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Investigation on Mechanical Properties of Kevlar Fiber and Al_2O_3 – SiC used Nano-polymer Composite

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ABSTRACT

Kevlar is a synthetic fiber that has become well-known all over the globe because of its many industrial uses. It functions well as a composite material and is mostly used in conjunction with other materials. This study discusses the fabrication of epoxy composites with different proportions of Al_2O_3 and SiC nanoparticles with Kevlar fiber. In this process, SiC, and Al_2O_3 nanoparticles were added to Kevlar fiber and fabricated the composite by a compressed moulding machine for shear, tensile and impact tests. From these test results, incorporating Al_2O_3 and SiC nanoparticles with Kevlar fiber under various compositions (1% to 4%) influences the composite mechanical behaviour such as strength. KBS 2 has the highest tensile strength of the four sample composites, measuring 5628 N/cm^2, among the Kevlar fiber reinforced polymer composites containing epoxy resin. This is the highest value among the composite samples. Additionally, it is worth seeing that the shear strength of the Kevlar fiber-reinforced polymer composite featuring the KAS 2 value of 7735 N/cm^2 has the highest value from the other composite including the KAS 1, KAS 3 and KAS 4. Moreover, the Kevlar fiber-reinforced polymer composite with KAS 2 (4.76 J) exhibits a larger impact strength than the composite with KAS 3 (3.42 J), KAS 1 (4.26 J, and KAS 4 (4.54 J). The findings indicate that Kevlar fiber reinforced with 3% Al_2O_3 and 2% SiC nanoparticles (KAS 2) exhibits superior strength and rigidity compared to the other nanoparticle combinations utilised in Kevlar fiber composites.

Keywords: Kevlar fiber; Aluminium oxide; Silicon Carbide; Shear test; Tensile; Impact.

1. INTRODUCTION

The analysis of the mechanical characteristics of polymer composites comprising Kevlar fiber and Al_2O_3-SiC involves a thorough investigation into the behaviour of these materials. The tensile strength and Young's modulus of the Kevlar fabric layered with binder inclusion have been improved by 26% and 5.7%, respectively (Chowdhury *et al.* 2021). The use of nanofillers improves the mechanical characteristics of Kevlar epoxy composites. Out of the samples that were inspected, the addition of 0.5% MWCNT resulted in the highest mechanical strength. By combining polymers with Kevlar fiber and Al_2O_3-MWCNT particles, this study aims to measure critical mechanical properties through various tests, including shear, tensile, and impact tests (Mourad *et al.* 2020).

The anti-ballistic value of composite laminates was not enhanced by the addition of TiC nanoparticles to Kevlar fibres. As a result, carbon fibers and Al-2024 composite laminates validate the most favourable mechanical characteristics and anti-ballistic efficacy, executing them the optimal material selection for ballistic applications (Kumaresan Gladys *et al.* 2022). The material undergoes deformation along a plane parallel to the forces applied in opposing directions. This test is significant for thoughtful the material resistance to shearing forces, essential for applications like cutting or sliding motions (Saleem *et al.* 2022).

According to measurements of the backface signature (BFS), more energy was absorbed by SiC+ UPE/EPX+Al-alloy than by SiC + KEV/EPX + Al-alloy. The ceramic layer displayed a higher energy absorption measurement compared to UPE/EPX and Al-alloy, achieving 80.5% of the total energy. Examining the kinetic and absorbed energy with Ansys Autodyn and explicit dynamic analysis. By analyzing shear behaviour, researchers can regulate how well the composite continues its structural integrity under shear stress, offering valuable data for design and application considerations. Evaluating shear behaviour delivers valuable insights into how fine the composite maintains its structural truthfulness under shear stress, informing design and application considerations (Shahabaz *et al.* 2023).

Tensile testing involves stretching a material until it reaches its breaking point, allowing researchers to measure its strength, elasticity, and ductility. Within the background of polymer composites, this test assesses the material's response to stretching forces, pretending scenarios such as pulling or stretching. The highest values of tensile strength (44.56 MPa), flexural strength (112.56 MPa), and impact strength (28.57 kJ/m^2) were achieved with 20 weight percent flax fibre and 8 weight percent SiC. The addition of SiC up to 8 wt% has a substantial impact on the mechanical characteristics of the composites (Sathish *et al.* 2020).

