Surface Analysis of Machined Fiber Glass Composite Material

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Abstract: - Machining glass fiber composite materials is a challenging task for nowadays manufacturers. Cutting process, accuracy and surface roughness of machined surface are affected by the anisotropic and non-homogenous structure of glass fiber plastics. In this paper is studied the influence of two cutting parameters, cutting speed and feed rate, on surface roughness during slot milling.

Key-Words: - Glass fiber reinforced plastics, slot milling, surface roughness, cutting parameters

1 Introduction

Fiberglass was first modern composite material. It was developed in the late 1940s and was used as a material for aeronautics and automotive industry. Even now, glass fiber reinforced plastics (GFRP) is the most used composite materials. GFRP consists in two distinct materials, a polymer resin as matrix, reinforced with ceramic (glass) fibers. This material is light, tough, resilient and flexible, and has a very good ratio between strength and weight.

High abrasiveness of glass fiber and non-homogeneous structure of this composite make it very difficult to be machined [1]. However, conventional machining as turning, milling or drilling is possible in specific cutting conditions and using proper tools [2].

Machining glass fiber composites is a complex and challenging task, major difficulties being reported:

- surface damage by delamination, burning or cracks;
- rapid tool wear (worn cutting tools fail to cut fibers cleanly and affect machined surface);
- fiber orientation greatly influences the cutting forces;
- accuracy affected by debonding, fiber breaking, subsurface damage and bouncing back phenomenon of work piece material.

Recent studies on unidirectional glass fiber composites revealed the chip formation mechanism in orthogonal cutting. In case of long oriented glass fiber, degradation of the matrix adjacent to the fiber occurs first, followed by failure of the fiber at its rear side [3]. In orthogonal cutting process like turning, influence of fiber orientation, cutting parameters, tool geometry in GFRP has been studied [4], [5]. Milling and drilling glass fiber composites were also studied in search for an optimal solution of chip removal process [6], [7], [8].

As literature provides mostly information on orthogonal machining of oriented fiber composites, this paper is focused on end milling random short fiber GRFP at different cutting speeds and different feed rates.

The aim of this research is to study surface finish obtained by slot milling. There are many possible alterations of machined surface during milling process, its quality depending on workpiece material and many other factors (Fig.1). This paper investigates the influence of cutting parameters, especially cutting speed and feed rate on surface roughness and provides a qualitative analysis of machined surface.

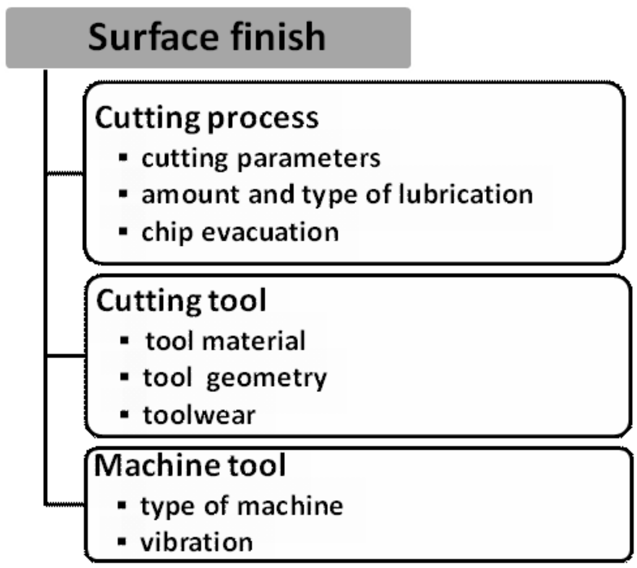

Fig.1 Machined surface finish – main influence factors

2 Experimental study

2.1 Workpiece material

The workpiece material used in this study was Delmat 68660 Glass Epoxy Laminate, a random glass mat based material bonded with high temperature epoxy resin. This material is an excellent insulating material for transformers and inductive appliances. It has good dimensional stability and very good mechanical and dielectric properties at elevated temperatures (Table 1).

