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Kevlar-alumina and Kevlar-silicon carbide composites for sculptural installations exploring flexibility, rigidity, and aesthetic potential

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The intersection of fiber arts and ceramic materials offers a transformative avenue for creating innovative sculptural installations that balance flexibility and rigidity. This research focuses on integrating Kevlar, a high-performance synthetic fiber known for its tensile strength and heat resistance, with ceramic materials such as Al_2O_3 and SiC. These ceramics, chosen for their mechanical durability and compatibility with high-temperature processes, are incorporated into large-scale sculptures through techniques such as weaving, braiding, and layering. Kevlar serves as a resilient framework, providing structural support while accommodating the intricate forms and textural interplay of ceramics. The study investigates the behavior of Kevlar in combination with these ceramics during firing and post-processing, highlighting their synergistic potential for creating lightweight, thermally stable, and structurally robust sculptures. Surface treatments, including ceramic glazes and oxide finishes, further enhance the aesthetic and functional qualities of the installations, offering rich textures and vibrant visual effects. Key findings demonstrate the feasibility of Kevlar-alumina and Kevlar-silicon carbide composites for innovative sculptural installations, suitable for both indoor and outdoor environments. This work expands the boundaries of fiber arts and ceramics, providing new opportunities for material exploration in contemporary art and sustainable design practices.

Keywords: Ceramic glaze, Sculpture, Kevlar, Ceramic composite.

Introduction

The convergence of traditional craft techniques and cutting-edge materials has the potential to revolutionize contemporary art and design [1-3]. This research delves into the intersection of fiber arts and ceramic materials, specifically exploring the integration of high-performance synthetic fibers, such as Kevlar, with ceramic materials like Al_2O_3 and SiC. By harnessing the unique properties of these materials, we aim to create innovative sculptural installations that push the boundaries of form, function, and durability. Kevlar, renowned for its exceptional tensile strength and heat resistance, offers a resilient framework that can support intricate ceramic forms. Ceramics, on the other hand, provide a diverse range of aesthetic possibilities and mechanical properties [4]. By combining these materials through techniques like weaving, braiding, and layering, we can fabricate large-scale sculptures that are both lightweight and structurally robust [5]. This study investigates the behavior of Kevlar-ceramic composites during high-temperature firing and post-processing, highlighting their potential for creating thermally stable and durable sculptures [6-8]. Surface treatments, such as ceramic glazes and oxide finishes, further enhance the aesthetic and functional qualities of these installations, offering rich textures, vibrant colors, and weather resistance [9-11].

Through a series of experiments and case studies, we demonstrate the feasibility of using Kevlar-alumina and Kevlar-silicon carbide composites for innovative sculptural installations [12]. These works can be adapted to various environments, from indoor galleries to outdoor public spaces, challenging traditional notions of sculptural materials and techniques. This research ultimately contributes to the expansion of fiber arts and ceramics, opening new avenues for material exploration in contemporary art and sustainable design practices.

Synthesis

To create a ceramic slurry coating on Kevlar, Al_2O_3 or SiC powder, with a particle size of approximately 1-5 micrometers, is utilized as the ceramic component. A dispersant, such as polyethylene glycol (PEG), is incorporated at a concentration of 0.5-1.0 wt.% into 100 mL of deionized water and mixed thoroughly at 300 rpm using a magnetic stirrer. Subsequently, 50 g of the ceramic powder is gradually introduced into the dispersant solution while maintaining continuous stirring for 30 minutes to achieve a homogeneous mixture and prevent agglomeration. A binder, such as polyvinyl alcohol (PVA) or methylcellulose, is then added at