Aramid-carbon hybrid fibre reinforced polymer (FRP) laminates enhance composite armour systems made of ceramic and FRP laminates. The 7.62 M61 AP is simulated using a finite element model (FEM) against Al_2O_3/FRP coverings for the composite structure. Results show that a constant carbon fiber proportion improves ballistic performance and geometry integrity. Parameters such as ultimate tensile strength, yield strength, and Young's modulus provide insights into the material's ability to withstand stretching forces and overall stiffness, crucial for load-bearing applications (Wu *et al.* 2022). Impact testing evaluates a material's capacity to absorb energy and endure sudden forces, resembling real-world scenarios like collisions or impacts. Many times, silica particles and polyethylene glycol have been used to prepare Shear Thickening Fluid (STF). Besides this, hybrid Shear Thickening Fluid (STF) suspensions have been described in which ceria, SiC (silicone carbide), Al_2O_3 (aluminium oxide), CNT (carbon nanotube), GO (graphene oxide), $CaCO_3$ (calcium carbonate) cellulose beads, and ceria have been proposed as additives to enhance the shear-thickening characteristics (Islam *et al.* 2024).

For polymer composites, this test is essential for assessing resilience and toughness, particularly in environments with dynamic loading conditions. Alumina samples containing various compositions (A00, A40, A50, and A60) underwent mechanical testing that revealed the inclusion of ceramic reinforcement decreased the deformation and tensile strength. Resistance to impact fell as well. The shore D hardness of Alumina (A40, A50, and A60) increased significantly over pure Alumina (A00) (Cardoso *et al.* 2022).

The composite to controlled impacts and measuring parameters like impact strength and energy absorption, researchers can gauge its ability to withstand fracture and deformation under sudden loading, offering insights applicable across various industries, from automotive to sports equipment (Nieberle *et al.* 2021). The findings of this study establish that the addition of flax fiber and a 7 wt. % SiC filler importantly improves the mechanical characteristics of the composite. Based on our findings, we have determined that ceramics-filled composites may be used as alternative brake pad materials in place of asbestos and synthetic-based materials. Nanoparticles added with epoxy in the glass fiber composite examined the tensile and flexural strength. The experimental results specify that the composite containing four weight percent of Al_2O_3/SiC displays the most favourable tensile and flexural properties. The material has a notable ultimate tensile strength of 170.84 MPa and flexural strength of 162.56 MPa. This makes it very suitable for applications that frequently use epoxy-based composites, such as tennis and badminton rackets (Kumar *et al.* 2023). Examining the mechanical properties of polymer composites reinforced with Kevlar fiber and Al_2O_3-SiC particles ((1% to 4%) through shear, tensile, and impact tests provides a complete understanding of their performance under different loading conditions. Shear and tensile tests are to be done in the universal testing machine (UTM) and charpy impact test in the pendulum impact testing machine. Have to compare the samples prepared with the different percentages of nanoparticles reinforced composite. This study focuses on evaluating key mechanical properties through various tests, including shear, tensile, and impact tests.

2. MATERIALS AND METHODS

2.1 Materials

In commercial applications, Kevlar is the type of fiber used because it consists of strong, lightweight para-aramids linked to Technora and Nomex of other aramids. Cotton fibers, textiles and fabrics are typically used to make a significant composite material portion. To generate the yellow colour of Kevlar fiber, linear and lateral orientations of polymer chains combined to link the strong and weak electron system. If they are bent in a loop the fibers become internally twisted. In composite materials, these unique fiber characteristics are carried out. Kevlar fiber is bought from the Fiber region, valasaravakkam, Chennai.

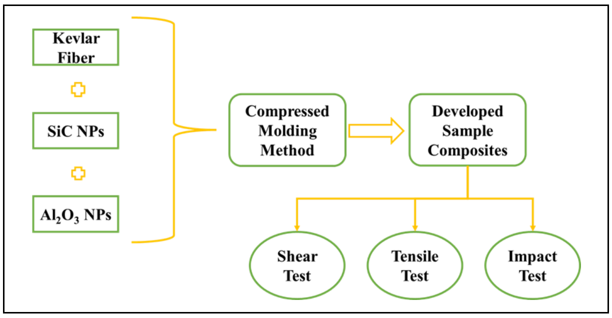

Fig. 1: Sample Composite Preparation and Testing Methods

Table 1. Mechanical Properties of SiC and Al_2O_3 Nanoparticles

Sl. No	Properties	Silicon Carbide (SiC)	Aluminium Oxide (Al_2O_3)
1	Density	3.35	3.96
2	Coefficient of thermal expansion	4.7	7.5
3	Thermal Strength (MPa)	598	418

Binding between the fiber layers, epoxy resin gives grew at bindings among them. LY 556 epoxy resin is used at room temperature with HY 951 hardener in the ratio of 10:1 matrix composition to obtain optimum impart strength and interfacial adhesion to the composite. The hardener will cure into a solid because the polyester resin is a liquid. Epoxy resin and hardener are bought from the fiber region, Valasaravakkam, Chennai. Sample composite preparation and testing methods are explained in Fig. 1.

