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Characteristics of Pinewood Dust Combined with Vinyl Ester Composites Through Material Testing and Machining

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Article abstract

Natural fibre reinforced polymer (NFRP) composites can be environmentally friendly and cost-effective alternatives to synthetic fibre-reinforced composites. Major industries have expressed significant interest in the advancement of new natural fibre-reinforced composite materials. However, these materials perform poorly on their own and require further analysis since accessible information is lacking in the literature. This paper presents the results of previously reported works on natural fibre reinforced polymer composites, with strong attention to the types of fibres employed, the polymers used in the matrix, the treatment of fibres as well as the test parameters. The best proportion of composites is consequently selected. Composite materials are tested using a CNC router machine. Pinewood dust is combined with vinyl ester resin. A hand layup technique is used to prepare the samples. The availability of relevant pinewood dust and the volume of pinewood dust to be used are first determined to continue with the experiment. According to the findings, the impact of machining performance is successfully evaluated by employing the tensile strength test, Charpy V-notch impact test, flexural strength test and surface roughness measurement. The findings are derived from the microscopic assessment of the surface roughness of pinewood dust (PWD) fibre reinforced vinyl ester resin.

Keywords
Natural fibre
Pinewood
Vinyl Ester
End Mill Machining

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1 Introduction

The environmental limits on our ability to protect our world are becoming increasingly severe. As a result of these considerations and other economic and ecological issues, the use of natural fibres in the composite sector has proven to be an unquestionable success in non structural applications over the past several decades. Currently, research have highlighted the appropriate use of natural fibre composites in structural applications, mainly polymer matrices reinforced with pinewood dust fibres.

As a result, finishing procedures such as milling on natural fibre reinforced polymer (NFRP) composites are becoming increasingly critical for completing the required processing stages.

The conventional manufacturing procedures for composite materials are in capable of producing parts with near net shapes (i.e., holes, precise dimensions, high quality peripheral surfaces, etc.), which is especially true when creating long fibre composites [1]. The available literature has proven that the machinability of composite materials differs from that of homogeneous materials in several crucial aspects. Machinability refers to the ease with which a material can be cut (machined), allowing for the removal of materials with little cutting force, good surface finish and preserved structural integrity.

The heterogeneity of composite materials is a contributing factor to machining difficulties since the difference in mechanical characteristics between the fibres and matrix is highly significant. The machining procedure of NFRP composites is more complicated compared to other composites. Natural fibres are composite materials composed of cellulose micro fibrils embedded in natural polymers of hemicellulose and lignin, which are also composite materials as well [2], [3].

Heterogeneity is thus present within each crude fibre. Natural fibres are also gathered in a bundle of dozens of elementary fibres with random sizing, geometries and diameters [4]. Therefore, a promising approach for investigating the properties of NFRP materials is required for manufacturing process investigation, material performance analysis [5] and material characterisation. This research has developed pinewood dust reinforced vinyl ester as a composite material using wood dust waste material. The aim of this research is to investigate the qualities of wood dust composites. It is anticipated that the research outcome will create a satisfactory product from wood dust waste.

For this reason, the author's previous works [6], [7], [8], [9] have focused on the multiscale analysis regarding the machinability of the main structures of NFRP materials. The published works regarding surface roughness are summarised.

2 Materials and Methods

2.1 Materials

2.1.1 Preparation of Material Specification of Pinewood Dust (PWD)

In this study, a pinewood dust reinforced vinyl ester composite panel with the dimensions of 300mm x 210mm x 10mm was used as the workpiece material. The fibre's aspect ratio and volume fractions are 70% and 30% vinyl ester [10]. The choice of this fibre aspect ratio is based on the benchmarks that have been made before determining each appropriate ratio [11].

Each composite plane consists of 650 grams of vinyl ester with a fibre volume of 70%. A combination of hand layup and compression methods was used to prepare the natural composite samples. Pinewood dust was initially dried at 105˚C to remove storage moisture. Next, a measured quantity of vinyl ester resin was mixed with a catalyst (MEKP) for rapid curing. The detailed manufacturing process described by the work conducted by [12] was similarly followed.

The vinyl ester matrix has a specific density of 650 grams and a flashpoint of 23-29˚C (74-84˚F). The composite layup was subjected to compressive (compaction) pressure and left for 24 hours at room temperature for curing. Next, the samples were post cured for one hour at 105˚C using a standard oven. No significant reduction in the weight of the sample was observed. Previous studies also believe composites can be produced from a vacuum process [13].

2.1.2 Preparation of Sample for the Tensile Test

This experimental test procedure required the universal tensile testing machine (INSTRON model 5969). Each sample was tested using three specimens with different parameters. This test also involves the pulling process. The test technique adhered to the procedure from start to finish. The (ASTM) 3039 was used to test the specimens. The sample size for testing is 100mm x 25mm x 10mm. The basic mechanical properties of structural materials such as maximum stress strength represent fundamental material characteristics [14].

