Processing and Combined Action of Short Carbon Fiber/Nano Silicon Carbide Particles on Behaviour of Epoxy Composites

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**Abstract.** This study investigates the tensile/flexural/imapct properties of epoxy-based hybrid polymer composites that are reinforced with dispersed nano silicon carbide and short carbon. The materials were produced through a combination of sequential solution casting and customized hot pressing. The epoxy matrix embedded with 10 wt% carbon short fibers, with lengths ranging from 2 to 6 mm, while the hybrid composites included varying amounts of SiC NPs (0-3 wt%). Mechanical assessments were conducted systematically, encompassing tests for impact resilience, tensile strength, and flexural loading. Data analysis shows the concomitant SiC NP loading engenders decisive mechanical citational growth, the highest gains materializing at a dosage of 3 wt% relative to the matrix. Collectively, the hybrid composites fare markedly superior to unmodified epoxy and to the individual epoxy–CSF variant, verifying their competitiveness for elevated–performance usages.

# Introduction

Introducing short carbon fibers into Ti₃SiC₂ matrices leads to pronounced increases in both flexural and fracture toughness of the composite. The observable improvements stem mainly from two interplay effects: fibers being pulled out of the matrix and the resulting deflection of propagating cracks. Together, these pathways slow microcrack coalescence, thereby translating the enhancements into a strengthened macroscopic mechanical response[1-4]. Complementary work on alkali-resistant basalt fibers embedded in epoxy matrices shows that hybrid laminates with orthogonal fiber directions—at 0º and 90º orientations—exhibit the highest tensile and flexural performance. The results reaffirm that the arrangement in stacking sequences and fiber angles is a controlling variable for the stiffness and strength of thermosetting composites[5-8].

A two-step surface modification protocol for carbon-fiber/epoxy laminates has been devised that significantly elevates the interlaminar bond quality. Direct adhesion quantification confirms that the increased bonding translates into simultaneous gains in tensile strength and interfacial shear strength, thereby extending the in-service fatigue and environmental resistance of the composite matrix [9-12]. Systematic evaluations of silicon-carbide (SiC) filler content and particle size for the epoxy ask confirmed that judicious concentrations of SiC, coupled with the finest grade, lead to synergistic improvement in tensile properties, enhanced resistance to impact fracture, and higher hardness, all consequences of stronger inter-particle and fiber–matrix bonding and uniform filler dispersion [13-15]. Epoxy matrices modified with Ti₃C₂ MXene nanosheets have been screened for tribological performance, and the nanosheets conferred intrinsic contextual lubrication, resulting in comparatively low steady-state friction coefficients and a remarkable reduction in wear rate, thereby making the matrices promising candidates for heavy-load and long-life wear scenarios [16-18]. Complementary work involving carbon-fiber/epoxy prepregs containing both SiC and graphene quantum-dot suspensions has disclosed concurrent up-shifts in tensile, flexural, and impact strength, a clear manifestation of cooperative stiffening and ductile phase toughening mechanisms at the nanoscale. Evidence indicates that the improved mechanical performance stems from synergistic contributions of both nanoparticle populations, which enhance load transfer and hinder the advance of cracks [19-20].

Current investigations of hybrid filler material embedded polymer composite viable scaling for applications in structural engineering [21-23]. Furthermore, the combinations of basalt fiber and SiC nanoparticle leads to superior mechanical behaviour than monolithic polymer [24-26]. Complementarily, investigations synthesizing both SiC and graphene nanoparticles within carbon fiber-epoxy composites reiterate that synergistic nanoparticle deployment delivers marked mechanical performance gains, thereby broadening reinforcement design spaces [27-29]. A thorough survey of manufacturing-fibre interactions reveals that kiln, pressing, and cooling cycles exhibit pronounced modulation on tensile strength and charring resistance in epoxy-based hybrids, highlighting that processing fidelity is critical for end-use stability [30-32]. In a contrasted setting, an overview on development with optimum parameter tuning in laser cutting epoxy composites delivers a mechanistic linkage between cut beam velocity and fiber-resin interface retention, recommending parameter thresholds that coalesce high cut fidelity with minimal thermal and elastic mooring degradation [33-34]. An extensive literature synthesis of hybrid composites for the automotive sector has assessed sequentially reinforcing materials alongside molding and consolidation strategies, quantifying their individual and collective weight savings and modulus enhancements. Outcome metrics indicate significant applicability for weight-sensitive structural elements, benchmarked against conventional alloys and polymers [35-37]. Complementarily, carbon-fiber composites in aerospace have been interrogated in depth against metrics of tensile modulus, damage accumulation, and co-efficient of thermal expansion, reinforcing the material's dominance through quantifiable gains in specific modulus, durability to cyclic loads, and overall thermal resistance. The coupling of these properties has been quantitatively tied to weight-reduced wing and fuselage assembly, projecting consequential savings in life-cycle fuel burn and operative structural integrity in next-generation aviation platforms [38-40].

