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RESEARCH REGARDING MODELING MACHINABILITY BY MILLING OF POLYMERIC COMPOSITE SANDWICH PRODUCTS

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Abstract: *Milling is a machining operation most frequently involved in manufacturing parts of polymeric composites sandwich products. Due to their multi-component structure and to the special character of the individual components of polymeric composites sandwich products, the machining by milling of this has differences from those imposed by metal working operations. It is essential to ensure that the tool conditions selected are suitable for the material in order that machining result is satisfactory. Polymeric composites sandwich products are more difficult to machine than metals products, mainly because they are anisotropic, non-homogenous and they have three types of materials (fiber glass for the facesheets, an epoxy resin and a polyester core between the two faces) and these materials are put together inside the same product. During milling process, defects are introduced into the work piece and tools wear rapidly. Milling of polymeric composite sandwich products can be used with proper tool design and operation conditions. The objective of this paper is to investigate the factors with control machining, surface quality and tool wear in order to have optimal machining parameters and obtaining processed surfaces with superior quality and precision.*
Keywords: *Modeling, Machining, Milling, Polymeric Composite Sandwich.*

1. INTRODUCTION

In the last years, rapid advances in construction material technology have enabled civil engineers to achieve impressive gains in the safety, economy, and functionality of structures built to serve the common needs of society. To meet the market need, researchers and industries are developing manufacturing methods without a reference that thoroughly covers the manufacturing guidelines. Polymeric composite sandwich products are the material of choice because of their weight and strength advantages.

Aerospace manufacturers demand stronger and lighter materials. By their nature, these materials are predisposed to complications when it comes to milling and drilling. Polymeric composite sandwich products have been used in applications such as aeronautics, cars, building, and energy. Engineers realized their advantages in terms of weight reduction, corrosion resistance, and the possibility of tailoring components in order to have a better withstand predicted mechanical loads. [6]

The selection of the materials depends on the performance and intended use of the product. A summary of polymeric composite sandwich products benefits include: light weight, high strength-to-weight ratio, directional strength, corrosion resistance, weather resistance, dimensional stability (low thermal conductivity, low coefficient of thermal expansion), non-magnetic, high impact strength, low maintenance, long term durability, part consolidation, small to large part geometry possible, tailored surface finish.

2. COMPONENTS OF POLYMERIC COMPOSITE SANDWICH PRODUCTS

a) Facesheets

The facesheets of the polymeric composite sandwich products are made of fiberglass with epoxi resin, where the fiberglass distribution are random.The dimensions of samples test in this paper are: 100x200 and the height is variable. The height depends to the facesheet thickness, and there are 3 categories of the skin made of fiberglas with epoxy resin: 1.5, 2 and 4 mm. However, the facesheets will have their mechanical properties substantially altered by the epoxy resin with hardener that is used to bond it the sandwich core, with some features and product benefits presented in table 1 and 2.

Table 1. Features and product benefits

-Good durability -Easy impregnation -Hight tensile strength, suitable for filament winding or continuous laminating	-Good resistance to watering and chemical agents in anticorrosion applications -Excellent clarity of the laminates

Table 2. Product availability (roll characteristics)

Standard weight(g/m^2)
300
450
600

b) Core

The core is made of extruded polyester with are the density bigger then expanded polyester, with characterstics in table 3.

Table 3. Characteristics of core polystiren (Apla Xfoam)

		Unit	Apla Xfoam
Density		Kg/m^3	28
Thermal conductivity – λ (10^o)		W/mK	0.030
Compressive strength at a strain of 10 %		N/mm^2	0.30
Immersion parts water absorption		% volume	0.5
Permeability to water vapor		Ng/Pa sec m^2	1.9
Fuel grade		-	C2
Dimensions	Length	mm	2500
	Width	mm	600
	Thickness	mm	25-50

c) Adhesive

The comercial name of the adhesive is SIKA, and is a resin (component A) combined with a hardener (component B). The resin and hardener are used for the bonding the facesheets with the core. It takes a few hours to strenghten, and the technical dates are represented in table 4.

