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Characteristics of Coconut Fibre Combined with Vinyl Ester Composites through Material Testing and Machining

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In today's manufacturing industry, composites are widely used. This is primarily due to the highly variable material properties that can be obtained by combining various materials as reinforcements and matrices. However, modern environmental concerns have pushed researchers and engineers to seek materials from organic and renewable sources. The study will look into composite surface roughness during the cutting process, which will involve milling with a CNC router machine. A portable surface roughness tester will be used to obtain a surface roughness average (Ra) reading, and microscopes will be used to examine the composite surface roughness behaviour under a microscope. Based on the results of the experiment, 82 wt.% vinyl ester resin on coconut fibre composite provides the best material properties. With a constant feed rate of 500 mm/min applied to spindle speeds of 5,000, 20,000, and 30,000 rpm, the 5,000 rpm showed the best surface roughness average performance compared to the other two. Further research focusing on feed rates may be required to better deduce the material machining data.

Keywords: Vinyl Ester, End Mill Machining, Coconut Fibre, Natural Fibre

1 Introduction

Composites have been used in various facets of engineering due to their diverse selection for reinforcements and matrices. [1] described that engineering materials during the time and a few decades back had already been asserted by composites, plastics, and ceramics [1]. It proved that composites had already made an early entrance in actual application in engineering materials. The selection of fibre reinforcements in composites also spanned organic sources such as natural fibres made of plants (e.g., jute, kenaf, PALF, etc). Quoting [1] "reinforcement with natural fibre in composites has recently gained attention due to low cost, easy availability, low density, acceptable specific properties, ease of separation, enhanced energy recovery, CO2 neutrality, biodegradability and recyclable in nature." [1].

Naturally, coconut fibre is no exception. Coconut fibre is widely available in Malaysia as a byproduct of the country's demand for coconuts for coconut milk and cattle feed. One of the issues that this study is attempting to address is the scarcity of data on machining performance, such as the surface roughness of the composite material. The parameter was critical in determining the material's machinability for the fabrication and production process. Because this composite is made of coir in the form of a chopped strand mat (CSM), any previous studies involving the exact composition were unavailable for access to produce proper initial guesses of its properties.

Another general issue with the production of composites is their high manufacturing costs. Due to the numerous processes that the material went through from its raw form to the final composite, synthetic-based composites are generally expensive to produce. Material availability is also a challenge because the proposed material must be readily accessible to function as a suitable alternative material to meet material sustenance requirements. As a result, the focus of this research will be on producing coconut fibre mixed vinyl ester composite material from entirely recycled sources, with coconut fibre obtained in mat form and vinyl ester resin. After that, the composite will be milled to test its machining performance.

2 Materials and Methods

A hand layup process is used to produce the composite material. The composite includes coconut fibre (CSM or chopped strand mat) and vinyl ester resin, which is measured in weight percent resin. Before calculating the amount of resin required to achieve the desired specimen wt.%, the coconut fibre mat was weighed. This paper employs specimen ratios of 80, 82, 84, 86, and 88 wt.% vinyl ester resin. When the resin mass is weighed in proportion to the mass of the coconut fibre mat, the mat is hot pressed to a constant thickness of 10 millimetres. To accomplish this, the mat is fed into the hot press machine for 3 minutes at a temperature of 70°C. To avoid sticking, an anti-sticking spray is applied to the plastic mould and a transparent cover. Before putting in the coconut fibre chopped strand mat, some resin is poured into the mould to floor it. The remaining resin is poured into the mould after the mat has been placed. The transparent cover is applied to the top of the composite before adding load to keep the final thickness of 10 millimetres. It is then allowed to rest for 24 hours before being removed.

The surface roughness analysis was performed on only one of the specimens. The specimens then are tested for tensile, Charpy impact, and flexural strength. The specimen with the best characteristics was chosen. The specimen is then cut with an 8-millimetre diameter endmill at 5,000rpm, 20,000rpm, and 30,000rpm spindle speeds. The feed rate and depth of cut are both fixed at 500 mm/min and 1 mm. The surface roughness of each cut was measured with a portable surface roughness tester before further examination of the fibre-matrix bonding with a microscope. The outcome was then obtained before concluding the suitability of the composite material to be used.

