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QUALITY OF MACHINING IN THE COMPOSITE OF BANANA STEM FIBER AND POLYURETHANE DERIVED FROM CASTOR OIL

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Abstract. *The production of goods using planted forest raw materials, such as MDF, has been questioned by consumers and researchers due to environmental issues involved in their manufacturing process, such as the use of petroleum source polymers, the destination of the waste generated by the processes the end of the product's life. In this scenario, the aim is to develop materials that use raw materials and inputs from renewable sources and to promote the recycling of waste. A proposed solution is the composite reinforced with natural fibers, but lack knowledge about machining possibilities through existing systems, as well as the superficial results after the necessary processes that are important for commercial use. The aim of this work was to analyze the machinability of the composite of banana stem fiber agglutinated with polyurethane derived from castor oil through a CNC milling machine, evaluating surface roughness and delamination. It was found that the surface roughness showed better results with increased cutting speed and feed rates intermediates. Delamination is mainly influenced by the arrangement and geometry of the fibers used in the composite panel, having no relationship with cutting speeds and feed rate.*

Keywords: *Composites - Natural fibers – Milling - Surface roughness - Delamination*

1. INTRODUCTION

Market segments, such as construction and furniture industries, use fiberboard or wood particleboard to execute their products and services (Deus, 2014). For their manufacture, raw materials from forests are used, mixed with binding compounds that can be harmful to the environment and to humans (Silva, 2012; Silva, 2013). An alternative to this problem are the composites that use waste discarded by extractive and manufacturing processes, such as the banana tree stem (Merlini, 2011). This substitution also seeks to respond to environmental issues, such as waste generated by production processes and materials used in the production of goods (Calegari et al, 2016; Teixeira et al, 2016). In order to obtain these composites, adhesives are used, such as polyurethane derived from castor oil (Merlini, 2011).

For the commercial use of natural fiber composites, it is necessary to know their machinability in manufacturing processes through drilling, cutting and milling (Mahmoud et al, 2016). These materials require quality on the machined surface, since machining and driling made will be used later for assembly, application of coatings, paints, or provide visible aesthetic details.

The irregularity of a machined part is characterized as roughness, which are undulations caused by the tool when passing through the part, due to vibrations, tool bending and machining force. Roughness is one of the parameters for evaluation of machining quality (Machado, 2011). The removal or insufficient cutting of the fibers used as reinforcement in composites is called delamination, used as a method of measuring the quality of the channel generated by milling (Chandramohan, 2011).

The machining of these composites differs from traditional materials due to the anisotropy and abrasiveness of the fibers, which can lead to different types of defects, such as delamination and fiber displacement (Gohil et al, 2015).

Parameters such as cutting speed, feed and depth of cut was used to evaluate the roughness and delamination in natural fibers composites with polyester and epoxy matrix (Mahmoud et al, 2016; Babu et al, 2013; Azmil et al, 2016). Sheikh-Ahmad et al. (2012) describe multidirectional characteristics of the fibers used as reinforcement in composites, causing a variation of the orientation during the cutting path. The cut occurs differently from other ductile materials, causing a series of fractures parallel or through the direction of the fibers (Fig. 1).

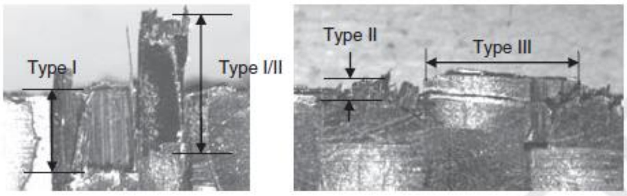

Figure 1. Types of delamination in composites with natural fibers (Sheikh-Ahmad et al, 2012).

Industries that use reconstituted panels use computerized numerical control machines (Deus, 2014), as cutters and milling machines for cuts, inserts and drills. Cutting data, such as speed and tool types, for new natural fiber composites are required for the use of the material in existing processes (Mahmoud et al, 2016).

2. COMPOSITE OF BANANA STEM FIBER AND POLYURETHANE DERIVED FROM CASTOR OIL

Composites can be defined as multiphase materials, chemically different, composed of different materials, providing the best combination of their properties (Merlini, 2011). They are usually constituted by two phases, the matrix, which is continuous and involves the second phase, called dispersed or reinforced (Callister, 2012). They can be classified from the geometry of their dispersed phase into fiber reinforced and structural reinforced particles. The appropriate combination of matrix and dispersed phase provides the creation of materials with specific properties, used in the aerospace, biological, submarine, transport and engineering industries (Merlini, 2011).