Table 4. Technical date of SikaForce 7718 L30

Properties	**Component A** SikaForce 7718 L30	**Component B** SikaForce 7010
Basic chemical composition	Polyols with filler	Isicyanat derivaties
Color	Beige	Brown, transparent
Color after mixing	Beige	
Strengthening mechanism	Repeated additive	
Density	Aprox. 1,6g/cm^3	Aprox. 1,2g/cm^3
Density after mixing	Aprox. 1,5g/cm^3	
Mixing ratio -- /volum -- /weight	100 100	25 19
Viscosity	Aprox. 10000 mPa-s	Aprox. 250 mPa-s
Viscosity after mixing	Aprox. 3000 mPa-s	
Application interval	Aprox. 35 min	
Temperature range for application	15-30^o	
Tensile strength	Aprox. 11N/mm^2	
Elongation at break	Aprox. 11%	

3. MACHINABILITY CONCEPT AT MILLING POLYMERIC COMPOSITE SANDWICH PRODUCTS

Milling the polymeric composite sandwich products are probably the greater risk than the potentially toxic chemicals used in composites manufacture, like: dust and decomposition products arise and essential to minimize this risk by extraction at source, or entrapment in a stream of gas or water. Machining by milling shows that are breaking micro zone who become primers of break for the polymeric composite sandwich structures. The three principal machining processes are classified as turning, drilling and milling, where the milling operation is the operations in which the cutting tool rotates to bring cutting edges to bear against the work piece. Milling machines are the principal machine tool used in milling. [2]

Milling is an operation most frequently involved in manufacturing parts of polymeric composites sandwich products. In milling, a rotating tool with multiple cutting edges is moved slowly relative to the material to generate a plane or straight surface.

The direction of the feed motion is perpendicular to the tool's axis of rotation. The speed motion is provided by the rotating milling cutter. The specified machining accuracy is achieved by reducing errors in the positions and displacement of the executive components of the milling tool.

The second approach is to optimize the factors regulation the characteristics of the technological process-specifically, to select the best cutting conditions and cutter geometry, the best tool material, and so on.

To find optimal milling conditions that ensure specified product quality and precision, with specified productivity, we need to take account of a whole set of factors directly responsible for milling errors, such as the expected milling forces and parameters characterizing the rigidity of the technological system.

There is a continuously variable angle of the milling tool due to random distribution of reinforcing elements in the form of chopped fibers. Random distribution is in terms of positioning geometry and fibers concentration. Milling is an intermittent and random phenomenon in terms of mathematical modeling of cutting. Optimization of the geometric and structural parameters of the tool, the milling conditions and the state of the machined surface permits determination of the state of the machined surface, determination of the features of the technological process permitting greater productivity in machining complex surfaces.

Milling the polymeric composite sandwich products cannot be assessed with a single evaluation criterion. It is proposed to use the name of milling function, meaning any relationship of dependence between sizes interacting in that milling process. [3]

$$Y = \Gamma(X_1, X_2, \ldots, X_j) \quad \textbf{(1)}$$

Where: x_j (j = 1, 2, k) are independent variables (example: characteristics of the work-piece, milling tool parameters, the milling regime parameters, etc.) Y-dependent variable (example: tool wear, milling forces, processed surface roughness, processing cost, etc.) Γ represents the concrete form of the dependence relationship (polynomial function, exponential, etc.).

3.1. Milling conditions

Relative motion is required between the tool and part to perform a milling operation. The primary motion is accomplished at a certain milling speed. In addition, the tool must be moved laterally across the part. This is a much slower motion, called the feed. The remaining dimension of the cut is the penetration of the milling tool below the original part surface, called the depth of cut. Collectively, speed, feed, and depth of cut are called the milling conditions. They form the three dimensions of the milling process, and for certain operations, their product can be used to obtain the material removal rate for the process:

$$R_{MR} = vfd \quad \textbf{(2)}$$

Where: R_{MR} - the material removal rate in *mm*^{3}*/s*, v - the milling speed in *m/s*, f - the feed in *mm*, d - the depth of cut in *mm*.