2.1.3 Preparation of Sample for the Impact Test

The Charpy impact test was conducted using the Charpy impact tester machine at the Universiti Teknikal Malaysia Melaka (UteM) Mechanical and Manufacturing Engineering Technology Laboratory. The material was cut according to the (ASTM) A370 standard, which is 100mm x 10mm x 10mm. The Charpy impact test using the INSTRON CEAST 9050 was in accordance with the (ASTM) A370 standard. It requires a V-notch that helps produce a stress concentration for increasing the probability of brittleness, rather than ductility, and fractures.

2.1.4 Preparation of Sample for the Flexural Test

The specimens for the flexural test were cut according to the (ASTM) D7264 standard. The Universal Testing Machine, INSTRON 5969, was used. To conduct this test, three samples were cut for each parameter. The length of the support span was set at a ratio of 16:1 to the sample thickness. Therefore, the dimension of the sample is 100mm x 10mm x 2.4mm.

2.2 Methods

2.2.1 Tensile Strength Test

The tensile strength test requires rectangular specimens measuring 250mm x 25mm x 10mm to be subjected to a tensile force with a pulling speed of 2mm.min^{-1} [15]. The samples were inserted into the chuck with the mark upside down for proper alignment. In this test, three specimens for each percentage were tested. As shown in Figure 1, testing was conducted using an Instron 5969 machine. The test was performed until the tested specimens experienced fracture [16]. After completing the tensile test according to the (ASTM) 3039 standard, the characteristic curve, specific deformation, longitudinal elastic modulus and rupture tension of each reinforced composite were determined. The average deformation energy for each sample was calculated based on the load curves of each sample.

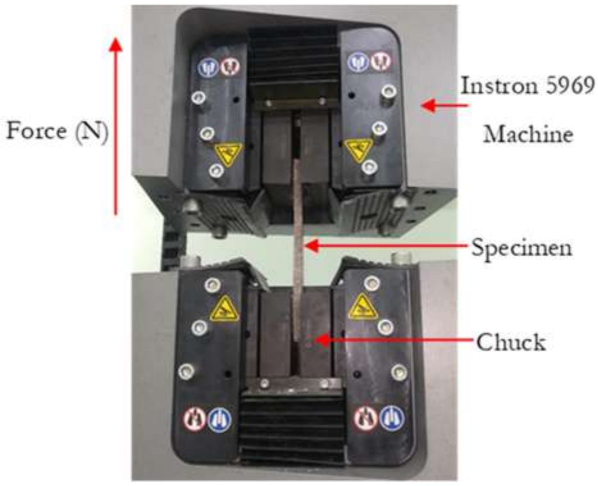


Fig. 1 *Setup of specimens for the tensile strength test*

2.2.2 Charpy Impact Test

The Charpy impact test is a standard test with a fixed specimen size, as shown in Figures 2 and 3. The typical specimen measurement is 100mm x 10mm x 10mm with unit energy of joule, J. Impact energy is used to assess the amount of labour necessary for shattering a test specimen. The specimen absorbs the energy and eventually yields to the striker. A fracture occurs when the V-notch square specimen‘s ability to absorb additional energy is exhausted. The hammer is launched from its original height towards the specimen at a speed of 3.8 metres per second in one swift motion. This test determines the amount of energy required to break the material as well as the material’s toughness.

