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The Influence of the Cutting Conditions on the Machined Surface Quality When the CFRP is Machined

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Abstract

Composite materials offer very interesting mechanical and physical properties. Recently, they are an increasingly sought-after commodity particularly in the military, aerospace and automotive industries. This is mainly due to the ratio between their weight and the high values of their mechanical properties, which often reach higher values than commonly used materials. This article is focused on milling of composite materials, specifically fiber reinforced plastics produced by filament winding, in terms of cutting conditions which can be used for good surface quality. The proposal of technology, such as determination of cutting conditions, is a very difficult issue because there are many problems with delamination of reinforcement, high tool wear and with filtering of powder which is formed from the chips of these materials.

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1. Introduction

The issue of machining composite materials is still not sufficiently researched. There are many publications which are focused on the machining of the composite materials such as GFRP and CFRP composites. But there are not much information about the cutting conditions which are usable for the milling process in terms of the machined surface quality and its deterioration by the heat which is formed due to the machining process. The problems with the heat deterioration are described in [9]. Reference [1] is very important and offers basic information for

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machining of these materials. Reference [3] is newer, very substantial book containing an extensive description of this issue. There is much usable information about drilling, turning, grinding and milling of these materials. But each type of composite has its own specific characteristics (such as different tensile strength in different load directions) which affect the machining process. The characteristics can be changed for example by changing the matrix and reinforcement material and by changing the orientation of the reinforcement in the product volume. When a resistant composite is machined, there can be extremely abrasive tool wear due to high values of mechanical properties of the reinforcement [6]. This raises higher demands on the machine due to the use of a high cutting speed. It is very difficult to achieve the desired surface quality due to many factors which affect the course of machining. The inhomogeneous composition of FRP composites creates shock which must be absorbed by the cutting tool. Machining of some types of FRP composites creates health risks. [8] In some cases, working without protective equipment can be dangerous. All of these aspects have to be considered before making a proposal of technology. The aim of this paper is to describe the determination of usable cutting conditions for a given type of material.

2. Milling of FRP composite materials

Milling of FRP composites is mostly used as a finishing operation such as deburring and removal of excess matrix. In some cases grooves and holes have to be made - mainly for fasteners. Conventional milling is recommended, because it generates horizontal cracks. Climb milling generates vertical cracks, which are formed in the machined surface [4]. When the CFRP is machined, it is necessary to use suction machine because the chip is in the dust form. [10]

The factors which have the greatest effect on the surface quality are cutting tool geometry, cutting condition and ratio between quantities of each phase in the volume. But the most significant factor when a FRP composite is machined is the angle between the direction of feed and the fibers.

The angle is shown in fig.1. This angle changes as the tool rotates. Therefore, the fiber orientation is important where the cutting tool enters in conventional milling and where the cutting tool exits the cut for climb milling. For FRP with thermoset matrix $\beta = 0^\circ$ is recommended, for FRP with thermoplastic matrix $\beta = 90^\circ$. When it is machined at other values of angle β it may lead to buckling, breaking and tearing of the fibers. [1, 2, 3]

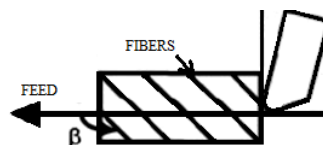


Fig. 1 Representation of the angle β .

The geometry of the cutting edge is chosen according to the type of material which will be machined. For milling CFRP composites it is recommended to choose the rake angle in the range of $0-7^\circ$. Then the recommended wedge angle is 75° . Greater rake angle leads to smaller cutting forces during machining and less smearing of matrix on the surface. Overall, it is recommended to choose a more positive rake angle for better surface quality. The flank of the cutting tool is scratched by the material which has been compressed and due to elastic deformation returns to the initial position. Therefore it is recommended to choose a greater clearance angle for a moderate improvement of surface quality. The edge radius should be minimized in a ratio to the depth of cut. A greater radius leads to a larger elastic deformation and to larger flank wear [1].