3.2. Variables of the process

The general goal of process model formulation is to quantitatively relate the dependent process variables to the independent variables. For example: milling speed, depth of cut, feed rate, milling tool, geometry, milling fluid. The process parameters determine process behavior, and process performance is described by the dependent variables.

For example: milling forces, milling zone temperature, tool-chip friction, finished surface roughness, milling surface region (sub-surface) properties. Assessment of machinability by milling is done by analyzing the influence of various factors, representing in figure 1, for the behavior of materials. [1]

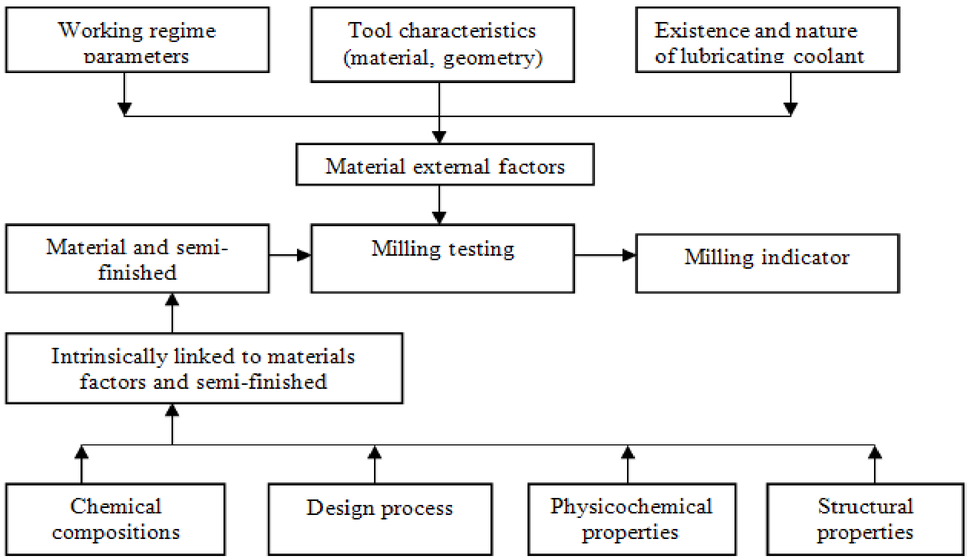


Figure1. The factors influencing the milling process at the polymeric composite sandwich products

Milling is not just one process; it is a group of processes. The common feature is the use of a milling tool to form a chip that is removed from the work part, called “swarf”. The chip flow for the milling process is represented in figure 2. To perform the operation, relative motion is required between the tool and part, represented in figure 3. This relative motion is achieved in most milling operation by means of a primary motion, called "milling speed" and a secondary motion called "feed"'. The shape of the tool and its penetration into the part surface, combined with these motions, produce the desired shape of the resulting part surface. Milling use the rotating multiple-milling-edge tools. Although the shapes of these tools are different from a single-point tool.

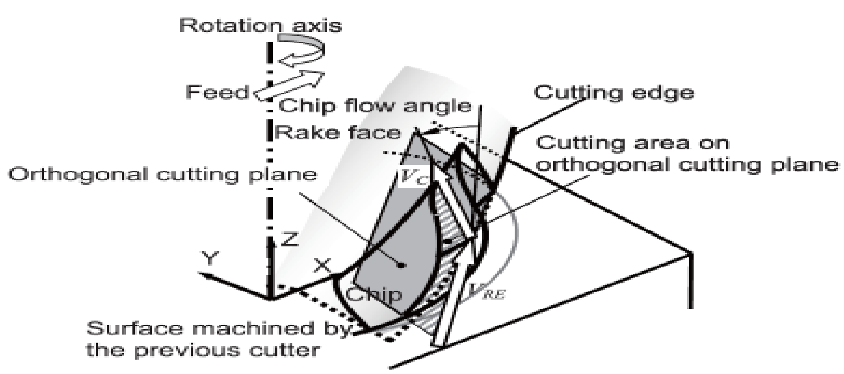


Figure 2. Chip flowing in milling process at the polymeric composite sandwich products

