Investigation of Hybrid Composite Properties Fabricated from Bagasse Fibers Reinforced with Al_2O_3 and SiC for Light Weight Applications

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Abstract: The primary purpose of this study was to investigate mechanical properties of hybrid composite fabricated from bagasse fibers reinforced with Al_2O_3 and SiC for automotive purposes. The technique applied was referred to as the hand layup technique for the fabrication of composite. The experiment was conducted based on Taguchi L9 orthogonal array design. Data shows that the maximum tensile and flexural strength were 39.9 and 56.1 MPa respectively. Hardness and impact strength were 75.05 HV and 14 J respectively. The results indicated that the increasing Al_2O_3 and SiC wt.% increase the tensile strength and after bagasse fiber wt.% reaches optimum values the tensile strength decreased. Increasing Al_2O_3 wt.%, increases flexural strength and after bagasse fiber and SiC wt.% reaches optimum values, flexural strength was decreased. Increasing bagasse fiber wt.% increases the hardness of composite, and increasing Al_2O_3 and SiC wt.% increases the hardness, then after reaching optimum values the hardness was decreased. Increasing Al_2O_3 wt.% after the optimum values decrease the impact strength, and increasing bagasse fiber and SiC wt.% increase impact strength. The developed hybrid composite material was found to be improved the properties of composites after addition of Al_2O_3 and SiC powder as filler materials. This thesis recommends higher institutes, automotive companies, manufacturing companies, the construction sector and the government to conduct on how to utilize this abundant waste of bagasse fiber resource.

Keywords: Hybrid composite, Alumina, silicon carbide, Bagasse fiber, Hand lay-up.

1. INTRODUCTION

Composite materials are formed when two or more materials with different properties are combined. The properties of composite materials are superior to individual constituents. This has provided the main motivation for the research and development of composite materials, Kawade and Narve (2017). The composite properties may be the volume fraction sum of the properties of the constituents or the constituents may interact in a synergistic way resulting in improved or better properties, Verma (2012) Advantages of composites over their conventional counterparts are the ability to meet diverse design requirements with significant weight savings as well as the strength-to-weight ratio, Marimuthu and Chandramohan (2011). Natural fibers are well suited for making automobile parts and they can be used as wood substitutes in the construction sector were studied by Mochane *et al.* (2019). Bagasse fiber one of the natural fiber. Ethiopia currently produced an average of 893,270 tons of Ethiopian Sugarcane Bagasse (ESCB) annually. Though some portion of it is burnt to provide energy and some used as livestock feed, on average nearly 123,011 tons of surplus is to spare without any considerable application, Ayele *et al.* (2014).

Tadesse and Teshale, (2017) Provides a new area for research development in Ethiopia in which the bagasse can be converted to nitrocellulose and used for different applications including reinforcing in the polymer matrix that can address issues regarding bagasse. The hybridization of composites is one of the most efficient ways of enhancing the mechanical properties of composite material laminates. This new methodology is known as hybridization in which one or more fibers and filler particles are added into a composite, Wankhade *et al.* (2020). The natural fiber composites are manufactured by hand layup, spray lay-up, compression moulding, filament winding, and injection moulding methods, Srinivas *et al.* (2017). Alumina (Al_2O_3) has excellent hardness, dielectric property, wear resistance and chemical inertness properties, Sathiyarasu *et al.* (2020). Silicon carbide is the one of the best filler material that is being used in composite, Rajesh *et al.* (2014). The benefits of using SiC as reinforcement are improved stiffness, strength, thermal conductivity, wear resistance, fatigue resistance, reduced thermal expansion and

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dimensional stability, Devendra and Rangaswamy (2012). Unsaturated Polyester resin with the brand name (TOPAZ-1110 Phthalic Anhydride) was used as matrix material.

In this study, fabrication of a hybrid composite reinforced with Al_2O_3/SiC, bagasse fibers and polyester were investigated. Sample preparation of a hybrid composite was performed based on the Taguchi method and hand layup technique. After preparation of samples, the mechanical properties and morphological analysis of the hybrid composite were performed based on ASTM standard method for each test.