Natural fiber-reinforced composites, due to their positive environmental impact, may replace synthetic fibers obtained from petroleum sources in some applications (Mahmoud et al, 2016; Merlini, 2011).

From renewable raw material (Cangemi et al, 2009), biodegradable (Cangemi et al, 2008), low degree of toxicity (Merlini, 2011; Calegari et al, 2016; Santos et al, 2013), the polyurethane derived from castor oil can be used as a polymer matrix (Protzek et al, 2016).

The use of banana stem fibers as reinforcing phase in composites is justified by the fact that Brazil is one of the world's largest producers of the plant, and after harvesting the fruit, the unused stalks are left to decompose in the environment. The fibers are removed from their pseudocaule through manual processes with the aid of cutting tools (Merlini, 2011). The composite obtained can be used as raw material in the manufacture of furniture, decorative articles, partitions, packaging, among other applications (Calegari et al, 2016; Mahmoud et al, 2016).

The aim of this work is to analyze the machinability of a composite obtained with the use of residues from the banana stem agglutinated with polyurethane derived from castor oil, through a CNC milling machine, looking for suitable cutting parameters on surface finish.

3. EXPERIMENTAL PROCEDURE

3.1 Preparation of banana stem fiber

The preparation of the composite used in the tests began with the preparation of the fibers removed from the pseudocaule of the banana tree for a first drying (Fig. 2). The pseudocaule was hand-divided into strips approximately 1000 mm long and 30 mm wide. The thickness is given by the manual separation made in the stem, causing a natural cut stimulated by the very arrangement of the fibers of the material. The strips waited 7 days to dry naturally outdoors, without the aid of equipment. After this time, the fibers were cut into pieces of approximately 5 mm in length, effected manually with the aid of scissors. After this cut, they were kept in an oven for approximately 24 hours at 60 ° C.

(a) (b)

Figure 2. Pseudocaule of the banana tree: (a) removal of the fibers; (b) cross-section.

3.2 Preparation of polyurethane derived from castor oil

The polyurethane used in this work was acquired by the company Kehl, from São Carlos - SP, Brazil. It was supplied as a bi-component, a poliol and a pre-polymer, AG 101. The preparation of the polymer was made according to the supplier instructions, and the ratio poliol and pre-polymer was 1:1.

3.3 Preparation and molding of composite board

The fibers and the polymer were mixed manually with a 50/50% ratio. The mixture was pressed in a hydraulic press at a pressure of 3 MPa for 1 hour at 60 ° C, forming the workpieces, 7 mm thick (Fig. 3).

Figure 3. Composite workpiece

3.4 Density, swelling and bending tests

The density analysis of the specimens was carried out according to standard EN317: 2002.

In swelling analysis, the assay was performed by submerging 5 samples of the composite in distilled water for 2 and 24 hours.

The mechanical characterization of the composites was done through the bending test. The three-point flexural tests were performed according to ASTM D790-03 using a universal EMIC DL10000 test machine with a load cell of 5 kN and a test speed of 2 mm / min.

3.5 Sample preparation

The sample was squared on a table sliding circular saw Invicta Delta with 80 trapezoidal teeth, titanium micro grain coating, ensuring the square and symmetry of the plate for the tests. The plate obtained the final measurements of 145 x 125 mm, with the thickness of about 7 mm. Then through-holes were executed located 10 mm from the corners of the plate, in a vertical bench drilling machine, using a twist drill. These holes were used to fix the plate to the cutting table of the CNC milling machine with screws (fig. 4). This fastening was also used to ensure that the plate did not vibrate or suffer movement during machining operations.

Figure 4. Composite plate fixed to the CNC table and the milled channels.