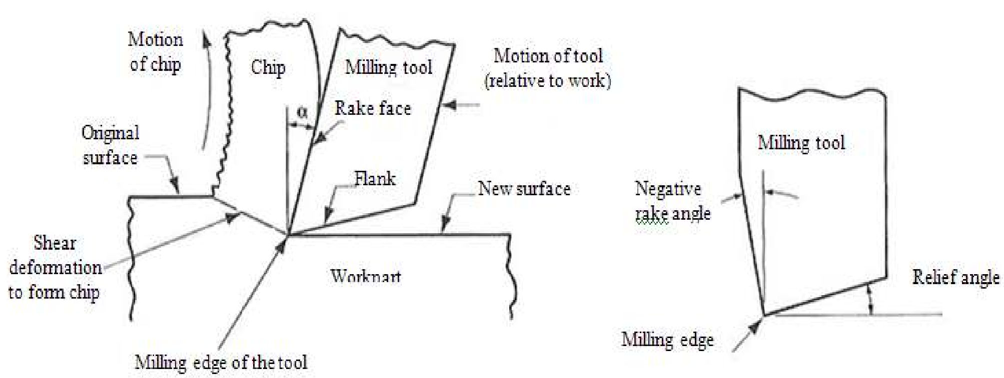


Figure 3. Basic milling process at the polymeric composite sandwich products

The machinist needs three values: **S**, **F** and **Depth** when deciding how to mill a new material with a new tool. However, he will probably be given values of $\mathbf{V_c}$ and $\mathbf{F_z}$ from the tool manufacturer. **S** and **F** can be calculated from them:

Spindle Speed:

$$S = \frac{1000V_c}{\pi D}$$

(3)

Feed rate:

$$F = zSF_z \qquad (4)$$

Where, Surface cutting speed (V_c), Spindle speed (S), Diameter of the tool (D), Feed per tooth (F_z), Feed rate (F).

During milling of polymer composite sandwich products tool comes in contact with plate glass fiber and thus appears the *abrasion wear*, and during milling at the core of extruded polystyrene thus appears *adhesion wear*, represented in figure 4. [5]

Effects of milling tool wear are: increase surface roughness; increasing the required mechanical technology system components, leading to increased energy consumption.

Tool wear phenomenon will: deteriorating processing accuracy; obtaining a large rough-processed surface. *Factors causing wear of milling tools are:* the friction between elements in contact; heat during cutting; structural changes in the material tool; phenomena of adhesion and abrasion between the tool and the work part material, and the fibers pulling represented in figure 5. The hole left behind when the fiber is removed of the process of milling, and the final surface remains with some defects, there are representing in figure 6.

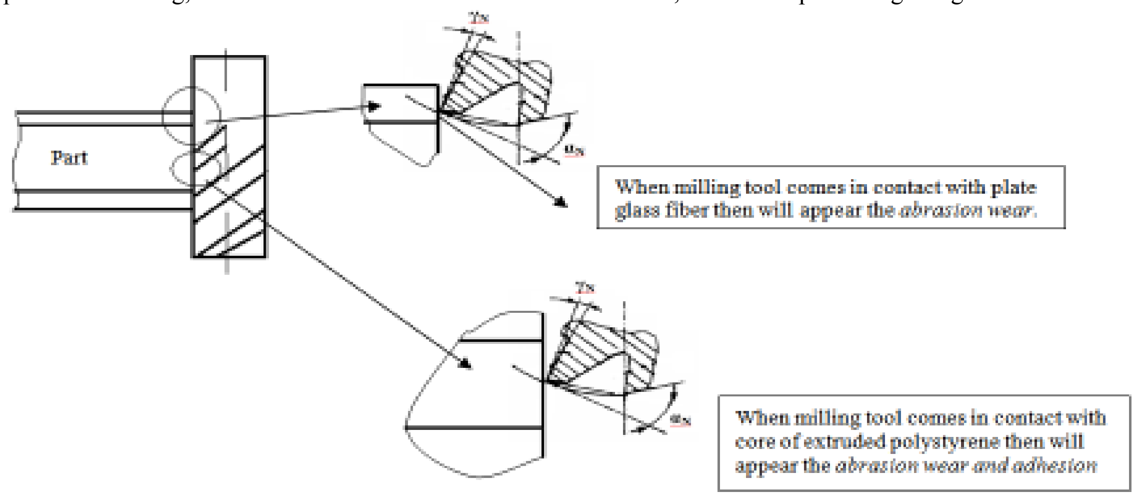


Figure 4. Abrasion wear and adhesion wear in time of milling process at the polymeric composite sandwich products