2.1 Materials

2.1.1 Preparation Material of Coconut Fibre

As the workpiece material for this investigation, a panel made of coconut fibre reinforced vinyl ester composite was utilised, and its dimensions were 300 millimetres by 210 millimetres by 10 millimetres. 82% and 18% of the fibre's volume are composed of vinyl ester, respectively, according to the aspect ratio[2] The benchmarks that were created before identifying each suitable ratio were the basis for the determination that led to the selection of this fibre aspect ratio[3].

Each composite plane is made of a vinyl ester that weighs 605.89 grammes and has a fibre volume that is 82% of its total. The natural composite samples were prepared using a variety of techniques, including hand layup, compression, and a combination of the two. The moisture from the coconut fibre was first removed by drying it at 105 degrees Celsius. After that, a predetermined amount of vinyl ester resin was combined with a catalyst (MEKP) to hasten the curing process. Similarly, the thorough manufacturing procedure that was labelled in the study that was carried out by [4] was followed.

The specific density of the vinyl ester matrix is 605.89 grammes, and its flashpoint ranges from 23-29 degrees Celsius (74-84 degrees Fahrenheit). Following the application of compressive (compaction) pressure to the composite layup, the assembly was allowable to cure at room temperature for 24 hours. A regular oven was used to post-cure the samples for an additional hour at 105 degrees Celsius. There was not a discernible drop in the overall weight of the sample that was experiential. According to the findings of previous research, composites may also be manufactured using a vacuum technique.[5]

2.1.2 Preparation for the Tensile Test

Use the tensile testing machine (model 5969 made by INSTRON). The specimen was put through a series of tests using a total of three separate specimens and parameters. In addition, the pulling method is utilised throughout this exam. The testing methodology adhered to the procedure in its entirety, from start to finish. (ASTM) 3039 was utilised in the examination of the samples. The testing sample size is 100 millimetres by 25 millimetres by 10 millimetres. Fundamental material qualities include things like a material's maximal stress strength and its basic mechanical properties, which are used in structural materials.[6]

2.1.3 Preparation for the Impact Test

The Charpy impact test was completed. The material was sliced to conform to the (ASTM) A370 standard dimensions of 100 millimetres by 10 millimetres by 10 millimetres. The Charpy impact test was carried out in accordance with the (ASTM) A370 standard by utilising the INSTRON CEAST 9050. It is necessary to have a V-notch to assist in the process of stress concentration.

2.1.4 Preparation of Sample for the Flexural Test

The (ASTM) D7264 standard was used to cut the sample for the flexural test. It was determined that the INSTRON 5969 Universal Testing Machine would be the best option. To carry out this test, 3 samples were cut for each of the parameters. It was decided that 16 times the sample thickness would be an appropriate length for the support span. Because of this, the dimensions of the sample are 100 millimetres by 10 millimetres by 2.4 millimetres.

2.2 Methods

2.2.1 Tensile Strength Testing

For the tensile strength test, the dimensions 250 millimetres by 25 millimetres by 10 millimetres must be stretched with a pulling speed of two millimetres per minute [7]. To ensure proper alignment, it is put into the chuck with the mark. In this particular test, three different specimens representing each % were examined. An Instron 5969 machine was utilised throughout the testing process. The test was carried out until a fracture occurred in one of the specimens being evaluated[7]. Following the conclusion of the tensile test conducted by the criteria of (ASTM) 3039, the characteristic curve, longitudinal elastic modulus, and rupture tension of each reinforced composite were calculated. Based on the load curves of each sample, we were able to determine the average amount of deformation energy that each sample possessed.