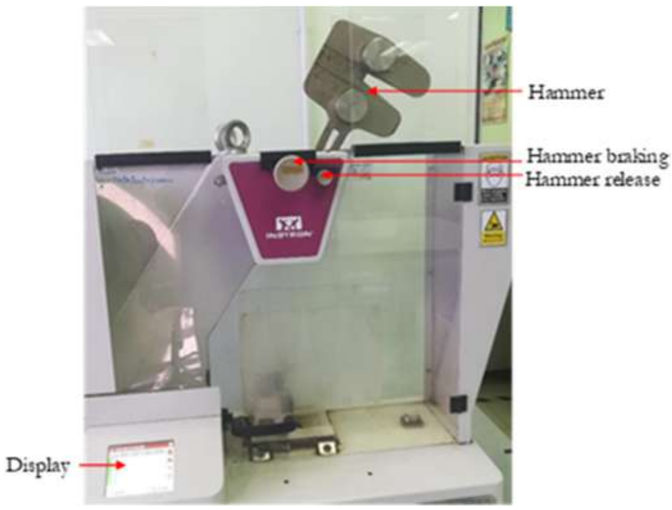


Fig. 2 *Charpy Impact Test Machine (INSTRON CEAST 9050)*

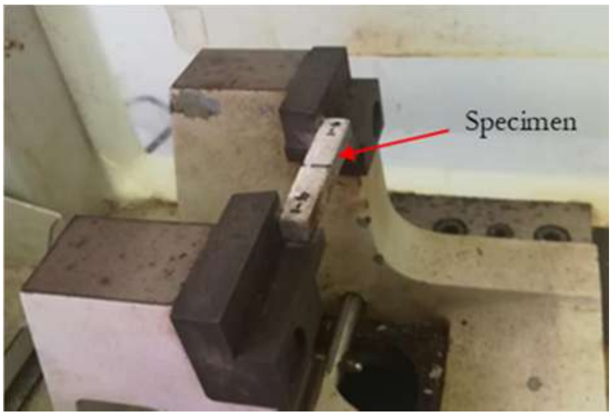


Fig.3 *Setup of specimen for the impact test*

2.2.3 Flexural Strength Test

The flexural strength test was conducted to determine the flexural properties of the NFRP composite materials. The test was carried out according to the (ASTM) D7264 standard using the Universal Testing Machine, INSTRON 5969 (standard test method for flexural properties). Figure 4 displays the specimens shaped as rectangular bars and placed on two supports. An average load was applied to the specimens with the maximum load captured at 58.0682N. The crosshead speed was maintained at 2mm.min^{-1} [17]. A detailed test report is presented below in Table 1.

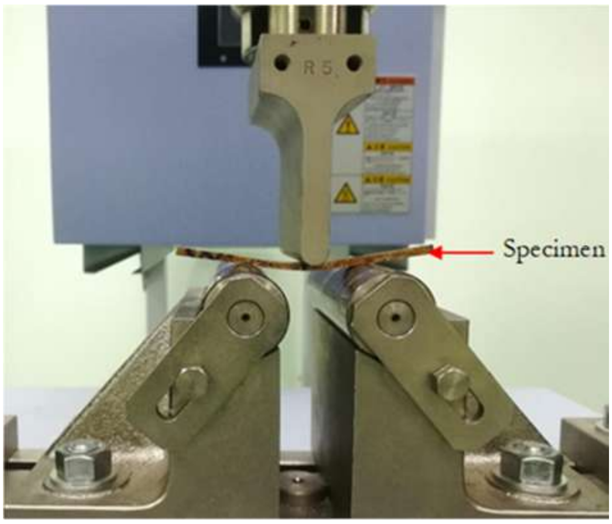


Fig. 4 *Setup of specimen for the flexural test*

Tab. 1 *Flexural strength testing of specimens*

Maximum Force (N)						
Specimens	30%	40%	50%	60%	70%	80%
Average	40.876	64.272	40.012	60.076	58.068	61.009
Std (σ)	13.851	16.107	5.6239	2.0791	3.3628	3.4368

2.2.4 CNC Router Machining

The surface cutting experiment was conducted using a CAM-220 computer numerical control router machine.

For this experiment, a holding device to specifically hold the workpiece securely on the platform was employed. The samples may vibrate if not held in place by this holding fixture which may cause damage to the surface, thereby affecting the accuracy of results. Figure 6 presents an overview of the complete experimental setup. All cutting trials were accomplished without using a coolant to avoid contamination of the NFRP laminate [18].

Furthermore, no pre-cut surface was created in this experiment to measure the thrust force. As shown in Figure 5, the RhinoCAM 2016 software was used to mark every edge of the sample's surface in this experiment. The distance between the centre point of the surface and its edge was 3cm. This distance is necessary to ensure that the end mill tool bit does not come into contact with the holding fixture, resulting in tool damage. Using a dial gauge, the flatness of the workpiece and the rounding out test of the spindle was measured before the experiment began to guarantee that data collected throughout the experiment are accurate. Next, the workpiece was cut using a variable spindle speed and a constant cutting feed rate combination.

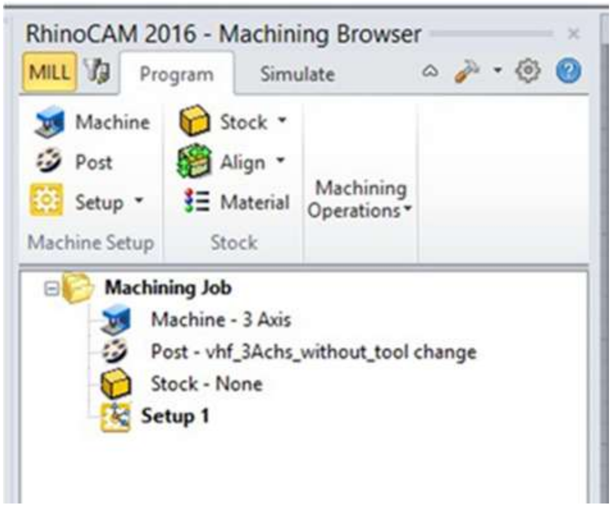


Fig. 5 *Setup of parameter in RhinoCAM 2016*

The experimental research was first conducted with spindle speeds of 5,000, 20,000 and 30,000rpm with a tool feed rate combination of 0.5 mm.rev^{-1}. The results were compared with theoretical predictions. Table 2 provides a summary of the general parameters. This method was used to program all process parameters and depth of cut for the materials to be cut. This preliminary inquiry determines the workpiece's ideal surface roughness and parameter range by analysing various workpieces.