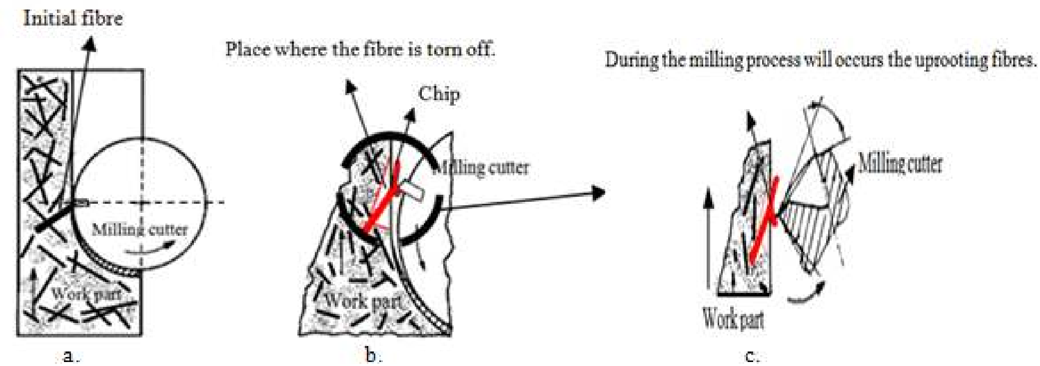


Figure 5. a) The first contact between the milling tool and fibers; b) appearance of the chip and starting pulling fibers.; c) the uprooting of the fiber.

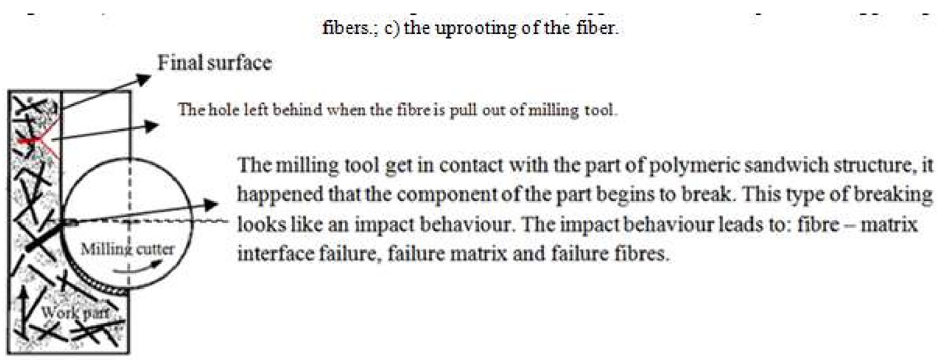


Figure 6. The final result when the fiber is removed from the polymeric composite sandwich products

3.3. Fiber failure criterion

In general, reinforcing fibers are considered to be transversely isotropy, and the tensile and compressible strengths in the longitudinal direction are remarkably high relative to strengths in transverse directions. Rationally, a quadratic failure criterion incorporating first order and second –order stress invariants is employed to evaluate the synthetic effect of multi-axial stresses. The quadratic failure criterion for fiber takes on a similar to the Tsai-Wu failure criterion for ply, but is three-dimensional, involving six stress components and the maximum stress failure criterion: [7]

$$\sum_{j=1}^{6}\sum_{i=1}^{6} F_{ij}\,\sigma_i\sigma_j + \sum_{i=1}^{6} F_i\,\sigma_i = 1 \qquad \textbf{(5)}$$

