International Journal of Advances in Engineering and Management (IJAEM)
Volume 3, Issue 5 May 2021, pp: 33-42 www.ijaem.net ISSN: 2395-5252

Evaluation of Mechanical Properties and Simulation of Kevlar Epoxy Reinforced Composite with Silicon Carbide Filler

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Submitted: 01-05-2021 Revised: 09-05-2021 Accepted: 10-05-2021

ABSTRACT: In modern manufacturing sector, the para-aramid (Kevlar) composite material evolves as an alternative to metallurgical alloy products due to appreciable raise of tensile and flexural strength with wear resistance. In this paper, Kevlar epoxy sample is prepared with three different micro scale weight percentages of (3%, 5%, 7%) silicon carbide (SiC) using hand lay-up technique. In this investigation, for each weight percentages (wt %) of SiC a comparison on experimental validation is made for three samples to reinforce with Kevlar epoxy to identity the significant change in mechanical properties. The three variations of Silicon Carbide constituents with Kevlar reinforced epoxy composites are experimentally tested and compared with mathematical and simulation analysis for identification of enhanced mechanical properties such as tensile and flexural strength. A better correspondence has been obtained between results drawn from mathematical, Autodesk fusion simulation and experimental approaches. The improvement in tensile strength up to 289.22 Mpa and flexural strength of 234.39 MPa with the addition of 7% weight percentage of Silicon Carbide in Kevlar fibre reinforced epoxy composite in experimental testing to explore uniqueness and achieved better results.

Keywords: Composite material, Kevlar, Mechanical properties, Silicon Carbide.

I. INTRODUCTION

To meet technological advancement globally the conventional metal components are mostly replaced with composite materials due to light weight and high strength and stiffness characteristics. A composite is a heterogeneous material consisting of two or more distinct materials bonded together has better properties than any of its constituents. There exists a wide range ofiber reinforcement combination to form as a composite material i.e glass fibers, carbon fibers, aramid fibers and natural fibers etc exhibit improved characteristics when subjected to mechanical test (Shankar A. Hallad, 2018).The fabrics of high strength woven are treated as ideal materials and applicable in structural and aerospace systems with a large deformations and high strength are required (Deju Zhu 2011) [1,2]. The essence of development for high strength composites led to grasp the attention of many researchers to investigate experimentally behavior of composite material when compared with different weight percentage of filler composition [3,4]. To enhance the design of composite material for wide application, a detailed study on characterization of the various salient mechanical parameters such as friction, hardness, wear performance, Impact strength, Tensile strength, flexural strength is required and to improved. According to several research findings the attempt made to attend an incremental level of mechanical properties in composite fiber reinforcement with variation in filler wt percentage. Generally, low fracture energy results to reduce impact strength, fracture toughness, leads to delamination forming unwanted inter laminar crack (P. Priyanka 2017). The remarkable properties such as high tenacity, modulus, strength, and low electrical conductivity made carbon fibre interesting with wide application (Fang Guo). Unlike the glass and carbon fiber, the attractive inherent properties like high strength modulus and behavior with low density, impact strength the anisotropic natured para-aramid (Kevlar) fibers as excellent commercial form of applications (Thingujam Jackson Singh 2015) [5,6]. The core material in any flexible component fabricated mostly with Kevlar 29, 49, 300 grade fibers exhibits high mechanical properties (Azrin Hani, 2011).

In view of above literature, to the author's knowledge in this experimentation the improved mechanical characteristics are achieved with the reinforcement of Kevlar composite with epoxy resin containing with 2%, 4%, 6% of SiC particle shows excellent improvement in mechanical properties.

II. SPECIMEN FABRICATION PROCESS

The composite specimen preparation involves basically with selection of composite reinforcement with resin, heater and concentration of filler with different weight percentage. This fabrication process involves in the formation of a layer by layer orientation of laminates of bi-direction fiber angle. The fabric and roving properties of Aramid fabric is listed in Table 1 below. The main objective of this investigation is to convert fiber reinforced polymer composite with low density and high strength characteristic [7,8].

Table1: The fabric and roving properties of Aramid (Kevlar-49) Bi-directional fabric.