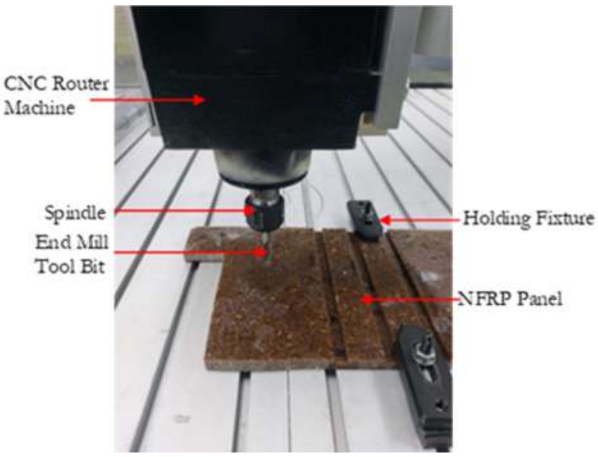


Fig. 6 *CAM-220CNC router machine*

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

The end mill tool bit used in the experiment was fixed to a single geometry type throughout the entire experiment. The two (2) flute end mill tool bits shown in the illustration are made of High-Speed Steel (HSS) [19] with a shank diameter of 8mm [20] and a flute length of 23mm. The overall length of the tool is 60mm, as shown in Figure 7. According to the tool datasheet, the minimum spindle speed is 5,000rpm, and the maximum cutting depth is 3mm. The drill bit used for all test runs is a brand new piece of equipment. The cutting test was accomplished at three different spindle speeds: 5,000rpm, 20,000rpm and 30,000rpm, with a constant feed rate of 0.5 $mm.rev^{-1}$ and a continuous feed rate of 0.5 $mm.rev^{-1}$. This method was repeated three times for each machining condition under consideration to ensure the precision and repeatability of the experimental results. Previous studies also used end mill tool bits made of HSS in experiments for the cutting process [21].

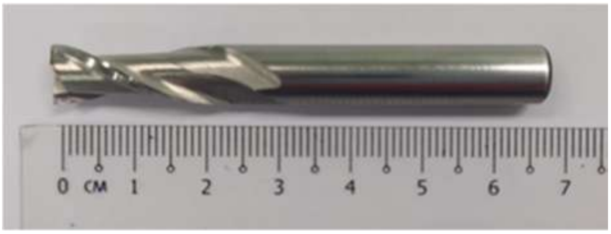


Fig.7 *End mill tool bit*

2.2.6 Measurement of Surface Roughness

Surface roughness is tested with the Mitutoyo surface test SJ-410 in Figure 8, available from the Universiti Teknikal Malaysia Melaka (UTeM). It has been most typically used to measure the roughness of a surface by using an apparatus in which a stylus travels across a surface, the movement of the stylus is amplified, and the signal is recorded. The result is often measured as the difference between the deviation of the trace above and below the centre line[22]. The distance that the stylus travels across the surface is 5mm. Therefore, testing the surface roughness necessitates using a flat surface free of any rough edges to avoid stylus damage.

Fig. 8 Surface roughness machine

2.2.7 Microscopic View

Microscopy is the technical area of using microscopes to examine materials and objects that are too small to be seen with the naked eye (things that are out of the normal eye's resolution range). The optical microscope, often known as the "light optical microscope," is a type of microscope that magnifies pictures of tiny materials using visible light and a lens system, as shown in Figure 9. A micrograph can be created by capturing an image from an optical microscope with ordinary light-sensitive cameras. The zoom of 5x µm provides a broad observation range. The SMZ745T also incorporates an optical path switching lever that enables easy switchover between the eyepiece and camera.

Fig. 9 Nikon SMZ 745T

3 Results and Discussion

3.1 Tensile Test

Increasing the fibre content makes composites stronger. The highest specific strength is achieved with seventy percent of fibre (%) content. This is due to solid interfacial bonding between pinewood dust and the vinyl ester matrix. However, the tensile strength of the produced composite begins to decrease with further additions of pinewood dust. This result is similar to [23] who examined the effect of sawdust reinforced polypropylene. Tensile strength increases with the increase in sawdust content. The impact of wood dust loading on the tensile and physical properties of unsaturated polyester has been determined by [24]. Tests were carried out at room temperature and as per the standards mentioned.