2.2 Methods of fabrication

Using the resin transfer moulding technique for plastic casting, a liquid synthetic resin is poured into the mould; this hardening permits. Dentistry and industrial prototypes like small-scale production are mainly used. It is used in the production of toys with a little initial investment, as well as small-scale jewellery production. Plastic polyester is a monomer for making the process of synthetic resin. Table 2 shows the various combinations of nanoparticles to the Kevlar fiber to prepare a sample composite. Composite preparation based on the weight percentages. KAS 1 has a composition of 1% SiC, 4% Al_2O_3, 55% Epoxy, 40% Kevlar fiber, KAS 2 has a composition of 2% SiC, 3% Al_2O_3, 55% Epoxy, 40% Kevlar fiber, KAS 3 has a composition of 3% SiC, 2% Al_2O_3, 55% Epoxy, 40% Kevlar fiber, KAS 2 has a composition of 4% SiC, 1% Al_2O_3, 55% Epoxy, 40% Kevlar fiber.

Table 2. Sample Composite various samples

S. No.	Sample Composite	Composition
1	KAS 1	SiC (1%) + Al2O3 (4%) + Epoxy
2	KAS 2	SiC (2%) + Al2O3 (3%) + Epoxy
3	KAS 3	SiC (3%) + Al2O3 (2%) + Epoxy
4	KAS 4	SiC (4%) + Al2O3 (1%) + Epoxy

During the setting process, the liquid monomer polymerizes into the polymer and hardens into a solid.

- To make sure your mould stays there when casting, anchor it to a base.
- Carefully pour the reinforcement until the mould is filled (length 76.2 mm, width 12 mm, thickness 7.6 mm as per ASTM D5379 for shear test, length 165 mm, width 25 mm, thickness 7 mm as per ASTM D638 for tensile test, length 150 mm, width 12.7 mm, thickness 3.5 mm as per ASTM D790 for impact test).
- Use the mixing head to mix at the speed of 18rpm, the reinforcement into the resin until it is completely combined.
- Bring the resin to a minimum surrounding temperature of 16 ºC, and then, after accurately measuring the methyl ethyl ketone peroxide (MEKP) catalyst (1% to 2%), mix it in thoroughly.
- Carefully pour the catalysed resin mixture into the mould so that no air bubbles are introduced into the sample.
- Let the casting cure for about four hours at ambient temperature (25 °C).
- Attaching pure resin castings, using epoxy glue, requires caution since they are fragile.

Particles of mineral powder mixed with resin make the material opaque, but it is still possible to colour it and make it harder.

2.3 Experimental Setup

The universal testing machine (Fig. 2) is loaded at various angles in the holder. When conducting tests in the universal testing equipment maximum load rating should be 400kN. The butterfly specimen that has been placed in the fixture with one of the angles being 90 degrees has completed the shear test. Different compositions of sample composites are positioned at 90-degree angles in the universal testing machine to assess load and strain. To measure a stationary force in the tensile test in the ability of the material. Specific dimensions as per ASTM standards should be provided to test in the machine.

Fig. 2: Universal Testing Machine

The universal testing machine has a specification capacity is 2000kN and a maximum grip distance of 1100 mm for tensile tests and 90 mm, 50 mm/min for shear tests. The Arcan fixture is used for experimenting with the four samples to create a uniform plane stress state in a specimen test section. The pendulum impact testing machine has a specification of 21.68 J capacity at a releasing angle of 150 degrees. The Charpy impact test determines the material during fracture in the amount of energy absorbed. The energy absorbed by the material serves as a tool for quantifying and ductile-brittle transition for studying the temperature dependent. IS 1757 standard-based specimen is prepared for test material.

3. RESULTS AND DISCUSSION

3.1 Shear Test

The results of the shear tests are presented in Table 3. Fig. 3 illustrates a sample graph acquired from universal testing equipment. The graph represents a consistent and linear increase in the load value across the applied load 38 MPa at a loading rate of 500 mm/min, indicating that all four samples exhibited an elastic behaviour. KAS 1, KAS 2, KAS 3, and KAS 4 have 6847, 7735, 4681, and 3840 N/cm^2 of shear strength respectively. The highest shear strength is obtained by KAS 2 and the lowest shear strength is obtained by KAS 4.