3.6 Milling

The end milling operations were performed on a 3-axis CNC milling machine Vetor (Fig.5). The cutting tool used was a 2 flute uncoated cemented carbide end mill, 5 mm diameter, 60 mm length and 25 mm overhang. Channels have been opened with 15 mm wide type in a raster strategy, stepover 3.5 mm and depths of 2 and 4 mm, resulting discordant sections on both sides of the channels. The milled channels had 125 mm length. Cutting paths were first designed in Autocad 2016 software to determine milling paths. Then, the cutting program was developed in the CAM Artcam / Delcam 2008 software, to generate the cutting paths. The adjustment of the milling spindle rotation was performed using the existing frequency inverter on the machine, according to the values determined in Table 1, and the rotation was calibrated with a digital laser tachometer Icel TC5010 model, during the process. The CNC milling machine management software is the Mach3.

Figure 5. CNC milling machine used in the study.

Table 1 show the values of the cutting speed (V_c), feed rate (V_f) and machining depth (a_p) used in the study, determined from values found in previous works already carried on composite of natural fibers with polyester matrix (Babu et al, 2013) and with epoxy matrix (Azmil et al, 2016). The choice of these values is justified as a starting point for the research, as it provides comparative data for the analysis of those interested in the use of these materials, and for being considered also composites with natural fibers, similar to the composite tested in this work. From the values considered optimal by the researchers, parameter variations were determined to provide a more comprehensive investigation of the results in the machining of the composite in question, especially a higher value in the depth of cut. This higher value of depth is justified by the need to investigate the behavior of the material in deeper millings, for full cut or channels for assemblies.

Table 1. Machining parameters.

Tests	RPM	V_c (m/min)	V_f (m/min)	a_p (mm)
1	2000	37,68	0,2	2
2	2000	37,68	0,3	2
3	2000	37,68	0,4	2
4	5000	94,2	0,2	2
5	5000	94,2	0,3	2
6	5000	94,2	0,4	2
7	2000	94,2	0,2	4
8	2000	94,2	0,3	4

3.7 Measurement of surface roughness

Taylor Hobson Surtronic s-128 surface roughness tester was used to measure the workpiece surface roughness. The roughness parameters are defined as sampling length (cut off) 0.8mm x 5, based on the Ra values obtained in studies with similar materials (Babu, 2013). The measurements emphasized the parameters of average (Ra) and total (Rt) roughness, given in units of micrometer (µm). Two measuring points were chosen (Fig. 6).

Figure 6. Points of measurement of the roughness and the rugosimeter used in the measurements.

3.8 Delamination measurements

Measurement of delamination was determined by microscope observation using Olympus model SZX 10 with 10x magnification. The images were analyzed in the Analysis Get It software. The defects found in each milled channel were quantified and the significant defects were analyzed.

4. RESULTS AND DISCUSSION

4.1 Values of density, swelling, water absorption, maximum stress and elastic modulus in flexion

Table 2 shows the values of density, swelling, water absorption, maximum tensile bending stress and modulus of elasticity in tension for the banana / PU composite.

Table 2. Test values in samples of the banana / PU composite

Density	(0,71±0,03)g/cm³
Swelling	(2,69±1,45)%
Water absorption	(10,08±1,88)%
Maximum tensile bending stress	3,51 MPa
Modulus of elasticity in tension	0,39 GPa

It is noted that the density of the composite was close to the value of the available commercial MDF panel thickness of 6 mm. The swelling values are less than 12%, recommended value for MDF by NBR 15316-2. These values can be attributed to the wetting efficiency of the banana fibers by the PU values of absorption and swelling. According to Vasco (2017) the isocyanate reacts with the OH of the natural fibers forming the urethane bond, which justifies the flexural tension values found.

4.2 Analysis of the average (Ra) and total (Rt) roughness for end milling

Table 3 shows the values of average roughness (Ra) and total roughness (Rt) measurements in two points of samples with an average Ra for each channel machined.

Table 3. Values of average roughness (Ra) and total (Rt) measurements on the samples.