Table **1** shows short summary of selected research works.

Research Gap

Several researches were done on experimental investigation of bagasse fibers reinforced polyester composite. From literature reviews there was no experimental investigation done on alumina and silicon carbide reinforced bagasse fibers and polyester matrix. In addition to this the improvement of mechanical and physical properties of composites with the addition of alumina and silicon carbide was not done.

2. MATERIALS AND METHODS

2.1. Materials

Alumina was the most commonly used filler material for polymer matrix composites due to its relatively high hardness, good oxidation resistance, and chemical stability. It was the most widely used filler materials. Alumina is ceramic materials used as the filler in the present study were purchased from Bangaiere Fine chem- Bangalore; India. Aluminum oxide is a chemical compound made from aluminum and oxygen with the chemical formula Al_2O_3. It was commonly called alumina. It has strong ionic interatomic bonding and commonly occurs in its crystalline polymorphic phase α-Al_2O_3 was investigated

Table 1: Summary of Literature Survey

No	Authors	Matrix type	Fiber type and fillers	Method	Results
1	Athijayamani *et al*., (2016)	vinyl ester	Bagasse fiber	hand lay-up technique	Tensile and flexural strength were 63.2 and 62.6 MPa respectively
2	Dhibar *et al*., (2018)	Polyester	Bagasse fiber	hand lay-up technique	Tensile strength was 12.73 Mpa, Compression strength was 2.315 MPa and water absorption was 27.66%
3	Tripathi and kumar, (2016)	Epoxy	Bagasse fiber	hand lay-up technique	Tensile and flexural strength were 58.36 and 59.6MPa respectively and hardness was 98 HRL
4	Ramlee *et al*., (2019)	Phenolic	OPEFB and bagasse fiber	hand lay-up technique	Tensile strength was 5.56 MPa, water absorption was 15.4% , density was 0.521g/cm^{3}and void content was 6.45%
5	Aynalem and Sirahbizu, (2021)	Polyester	Flax fiber Al_2O_3	hand lay-up technique	Tensile strength was 37.06 MPa and impact strength was 85.5 KJ/m^2
6	Rajesh *et al*., (2014)		Al_2O_3 and SiC	Resin transfer moulding	Tensile, shear and biaxial strength were 61.23, 76.85and 53.52 MPa respectively. Impact strength was 4.38J and hardness value was 61.5 BHN.
7	Cao *et al*., (2016)	Aliphatic polyester	Bagasse fiber	Hot mounting Press	Tensile was 26.77 MPa flexural strength was 50.86 Mpa and Impact strength was 11.27KJ/m^2
8	Subramonian *et al*., (2016)	Polypropylene	Bagasse fiber	Hot pressing.	Tensile and flexural strength were 19.6 and 57 MPa respectively. hardness value was 104.7 HRC
9	Zakaria *et al*., (2020)	Polyester	Bagasse fiber	Hot pressed	Tensile and flexural strength were 18 and 38 MPa respectively.
10	Mathur *et al.,* (2018)	Epoxy	Bagasse fiber	hand lay-up technique	Tensile and flexural strength were 22.085 and 36.62 MPa respectively.
11	Swain and Biswas, (2017)	Epoxy	Jute fiber Al_2O_3	hand lay-up technique	Hardness value was 37.9HV, tensile strength was 98 MPa and void content was 4.23%

(Yohanes, 2019). This alumina with an average particle size of 70-230 meshes ASTM with a density of 3.94 g/cm^3. The properties of alumina are explained in Table **2**.