2.2.2 Impact Testing

Standardised test with a specimen size that remains constant throughout the procedure. The joule (J) is the unit of energy, and the standard size of the specimen is 100 millimetres by 10 millimetres by 10 millimetres. The amount of effort needed to shatter a test specimen is proportional to the quantity of impact energy that is applied to it. The energy is taken in by the specimen, who ultimately gives in to the pressure applied by the striker. A fracture takes place when the V-notch square specimen's capacity to absorb additional energy is depleted and it cannot take any more. The hammer is brought down from its starting height in a single, fast action, and then hurled in the direction of the specimen at a speed of 3.8 metres per second. Both the amount of energy needed to break the material and the material's resistance to breaking are determined by this test.

2.2.3 Flexural Strength Testing

An evaluation of the flexural strength of the natural fibre composite materials was carried out so that their flexural properties could be determined. The procedure adhered to the ASTM D7264 standard, which is the standard test technique for flexural properties. The test was carried out on a Universal Testing Machine, model INSTRON 5969. The specimens were put through an average load, with a maximum load of 74.3972N being recorded. The speed of the crosshead was kept constant at 2 millimetres per minute [7]A comprehensive report of the tests is provided down here in Table 1.

Tab. 1 *Flexural strength test of samples*

Maximum Force (N)					
Sample	80%	82%	84%	86%	88%
Average	36.4780	44.0756	55.3661	74.3972	19.3104

2.2.4 CNC Mini Router Machine

Carried out with the assistance of a CAM-220 CNC mini router machine. To keep the workpiece firmly in place on the platform throughout this experiment, a holding mechanism was utilised. If the samples are not kept in place by this holding fixture, then they may vibrate, which could result in harm to the surface as well as an inaccurate representation of the data. A high-level view of the full experimental setup is presented in Figure 1. Because we did not want to risk contaminating the NFRP laminate, all of the cutting tests were carried out without the use of a coolant[8].

In addition, a precut surface was not used at any point throughout this experiment to do the measurement of the thrust force. As can be seen in Figure 5, the RhinoCAM 2016 software was utilised in this investigation to mark each edge of the surface of the sample. There was a space of three centimetres that separated the surface's middle from its edge. This distance must be maintained at all times to prevent damage to the tool if the holding fixture comes into contact with the end mill tool bit. Before beginning the experiment, a dial gauge was used to measure the flatness of the workpiece as well as the rounding out test of the spindle. This was done to guarantee that the data that was obtained throughout the experiment was correct. After that, the piece of work was cut by utilising a combination of variable spindle speed and a cutting feed rate that remained constant.

The experiment started with spindle speeds of 5,000, 20,000, and 30,000 rpm with a tool feed rate combination of 0.5 millimetres per revolution (mm.rev-1). A comparison was made between the findings and the theoretical predictions. The general parameters are outlined in Table 2, which also contains a summary. This method was used to programme all of the process parameters, including the depth of cut, for the materials that were going to be cut. This pilot analysis identifies the optimum surface roughness and parameter range of the workpiece by assessing a variety of workpieces to identify their ideal values.

The experimental study began by utilising spindle speeds of 5,000, 20,000, and 30,000 rpm in conjunction with a tool feed rate combination of 0.5 millimetres per revolution. The findings were scrutinised in light of the theoretical projections. The general parameters are outlined in Table 2, which may be found below. Using this procedure, all of the process parameters, including the depth of cut, were programmed for the materials that were going to be cut. By examining several different workpieces, this preliminary investigation will establish the ideal surface roughness of the workpiece as well as the parameter range.