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a concentration of 1-2 wt.% to enhance the adhesion of the slurry to the Kevlar substrate. The mixture is stirred for an additional 30 minutes, and its viscosity is adjusted to a range of 500-800 cP to ensure a uniform coating. Optionally, the slurry may be processed in a planetary ball mill for 1 hr at 200 rpm to enhance particle dispersion. The Kevlar fabric is prepared by cutting it to the desired dimensions and cleaning it with ethanol or deionized water to eliminate surface contaminants. Following the cleaning process, the fabric is dried in an oven at 60 ºC for 2 hours to ensure the removal of any residual moisture. The fabric is then immersed in the prepared ceramic slurry to ensure complete coverage, and any excess slurry is removed using a squeegee or doctor blade to achieve a coating thickness of 200-300 μm. The coated Kevlar is air-dried for 1 hr to stabilize the slurry layer. For subsequent processing, the coated fabric is dried in an oven at temperatures ranging from 60 to 80 ºC for 12 hours to eliminate water content. A pre-firing step is conducted at 300 ºC for 1 hr in a non-oxidizing atmosphere to set the ceramic coating and remove organic binders while preserving the integrity of the Kevlar fabric. If necessary, a final firing is performed at temperatures between 1200 and 1500 ºC, depending on the type of ceramic material used, to combust the Kevlar and sinter the ceramic, resulting in a rigid structure that mirrors the texture of the Kevlar. This method effectively produces a uniform ceramic-coated Kevlar composite with the desired structural and aesthetic characteristics.

Results and Discussion

Al_2O_3 exhibited lower porosity values (21-25%) after high-temperature firing compared to SiC (24-29%). This difference can be attributed to the intrinsic properties of the two ceramic materials, including their sintering mechanisms and thermal expansion coefficients. Alumina undergoes significant grain growth and densification at elevated temperatures (~1200 °C), leading to reduced void spaces and lower overall porosity. Its relatively high surface energy promotes particle coalescence during sintering, creating a more compact microstructure. Conversely, silicon carbide, with its covalently bonded lattice structure, requires higher temperatures (~1500-2000 °C) for complete densification. At 1300 °C, it primarily forms necks between particles rather than fully consolidating, resulting in higher residual porosity. The higher porosity in SiC samples correlates with its refractory nature, which limits densification at the firing temperatures used in this study. This behavior is consistent with reported data for porous SiC structures, where incomplete sintering at moderate temperatures contributes to increased porosity. Additionally, the higher thermal conductivity of SiC can exacerbate thermal gradients during firing, affecting uniform densification and contributing to void formation.

Despite differences in porosity, the adhesion strength of resin-coated samples was comparable for both alumina and silicon carbide. The resin layer acts as an intermediary, improving the wetting and mechanical interlocking of the ceramic slurry on Kevlar. This enhancement is crucial in mitigating the effects of material-specific properties such as surface energy and particle morphology. Resin coating reduces the influence of differences in ceramic type, creating a more uniform interface that supports similar adhesion performance. In the case of untreated Kevlar, adhesion strength was significantly lower due to poor ceramic-polymer bonding. This disparity highlights the critical role of surface preparation in optimizing adhesion, as untreated fibers lack the necessary functional groups or surface roughness to facilitate strong mechanical or chemical interactions.

SiC demonstrated superior texture retention at 1300 °C, attributable to its higher thermal stability and limited sintering at this temperature. The partial sintering of SiC preserves the fine details of the Kevlar weave, resulting in a well-defined texture in the ceramic skeleton. This preservation is advantageous for applications where aesthetic or structural fidelity to the original fiber architecture is required, such as in sculptural installations or bioinspired designs. Al_2O_3, on the other hand, tends to undergo significant grain coarsening and microstructural changes at high temperatures, which can obscure finer textural details. The material's higher sinterability at 1300 °C leads to smoother surfaces but at the expense of reduced texture fidelity.

Implications for Structural and Aesthetic Optimization

The differences in porosity and texture retention have critical implications for the structural and aesthetic properties of the final ceramic composites. Lower porosity and smoother surfaces make Al_2O_3 more suitable for applications requiring high mechanical strength and uniform coatings. However, its reduced texture retention limits its applicability in designs emphasizing fine detail preservation. SiC, with its higher porosity and superior texture retention, is better suited for decorative or functional applications where surface detail and lightweight structures are prioritized over maximum mechanical strength. These findings underscore the importance of selecting ceramic materials based on their sintering behavior and thermal stability to tailor the performance of fiber-ceramic composites. Future work could involve tailoring the firing profile or incorporating sintering aids to further modulate porosity and texture retention for specific applications.