Table 2: Properties of Alumina (Aynalem and Sirahbizu, 2021)

Description	Alumina
Density (g/cm^3)	3.95
Tensile strength (MPa)	200 – 660
Young's modulus (GPa)	380
Bending strength (MPa)	200 – 600
Compressive strength (MPa)	1900 – 2000
Poison' s ratio	0.25 - 0.3
Coefficient of thermal expansion (^{o}C)	7.39×10^{-6}

Silicon carbide powder is ceramic materials used as the filler in this it were purchased from Bangaiere Fine chem- Bangalore, India. These powders with an average particle size of 220 meshes ASTM with a density of 3.22 g/cm^3. Silicon carbide exhibits favorable mechanical and chemical properties at high temperatures for many applications. The benefits of using SiC as reinforcement were improved stiffness, strength, thermal conductivity, wear resistance, fatigue resistance, reduced thermal expansion and dimensional stability was studied (Devendra and Rangaswamy, 2012). Silicon carbide was produced by combining silica sand and carbon in ancheson graphite electric resistance furnace at a high temperature. It was also prepared by the thermal decomposition of a polymer under an inert atmosphere at low temperatures. It has low density, high strength, high hardness, high thermal conductivity and also excellent thermal shock resistance. Silicon carbide was one of the best filler material that used in composite as investigated (Rajesh *et al*., 2014). Silicon carbide was selected due to these properties.

Bagasse fibers were selected it have lower thermal conductivity, low density, are environmentally friendly, renewable, cheap, have good stability, are no toxic, and high strength. For this study, fresh bagasse fibers were taken from the wonji sugar factory found in Adama town, Ethiopia. Bagasse fibers sieved with 2 mm opening diameter of sieve and lengths of bagasse fibers were from particle size to 10 mm. General Purpose Polyester Resin was an unsaturated polyester resin. Unsaturated Polyester resin with the brand name (TOPAZ-1110 Phthalic Anhydride) was used.

The characteristics of unsaturated polyester resin are given in Table **3**.

Table 3: Characteristics of UPR (Aynalem and Sirahbizu, 2021)

Description	UPR
Density (g/cm^3)	1.09-1.35
Tensile strength (MPa)	40
Young's modulus (GPa)	3.3
Flexural strength (MPa)	45
Poison's ratio	0.44
Maximum elongation (%)	1

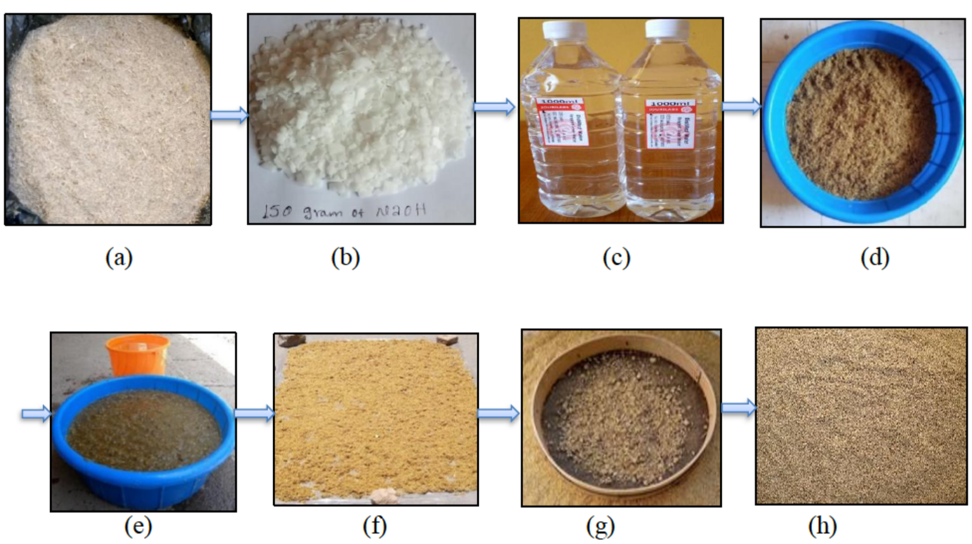

Figure 1: Alkali treatments of bagasse fibers. (**a**) fresh Bagasse fiber (**b**) NaOH (**c**) distilled water (**d**) Soaked bagasse fibers (**e**) washed (**f**) cured (**g**) sieved (**h**) treated bagasse fibers.