Properties	Specification
Warp (0^0 Direction)	3000D
Weft (90^0 Direction)	3000D
Ends Nos./cm	6.7
Picks Nos./cm	6.7
Weave Style	Plain
Thickness, mm	0.57
Width, mm	1005
Fabric aerial weight, g/m^2	487
Linear density	3040
Density, g/cc	1.44
Modulus, GPa	>72
Elongation at the time of break, %	2.8-4.2
Tenacity, N/tex	>2

2.1 Preparation of composition

The fiber reinforced polymer composite preparation includes with the combination of Kevlar-49 fiber, epoxy resin, hardener in an appropriate composition. The selection of material is a foremost stage to endure high load application on a composite specimen. A single layer woven Kevlar fiber is considered initially as reinforcement material epoxy LY556 with viscosity 10,000-12,000 mPa.s at 25^0 C of temperature is considered as resin made from thermosetting process. A low viscosity with 10 – 20 mPa.s, density of 0.97 0.99 gm/cc at room temperature unmodified, aliphatic polyamine type of Aradur (HY 951) model hardener is using in this fabrication process.

The preparation of epoxy hardener is a prerequisites followed to accumulate bonding of fiber particle in matrix from and acquire high strength composite. A combination ratio of hardener (HY951) with epoxy resin in a measurable value of 100:10 is mixed together for 3 min in a beaker containing 180 grams of epoxy and 18 grams of hardener. The change in percentage of resin and hardener ratio will high influence the polymer matrix reinforcement. As the above cause of action is suiTable for hand lay process, the ideal setting time for epoxy resin and hardener is 15 hours respectively. The combination of epoxy resin and hardener are mixed with SiC with variation in its percentage of 2, 4, 6%.

2.2 Hand lay process

Initially mould preparation involves rust and unwanted particles removed using 80 grade fine emery paper, also applied acetone, grease on mould and rubbed with release agent i.e wax polish and allow it to dry for few minutes. The Kevlar fiber of dimensions 200 x 200 mm placed on mould in horizontal directions. A uniformly distributed liquid composition of epoxy resin and hardener with Silicon carbide is poured on each new layer of Kevlar fiber and pasted with another Kevlar fiber alternatively to form a 8 layers of laminates with the addition of each new layer of Kevlar fiber on another Kevlar fiber with the mixture epoxy resin hardener and SiC accommodated between the composite layer [9,10]. The laminates are pressed with a roller to remove air trapped within the layers is expelled out to obtain required bonding between layer to layer. The curing for above fabrication process of polymer matrix composite is performed at room temperature for a time period of 24 hours to obtain a eight layered Kevlar fiber reinforced polymer matrix composite. To avoid degradation of material properties, a stabilizer of fiber composite properties must be applied to prevent fiber strength drop due to moisture absorption effect from the air. The laminates are processed for post curing with the aid of oven at temperature 75^0C for a time of 45 min with equal distribution of temperature. After conducting post curing process, the specimens for tensile and flexural test are drawn according to ASTMD 638 and ASTMD 790 standard dimensions with variation in SiC concentration percentage (2%, 4%, 6%). The Aramid fabric (i.e Kevlar-49) with 0.5 mm each fiber thickness is layered up to 8 plies of composite with total thickness of 4mm.

Fig 1: The extruding of fabricated Kevlar fibre reinforcement of polymer epoxy laminate from the mould.

2.3 Calculation (volume to weight ratio):

The weight of each layer depends on the mixture area of the layer and grams per square meter (GSM) of Kevlar fibre. The addition resin and hardener for particular weight of resin as per required measurement level enables better analysis with highly accurate results.

Weight of each layer = Area of the layer X GSM of Kevlar fibre

=210mm X 210mm X 220 GSM

=0.21m X 0.21m X 220 GSM

=9.702 Grams

And for 8 layers =9.702 X 8=77.616 gms.

Weight of resin = Weight of 8 Layers = 77.616 Grams

Hardener (100:10) ratio=10 X 77.616/100=7.76 Grams.

For filler Proportions:

1. For 2% =2/100 X 77.616=1.552gms.
2. For 4%=4/100 X 77.616=3.104gms
3. For 6%=6/100 X 77.616=4.656gms.

III. MECHANICAL CHARACTERIZATION

The Kevlar reinforced polymer matrix with three variations in SiC composition are examined for mathematical, software simulation and compared with experimental results. Among three variations (2%, 4%, 6%) of SiC concentration with Kevlar fiber composite, the specimen with better tensile and flexural characteristics are identified with experimentation and software analysis for interpretation of results. The specimen of fabricated composite machined into required dimensions as per ASTM standards to conduct test.