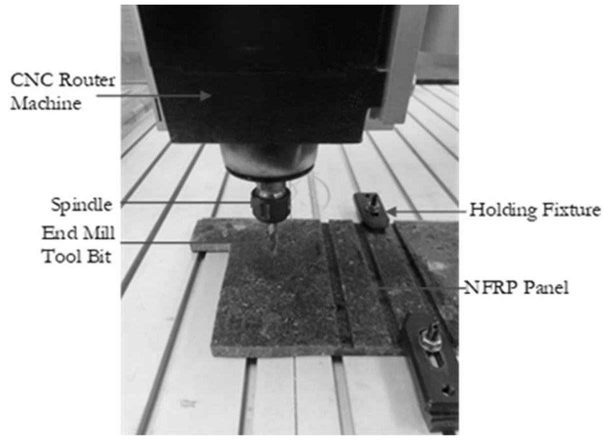


Fig. 1 *CAM-220 CNC mini router machine*

Tab. 2 *Parameters of machining setup*

Run	End Mill Tool Bit Diameter (mm)	Spindle Speed (rpm)	Feed Rate (mm.rev^{-1})
1	Ø 8	5,000	0.5
2	Ø 8	20,000	0.5
3	Ø 8	30,000	0.5

2.2.5 Cutting Parameters

Throughout the entirety of the experiment, the geometry of the end mill tool bit that was being used remained unaltered at its previous setting. The figure depicts two (2) flute end mill tool bits that are made of High-Speed Steel (HSS)[9], have a shank diameter of 8mm [10], and have a flute length of 23mm. The entire length of the instrument is sixty millimetres. According to the datasheet for the tool, the lowest possible spindle speed is 5,000 revolutions per minute, and the highest possible cutting depth is 3 millimetres. Each one of the test runs has been performed using a freshly manufactured drill bit. Carried out at three distinct spindle speeds: 5,000 rpm, 20,000 rpm, and 30,000 rpm. A fixed feed rate of 0.5 mm.rev-1 and a continuous feed rate of 0.5 mm.rev-1 were both utilised throughout the procedure. To ensure the precision and repeatability of the experimental results, this approach was carried out three times, once for each of the machining conditions that were taken into consideration. Experiments involving the cutting process have also taken use of end mill tool bits constructed of HSS in previous investigations.[11]

2.2.6 Testing of Surface Roughness

The degree of roughness of the surface is assessed with the help of the Mitutoyo surface test known as the SJ-410. Utilising a device in which a stylus moves across a surface while the movement of the stylus is amplified and the signal is captured has been the way that has been utilised the most frequently for determining the degree to which a surface is rough. This has been true for the overwhelming majority of the applications that have been submitted. The difference between the deviation of the trace both above and below the centre line is frequently used as a criterion for evaluating the outcome[12]. During each pass, the stylus will traverse a distance of five millimetres (mm) across the surface it is tracing. It is vital to utilise a surface that is entirely level and free of any rough edges to prevent causing damage to the stylus while measuring the surface's roughness.

2.2.7 Microscopic View

A micrograph can be produced by using regular cameras that are sensitive to light to take a picture of an image produced by an optical microscope. The 5x magnification provides a large viewing area for the user. The SMZ745T comes equipped with an optical path-switching lever, which allows for a speedy transition between the camera and the eyepiece.

3 Results and Discussion

3.1 Tensile Test

Each specimen received three (3) samples, for an overall of 15 specimens. The data below is an average of the three raw data sets. Figure 1 depicts the correlation of tensile strength (MPa) among each specimen.