Table1

Key characteristics	Unit	Value
Density	g/cm^3	1.9
Tensile Strength at 23°C	MPa	250
Flexural Strength at 23°C	MPa	400
Flexural Strength at 150°C	MPa	200
Compressive strength	MPa	300
Bonding strength (10mm thick)	N	6000
Heat resistance	^{o}C	180
Surface resistivity	Ohm	10^{12}
Volume resistivity	Ohm·cm	10^{13}

For the experiments, sheets of DELMAT 68660 composite with 8 mm thickness were cut in square pieces of 500mm x 500mm

The structure of workpiece material was visualized using a JEOL 6400-F Scanning Electron Microscope. In Fig.2 it can be observed the fiber density and the orientation of tested GFRP:.

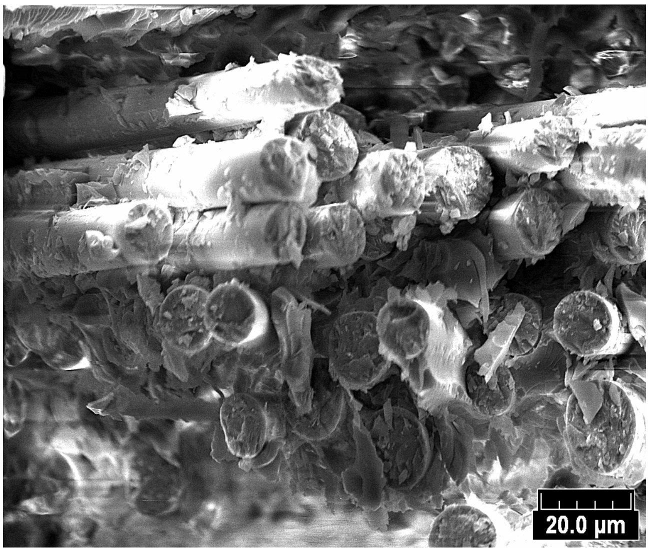

Fig.2 Microscopic structure of workpiece material

The anisotropic structure makes more difficult machining fiber reinforced composites by chip removing processes, especially due to vibrations and variable cutting efforts.

2.2 Cutting tools and milling machine

Milling experiments were carried on a vertical HURON KX8 High Speed Milling Center with a 24 Kw and 24000 rpm/min spindle.

Two fluted carbide monoblock tools provided by Diager Industries were used for cutting parallel slots in the workpiece (Fig.3) during the tests.

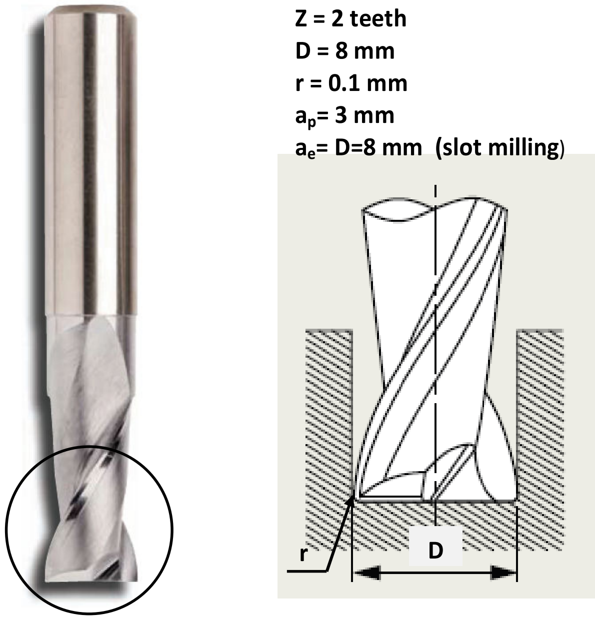

Fig.3 Cutting tool - two fluted end mill

2.3 Cutting conditions

In order to determine the influence of cutting parameters on surface finish, a series of milling tests were performed in dry conditions with different cutting speed and feed rates. Preliminary tests showed that the depth of the cut had not a significant influence during slot milling the GFRP. Therefore, cutting depth was kept constant and the cutting speed and the feed rate were modified as listed in Table 2. For each combination of parameters it was used a new end mill and machining process continued until it was considered worn out at Vb 0.2 mm.

Table 2

Cutting parameter	Unit	Values
Cutting speed	m/min	46; 70; 105
Feed rate	mm/tooth	0.1; 0.2; 0.46
Radial depth of the cut	mm	8
Axial depth of the cut	mm	4

To reduce vibrations and hold the workpiece in place during milling, it was fixed by the machine table by cap screws and nuts in the center and on the sides.