3.1 Tensile test

The design parameters of structural component influenced with advancement in tensile properties (Amal Nassar). With the aid of milling machine, a constant cross section with bevelled tabs adhesively bonded ends specimen samples are prepared in dog bone shaped with Length = 165mm, Width= 19mm, Thickness=3mm as per ASTM D 638 Standards for tensile test.

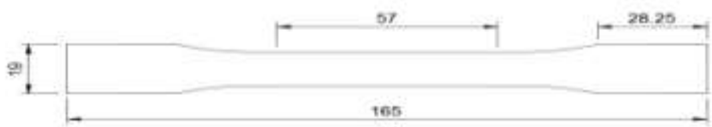

Fig 2: Specimen per ASTM D 638 Standards for tensile test.

A compliant and strain compatible material is used for the end tabs to reduce stress concentrations in the gripped area to promote tensile failure in the gage section. Any high elongation adhesive system can be used for mounting the end tabs to the test Specimen. For better confirmation of results, each test is repeated for three times experimentally in order to obtain efficient calibration and compared with analytical results in Autodesk Fusion software. The magnitudes of load applied on specimen for tensile strength is 20 KN capacity with universal testing machine by wedge action grips under 32^0C temperature. The load was applied till fracture with

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Volume 3, Issue 5 May 2021, pp: 33-42 www.ijaem.net ISSN: 2395-5252

a grip displacement rate of loading maintained at 5 mm/min. Similarly, experimentation practically conducted on three identical test samples with variation in wt % of SiC.

Fig 3: The specimen sample prepared in dog bone shaped for experimental analysis.

3.2 Flexural test:

The objective of flexural test performance is to identify the ability of material to resist bending under load (Amal Nassar). To determined Flexural properties, such as Flexural strength, Flexural modulus, and Poisson's ratio of flat composite laminate by static Flexural tests the uniform cross sectional specimen is placed at bevel tabs adhesively bonded at its ends. The dimension Specimen accordance with ASTM D 256 for fluexural test are considered as length =127 mm, Width = 12.7 mm, Thickness = 4 mm in Fig 4 below. The span length between the supports with 20KN load, cross head speed of 5 mm/min is employed to measure the amount of failure with applied load in the gage section. The Kevlar/epoxy is made of bi-directional 0-90^0 cross-ply fiber in shown in Fig 5 (a) below. A three point bending load test with universal testing machine is conducted for flexural test on three specimens of each SiC fiber reinforced polymer composite is shown in Fig 5 (b) below.

Flexural Strength, $\sigma_f = 3FL/2Wt^2$

Where, F is applied load, L is support span, w and t are width and thickness of the specimen.

Fig 4: Flexural Specimen drawing

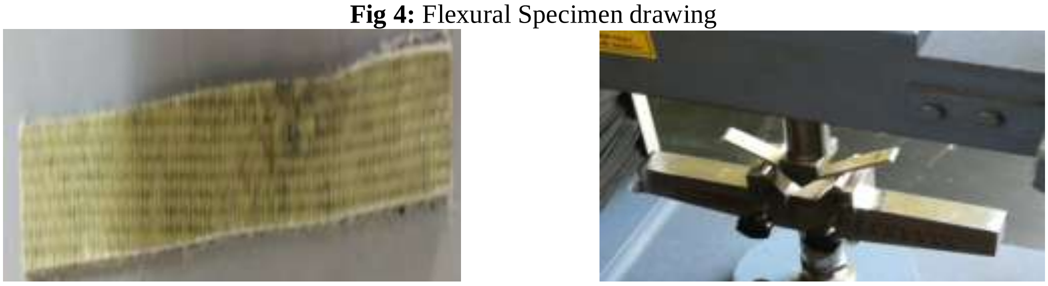

Fig 5 (a) the flat Specimen laminate for flexural test (b) The specimen subjected to Flexural test

IV. RESULTS AND DISCUSSION

From the above conducted investigation, the ratio of improvement in tensile and flexural properties due to Kevlar fibre reinforcement of polymer matrix composite due to the addition of SiC in prescribed level in represented in experimental results. The performance of numerical and software analysis are also required to compared with experimental calibration to prove the accuracy.