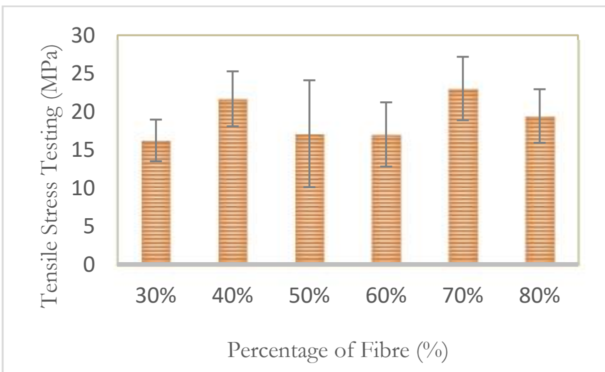


Fig. 10 Tensile stress testing of specimens

From figure 10, the bar chart pattern shows similar consistency. According to Figure 10, 60 vol% of fibre dominates the result of tensile stress in an experiment which is 17.030 MPa lower than another percent of the composite. This indicates it has the maximum stress available in that 70 vol% of fibre which is 23.028 MPa. Meanwhile, 30 vol% of fibre shows the worst result, which is 16.243 MPa in tensile. In accordance with the present results, previous studies have demonstrated slightly different due to different materials [25].

3.2 Impact Test

The ASTM A370 impact test was performed on six samples of pinewood dust vinyl ester resin composites, each of which contained different combinations of pinewood dust and vinyl ester resin. All samples were prepared with a 2mm deep notch in the centre of the edge on all sides. As shown in Figure 11, the impact strength of pine wood dust and vinyl ester rises in proportion with the increase in material composition. The impact strength of 70 volume percent pinewood dust fibre is 2.55J, whereas the impact strength of 40 volume percent pinewood dust fibre is approximately 2.0J, which is lower than the impact strength of other composites. The high interfacial adhesion between the matrix and pinewood dust may account for the increased impact strength. If this strong link fails during fracture, a more significant amount of power is required to break the composites apart. The following equation is:

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

Tab. 3 *Impact strength testing of specimens*

Fibre	30%	40%	50%	60%	70%	80%
Average	0.002136736	0.002010419	0.002091216	0.002074087	0.0025571	0.002448581
Std (σ)	0.000338198	0.000217094	4.7680E-05	0.00020043	0.000727686	0.000258316

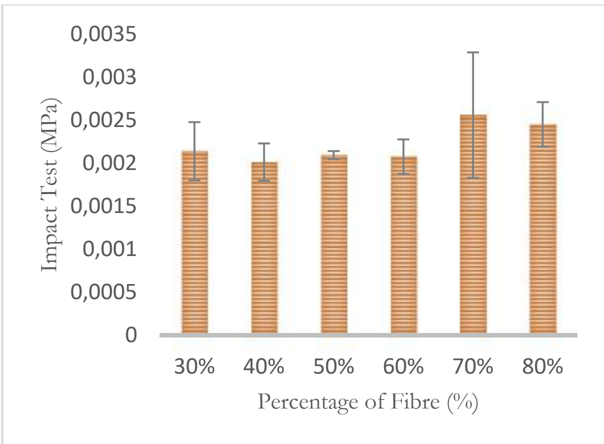


Fig. 11 *Impact strength testing of specimens*

As for impact strength, 70 vol% of fibre has 0.00255MPa, which is higher than others. Thirty percent is slightly lower, which is 0.0021MPa, followed by 80 percent of pinewood dust, which is 0.0024MPa. However, 40 vol% of fibre is again placed at the bottom with a value of 0.0020MPa. The results of this experiment show that it is interesting to note how the reinforced fibre reacts to the direction; the 70 vol% fibre gives a better result. This is due to the excellent bond achieved between the composite mixture and fibre. The results of this experiment will now be compared to the findings of previous work [12].

3.3 Flexural Test

The test specimens were prepared according to the ASTM standard using the INSTRON 5969 equipment. The specimens were placed in the test machine, the weight was released, and the amount of energy required to break each specimen was recorded and shown on the computer screen to measure the toughness of the tested materials. The results of the impact test on the specimens are presented in Figure 12. Flexural strength was attained at a 70 vol% pinewood dust concentration, the highest and most optimal for the application. This was demonstrated by the use of tensile and impact tests. The results can be attributed to the effects of good mechanical interlocking of the matrix chain with the reinforcement.