2.4 Measuring instruments

Real-time measurements were taken for temperature and cutting forces and then machined surface was studied.

The temperature was measured using a Chauvin Arnoux CA 1880 thermal imaging camera with measurement range between 0 and 1000°C. Data was recorded on a computer in video format files.

Vibrations and instant components of cutting forces on axes X, Y and Z were measured with a KISTLER dynamometric platform also connected to a computer during milling.

Post machining surface roughness of workpiece was measured using a contact stylus method with a Taylor-Hobson roughness tester Surtronic 25 (Fig.4). Surface profile and three surface roughness parameters were determined for each combination of cutting speed and feed rate:

- Average Roughness (Ra), the arithmetic average variation from mean line over the evaluation length;
- Maximum Height of the Profile (Rt), the distance from the highest peak to the deepest valley over the evaluation length;
- Average Maximum Height of the Profile (Rz), the average Rt over five evaluation lengths.

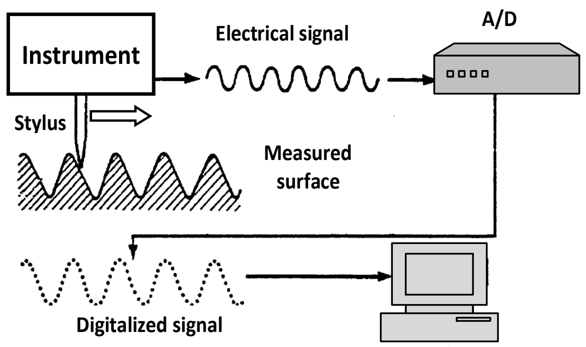

Fig.4 Measuring surface roughness by stylus technique

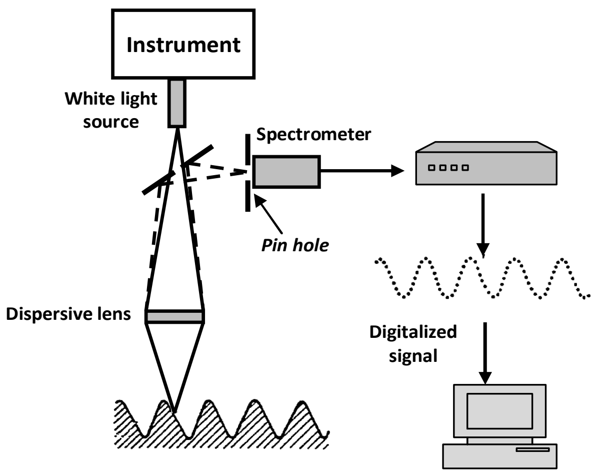

Fig.5 Non contact optical surface roughness analysis

Machined surface finish of was also studied using a profilometer with Nobis chromatic confocal optical gauge. Samples of 3 x 3 mm were detached from the machined surface and analyzed (Fig.5). Surface height was deduced using an optical aberration technique which focuses the white light at different profile heights. Besides, calculating surface roughness parameters, this technique allows viewing the 3D topography. Unfortunately, it is expensive and time consuming.

3 Results and discussion

Surface roughness plays a critical role in applications involving sliding surfaces, contact wear and vibration control. It has also an important impact in contact resistance (electrical or thermal), in fluid dynamics influencing lubrication and also in fatigue and crack development [9].

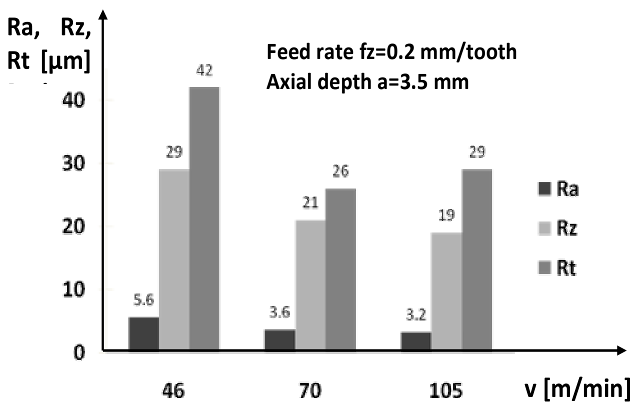

Fig.6 Variation of surface roughness with cutting speed

In Fig. 6 and Fig. 7, can be observed the influence of cutting speed and feed rate on measured roughness parameters Ra, Rz and Rt.