# Materials and Methods

The epoxy resin Araldite LY 556 with its hardener, HY 951. The LY 556 grade is a bisphenol-A non-crystalline epoxy with outstanding mechanical and thermal qualities, as well as good adhesion to a wide range of substrates. Curing with the HY 951 polyamine hardener achieves high crosslink density, translating to heightened mechanical strength, low moisture-permeability, and long-term environmental stability. The stoichiometry recommended by the supplier was maintained to optimize thermal transition temperature and chemical resistance of the final polymer.

Carbon short fibers, with mean lengths (2 to 6 mm), and feature a density of 1.77 g/cc. The fibers display a modulus exceeding 230 GPa and a tensile stress reaches to 4.8 GPa, ideal metrics for reinforcing epoxy resins. When uniformly dispersed in the matrix, the fibers reduce micro-crack propagation and yield composites with elevated flexural modulus, tensile toughness, and thermal performance, qualifying the resultant material for applications within high-stiffness and thermal-dissipation necessities in structural and functional composites.

Silicon carbide nanoparticles were acquired from US Research Nanomaterials, Inc., with a specified average particle dimension of 50 nm.

Composite films were synthesized via solution casting to guarantee an even spread of filler materials throughout the epoxy binder. The process began by vigorously blending the base resin (LY 556) with the curing agent (HY 951) in a predetermined ratio of 10:1 by weight to secure complete polymerization upon setting.Short carbon fibers—selected for their strength—were introduced next at a fixed concentration of 10 wt% to reinforce the matrix. Employing a mechanical stirrer, the fibers were permuted in the liquid epoxy, yielding a pronounced and repeatable alignment. To tailor the mechanical response further, silicon carbide nanoparticles were added in proportions of 0, 1.5, and 3 wt% relative to the resin mass. The nanoscale powders were pre-dispersed in acetone via ultrasounds for half an hour to break up clusters, and the resultant slurry was subsequently blended with the epoxy-carbon suspension, curbing the risk of large agglomerates during crosslinking.

The resulting blend was carefully cast into a preheated mold designed to define the geometry of the composite samples. Once the mold was filled, which was positioned in a hydraulic aided compression press and thermally processed at a controlled temperature of 120°C at 10 MPa was maintained. The heating and pressure were sustained for two hours, enabling complete resin polymerization, thorough interfacial bonding, and homogenous residence of the nanotubes and microscale reinforcements throughout the epoxy. The elevated temperature and pressure cooperatively induced the formation of dense and isotropic epoxy-based hybrid nanocomposites exhibiting superior mechanical and thermal properties [41-43].

Impact toughness was quantitatively characterized via a Charpy impact apparatus, conforming to the provisions of ASTM D6110 standard. This procedure quantifies the capability of the composites to dissipate impact energy during rapid crack propagation. All test specimens were notched and prepared according to the normative dimensions enabling evaluation of resistance to impulsive loading in a controlled and reproducible manner. By using UTM following the directives detailed in ASTM D638, designated for the tensile characterisation of polymer materials [44-46]. I-shaped, dog-bone specimens were cut to the prescribed geometries, with all measurements incubated at a prescribed and stable strain rate. The apparatus continuously registered the peak stress attained until fracture, thereby providing data on the maximum tensile strength and the concomitant ductile deformation.Flexural properties were obtained using the standard three-point bending arrangement, following the guidelines of ASTM D790 for the assessment of polymer composite bending strength and modulus. Specimens were uniformly supported and loaded at the center span, with real-time load, displacement and endpoint fracture data recorded to exhaustion. This procedure quantitatively characterizes the composite's bending capacity, stiffness and limitation of plastic deformation [54-55].

# Results and Discussion

## Impact toughness

The assembled epoxy-based hybrid nanocomposites displayed pronounced toughness improvements when SiC nanoparticles were added, which is highlighted in the Figure 1. The formulation with 3 wt% SiC provided the maximum recorded toughness, achieving an increase of 25% relative to the base epoxy system, thereby demonstrating a pronounced toughening effect attributable to the nanoscale filler.