Tests	V_c	V_f	a_p	Ra point 1 (µm)	Ra point 2 (µm)	**Ra (average) - µm**	Rt point 1	Rt point 2
1	37,6	0,2	2	7,36	15,0	**11,18**	76,4	87
2	37,6	0,3	2	8,36	17,50	**12,93**	44,2	119
3	37,6	0,4	2	7,90	7,13	**7,51**	64,4	52,8
4	94,2	0,2	2	8,95	8,29	**8,62**	60,5	59,8
5	94,2	0,3	2	4,80	5,49	**5,14**	60,1	49,6
6	94,2	0,4	2	12,1	6,92	**9,51**	84,6	49,8
7	94,2	0,2	4	6,85	9,73	**8,29**	53,0	74,8
8	94,2	0,3	4	7,82	8,57	**8,19**	53,8	111

In samples 1, 2 and 6 a significant difference can be observed in the values of Ra as well as in Rt. These differences are a consequence of the reinforcement used in the composite, where the process of obtaining the fibers, executed manually, provided different dimensions and shapes. These fibers, when added to the polyurethane, are randomly positioned. At the moment of pressing, this random positioning generates regions with less matrix filling. Chegdani et al. (2015) evaluated the tribological behavior of three different types of natural fibers during milling. The authors describe that natural fibers are soft due to the high content of cellulose, and with the contact with the cutting tool can deform. The cut is dependent on the stiffness of the fibers and the adhesion between them. This creates a viscoelastic behavior, causing a slip between the fibers during the cutting, disrupting the cutting process and contributing to the increase of the roughness.

The increase of the depth of cut did not alter the values of the surface roughness in relation to the smaller depths, showing the same behavior of the smaller depth.

Figure 7 shows the difference accounted for the measurement of test 2, illustrating the previous comments. Rt of point 1, with a value of 44.2 μm and of point 2, of the measurement with 119 μm, in the same profile, caused a significant difference in the value of the average roughness. This shows the existence of gradients due to the behavior of the fibers during the cutting process.

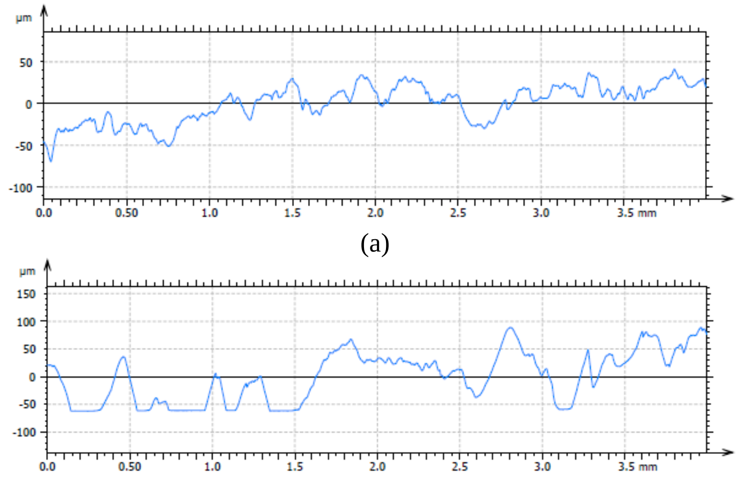

Figure 7. Measurements of the roughness of point 1, in sample 2, for Ra = 8.36 μm / Rt = 44.2 μm (a). Measurements of the roughness of point 2, in sample 2 for Ra = 17,5 μm / Rt = 119 μm (b).

Figure 8 shows the surface roughness for different machining parameters. The best result was with Vf = 0.3 (m / min) and Vc = 94.2 (m / min). The highest value was found with Vf = 0.3 (m / min) and Vc = 37.68 (m / min). The values of Ra found in the tests were below those found by Deus (2014) in the MDF milling, but above those found by Babu (2013) in the milling of polyester matrix banana fiber composites. There was a tendency of decreasing of Ra values with the increase of Vc in the advances of 0.2 and 0.3 m/min. For an advance of 0.4 m/min the lower Vc presented a better roughness.

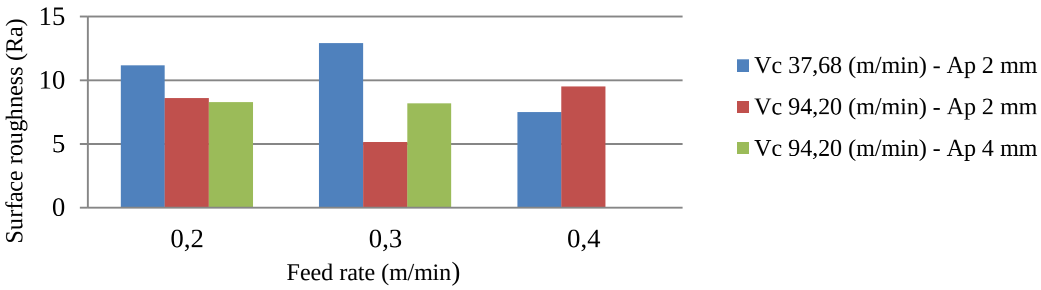

Figure 8. Surface roughness for different cutting parameters.