As in metal machining, surface roughness has a better quality at higher cutting speeds. For given feed rate (0.2 mm/tooth) and axial depth (3.5mm), increasing cutting speed with 34 m/min (from 46 m/min to 70 m/min) reduced parameter Ra from 5.6 µm to 3.6 µm and parameter Rz from 29 µm to 21 µm. Increasing furthermore the cutting speed with 35 m/min up to 105 m/min a less significant variation of surface roughness was obtained. This time, Ra was reduced only from 3.6 µm to 3.2 µm and Rz from 21 µm to 19 µm, while a considerable amount of heat in the cutting zone and tool vibration were observed. Tool tip temperature during milling with cutting speeds over 100 m/min exceeded 200°C.

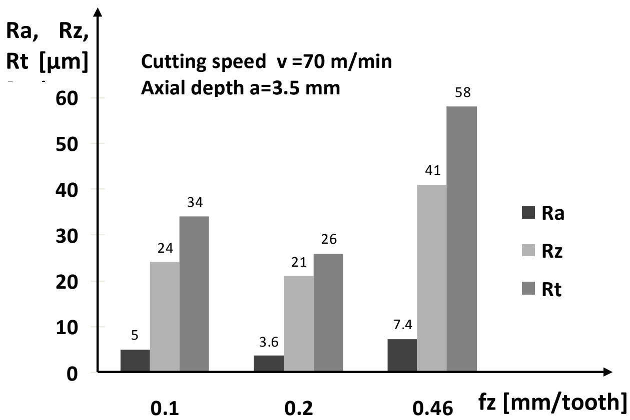

Fig.7 Variation of surface roughness with feed rate

Regarding the influence of feed rate on surface roughness, Fig.7 shows that in case of studied GFRP the smallest feed rate did not correspond to the best quality of finished surface as generally reported. It was verified the assumption that at 0.1 mm/tooth workpiece material is submitted to cutting process, being not subjected only to plastic deformation. Temperature and vibration measurements confirmed the assumption that the tool was cutting. A possible explanation of the atypical behavior could be the irregular way glass fibers are detached. Magnified images (Fig.8) show that sometimes grouped fibers are dislocated leaving wider and circular craters on the surface and other times narrow traces are left behind.

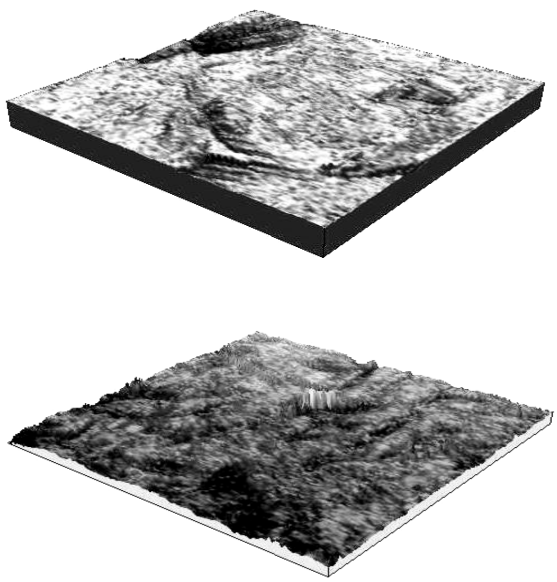
Fig.8 Profilometer images of machined surface

4 Conclusion

During machining composites, non-homogeneous structure and small discontinuous chips determine an irregular machined surface and machining glass fiber reinforced composites.

The surface quality presents minima at defined machining conditions, due to different fiber and matrix behavior. There is no trend to improve the surface quality while reducing feed or increasing the cutting speed, like it is the case in metallic materials.

Experiments revealed that from the surface finish point of view, the most appropriate solution in case of slot milling studied material corresponded to cutting speed of 70 m/min and feed rate of 0.2 mm/tooth.

Further research will corroborate these results with economical aspects of milling process.

Acknowledgments

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