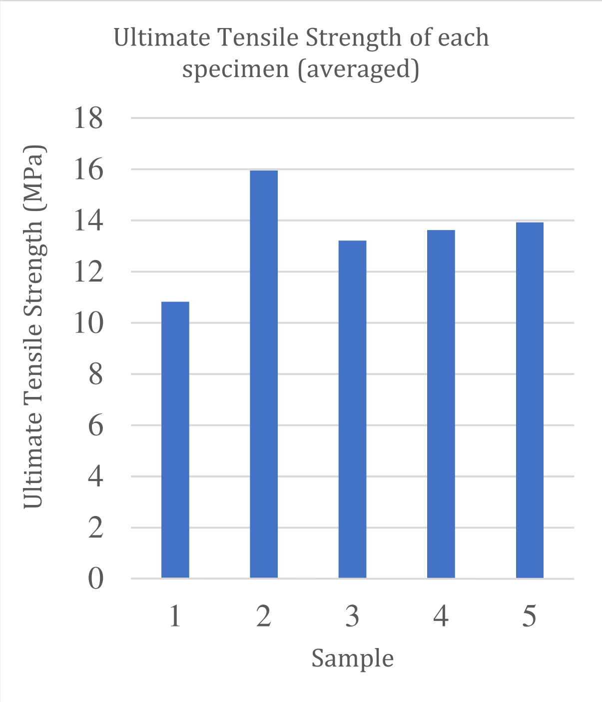


Fig. 2 *Tensile stress testing of specimens*

Specimen 2 has the best performance when compared to the other specimens, as seen in this comparison. The subsequent specimens, in the following order: 5, 4, 3, and 1, were then examined after that. This finding can be attributed to several different sources. First, there is room for human mistakes throughout the process of cutting the specimen. In this experiment, the specimen was hand-machined to the dimensions specified by D3039 ASTM Standard by utilising a band saw machine. These dimensions were then measured and recorded. After that, possible inaccuracies in the dimension could lead to differences in the data pattern. Because other automatic cutting tools, such as laser jets and water jets, were undergoing maintenance at the time of the experiment, the manual procedure that was described earlier had to be used instead.

Increasing the percentage of fibre in composites results in increased strength. When a material has a fibre content of seventy percent (%), it reaches its maximum potential specific strength. This is because of the durable interfacial connection that exists between the vinyl ester matrix and the coconut fibre. However, as more coconut fibre is added, the tensile strength of the composite that has been generated starts to decline. The findings of[13], which investigated the effect of coconut fibre reinforced polypropylene, are comparable to these findings. When there is a higher percentage of fibres, the material has a higher tensile strength. The effect that loading with coconut fibre has on the tensile strength and physical characteristics of unsaturated polyester was studied in[14], and the results were interesting. The tests were performed at room temperature and by the standards that were outlined.

The pattern of the bar chart may be seen in Figure 2, and it displays comparable constancy. According to Figure 2, the leading result of tensile stress in the trial was obtained from sample 5, and it was 13.916 MPa lower than the result obtained from another percent of the composite. This suggests that it has the extreme amount of stress that is possible in that sample 2, which is 15.948 MPa. In the meantime, the worst result was found in sample 1, which had a tensile strength of 10.819 MPa. Previous research has demonstrated slightly varied findings due to differences in the materials used, as shown by the present results.[15]

3.2 Impact Test

As was the case with the tensile testing and every other test, three samples were prepared for each specimen that was examined. The A370 ASTM Standard was utilised for the Charpy Impact Testing, and the sample size was 55x10x10 millimetres. Similarly, the data that were obtained are the average of the three raw data. The interpretation of the graph showing the correlation of fracture energy between the different specimens is provided below.

An impact test was performed on 6 distinct samples of composites made of coconut fibre and vinyl ester resin. Each of these samples included a different proportion of coconut fibre to vinyl ester resin. Every sample had a notch that was two millimetres deep and centred on the edge. As can be seen in Figure 3, the impact resistance of a material composed of vinyl ester and coconut fibre increases in direct proportion to the amount of the respective component.

The impact resistance of a composite made up of 84% coconut fibre is 1.286J, but the impact resistance of a composite made up of 88% coconut fibre is around 0.383J, which is lower than the impact resistance of other composites. Both of these values are lower than the impact resistance of other composites. The impact resistance of the material was greatly increased as a direct result of the matrix's strong interfacial adhesion to the coconut fibre. In the event that this robust connection fails during the process of fracture, a greater amount of force will be required to disassemble the composites. An equation can be written as follows:

$$Impact\ Strength = \frac{Average\ load\ break\ (j)}{Width\ of\ specimen\ (m)} \tag{1}$$

Tab. 3 *Impact testing of samples*

Specimen	80%	82%	84%	86%	88%
1(J)	0.014	0.455	1.294	0.429	0.292
2(J)	0.656	0.455	1.515	0.53	0.392
3(J)	0.8	0.467	1.051	0.492	0.467
Average(J)	0.49	0.459	1.287	0.484	0.384