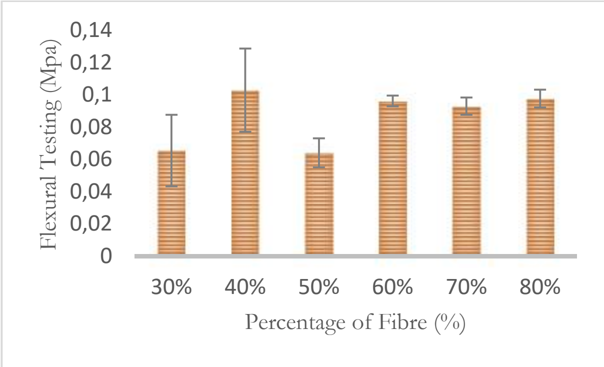


Fig. 12 *Flexural testing of specimens*

As for flexural strength, it can be seen clearly in Figure 12 that 40 vol% of fibre with 0.102 MPa has the highest flexural strength compared to others. Seventy percent is 0.092MPa, slightly lower than 60 percent of pinewood dust, followed by 80 vol% of fibre, which is 0.097MPa higher. However, 50 vol% of fibre shows the most insufficient flexural strength, which is 0.064Mpa compared to the previous study, slightly different due to different materials [25].

3.4 Surface Roughness Results

The effect of end mill on milling parameter, i.e., spindle speed, feed rate and end mill diameter, on the surface roughness by conducting an experiment is shown in. It was revealed that the lowest Roughness average (Ra) value, which was discovered at a spindle speed of 5,000rpm and a feed rate of 0.5mm.rev^{-1}, is 0.668 microns when the data was reviewed. Alternatively, the highest Ra value is 1.497 microns, attained with a rotational speed of 30,000 revolutions per minute and a feed rate of 0.5 microns per revolution. Generally, a lower spindle speed with a constant feed rate and constant diameter will decrease the surface roughness, but a higher spindle speed helps remove excess heat rapidly and also ejects the chips produced during the milling process. So, the lower spindle speed with a constant feed rate will produce lower surface roughness. Although, these results differ from some published studies [19].

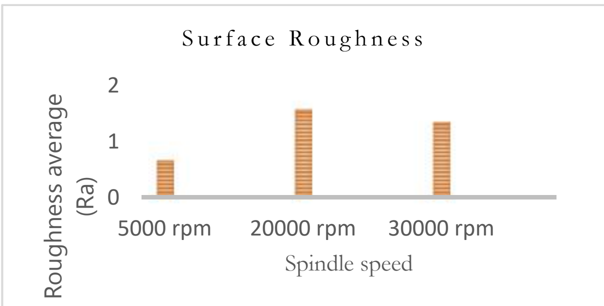
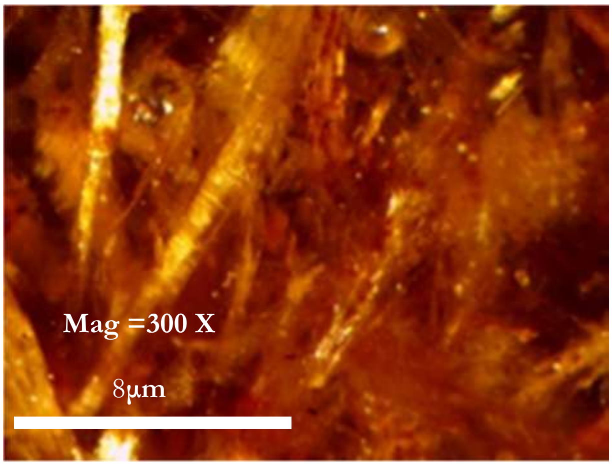


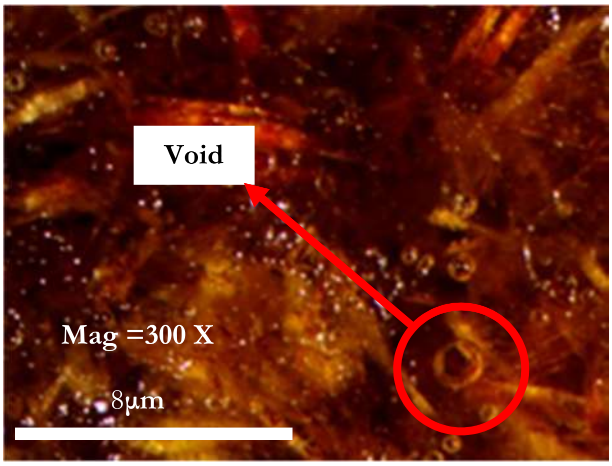
Fig. 13 *Average reading of Ra for pinewood dust at each spindle speed*