Table 3. Shear test result based on the various compositions of nanoparticles

Sl. No	Sample Composite	Thickness (mm)	Shear Strength (N/cm^2)
1	KAS 1	5	6847
2	KAS 2	5	7735
3	KAS 3	5	4681
4	KAS 4	5	3840

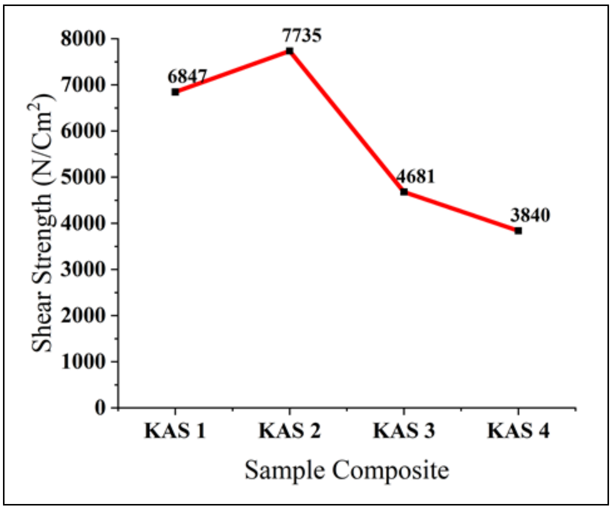

Fig. 3: Shear Strength vs Sample Composite

The increase of silicon dioxide concentration reduces the shear strength. Also, the higher concentration of the Al_2O_3 produced a higher strength than the lower Al_2O_3 concentration. Combination of these both nanoparticles higher concentration of Al_2O_3 and lesser concentration of silicon dioxide is required for the maximum shear strength. Compared to the fiber with 2% SIC and 3% Al_2O_3 nano particles KAS 1, KAS 3, and KAS 4 have 12%, 40%, and 51% of decrease. This is because of the various combinations of nanoparticles. The resin composite is superior to the epoxy resin composite when reinforced with Kevlar fibre-reinforced polymer. The graph illustrates that the curve follows a uniform trajectory, devoid of any sudden fluctuations in displacement, across all four distinct samples. The KAS 2 Sample composite has a high shear strength which is compared to the KAS 1, KAS 3 and KAS 4 sample composite having lower values.

3.2 Tensile Test

Each of the four specimens underwent a tensile test, and the results of that test are shown in Table 4. KAS 1, KAS 2, KAS 3, and KAS 4 have 5254, 5628, 4172, and 3969 N/cm^2 of tensile strength respectively. The highest tensile strength is obtained by KAS 2 and the lowest tensile strength is obtained by KAS 4. The increase of silicon dioxide concentration reduces the tensile strength. Also, the higher concentration of the Al_2O_3 produced a higher strength than the lower Al_2O_3 concentration. Combination of these both nanoparticles higher concentration of Al_2O_3 and lesser concentration of silicon dioxide is required for the maximum tensile strength. Compared to the fiber with 2% SIC and 3% Al_2O_3 nano particles KAS 1, KAS 3, and KAS 4 have 7%, 26%, 30% of decrease. This because of the various combinations of nano particles. Figure 4 illustrates a load-displacement curve that is representative of four distinct composite samples.

Table 4. Tensile test result based on the various compositions of nanoparticles

Sl. No	Sample Composite	Thickness (mm)	Tensile Strength (N/cm^2)
1	KAS 1	5	5254
2	KAS 2	5	5628
3	KAS 3	5	4172
4	KAS 4	5	3969

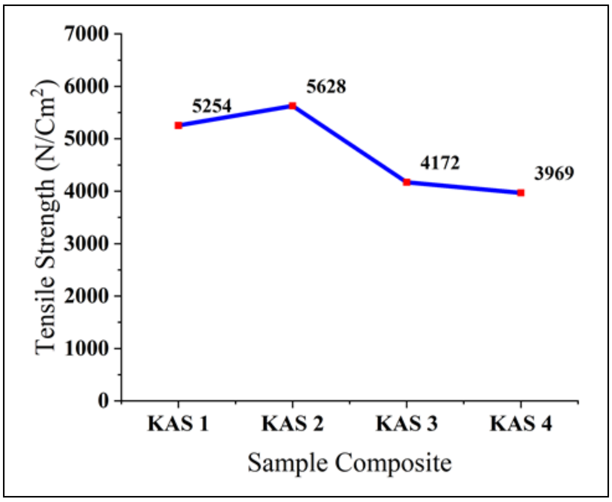

Fig. 4: Shear Strength vs Sample Composite

Kevlar fiber-reinforced polymer is used to strengthen the resin composite, which results in the composite being superior to the epoxy resin composite. The graph represents a consistent and linear increase in the load value across the applied load range, indicating that all four samples exhibited an elastic behaviour. The graph demonstrates that the curve follows a consistent path, without any dramatic oscillations in displacement, throughout all four different samples.