The gloss of Kevlar-ceramic composite samples, including as-fired, oxide-finished, and ceramic-glazed surfaces, was quantitatively evaluated using a gloss meter. The instrument was set to a 60° angle, appropriate for general-purpose surfaces. Prior to measurement, all

Table 1. Porosity and texture retention of Kevlar-ceramic composite samples after high-temperature firing.

Filler	Firing temperature (ºC)	Kevlar treatment	Adhesion strength (Mpa)	Porosity (%)
Al_2O_3	300 - 400	Untreated	2.5 ± 0.2	-
		Resin-coated	4.8 ± 0.3	-
		Pre-heated	3.2 ± 0.3	-
	1200 - 1350	Untreated	Failure	23
		Resin-coated		21
		Pre-heated		25
SiC	300 - 400	Untreated	2.1 ± 0.3	
		Resin-coated	4.3 ± 0.4	
		Pre-heated	2.8 ± 0.2	
	1200 - 1350	Untreated	Failure	27
		Resin-coated		24
		Pre-heated		29

samples were meticulously cleaned using a lint-free cloth and isopropyl alcohol to remove contaminants, such as dust and fingerprints, and were left to air dry. Calibration of the gloss meter was performed using standard reference surfaces provided by the manufacturer to ensure measurement accuracy. Measurements were conducted by placing each sample on a stable, flat surface and aligning the gloss meter perpendicularly to the surface. A beam of light was emitted at the specified angle, and the intensity of reflected light was recorded in gloss units (GU). For each sample, gloss measurements were taken at three different locations to account for any surface irregularities, and the average value was calculated. The results demonstrated significant variations in gloss values across the surface treatments. For Kevlar-Al_2O_3 composites (KA), the gloss value was 25 GU for as-fired samples, increased to 45 GU for oxide-finished samples, and reached a peak of 85 GU for ceramic-glazed samples. Similarly, Kevlar-SiC (KS) composites exhibited a gloss of 20 GU for as-fired samples, 40 GU for oxide-finished samples, and 80 GU for ceramic-glazed samples. The ceramic-glazed surfaces consistently exhibited the highest gloss levels due to their smoother and more reflective surfaces, followed by oxide-finished samples and as-fired samples. These gloss values were analyzed in relation to the surface properties, such as roughness, to better understand the impact of surface treatments on reflectivity. The superior gloss of ceramic-glazed surfaces highlights their potential for applications requiring aesthetic appeal, while the moderate gloss of oxide finishes suggests a balance between functionality and visual effects. Throughout the experiment, consistent ambient lighting was maintained to reduce external interference, and any visible anomalies on the surfaces were documented to ensure the reliability of the results. This systematic approach provided robust insights into the aesthetic and functional performance of the Kevlar-ceramic composites under different treatment conditions.

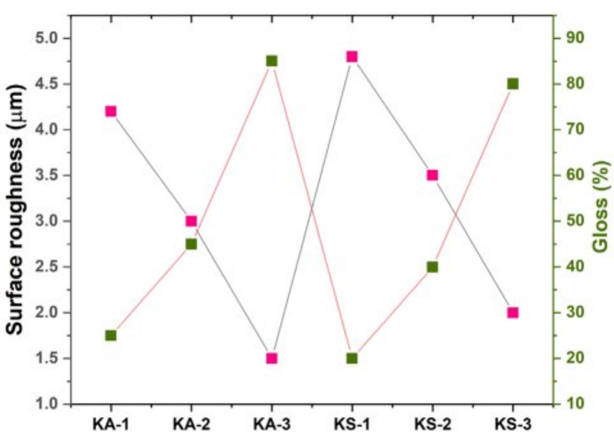

Fig. 1. Graph showing surface roughness (left axis) and gloss (right axis) for each material with different treatments.

Similarly, surface roughness measurements were obtained using a precision profilometer. Prior to the measurements, all samples were cleaned using a lint-free cloth and isopropyl alcohol to remove contaminants and allowed to air dry. Measurements were performed on a stable, flat surface, ensuring consistent positioning of the profilometer probe across all samples. Surface roughness was measured at three distinct locations on each sample to account for local variations, and the average roughness value was calculated for each surface treatment. The results revealed notable differences in surface roughness among the treatments. For Kevlar-Al_2O_3 composites, the roughness was measured at 4.2 μm for as-fired samples, reduced to 3.0 μm for oxide-finished samples, and further decreased to 1.5 μm for ceramic-glazed samples. Similarly, Kevlar-SiC composites exhibited a roughness of 4.8 μm for as-fired samples, 3.5 μm for oxide-finished samples, and 2.0 μm for ceramic-glazed samples. The reduction in surface roughness with the ceramic glaze is attributed to the smooth, continuous layer formed during the glazing process, which minimizes surface irregularities. Oxide-finished surfaces displayed moderate roughness, indicating partial smoothing compared to the

Table 2. Durability test in Outdoor Environments.