3.5 Microscope Results

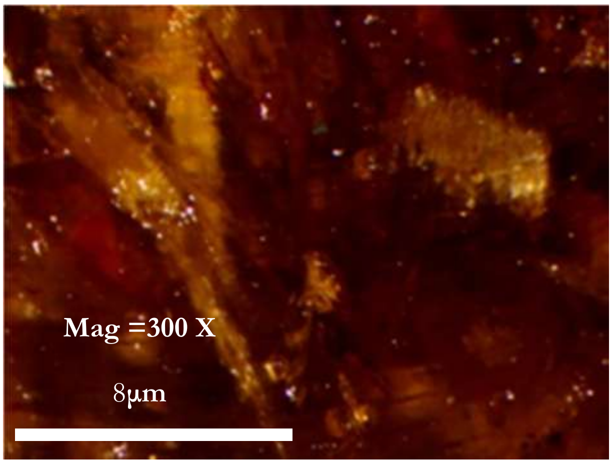
The results of the surface roughness test for pinewood dust are shown in Figure 13. It was revealed that under a Nikon SMZ 745T microscope, the cut surface was examined for evidence of bonding between the pinewood dust fibres and vinyl ester resin at the microscopic level. The microscope images are displayed in Figure 14. It was revealed that pinewood dust fibres would stick to vinyl ester in the area where the failure occurred without pulling out the fibre. Natural fibres can absorb most strains, and stress is effectively passed to the fibres. The pinewood dust was entirely coated with vinyl ester resin, a synthetic resin.



(a)



(b)



(c)

Fig. 14 *(a) 5,000rpm, (b) 20,000rpm and (c) 30,000rpm*

As a result of air bubbles, a few voids are visible (Fig. 14 b), indicating that smaller pinewood dust volumes have been added. Feed rate is found to be the most significant effect in producing the minimum value of arithmetic average surface roughness, (*Ra*).

4 Conclusions

The primary objective of this research is to investigate the significant parameters that determine the proportion of fibres in a composite reinforced with natural fibres, as well as the mechanical and physical behaviours of that composite. A discussion was included to provide a more thorough analysis of the mechanical and physical data measured during the tensile strength, Charpy V-notch impact, flexural strength and surface roughness tests. The results were analysed to determine the aspects that must be considered for increasing the quality of natural fibre contents in terms of mechanical and physical properties. The varying results between tensile, impact and flexural happen due to the inconsistency in thickness for each specimen due to a manual hand layup process. Even a slight increase in the thickness of the fibre composite without sacrificing much on the weight will affect the increasing/decreasing of the tensile, impact and flexural properties.

There are numerous ways to make the current experiment more realistic by extending it. And for future work, the present study is carried out without software. It is suggested to find a new method of an experiment by introducing the design of experiment (DOE) software other than manually calculating the ratio for pinewood and vinyl ester.

Acknowledgement

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References

[1] F. CHEGDANI, M. EL MANSORI, F. CHEGDANI, AND M. EL MANSORI. (2019). Science Arts & Métiers (SAM) New multiscale approach for machining analysis of natural fiber reinforced bio-composites.

[2] C. BALEY. (2002). Analysis of the flax fibres tensile behaviour and analysis of the tensile stiffness increase. [Online]. Available: *www.elsevier.com/locate/compositesa*

[3] K. N. KEYA, N. A. KONA, F. A. KOLY, K. M. MARAZ, MD. N. ISLAM, AND R. A. KHAN. (2019). Natural fiber reinforced polymer composites: history, types, advantages, and applications. *Materials Engineering Research*, vol. 1, no. 2, pp. 69–87, doi: 10.25082/MER.2019.02.006.

[4] R. HOSSAIN, A. ISLAM, A. VAN VUURE, AND I. VERPOEST. (2013). Processing dependent flexural strength variation of jute fiber reinforced epoxy composites. Vol. 8, no. 7, [Online]. Available: https://www.researchgate.net/publication/275034034

[5] J. ANDRZEJEWSKI, M. BARCZEWSKI, AND M. SZOSTAK. (2019). Injection molding of highly filled polypropylene-based biocomposites. Buckwheat husk and wood flour filler: A comparison of agricultural and wood industry waste utilization. *Polymers (Basel)*. Vol. 11, no. 11, Nov, doi: 10.3390/polym11111881.

[6] F. CHEGDANI, S. MEZGHANI, M. EL MANSORI, AND A. MKADDEM. (2015). Fiber type effect on tribological behavior when cutting natural fiber reinforced plastics. *Wear*, vol. 332–333, pp. 772–779, May, doi: 10.1016/j.wear.2014.12.039.