4.1 Mathematical Relations with Experimental loads:

To prove the ability of strength in composite material the application of tensile and flexural test are measurable factors. The assumption of load cases in this mathematical condition on composite material is treated as solid structures, remains plastic deformation when failure of structure initiate, Kevlar fibre is considered as brittle material. The numerical calculation for tensile strength and flexural strength for filler proportions of SiC to Kevlar are represented in the empirical formulation for as shown in below:

Tensile Strength, σ_t = Load / Area

=P/(w x t)

Where, P = load Applied (N); w= width (mm): t= thickness (mm)

For Kevlar reinforcement with 2% Sic then the applied Load, P = 11512.7 N

Tensile strength, $\sigma_t = \frac{11512.7}{13 \text{ x } 4}$ = 221.39 N/mm^2

For Kevlar reinforcement with 4% Sic, then the applied Load, P= 12846.7 N

Tensile strength, $\sigma_t = \frac{12846.7}{13 \text{ x } 4}$ = 247.05 N/mm^2

For Kevlar reinforcement with 6% Sic then the applied Load, P = 13352.4 N

Tensile strength, $\sigma_t = \frac{13352.4}{13 \text{ x } 4}$ = 256.77 N/mm^2

Flexural Strength, $\sigma_f = \frac{3FL}{2Wt^2}$

Where, F= Load Applied (N); L= Length (mm); w= width (mm); t = thickness (mm)

For Kevlar reinforcement with 2% Silicon carbide then applied Load, F = 333.4 N

Flexural strength, $\sigma_f = \frac{3 \text{ x } 333.4 \text{ x } 127}{2 \text{ x } 12.7 \text{ x } 4^2}$ = 312.5 N/mm^2

For Kevlar reinforcement with 4% Silicon carbide then applied Load, F = 343.2 N

Flexural strength, $\sigma_f = \frac{3 \text{ x } 343.4 \text{ x } 127}{2 \text{ x } 12.7 \text{ x } 4^2}$ = 321.75 N/mm^2

For Kevlar reinforcement with 6% Silicon carbide then applied Load, F = 440.2 N

Flexural strength, $\sigma_f = \frac{3 \text{ x } 440.2 \text{ x } 127}{2 \text{ x } 12.7 \text{ x } 4^2}$ = 412.68 N/mm^2

The improvement in the results of tensile and flexural strength is observed from above equations numerical analysis with addition of 2, 4, 6% of SiC to Kevlar fiber epoxy polymer matrix reinforcement.

4.2 Software analysis of tensile & flexural specimen

The software simulation is conducted by Autodesk Fusion 360 for both flexural and tensile strength with properties as shown in Table 1. Initially a trail test for tensile and flexural properties is conducted in software analysis to assess the effect of load on strength parameter are represented in Table 2 below.

Table 2: Trial Simulation Results with Assumption Loads for Tensile Test

Trial	Load	Stress	Elements	Nodes	Element Size
1	500 N	12.24 MPa	8737	15058	2 mm
2	1000 N	24.47 MPa	8737	15058	2 mm
3	1500 N	36.71 MPa	8737	15058	2 mm
4	2000 N	48.95 MPa	8737	15058	2 mm

Table 3: Trial Simulation Results with Assumption Loads for Flexural Test

Trial	Load	Stress	Elements	Nodes	Element Size
1	500 N	77.22 MPa	1968	3575	3 mm
2	1000 N	154.4 MPa	1968	3575	3 mm
3	1500 N	231.7 MPa	1968	3575	3 mm
4	2000 N	308.9 MPa	1968	3575	3 mm

It is seen clearly from the Fig 7 below that the software analysis for tensile test on Kevlar reinforcement with 2% SiC with load application of 11513N in principal X-axis to validate 229.5MPa as developed stress. The variation of tensile strength to applied load is observed in Fig 8 below with increase in wt % of filler composition as 4% Sic with Kevlar increases the stress developed to 258.6MPa with applied load as 12847.0N in principal X-axis. The Fig 9 below shows great increment in tensile strength with 6% Sic addition in Kevlar reinforcement to develop stress up to 259.8MPa with load application of 12788 N in principal X-axis. The Simulation results of tensile test on Kevlar with SiC are represented in Table 4 below.