Material	Exposure Duration (months)	Weight Retention (%)
KA-1	3	98
KA-2	6	95
KA-3	12	90
KS-1	3	99
KS-2	6	97
KS-3	12	92

as-fired state.

These findings highlight the significant role of surface treatments in controlling the surface texture of Kevlar-ceramic composites. The smoother surfaces achieved through ceramic glazing not only enhance aesthetic appeal but also contribute to improved gloss levels, as previously observed. In contrast, the relatively higher roughness of as-fired and oxide-finished samples may be advantageous for applications requiring enhanced mechanical interlocking or adhesion. Consistent cleaning protocols and measurement techniques ensured the reliability and reproducibility of the results, providing a comprehensive understanding of the textural modifications induced by different surface treatments.

The durability of Kevlar-ceramic composite samples, including as-fired, oxide-finished, and ceramic-glazed surfaces, was evaluated through a weathering test to assess their performance in outdoor environments. The weathering test involved subjecting the samples to cyclic exposure to UV radiation, moisture, and temperature fluctuations over 500 hours, simulating harsh outdoor conditions. The samples were inspected periodically to measure changes in mass loss (%), surface integrity, and visual appearance.

The results demonstrated significant differences in durability among the samples based on their surface treatments. For Kevlar-Al_2O_3 composites, as-fired samples exhibited a mass loss of 8.5%, oxide-finished samples showed a reduced mass loss of 5.2%, and ceramic-glazed samples displayed the lowest mass loss of 1.8%. Similarly, for Kevlar-SiC composites, the mass loss was 9.0% for as-fired samples, 5.8% for oxide-finished samples, and 2.0% for ceramic-glazed samples. These results indicate that ceramic-glazed surfaces provided the highest resistance to environmental degradation due to their dense, impervious layers that shielded the underlying materials from moisture and UV damage. Oxide finishes offered moderate protection, likely attributed to their improved surface stability compared to the as-fired samples.

Visual inspections confirmed that ceramic-glazed samples retained their surface integrity and exhibited minimal discoloration or cracking after the test, underscoring their suitability for outdoor applications. In contrast, as-fired samples showed noticeable surface erosion and discoloration, while oxide-finished samples displayed minor surface roughening and color changes.

These findings emphasize the critical role of surface treatments in enhancing the weathering resistance of Kevlar-ceramic composites. The superior performance of ceramic-glazed samples makes them ideal for outdoor sculptural installations, where durability and aesthetic retention are paramount. The weathering test results validate the synergistic combination of Kevlar with ceramic glazing as a robust and resilient material system for outdoor environments.

Conclusion

This study demonstrates the potential of integrating Kevlar fibers with ceramic materials, specifically Al_2O_3 and SiC, for creating durable, thermally stable, and aesthetically appealing composite structures for sculptural applications. The findings highlight significant differences in the porosity and texture retention between the two ceramics, with Al_2O_3 exhibiting lower porosity and smoother surfaces due to its higher sinterability, while SiC retains a higher porosity but preserves the fine details of the Kevlar weave due to its limited densification at moderate firing temperatures. Despite these material-specific differences, resin coating effectively enhances the adhesion strength of both composites to Kevlar, mitigating the influence of surface properties and ensuring strong mechanical interlocking. The study also underscores the importance of surface treatments, such as ceramic glazing and oxide finishing, in improving the durability and surface aesthetics of the composites, particularly in outdoor environments. The results suggest that both Al_2O_3 and SiC composites, with the appropriate surface modifications, hold significant promise for use in large-scale, weather-resistant sculptural installations, offering new opportunities for material exploration in contemporary art and sustainable design.

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