4.3 Analysis of delamination

Figure 9 shows the number of defects found in each machined channel. The defects considered relevant to the proposed use of this composite were quantified. The geometry and size of defects found possible not interfere with assembly parts, being within an acceptable tolerance. Defects by type were not separated as pointed out by Sheikh-Ahmad et al (2012).

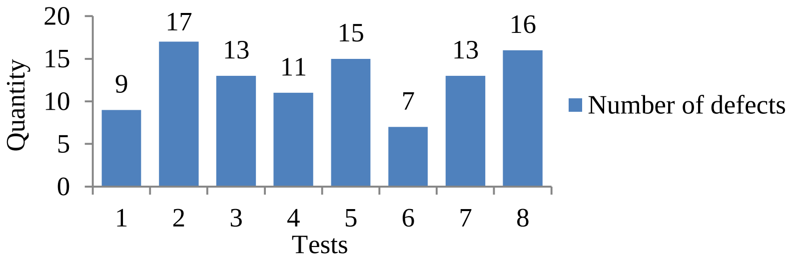

Figure 9. Quantities of defects (delamination) found in the machined channels.

The best result was obtained in test 6 (Vc = 94.2 / Vf = 0.4 / ap = 2 mm), with 7 defects. The worst result was obtained in test 2, with 17 defects (Vc = 37.68 / Vf = 0.3 / ap = 2 mm). There was no correlation between the surface roughness and the delamination, nor was there a tendency of the defects to decrease as a function of the increase of the cutting speed or the feed rate. The four types of defects pointed out by Sheikh-Ahmad et al (2012) were observed, due to the multidirectional direction of the composite fibers.

Figure 9 shows the defects found along the channel for the worst delamination result in workpiece 2. Both sides of the channel were milled with the tool cutting in the up milling direction due to the movement performed to open the channel. This method was used to determine the amount of defects found in all machined channels.

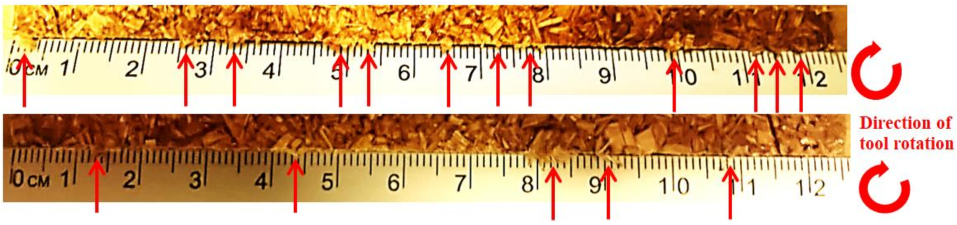

Figure 9. Defects presented in test channel 2 (Vc = 37.68 / Vf = 0.3 / ap = 2 mm).

Figure 10 (a, b, c and d) shows the images of the channels obtained in the microscopy, with the main defects observed.

