.org/10.1520/D0638-14

[35] Popelka A, Khanam PN, Almaadeed MA. Surface modification of polyethylene/graphene composite using corona discharge. J Phys D Appl Phys 2018; 51: 105302. https://doi.org/10.1088/1361-6463/AAA9D6

[36] Sun D, Stylios GK. Fabric surface properties affected by low temperature plasma treatment. J Mater Process Technol 2006; 173: 172-177. https://doi.org/10.1016/J.JMATPROTEC.2005.11.022

[37] Wang CX, Qiu YP. Two sided modification of wool fabrics by atmospheric pressure plasma jet: Influence of processing parameters on plasma penetration. Surf Coat Technol 2007; 201: 6273-6277. https://doi.org/10.1016/J.SURFCOAT.2006.11.028

[38] Zheng Z, Tang X, Shi M, Zhou G. A study of the influence of controlled corona treatment on UHMWPE fibres in reinforced vinylester composites. Polym Int 2003; 52: 1833-1838. https://doi.org/10.1002/PI.1372

[39] Ovaska SS, Geydt P, Rinkunas R, Lozovski T, Maldzius R, Sidaravicius J, Österberg M, Johansson LS, Backfolk K. Corona treatment of filled dual-polymer dispersion coatings: Surface properties and grease resistance. Polymers and Polymer Composites 2017; 25: 257-266. https://doi.org/10.1177/096739111702500402;WEBSITE:WEBSITE:SAGE;WGROUP:STRING:PUBLICATION

[40] Mittal KL, Netravali AN. Polymer Surface Modification to Enhance Adhesion, John Wiley & Sons, Ltd, 2024. https://doi.org/10.1002/9781394231034.FMATTER

[41] Corbin A-C, Soulat D, Ferreira M, Labanieh A-R, Gabrion X, Malécot P, Placet V. Towards hemp fabrics for high-performance composites: Influence of weave pattern and features. Composites Part B 2019; 107582. https://doi.org/10.1016/j.compositesb.2019.107582

[42] Sadeghi P, Cao Q, Abouzeid R, Shayan M, Koo M, Wu Q. Experimental and Statistical Investigations for Tensile Properties of Hemp Fibers. Fibers 2024; 12: 94. https://doi.org/10.3390/FIB12110094

[43] Dhaliwal GS, Dueck SM, Newaz GM. Experimental and numerical characterization of mechanical properties of hemp fiber reinforced composites using multiscale analysis approach. SN Appl Sci 2019; 1: 1-15. https://doi.org/10.1007/S42452-019-1383-6/TABLES/8

[44] Corbin AC, Soulat D, Ferreira M, Labanieh AR. Influence of Process Parameters on Properties of Hemp Woven Reinforcements for Composite Applications: Mechanical Properties, Bias-extension Tests and Fabric Forming. Journal of Natural Fibers 2022; 19: 714-726. https://doi.org/10.1080/15440478.2020.1761925

[45] Natesan R, Krishnasamy P. Fiber and matrix-level damage detection and assessments for natural fiber composites. Journal of Materials Science 2024; 59: 16836-16861. https://doi.org/10.1007/S10853-024-10191-9

[46] Çoban O, Bora MÖ, Sinmazçelik T, Cürgül I, Günay V. Fracture morphology and deformation characteristics of repeatedly impacted thermoplastic matrix composites. Mater Des 2009; 30: 628-634. https://doi.org/10.1016/J.MATDES.2008.05.042

[47] Palumbo D, De Finis R. Fatigue and Fracture Behavior of Composite Materials. Materials 2023; 16: 7292. https://doi.org/10.3390/MA16237292

[48] Tamin MN. Damage and Fracture of Composite Materials and Structures, Springer Berlin Heidelberg, Berlin, Heidelberg 2012. https://doi.org/10.1007/978-3-642-23659-4

[49] Shivanand. Effect of Strain Rate on Fracture Toughness of Hemp Fiber Composites. International Journal of Engineering Research & Technology 2018; 3. https://doi.org/10.17577/IJERTCONV3IS19215

[50] Shahzad A. Effects of Fibre Surface Treatments on Mechanical Properties of Hemp Fibre Composites, Compos Interfaces 2011; 18: 737-754. https://doi.org/10.1163/156855412X629583

[51] Kousik Kumaar R, Boopathy G, Bovas Herbert Bejaxhin A, Ramanan N. Considerations on Fractured Edge Dislocations of Mechanical Tested Hand Laid Hemp Flax GFRP Hybrid Polymer Composites with SEM Verifications. Journal of Polymer and Composites 2024; 11: 1-19. https://doi.org/10.2/JQUERY.MIN.JS

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