Where the coefficients F_{ij} and F_i can be determined and summarized as follows:

$$F_{11} = \frac{1}{T_f C_f}, \qquad F_{22} = F_{33} = \frac{1}{T_f^{'} C_f^{'}} \qquad \textbf{(6)}$$

$$F_{44} = \frac{1}{S_{f4}^{2}}, \qquad F_{55} = F_{66} = \frac{1}{S_{f6}^{2}} \qquad \textbf{(7)}$$

$$F_{1} = \frac{1}{T_f} - \frac{1}{C_f}, \qquad F_{2} = F_{3} = \frac{1}{T_f^{'}} - \frac{1}{C_f^{'}} \qquad \textbf{(8)}$$

$$F_{12} = F_{21} = -\frac{1}{2\sqrt{T_f C_f T_f^{'} C_f^{'}}} \qquad \textbf{(9)}$$

$$F_{23} = F_{32} = -\frac{1}{2T_f^{'} C^{'}} \qquad \textbf{(10)}$$

Where T_f, C_f, $T_f^{'}$, S_{f4} and S_{f6} are longitudinal tensile, longitudinal compressive, transverse tensile, transverse compressive, transverse-transverse shear, and longitudinal shear strengths of the fiber, respectively. Notice that the interactive terms are determined so that the quadratic failure criterion is expected to be equivalent to the generalized von Mises failure criterion when all stress components are zero except for two normal stress components.

On the other hand, since fibers are bonded together by matrix, matrix play a similar role under transverse and shear loads as fiber does under longitudinal load, which means that the strengths of matrix are major factors in determining ply strengths under those circumstances.

As a natural result, all terms regarding transverse and shear stresses can be temporarily eliminated from the fiber failure criterion.

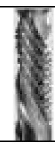
Additionally, the adoption of a quadratic failure criterion requires the transverse tensile and compressive strengths of fiber, which are difficult to measure through experiment, so simplification is needed albeit the quadratic form is preferred. Finally, the simplified fiber failure criterion becomes the maximum longitudinal stress failure criterion:

$$-C_f < \sigma_x < T_f \qquad \textbf{(11)}$$

Generally, fiber breakage under longitudinal tension or compression can be considered a brittle behavior, and hence no material property degradation model is needed.

Depending on the nature of the matrix material, the nature of reinforcement, the arrangement of the composite fiber, the core used for each type of polymer composite sandwich, literature recommends using carbide tools and titanium alloy, the milling part geometry specific to each type of material, table 5, for obtaining the quality products. [1]

Table 5. Type of milling tool of polymeric composite sandwich products

Reinforced polymer composites				
With fiberglass	Sandwich structures	With carbon	Solid carbide	Milling tool for fiber reinforced composites
				

When the tool is chosen improperly occurs frequently the pulling fiber from the wall of the surfaces processed and the polymeric composite sandwich products delaminating. Milling processing of polymer sandwich composites, the tool wear is different to the tool wear in the processing of metallic materials and is manifested by increased peak radius cutters. When processing the polymeric composite sandwich products with fiberglass for low wear of cutting tools it produce the mechanical damage of the processed surface (exfoliation, delaminating, grinding, "fish scales") and thermal damage (burns) occur at values of wear bit close to the maximum permitted. [3]. Tools used in milling requirements are: High resistance to wear; ray peak below 10 ... 15 mm; face roughness of clearance and settlement of less than 1.5 mm.

4. CONCLUSION

Using the results presented in this paper is obtained the polymer composite sandwich products with better resistance and industrial applicability. There is a continuing demand for milling tool innovations, shape and drill composite material applications in almost every industry sector. Composites, each presenting a unique composition, are rapidly replacing traditional building materials - steel and aluminum in aerospace applications, as well as within marine, building supply and automotive industries.

There are many challenges in industry to build lighter, stronger equipment to improve performance on ground vehicles, aircraft and ships in both commercial and defense industries. With the introduction of these advanced composite and composite-stack materials, development and utilization of proper cutting tool technologies have not kept pace with the new composites.

First it requires a good understanding of the polymeric composites sandwich products or stack materials characteristics that are to be machined. When these technology characteristics are combined, optimized solutions can be obtained, such as reducing cost and lead times, and improved part quality.

5. ACKNOWLEDGEMENT

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