The hardener (curing agent) used was with the brand name methyl ethyl ketone peroxide (MEKP) hardener. In this work, NaOH in flakes form was used for the treatment of bagasse fibers and it was purchased from local suppliers.

Unsaturated polyester resin and hardener were purchased from the local supplier World Fiber Glass and Water Proofing Engineering in Addis Ababa, Ethiopia. Sodium Hydroxide in flakes form was used for the treatment of bagasse fibers and it was purchased from local suppliers. NaOH treatment helps to remove lignin and hemicellulose from the surface of bagasse fibers and it has the advantages of activating the hydroxyl groups attached to cellulose and lignin.

Fiber−OH+NaOH→Fiber−O−,Na-+.+,H-2.O

For this study, the bagasse fibers were washed with clean water and dried in sunlight for 2 days. Then bagasse fibers were soaked to take a chemical treatment of bagasse fiber at a 3% concentration of NaOH. That means the bagasse fibers were soaked in 150 grams of sodium hydroxide mixed in five liters of distilled water at room temperature for 1hr. after that washed with clean water several times. Finally, the fibers were allowed to dry in bright sunlight for 3 days.

2.2. Methods

Based on L9 orthogonal design of experiment nine sampls of samples were used based on ASTM standard of performed test.

2.2.1. Design of Experiment

2.2.2. Hand lay-up Technique

Composites were fabricated by hand lay-up technique. The composites with 10, 15, and 20 wt.% of bagasse fibers, alumina and silicon carbide with 6, 8, and 10 wt.% were used for composites fabrication. The polyester resin and its hardener are also used as matrix materials. The fabrication process was conducted at room temperature. The mold plates were HDF or hardboard with 300 mm x 300 mm. The mold plates were covered with mold release wax and the mixture was poured into the mold plate. Then level the mixture to have a uniform thickness. Finally closing the mold plates by applying for the upper plate and fixed the two plates with four C-clamp at four corners. The

Table 4: Process Parameters and Levels

S. No	Factors	Parameter's designation	Level 1	Level 2	Level 3
1	Al_2O_3 content	A	6	8	10
2	Bagasse fiber content	B	10	15	20
3	Silicon carbide content	C	6	8	10

Table 5: Composition and Mass of each Sample of Composites

Samples	Composition (wt.%)				Mass (g)				
	Polyester	Al_2O_3	SiC	Bagasse Fiber	Polyester	Al_2O_3	SiC	Bagasse Fiber	Total
S1	78	6	6	10	353.80	27.20	27.20	45.36	453.60
S2	71	6	8	15	328.73	27.78	37	69.45	463
S3	64	6	10	20	301.80	28.30	47.16	94.32	471.60
S4	74	8	8	10	345.78	37.40	37.40	46.73	467.28
S5	67	8	10	15	319.10	38.10	47.62	71.44	476.28
S6	66	8	6	20	306.50	37.15	27.86	92.88	464.40
S7	70	10	10	10	337.40	48.20	48.20	48.20	482
S8	69	10	6	15	323	46.80	28	70.20	486
S9	62	10	8	20	296.80	47.88	38.30	95.76	478.80
Total					2913	338.81	338.74	634.34	

curing process takes 24 hr and nine experimental runs were finished in the same ways.

Testing Methods

Tensile strength test performed according to the ASTM D3039 on the computerized USM with a capacity of up to 2000KN. The specimen size tensile strength test was 300 mm × 30 mm × 5 mm.Tensile test was conducted in Ethiopian Conformity Assessment Enterprise (ECAE) in Addis Ababa, Ethiopia. Flexural Strength Test performed with ASTM D790-2010. Specimen's dimension of 170 mm × 25 mm × 5 mm. this test was done in Defense University, of Engineering College in Bushoftu, Ethiopia by using Computer Controlled universal testing machine which has a capacity of up to 50 KN. For Vickers hardness the Specimen's dimension of 30 mm × 30 mm × 5 mm. This test was performed in Adama Science and Technology University at Material Science Engineering laboratory, Adama, Ethiopia. Impact strength test of the composite was prepared as per ASTM D (prepared to a size of 55 ×13 mm × 5 mm. A notch has been prepared with a depth of 2.5 mm at 45° inclination. Impact strength test performed in Defence University of Engineering College, Bishoftu, Ethiopia.