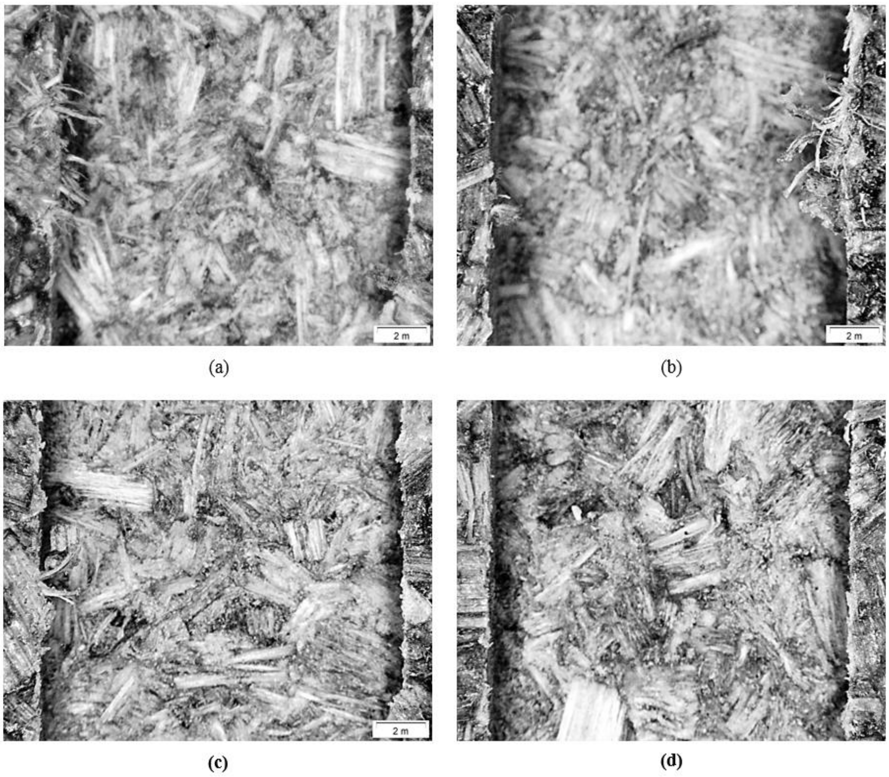

Figure 10. Detail of the major defect found in channel 2 (a). Detail of the major defect found in channel 7 (b). Detail of an inclined and uncut fiber in channel 5 (c). Detail of channel 6 with smaller amounts of delamination (d).

Figure 10 (a), 10 (b) and 10 (c) fibers can be observed which are not completely cut. As classified by Sheikh-Ahmad (2012), Type I defects, consisting of fibers broken into the machined edge, were not observed. The relevant defects found can be classified as type II, which are uncut and remain on the machined edge. This is because the fibers fold, divide and move away from the cutting path, not being cut, returning with a spring effect after the tool passes, especially in fibers which are located a layer below the surface fiber. As observed in the images, these defects occurred mainly in the fibers that have a negative slope in relation to the advance of the tool. The fibers with positioning at 0 ° or greater angles present these defects, but not significantly for the use of the studied composite. Type III defects, which are fibers parallel to the direction of the cut and leave small burrs attached to the cut fiber, creating a shaggy appearance, also appeared, but were not considered significant for the use of the material. Sheikh-Ahmad (2012) observes that the positioning of the fibers in the composites is the most important factor in determining the delamination of the material. Figure 12 (d) illustrates the best delamination results obtained in part 6. The edge presents a more homogeneous form and with minimum and acceptable defects. Figure 12 (a, b, c and d) also shows the multidirectional characteristic of the fibers positioned in the composite and the variation in size and shapes encountered.

5. CONCLUSION

The composite evaluated appears as an alternative to materials available in the market for use in parts with minor mechanical stress, such as packaging or certain pieces of furniture. The surface roughness of the machined channel showed results similar to those found in machining performed on the MDF. The use of the CNC milling machine for material machining found no restriction. The tool used did not suffer apparent malfunctions and did not appear residues fixed to the cutting edge, due to the influence of temperature in the process, despite the tests of cut with short duration. Regarding delamination, despite the defects pointed at the microscopic level, the quality of the machined edge can be considered satisfactory, due to the proposed use of this material.

As for machining, higher cutting speeds showed a tendency for better results. The different feed rates did not show a tendency to interfere in the definition of values. Depth of cut has not been shown to interfere with roughness or delamination results.

The best result achieved surface used Vc = 94.2 m / min and Vf = 0.3 m / min, obtaining an average roughness of 5.14 µm. This factor may vary depending on the random arrangement of the fibers in the composite panel, and also on the type of fiber used.

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7. REFERENCES

Azmil, H., Haron, C.H.C., Ghani, J.A., Suhaily, M., Sanuddin, A.B., Song, J.H., 2016. *Study on machinability effect of surface roughness in milling kenf fiber reinforced plastic composite (unidirectional) using response surface methodology.* Journal of Engineering and Applied Sciences.

Babu, G.D., Babu K.S., Gowd, B.U., 2013. *Effect os machining parameters on milled natural fiber-reinforced plastic composites.* Journal os Advanced Mechanical Engineering. 1:1-12.