[7] F. CHEGDANI, S. MEZGHANI, AND M. EL MANSORI. (2016). On the multiscale tribological signatures of the tool helix angle in profile milling of woven flax fiber composites. [Online]. Available: https://hal.archives-ouvertes.fr/hal-02151211

[8] F. CHEGDANI, S. MEZGHANI, AND M. EL MANSORI. (2017). Correlation between mechanical scales and analysis scales of topographic signals under milling process of natural fibre composites. *Journal of Composite Materials*. Vol. 51, no. 19, pp. 2743–2756, Aug, doi: 10.1177/0021998316676625.

[9] F. CHEGDANI AND M. EL MANSORI. (2021). Numerical Modeling of the Machining Behavior of Natural Fiber Composites. in *Encyclopedia of Materials: Composites*, Elsevier, pp. 197–208. doi: 10.1016/b978-0-12-819724-0.00016-1.

[10] N. GUPTA AND M. DODDAMANI. (2018). Polymer Matrix Composites. *JOM*, vol. 70, no. 7. Minerals, Metals and Materials Society, pp. 1282–1283, Jul. 01, doi: 10.1007/s11837-018-2917-x.

[11] P. BALAKRISHNAN AND M. A. HUSIN. (2020). Coconut Fiber Panel towards Acoustical Performance. [Online]. Available: https://www.researchgate.net/publication/342765959

[12] D. WANG. (2019). Machinability of natural-fibre-reinforced polymer composites: Conventional vs ultrasonically-assisted machining. *Composites Part A: Applied Science and Manufacturing*, vol. 119, pp. 188–195, Apr, doi: 10.1016/j.compositesa.2019.01.028.

[13] J. KUŽEL AND R. RŮŽEK. (2022). Vacuum System for Reinforcing Fabric Handling. *Manufacturing Technology*, no. 2, pp. 204–210, doi: 10.21062/mft.2022.027.

[14] J. SOBOTKA, P. SOLFRONK, AND D. KORECEK. (2020). Influence of stress state on the yield strength of aluminium alloy. *Manufacturing Technology*, no. 1, pp. 92–97, Jun, doi: 10.21062/mft.2020.005.

[15] Drilling behavior of flax/poly(lactic acid) bio-composite laminates: An experimental investigation. [Online]. Available: http://mc.manuscriptcentral.com/jnf

[16] J. FAJRIN AND N. HERLINA SARI. (2018). Shear properties evaluation of natural fibre reinforced epoxy composites using V-notch shear test. In *MATEC Web of Conferences*, Aug, vol. 195. doi: 10.1051/matecconf/201819502004.

[17] M. A. HUSIN AND S. LAU. (2018). Kenaf fibre composites as promising green-composites for automotive car door map pocket application The use of nature design... View project. [Online]. Available: https://www.researchgate.net/publication/325287917

[18] N. S. NASIR, N. A. WAHAB, B. BIN SOFIAN, R. IZAMSHAH, AND H. SASAHARA. (2021). Experimental Investigations Towards Hole Accuracy in Micro-Drilling of Carbon Fibre Reinforced Polymer Material. *Manufacturing Technology*, no. 3, pp. 381–386, doi: 10.21062/mft.2021.050.

[19] M. AMRAN. (2014). Jurnal Teknologi Surface Roughness Optimization in Drilling Process Using Response Surface Method (RSM). [Online]. Available: www.jurnalteknologi.utm.my

[20] N. A. WAHAB. (2019). Development and Analyzation of Linear Positioning Table for Drilling Machine. [Online]. Available: www.arpnjournals.com

[21] M. PAPROCKI, M. WYGODA, P. WYCZESANY, AND P. BAZAN. (2021). Symptoms of Wear HSS Cutting Tools in Different Wear Stages. *Manufacturing Technology*, no. 3, pp. 387–397, doi: 10.21062/mft.2021.047.

[22] N. A. WAHAB. (2020). Design Improvement of Fixable Clamping Jig for Milling Machine Based on Surface Roughness. Vol. 15, no. 4, [Online]. Available: www.arpnjournals.com

[23] E. FEREDE. (2020). Evaluation of mechanical and water absorption properties of alkaline-treated sawdust-reinforced polypropylene composite. *Journal of Engineering (United Kingdom)*, doi: 10.1155/2020/3706176.

[24] H. JAYA. (2018). The Effects of Wood Sawdust Loading on Tensile and Physical Properties of Up/Pf/Wsd Composites. In *IOP Conference Series: Materials Science and Engineering*, Dec, vol. 454, no. 1. doi: 10.1088/1757-899X/454/1/012193.

[25] Z. SALLEH, S. YUNUS, N. R. N. M. MASDEK, Y. M. TAIB, I. I. S. AZHAR, AND K. M. HYIE. (2018). Tensile and Flexural Test on Kenaf Hybrid Composites. In *IOP Conference Series: Materials Science and Engineering*, Mar. Vol. 328, no. 1. doi: 10.1088/1757-899X/328/1/012018.