3. RESULTS AND DISCUSSION

3.1. Tensile Strength Test

From experimental work result for the tensile strength of hybrid composite made from alumina and silicon carbide reinforced bagasse fiber and polyester material was obtained as follows. Figure **2** shows the tensile strength test results for all specimens. Specimen 1 has a tensile strength result of 35.3 MPa. This specimen was fabricated from 6 wt.% of alumina, 10 wt.% of bagasse fiber, and 6 wt.% of silicon carbide. Specimen 2 has a tensile strength result of 36.9 MPa. This specimen was fabricated from 6 wt.% of alumina, 15 wt.% of bagasse fiber, and 8 wt.% of silicon carbide. Specimen 3 has a tensile strength of 33.5 MPa. This specimen was fabricated from 6 wt.% of alumina, 20 wt.% of bagasse fiber, and 10 wt.% of silicon carbide. Specimen 4 has a tensile strength of 36.6 MPa. This specimen was fabricated from 8 wt.% of alumina, 10 wt.% of bagasse fiber, and 8 wt.% of silicon carbide. Specimen 5 has a tensile strength of 35.6 MPa. This specimen was fabricated from 8 wt.% of alumina, 15 wt.% of bagasse fiber, and 10 wt.% of silicon carbide. Specimen 6 has a tensile strength of 29.5 MPa.

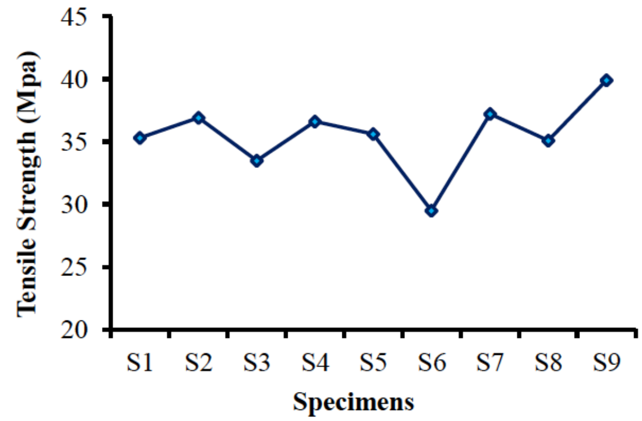

Figure 2: Tensile strength test results.

This specimen was fabricated from 8 wt.% of alumina, 20 wt.% of bagasse fiber, and 6 wt. % of silicon carbide. Specimen 7 has a tensile strength of 37.2 MPa. This specimen was fabricated from 10 wt.% of alumina, 10 wt.% of bagasse fiber, and 10 wt.% of silicon carbide. Specimen 8 has a tensile strength of 35.1 MPa. This specimen was fabricated from 10 wt.% of alumina, 15 wt.% of bagasse fiber, and 6 wt.% of silicon carbide. Specimen 9 has a tensile strength of 39.9 MPa. This specimen was fabricated from 10 wt.% of alumina, 20 wt.% of bagasse fiber, and 8 wt.% of silicon carbide. From this, the specimen 9 shows maximum tensile strength. Stress versus strain diagram for tensile strength given as below.

Figure **3** shows the stress-strain diagram of the tensile strength test. Specimen 1 has 1.6% strain. Specimen 2 has 1.67% strain. Specimen 3 has 1.7% strain. Specimen 4 has 0.598% strain. Specimen 5 has 0.82% strain. Specimen 6 has 1% strain. Specimen 7 has 0.977% strain. Specimen 8 has 0.79% strain. Specimen 9 has 1.2% strain.