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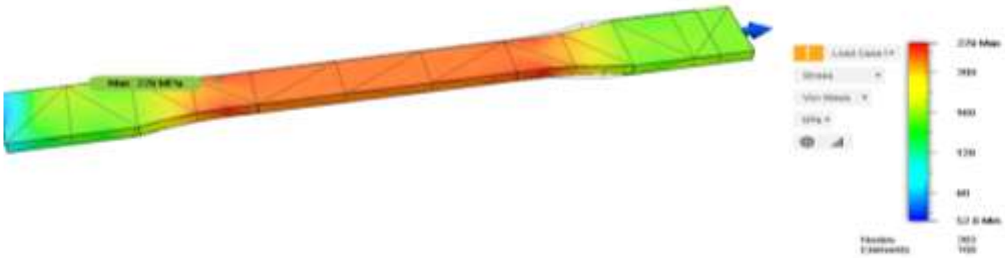

Fig 6: Tensile test simulation for Kevlar reinforcement with 2% Sic

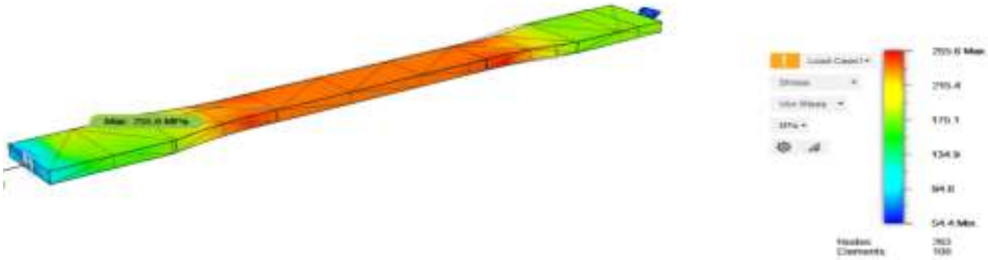

Fig 7: Tensile Test simulation for Kevlar reinforcement with 4% Sic

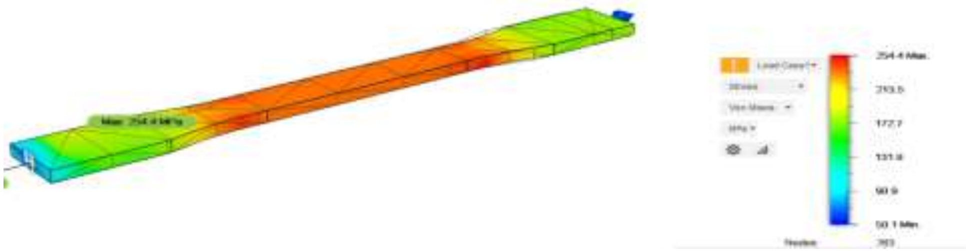

Fig 8: Tensile Test simulation for Kevlar reinforcement with 2% Sic

Table 4:Simulation results of tensile test on Kevlar with sic

Composition	Load	Nodes	Elements	Stress	Strain	Displacement	Reaction Forces
Kevlar + 2% wt% Sic	11513 N	263	108	229 MPa	0.001719	0.2358 mm	3590 N
Kevlar + 4% wt% Sic	12847 N	263	108	250.6 MPa	0.001912	0.2623 mm	4015 N
Kevlar + 6% wt% Sic	12788 N	263	108	254.4 MPa	0.001896	0.2602mm	4002 N

Flexural test:

From the Above Fig 9 it is seen clearly that the Flexural test on Kevlar reinforcement with 2% of Sic with 333.4 N applied load in principal X-axis and stress developed as 102.3 MPa. The Fig 10 shows increment in flexural strength developed as 105.3 MPa with the addition of Kevlar with 4% Sic with applied load of 343.2N in principal X-axis. The ultimate increase in flexural strength in software simulation is recorded as 135 MPa as shown in Fig 11 with the composition of Kevlar with 6% Sic subjected to the load 440.2N in principal x-axis. The Simulation results of flexural test on Kevlar with SiC are represented in Table 5 below.