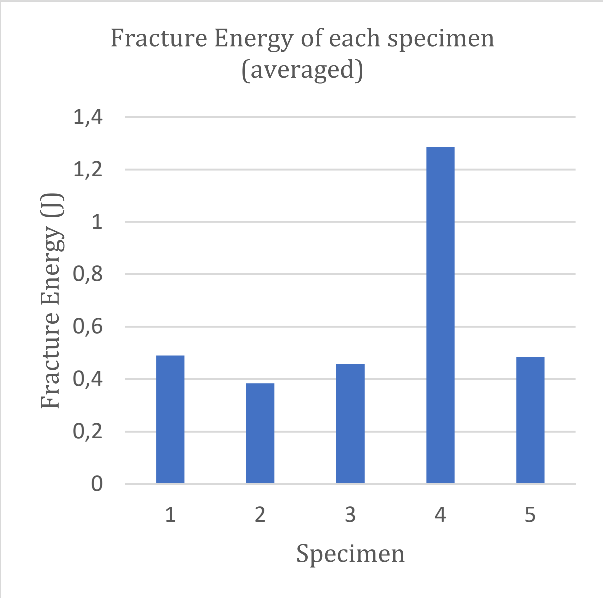


***Fig. 3** Impact strength testing of specimens*

According to the graph, the fracture energies of all of the specimens are lower than 0.5 Joules, except specimen 4, which has a fracture energy of 1.2 Joules. There is a possibility that this great gap was caused by two key elements. The first potential issue is the usage of a band saw machine for the cutting operation, which could lead to variations in the size of the notches that are produced.

Sample number 4 shows a value of 1.286 J, which is higher than the other samples when compared to the impact strength. Sample 1 has a value of 0.49J, which is a little lower than sample 5, which has a value of 0.4836J. Sample 2, on the other hand, has a value of 0.3836J, which places it once again in the worst position. The findings of this test indicate that it is fascinating to consider how the reinforced fibre responds to the pull out of fibre; sample 4 demonstrates superior performance. This is because the composite mixture and the fibre develop a strong link with one another. Now that the trial is complete, the findings will be compared to those obtained from earlier research.[6].

3.3 Flexural Test

The Ultimate Stress of the specimens was the parameter sought in this paper for flexural testing. This test was carried out by ASTM D7264, with a specimen dimension of 100 mm x10 mm x2.4 mm and a constant pressure speed of 1 mm/min. The results of this test are shown below:

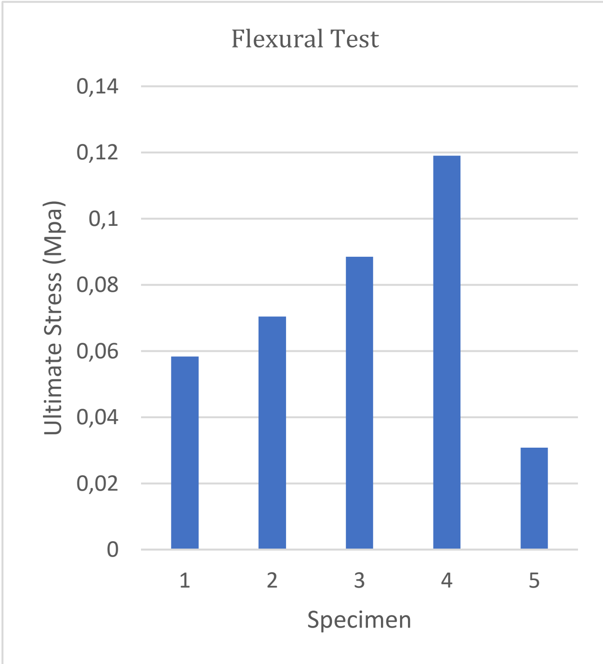


***Fig. 4** Flexural testing of specimens*

The results of the impact test showed an incremental trend that rose as the resin weight percentage did. On the other hand, specimen 5 showed a significant decline, which might be because of some concerns with the dimensions. During the process of sample preparation, the thickness of 2.4 millimetres was very difficult to manage due to the constraints imposed by the available machines. Sanding machines were utilised as a substitute during that time, which had an impact on the dimensional precision of the thickness.