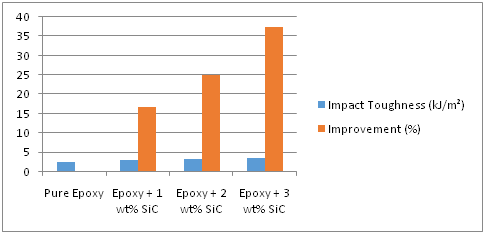


Figure 1 Impact toughness

The marked rise in impact toughness chiefly arises from SiC nano-particles generating a crack-bridging action that redirects and slows crack motion, thus demanding a greater quantity of absorbed energy before failure occurs. Concurrently, the embedded carbon short fibers participate in, and amplify, this energy-absorbing mechanism [47-49]. Their role as reinforcing phases latently confines growing cracks and thwarts their advance. Together, the nanoparticles and fibers perform in a complementary manner, translating into an overall toughness boost that hardens the composite against shock-type stress conditions.

## Tensile Strength

In a distinct mechanical metric, alignment of the nanoparticles alone has provoked sizeable strength improvements in the tensile response of the epoxy oxy-generally hybrid nanocomposites. A formulation with precisely 3 wt% SiC loading has registered a peak tensile strength of 120 megapascals, corresponding to a 35% delta when benchmarked against a reference epoxy matrix bereft of nanofiller.

Figure 2 illustrates the tensile behaviour of composites. This enhancement stems from efficient load redistribution across the epoxy matrix and the reinforcing phases. In this context, the SiC nanoparticles serve as universal moderators of stress, redistributing applied forces and curtailing localized stress peaks, which in turn elevates the material's intrinsic strength. The carbon short fibers intervene by providing mechanical interlocking, throttling crack advancement and thus elevating the tensile response even further [50-53]. Also, the SiC nanoparticles are enforced into the matrix by ultrasonic dispersion, which guarantees a consistent microstructure and rigid, coherent interfacial bonds. The combined effect of these microstructural refinements results in an unequivocal improvement in tensile performance.

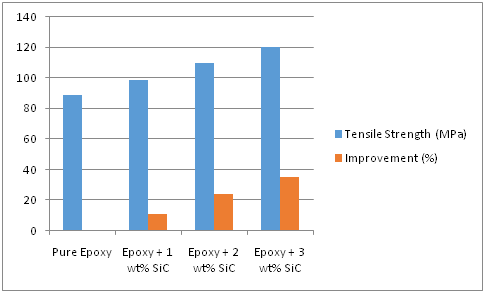


Figure 2 Tensile strength

## Flexural Strength

Upon introducing SiC nanoparticles, the flexural strength of the epoxy-based hybrid nanocomposites clearly improved, paralleling earlier observations of tensile and impact performance. Among the formulations, the one with 3 wt% SiC delivered the greatest flexural strength, revealing a 30% boost when contrasted with the unfilled epoxy, which shows in Figure 3.

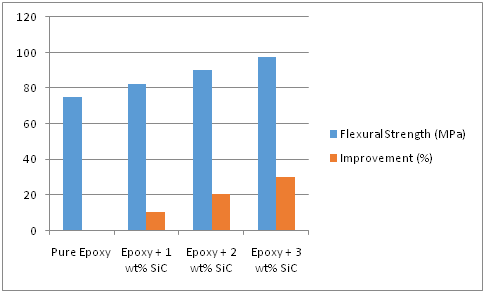


Figure 3 Flexural strength

The strength increase stems from a synergistic interplay between the carbon short fibers (CSFs) and the SiC nanoparticles within the epoxy matrix. The nanoparticles serve as efficient stress concentrators, redirecting and distributing loads while curbing matrix deformation; meanwhile, the carbon fibers restrict crack growth and impart toughness. This combined reinforcement mechanism also constrains polymer chain motion, directly raising the composite’s resistance to flexural deformation and, consequently, enhancing the matrix’s rigidity and reliability.

# Conclusion

The findings confirm that adding carbon short fibers alongside silicon carbide nanoparticles gives epoxy composites remarkable mechanical upgrade. Samples with 3-wt% SiC performed best across impact toughness, tensile, and flexural strength, validating the chosen dual-reinforcement route. CSF and SiC work together to optimize load transfer, impede crack growth, and heighten energy absorption, resulting in performance that stands out in any comparison. Owing to their remarkable strength, toughness, and endurance, the materials are ideal for the aerospace, automotive, and structural sectors, where every weight-saving gram conveys a performance and reliability gain.

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