Calegari, E.P., Oliveira, B.F., 2016. *Compósitos a partir de materiais de fontes renováveis como alternativa para o desenvolvimento de produtos.* Sustentabilidade em Debate - Brasília, v. 7, n. 1, p. 140-155.

Callister Júnior, W.D., 2012. *Ciência e engenharia de materiais: uma introdução*. 8. ed. Rio de Janeiro, RJ.

Chandramohan, D., 2011. *Drilling of natural fiber particle reinforced polymer composite material*. International Journal of Advanced Engineering. Stud.1: 134-145.

Chegdani, F., Mezghani, S., El Mansori, M., 2015. *Fiber type effect on tribological behavior when cutting natural fiber reinforced plastics.* Wear, 332-333, p.772-779.

Cangemi, J.M., Santos, A.M., Neto, S.C., Chierice, G.O., 2008. *Biodegradation of Polyurethane Derived from Castor Oil.* Polímeros: Ciência e Tecnologia, vol. 18, nº 3, p. 201-206.

Cangemi, J.M, Santos A.M., Neto, S.C., 2009. *Polyurethane: From Pillows to Condoms, a versatile polymer.* Química nova na escola. Vol. 31, N° 3, August.

Deus, P.R., 2014. *Analysis of the MDF milling CNC machining center.* 133 f. Thesis (Doctorate in Mechanical Engineering) – Faculdade de Engenharia do Campus de Guaratinguetá, Universidade Estadual Paulista, Guaratinguetá.

Gohil P.P., Chaudhary, V., Patel K., 2015. *Challenges in machining of natural fibre composites*. In: Manufacturing of natural fibre reinforced polymer composites. Springer, Cham.

Machado, A. R. et al., 2011. *Theory of machining materials* – 2. ed. – São Paulo: Blucher.

Mahmoud M. A. N.; Ramanathan A.; Khalid I. A., 2016. *Machinability of natural fiber reinforced composites: a review.* The International Journal of Advanced Manufacturing Technology.

Merlini, C., 2011. *Experimental analysis of polyurethane compositions derived form mamone oil and bananary fibers.* Dissertation (Master) - Pós-graduação em Ciência e Engenharia de Materiais da Universidade Federal de Santa Catarina, Florianópolis.

Protzek, G.R.; Koloski, J; Magalhães,W.L.E.; Neto,S.C.; Nascimento, E, M.; Azevedo, E., 2016. *Analysis of the physical properties of the sawdust and polyurethane composite derived from mamone oil.* XV Embramem - Encontro Brasileiro em Madeiras e em Estruturas de Madeira, Curitiba, PR, Brasil.

Santos, W.L.F., Silva, A.J.P., Cabral Junior, A.A., Mercury, J.M.R., 2013. *Fabricação de painéis de partículas de madeira tauari (Couratari oblongifolia) utilizando resina poliuretana de mamona.* Scientia Agraria, Curitiba, v.14, n.3, p.95-101, Set/Dez.

Sheikh-Ahmad, J.Y., Davim, J.P., 2012. *Cutting and Machining of Polymer Composites.* Wiley Encyclopedia of Composites, p.648-658.

Silva,D.A.L., 2012. *Life cycle assesment of mdp wood-based panel production in Brazil.* 207p. Dissertation (Master) – Escola de Engenharia de São Carlos, Universidade de São Paulo, São Carlos.

Silva, S.A.M., Christoforo, A.L., Panzera, T.H., Lahr, F.A.R. , 2013. *Medium density fiberboard manufactured with castor oil based polyurethane resin.*VÉRTICES, Campos dos Goytacazes/ RJ, v.15, n. 1, p. 7-20, jan./abr.

Teixeira, M.G., Santos Junior, E.C., Couto, E.C.S., 2016. *Application of ecology industrial concepts in product design with wood particulate waste eco-composite and discarded wooden pieces.* Revista Gestão Industrial. V.12, n01: p.200-219.

Vasco, M.C., Neto, S.C., Nascimento, E.M., Azevedo, E., 2017. *Gamma radiation effect on sisal / polyurethane composites without coupling agentes.* Polímeros, 27(2), 165-170.

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