3.3 Impact Test

The results of the impact tests are presented in Table 5. Fig. 5 illustrates a sample graph acquired from the Charpy impact test machine. The graph represents a consistent and linear increase in the load value across the applied load range, indicating that all four samples exhibited an elastic behaviour. KAS 1, KAS 2, KAS 3, and KAS 4 have 4.26, 4.78, 3.42, and 4.54 J of energy absorption respectively. The highest energy absorption is obtained by KAS 2 and the lowest energy absorption is obtained by KAS 4.

Table 5. Impact test result based on the various compositions of nanoparticles

Sl. No	Sample Composite	Thickness (mm)	Energy Absorbed (J)
1	KAS 1	5	4.54
2	KAS 2	5	4.78
3	KAS 3	5	4.26
4	KAS 4	5	3.42

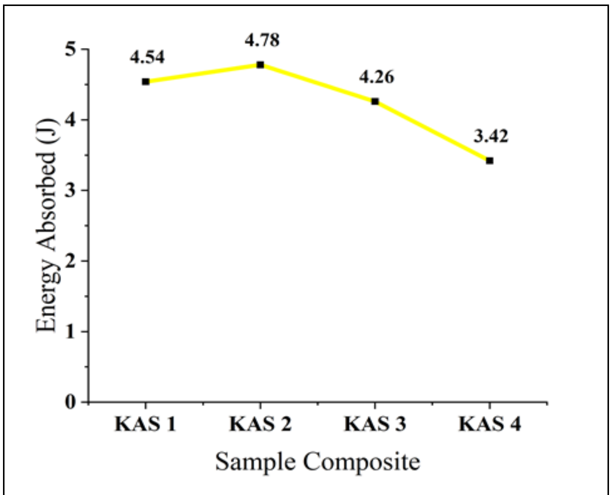

Fig. 5: Shear Strength vs Sample Composite

Increase of silicon dioxide concentration reduces the energy absorption. Also, the higher concentration of the Al_2O_3 produced the higher absorption than the lower Al_2O_3 concentration. Combination of these both nanoparticles higher concentration of Al_2O_3 and lesser concentration of silicon dioxide is required for the maximum energy absorption. Compared to the fiber with 2% SIC and 3% Al_2O_3 nano particles KAS 1, KAS 3, and KAS 4 have 5%, 11%, 29% of decrease. This because of the various combinations of nano particles.

It represents the slight increase from KAS 1 to KAS 2 and slightly decreases to KAS 3, KAS 4. When reinforced with Kevlar fiber-reinforced polymer, the resin composite exhibits superior performance compared to the epoxy resin composite. The graph visually represents that the curve exhibits a consistent path, without abrupt variations in displacement, throughout all four unique samples.

4. CONCLUSION

This study uses the nanoparticles-added epoxy composite technique to manufacture an Al_2O_3 and SiC-reinforced composite. Epoxy resin is used in the production process. Using an Arcan fixture, their mechanical qualities such as tensile strength, shear strength, and impact are tested. The results of this investigation are obtained, and the following conclusion is taken from the findings.

- The shear strength of the Kevlar fiber-reinforced polymer composite with the KAS 2 of value 7735 N/cm^2 is likewise higher than that of the Kevlar fiber-reinforced polymer composite with KAS 1 of value 6847 N/cm^2. Similarly, KAS 3 and KAS 4 have a value of 4681 N/cm^2 and 3840 N/cm^2 respectively, which has a lower strength than the combination of nanoparticles in the sample composite KAS 2.
- The Kevlar fiber-reinforced polymer composites with epoxy resin KBS 2 have a very high tensile strength of 5628 N/cm^2, which is compared to the all-other samples.
- Additionally, since adding fillers in the composite, silicon carbide and aluminium oxide, the composite has offered excellent strength and rigidity.
- The impact strength of the Kevlar fiber-reinforced polymer composite with the KAS 2 of value 4.76 J is likewise higher than that of the Kevlar fiber-reinforced polymer composite with KAS 4 of value 4.54 J.
- Therefore, from the findings KAS 2 has the highest strength than the other combination of Kevlar fiber with SiC and Al_2O_3 nanoparticles.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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