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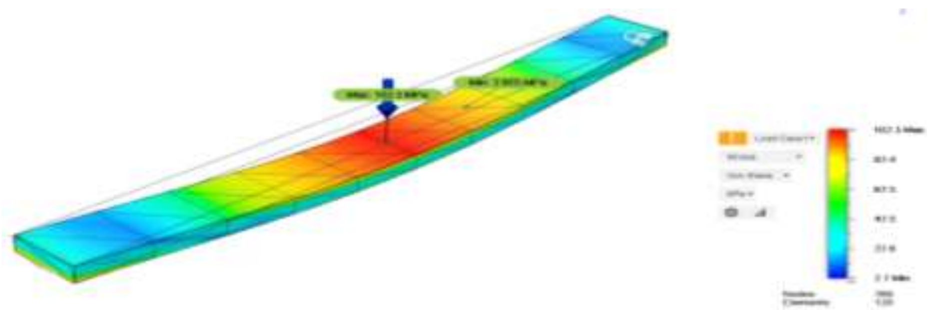

Fig 9: Flexural test simulation for Kevlar reinforcement with 2% Sic

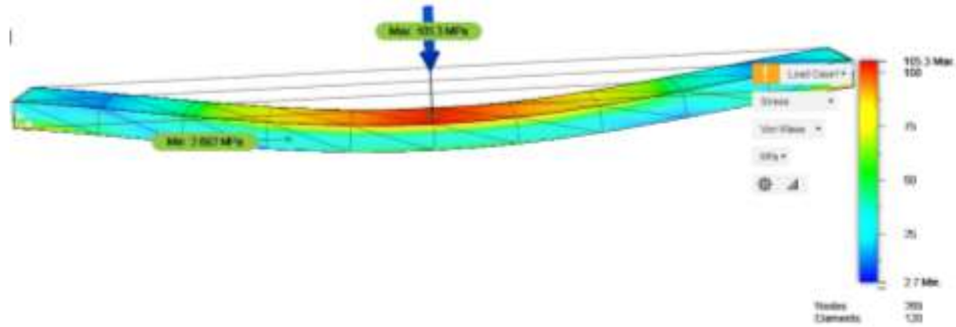

Fig 10: Flexural test simulation for Kevlar reinforcement with 4% Sic

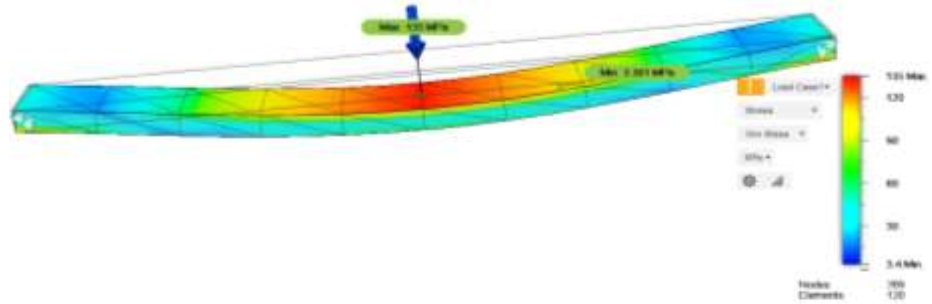

Fig 11: Flexural test simulation for Kevlar reinforcement with 6% Sic

Table 5: The Auto desk fusion simulation results of flexural test on Kevlar with sic

Composition	Load	Nodes	Elements	Stress	Displacement
Kevlar + 2% Sic	333.4 N	269	120	102.3 MPa	0.388 mm
Kevlar + 4% Sic	343.2 N	269	120	105.3 MPa	0.3975 mm
Kevlar + 6% Sic	440.2 N	269	120	135 MPa	0.5075 mm

4.3 Experimental results

It is to be noted that the tensile properties, such as tensile strength, tensile modulus, and Poisson's ratio of flat composite laminate are determined by static tension tests are shown in Table 6 below. The flexural properties such as yield force, yield deflection, maximum force, maximum deflection, flexural strength with yield, flexural strain and flexural modulus of elasticity are determined as well as reported in Table 7 below. The average value of three samples is considered as tensile and flexural strength values for each composition of SiC-filler Kevlar/epoxy composite. Further increase in SiC-filler wt% leads to decrease in mechanical properties gradually. The reason for reduction in tensile and flexural properties is that when the volume fraction is high, the bonding between the fibres may not remain strong.