By the ASTM standard, the sample for the test was prepared by making use of the Instron 5969 apparatus. The sample was placed in the testing machine, the weight was allowed to drop, and the amount of energy that was necessary to shatter each specimen was recorded and displayed on the screen of the computer. This was done so that the toughness of the materials that were being tested could be determined. The outcomes of the impact test carried out on the specimens are shown in Figure 11. The sample with the highest and most ideal concentration of coconut fibres, number 4, was the one that attained the desired level of flexural strength. To provide evidence of this, tensile and impact tests were carried out. The effects that were caused by the effective mechanical interlocking of the matrix chain with the reinforcement can be attributed to the results that were found, which can be found here.

Figure 4 demonstrates quite clearly that the sample with a flexural strength of 0.119 MPa, which is sample number 4, has the maximum flexural strength in comparison to the other samples. The pressure of sample 1 comes in at 0.058 MPa, which is followed by sample 2, which has a pressure of 0.070 MPa. Sample 3 has a pressure that is slightly higher than sample 2. However, sample 5 has the most inadequate flexural strength, which is 0.030Mpa in comparison to the earlier investigation, which was slightly different due to the use of various materials.[15]

3.4 Surface Roughness Results

The table portrayed the overall result of the tests. The highlighted ones were data with the highest magnitude. From here, it was deduced that specimen 4 (82 wt. % VE resin) was selected for the analysis. Three differing spindle speed of 5,000 rpm, 20,000 rpm, and 30,000 rpm with a constant feed rate of 500 mm/min was used and the surface cut produced from the three setups were analysed. For the surface roughness analysis, the roughness average (Ra) was taken as the output of the analysis. The result was as shown below:

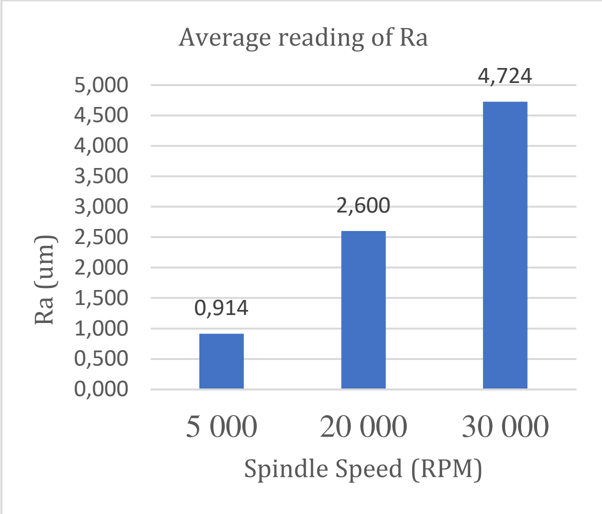


***Fig. 5** Average reading of Ra for pinewood dust at each spindle speed*

An incremental pattern from 5,000 to 30,000 rpm can be seen in the obtained data. Surprisingly, the highest spindle speed produced the greatest magnitude of Ra, implying that spindle speed has less influence on the cutting surface than feed per tooth (mm/tooth). It is also possible to conclude that the feed per tooth is the most important parameter to consider to achieve a good surface finish for the machined material. In terms of feed per tooth, the spindle speed and feed rate should be adjusted accordingly.