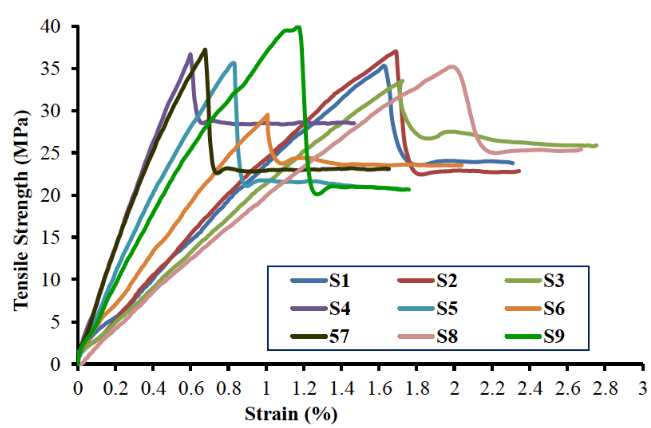

Figure 3: Stress vs strain for tensile test.

Table 6: Analysis of Variance for S/N Ratios of Tensile Strength

Source	DOF	Seq SS	Adj SS	Adj MS	F	P
Alumina	2	0.09367	0.09367	0.04683	1.91	0.344
Bagasse fiber	2	0.04631	0.04631	0.02316	0.94	0.514
Silicon carbide	2	0.15084	0.15084	0.07542	3.08	0.245
Residual Error	2	0.04902	0.04902	0.02451		
Total	8	0.33985				

3.2. Flexural Strength Test

From experimental work result for the flexural strength of hybrid composite made from alumina and silicon carbide reinforced bagasse fiber and polyester material was obtained as below what? Figure **4** shows the flexural strength for all specimens. Specimens 1, 2, and 3 were 56.1, 54.79, and 28.33 MPa respectively. Specimens 4, 5, and 6 were check it and 33.2 MPa respectively. Specimens 7, 8, and 9 were 45.27, 42.5, and 46.04 MPa respectively. From this, specimen 1 shows maximum flexural strength.

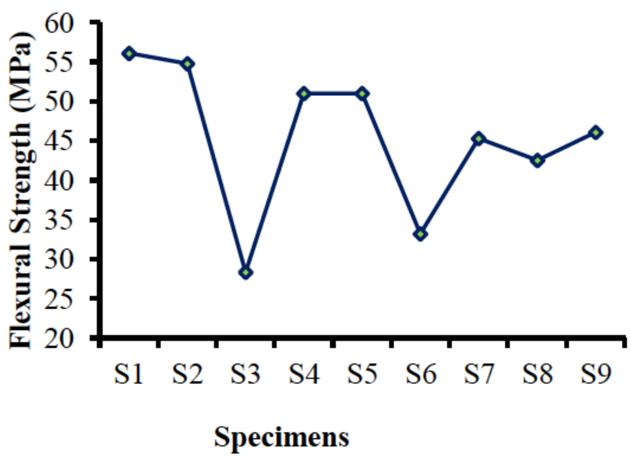

Figure 4: Flexural strength test result.

3.3. Hardness Test

Hardness is the confrontation of a material to deform, indentation or scratching the basic goal of hardness is to enumerate the resistance of a material to plastic deformation. Load during hardness test is 10 kg (99.1 N) on two trials on the specimens. For each test, two reputations are followed and an average value was taken. Figure **5** shows the Comparisons of hardness for all specimens. Specimens 1, 2, and 3 were 49.75, 58.55, and 55.55 HV respectively. Specimens 4, 5, and 6 were 66.3, 56.85, and 62.4 HV respectively. Specimens 7, 8, and 9 were 33.95, 48.4, and 75.05 HV respectively. From all specimens, the specimen 9 shows maximum hardness value and

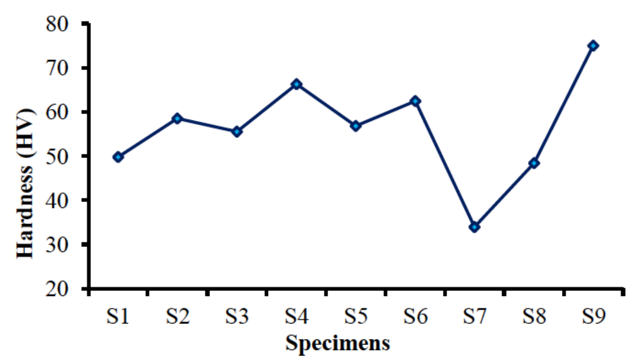

Figure 5: Hardness test result.