Table 6: The experimental results of tensile test on Kevlar reinforcement with different compositions of sic wt% filler

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Tensile Test (Kevlar + Silicon carbide)									
	2% SiC			4% SiC			6% SiC		
Mechanical properties	Specimen 1	Specimen 2	Specimen 3	Specimen 1	Specimen 2	Specimen 3	Specimen 1	Specimen 2	Specimen 3
Yield Force (N)	11248.23	10173.63	9916.85	9425.37	11136.10	9494.82	10302.49	8921.62	11843.71
Yield Elongation (mm)	11.48	10.32	10.63	11.85	13.56	12.46	13.87	11.84	14.62
Break Force (N)	11512.7	11062.7	10964.7	12150.4	12080.0	12846.7	13352.4	11852.1	12787.9
Break Elongation (mm)	11.81	11.10	11.47	14.55	14.52	16.29	16.75	14.72	15.82
Tensile Strength @ Yield (N/mm^2)	254.37	230.07	224.26	214.12	252.98	215.69	240.26	208.06	276.21
Tensile Strength @ Break (N/mm^2)	260.35	250.17	247.94	276.02	274.42	291.84	311.39	276.40	298.22
Max. Force (N)	11542.43	11087.43	10963.83	12150.44	12121.02	12846.71	13307.62	11852.08	12787.87
Modulus of Elasticity (N/mm^2)	1505.65	1659.13	1457.79	1251.16	1331.06	1296.85	1236.78	1217.27	1227.70

Table 7: The experimental results of flexural test on Kevlar reinforcement with different compositions of sic wt% filler

	2% Sic			4% Sic			6% Sic		
Mechanical properties	Specimen 1	Specimen 2	Specimen 3	Specimen 1	Specimen 2	Specimen 3	Specimen 1	Specimen 2	Specimen 3
Yield Force (N)	373.08	343.59	440.31	333.4	299.94	339.40	311.71	304.02	324.51
Yield Deflection (mm)	3.41	3.42	4.34	2.87	2.76	3.7	3.10	2.93	2.95
Max. Force (N)	382.5	353.0	440.2	333.4	304.0	343.2	312.3	313.0	333.4
Max. Deflection (mm)	6.6	6.6	6.1	3.4	3.1	4.6	15.2	11.1	15.6
Flexural Strength @ Yield (N/mm^2)	49.20	45.31	58.07	37.75	34.29	38.80	35.29	34.42	36.74
Flexural Strength @ Strain	226.81	209.36	261.02	183.20	167.84	189.500	171.59	171.98	183.20
Flexural Modulus of Elasticity(N/mm^2)	9695.84	8472.46	11336.74	8928.50	7653.62	7560.58	6584.33	4716.20	6682.45

For SiC filler Kevlar epoxy composites, three samples for each composition of 2%, 4%, 6% are tested for identification of better values to compare with simulation and mathematical results. From the observation recorded in Fig 12 & Fig 13 based on tensile and flexural test shows that the experimental results (average value of three samples) prove the accuracy and uniqueness of fabrication process to achieve fine improvement in mechanical properties in Kevlar epoxy composite with three different type of filler SiC. However, results drawn for tensile test with three different approaches such as mathematical, software analysis and experimental procedure obtain reasonable validation. But, mathematical results are not much close to other two approaches in flexural testing.

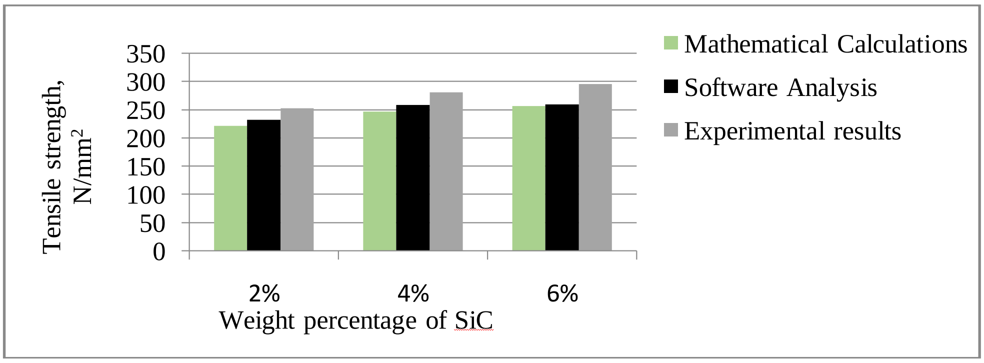


Fig 12: The comparison of tensile strength for mathematical, software analysis and experimental results.