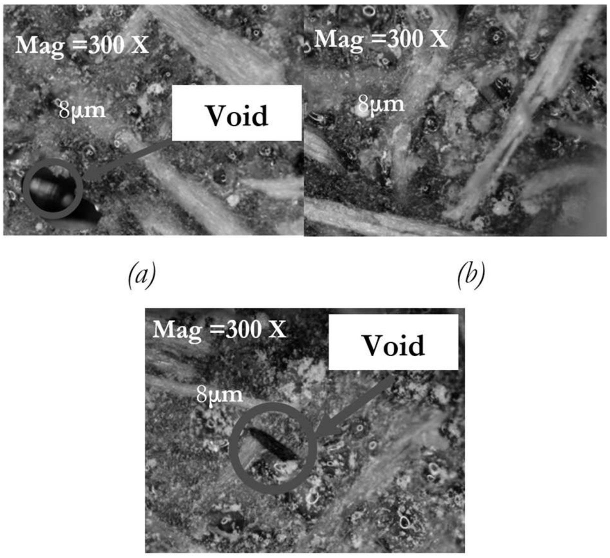
***Tab. 4** Surface roughness results*

Spindle Speed (rpm)	**Reading 1** (µm)	**Reading 2** (µm)	**Reading 3** (µm)	**Average** (µm)
5,000	0.900	0.855	0.987	0.914
20,000	2.473	2.646	2.682	2.600
30,000	4.170	4.581	5.421	4.724

Experiments give evidence that milling variables such as spindle speed, feed rate, and end mill diameter affect surface roughness. The end mill is considered to be a part of these milling characteristics. The data were studied, and it was discovered that a spindle speed of 5,000 rpm and a feed rate of 0.5mm.rev-1 generated the roughest surface, with an average Ra value of 0.914 microns. This was the conclusion reached after the data were examined. This was the lowest Ra value that could be found. Alternately, the greatest Ra value that can be achieved is 4.724 microns when the rotating speed is 30,000 rpm and the feed rate is 0.5 microns per revolution. In most cases, lowering the spindle speed while maintaining a consistent feed rate and diameter will result in a smoother surface. On the other hand, increasing the spindle speed quickly removes surplus heat and ejects the chips that are formed during the milling process. Therefore, the surface roughness will be reduced when the spindle speed is reduced while the feed rate remains the same. Despite this, our findings contrast with those of other published investigations.[9]

3.5 Microscope View

The results of the surface roughness test are in Figure 5. Under a microscope modelled after the Nikon SMZ 745T, the sliced surface was scrutinised for any signs of microscopic bonding between the coconut fibres and the vinyl ester resin. The pictures captured by the microscope are shown in Figure 6. It was found that coconut fibres may stick to vinyl ester in the area where the failure took place without being taken out of the material. Natural fibres can absorb most stresses, and this allows the stress to be properly transferred to the strands. To thoroughly cover the coconut fibre in a layer, a synthetic adhesive known as vinyl ester resin was utilised.



(a) (b)

(c)

Fig. 6 *(a) 5,000rpm, (b) 20,000rpm and (c) 30,000rpm*

Because of the presence of voids, Fig. 6a reveals the presence of a few voids, which is evidence that additional volumes of coconut fibre have been included. It is encouraging to compare this figure with that discovered by[16], which discovered that a low value of feed rate can be used to produce a satisfactory surface quality.[16] found that this was the case. It has been discovered that the feed rate is the factor that has the most significant impact on the final value of the calculation of average surface roughness.

4 Conclusions

The fundamental objective of this study is to explore the significant criteria that determine the proportion of fibres in a natural fibre reinforced composite, in addition to the mechanical and physical properties of that composite material. According to the findings, the combination of coconut fibre reinforced vinyl ester composite and 82 weight percent vinyl ester resin was by far the greatest combination ratio for further development as an alternative material for products. This combination might be used in a variety of applications. As a result of the human hand layup process, there are irregularities in the thickness of each specimen, which causes discrepancies in the findings obtained for tensile, impact, and flexural testing. Using the vacuum bagging process to make the composite because it ensures proper bonding of the coconut fibre and vinyl ester resin while also reducing the number of air bubbles that are trapped; and for surface roughness, controlling the feed rate parameter rather than the spindle speed will provide more reliable material machining data. These are just two of the many suggestions for improvements that can be made to improve experimental output.

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