Table 7: Analysis of Variance for S/N Ratios of Flexural Strength

Source	DOF	Seq SS	Adj SS	Adj MS	F	P
Alumina	2	0.00313	0.00313	0.001567	0.01	0.994
Bagasse fiber	2	1.37602	1.37602	0.688009	2.51	0.285
Silicon carbide	2	0.45276	0.45276	0.226379	0.83	0.547
Residual Error	2	0.54733	0.54733	0.273664		
Total	8	2.37924				

Table 8: Analysis of Variance for S/N Ratios for Hardness

Source	DOF	Seq SS	Adj SS	Adj MS	F	P
Alumina	2	0.3676	0.3676	0.1838	1.43	0.412
Bagasse fiber	2	0.5893	0.5893	0.2947	2.29	0.304
Silicon carbide	2	0.8286	0.8286	0.4143	3.22	0.237
Residual Error	2	0.2571	0.2571	0.1285		
Total	8	2.0426				

Figure **5** shows the hardness test values and deformation area of specimen 9 during the test.

3.4. Impact Strength Test

Figure **6** shows the impact test results. From this, the specimens 1, 5, and 9 have impact values 5J. Specimens 2 and 3 have impact values 14 and 6.5 J. Specimens 4 and 6 have impact values 8.5 and 10 J. Specimens 7 and 8 have impact values 5.5 and 7.5 J. Specimens 7 and 8 have impact values 5.5 and 7.5 J. The maximum impact strength was obtained at specimen 2 with 14J.

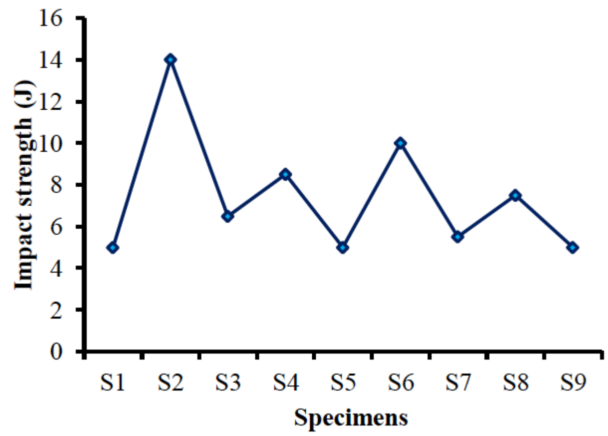

Figure 6: Impact test result.

Table 9: Analysis of Variance for S/N Ratios for Impact Strength

Source	DOF	Seq SS	Adj SS	Adj MS	F	P
Alumina	2	2.198	2.198	1.0992	0.20	0.835
Bagasse fiber	2	1.793	1.793	0.8963	0.16	0.861
Silicon carbide	2	4.231	4.231	2.1155	0.38	0.724
Residual Error	2	11.126	11.126	5.5630		
Total	8	19.348				