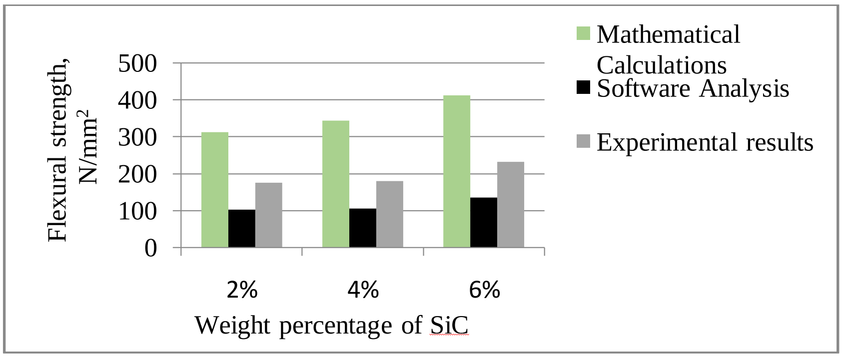
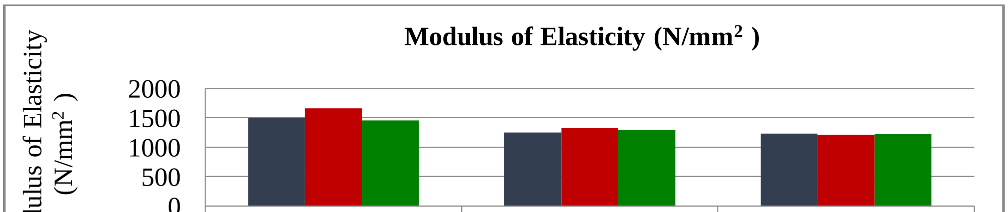


Fig 13: The comparison of flexural strength for mathematical, software analysis and experimental results.



	2% Sic	4% Sic	6% Sic
specimen 1	1505.65	1251.16	1236.78
specimen 2	1659.13	1331.06	1217.27
specimen 3	1457.79	1296.85	1227.7

Fig 14: The Modulus of elasticity for three specimens and 2%, 4%, 6% SiC reinforced with Kevlar fiber.

From the above Fig 14 the modulus of elasticity for three specimens and 2%, 4%, 6% SiC reinforced with Kevlar fiber are shown. It indicates that the maximum modulus of elasticity is found for the specimen 2 with 2% SiC composition and the minimum modulus of elasticity is found for the specimen 2 with 6% SiC composition.

V. CONCLUSION

It is to prove that a significant addition of Sic particle with in a small wt % can improve mechanical properties of Kevlar/epoxy composites. The Bi-directional 0-90^0 angular cross-ply tabs of non woven Kevlar -epoxy have shown satisfactory results with the addition of 2%, 4%, 6% Sic particle.

From the above results, the tensile strength of Kevlar/epoxy reinforcement with 6% Silicon carbide has increased by 16% and Kevlar/epoxy reinforcement with 4% Sic has increased by 12.11% than Kevlar/epoxy reinforcement with 2% Sic. The Flexural Strength of Kevlar/epoxy reinforcement with 6% Sic has increased by 32% and Kevlar/epoxy reinforcement with 4% Sic has increased by 4% and than Kevlar/epoxy reinforcement with 2% Sic. Hence the present study not only discloses that different proportions of SiC overseen through the polymer promotes the performance of composites, but that unique tailored properties are improved by changing the proportions of the SiC filler on the matrix.The investigation in this paper indicates that the mechanical properties are dependent on the fiber filler SiC and bidirectional orientation of polymer composites. The ratio of uneven level of sic wt % filled in the gap between the fiber reinforced polymer matrix leads to reduction in the tensile strength. This is due to insufficient bonding less possibility of load transfer from one end to another of specimen uneven distribution of epoxy composition in polymer matrix leads to heterogeneous nature. The theoretical analysis based on Autodesk fusion software mechanical properties such as tensile strength and flexural strength are compared with practical experimental results. There is not a much depression associated with theoretical and practical results. Furthermost, when compared to different compositions of SiC wt% with epoxy resin, hardener, Kevlar fiber composite 6% wt of SiC exhibit an excellent mechanical properties. Owing to acquire exact efficiency and accurate results, these samples of specimens are used for experimentation and further compared with Autodesk fusion results.

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