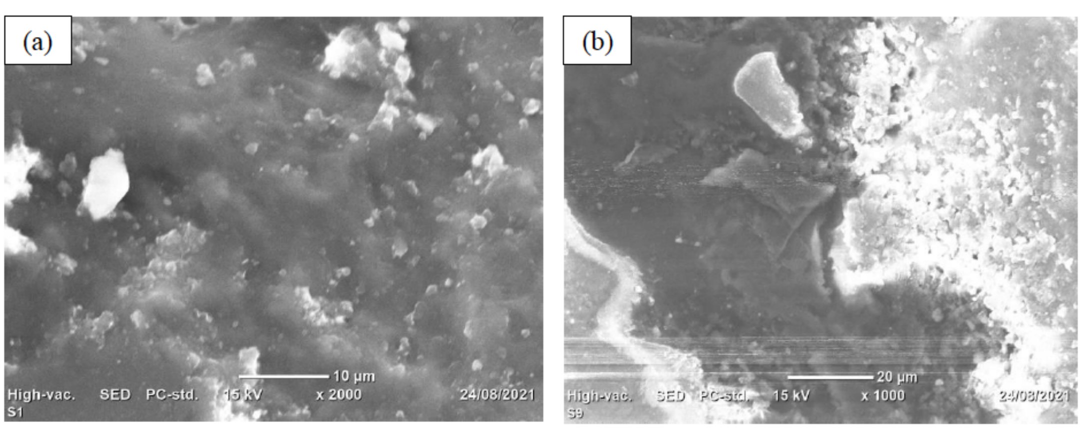

Figure 7: SEM Image (**a**) specimen 1 (**b**) specimen 9.

Table 10: Comparison with the Previous Work

No	Authors	Matrix Type	Fiber Type and Filler	Methods	Results
1	Dhibar *et al*., (2018)	Polyester	Bagasse fiber	Hand lay-up technique	Tensile and compression strength were 12.73 and 2.315 MPa respectively. water absorption was 27.66%
2	Ramlee *et al*., (2019)	Phenolic	OPEFB and bagasse fiber	Hand lay-up technique	Tensile strength was 5.56 MPa, water absorption was 15.4% , density was 0.521g/cm^{3}and void content was 6.45%
3	Cao *et al*., (2006)	Polyester	Bagasse fiber	Hot mounting Press	Tensile and flexural strength were 26.77 and 50.86 MPa respectively. Impact strength was 11.27KJ/m^2
4	Subramonian *et al*., (2016)	Polypropylene	Bagasse fiber	Hot pressed	Tensile and flexural strength were 19.6 and 57 MPa respectively. hardness was 104.7 HRC
5	Zakaria *et al*., (2020)	Polyester	Bagasse fiber	Hot pressed	Tensile and flexural strength were 18 and 38 MPa
6	Mathur *et al*., (2018)	Epoxy	Bagasse fiber	Hand lay-up technique	Tensile and flexural strength were 22.085 and 36.62 MPa respectively
7	Current work	Polyester	Bagasse fiber and Al_2O_3 and SiC	Hand lay-up technique	Tensile and flexural were 39.9 and 56.1 MPa respectively. Hardness was 75.05 HV, impact was 14J.

3.5. Morphology Analysis

Figure **7** shows SEM morphology used to check the bonding and filler material distribution in the matrix. SEM images were taken for the specimens to observe the microstructure. The images were taken for the hybrid composite made from alumina and silicon carbide reinforced with bagasse fiber and polyester and the images were analyzed in the scanning electron microscope. The Scanning electron microscope image shows the dispersion of the bagasse fiber and filler materials alumina and silicon carbide with the polyester matrix.

Comparison with the Previous Works

This study was compared with the previous work by different properties of composite materials were given in Table **10**. From this filling alumina and silicon carbide in bagasse fiber was improved the properties of hybrid composite.

4. CONCLUSION

The following conclusions can be made based on the study carried out:

The results indicated that the increased Al_2O_3 wt.% tensile strength was increased. It decreased after adding more than 8 wt.% of SiC and 10 wt.% of bagasse fiber. When Al_2O_3 wt.% was increased, its flexural strength was also increased. While it was decreased when more than 10 wt.% of bagasse fiber, and 8 wt.% of SiC were added. As wt.% bagasse fiber of increased the hardness of composite was increased. More than 8 wt.% of Al_2O_3 and the SiC hardness of the composites were decreased. More than 6 wt.% of Al_2O_3, 15 wt.% of bagasse fiber and 8 wt.% of SiC impact strength of composite was decreased.

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