3. Usable cutting tools

The most commonly used cutting tools are tools with indexable inserts, monolithic cutting tools made from sintered carbide with different coatings and so-called Burr tools as in fig. 14 (e), (f). Cutters with straight teeth are used (fig. 2 (a)), as well as with teeth in a helix fig. 2 (b), (c), (d), but it is recommended to choose a tool with teeth in a helix. Tools with straight teeth clog faster (due to worse chip removal from the cutting area). This leads to compression of the machined surface and to deterioration of its quality. Tools with teeth in a helix have one great

disadvantage. The teeth in a helix generate axial force which can cause delamination of layers which are not supported against this cutting force (outer layer of the machined material). This undesirable phenomenon has been solved by using teeth in counter-rotating helices fig 2 (d).

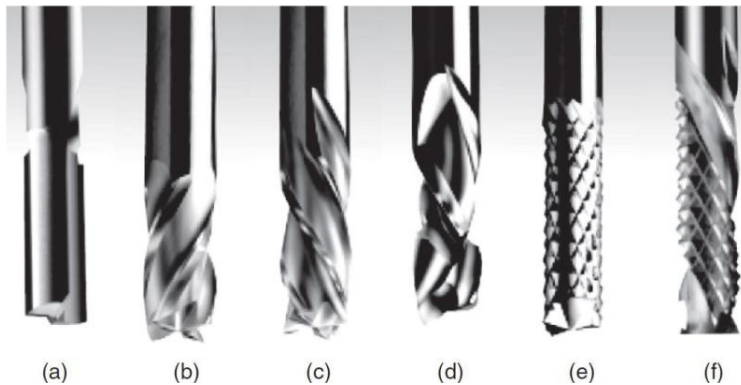


Fig. 2. Tools for milling composite materials [3].

4. Cutting conditions

Various types of polymers exhibit a transition from ductile to brittle fracture due to different strain rates. This factor affects the quality of the machined surface. Therefore cutting conditions must be selected according to the construction and composition of the FRP composite.

In most cases high cutting speed and less feed per tooth are used. Increasing the feed rate causes very large thermal stresses and deterioration in the quality of the machined surface [3]. Higher cutting speed causes failure of the material under less stress and brittle fracture. On the other hand, increasing the cutting speed increases the cutting temperature. Most FRP composite materials have a ‘critical cutting speed’. When the critical cutting speed is exceeded it leads to irreversible damage from the heat of the matrix. The critical cutting speed for Carbon/PEEK composite is 75 m/min. The depth of cut should be relatively small with regard to the size of the radius of the cutting edge [6] [3].

5. Proposal of suitable machining technology

The experiment was carried out on 104/90 mm pipe made of CFRP composite produced by filament winding. The matrix was epoxy resin and the reinforcement was wire fibres with a high modulus of elasticity. The angle β was 0° . Grooves were made in the pipe as can be seen in Fig. 3 (b). The grooves were made using six variants of cutting conditions in the circumference of the tube.

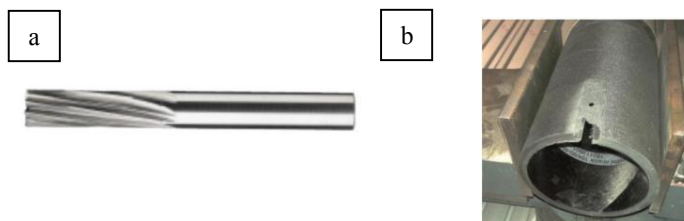


Fig. 3 (a) Cutting tool No. 1 [7]; (b) Machined tube.

The aim was to find suitable cutting conditions which ensure good surface quality. The cutting tool used was end mill see Fig. 3 (a) - diameter 8 mm, teeth in a helix with positive geometry. The cutting condition was determined as shown in Tab. 1. The revolutions of cutting tool were constant so that the cutting speed was constant too. For the test 20 000 revolutions per minute was set. The feed speed was varied.

Table 1. Cutting conditions.

	Variants of feed speeds					
HC650 – Feed speed [mm/min]	150	200	250	300	350	400
Revolutions [1/min]	20 000					

6. Equipment used

The milling machine used was a CNC machine built by Compo-Tech s.r.o. (Fig. 4 (a)). The spindle of this machine was Kress – FME – 1050-1 – 1050W (Fig. 4 (b)). A very important property of this spindle is the usable value of revolutions 5000 – 25000 r/min.

The Mahr PS1 was used as the measuring tool for the roughness parameters and the optical microscope Multicheck PC500 was used for photographing the bottom surface of the grooves.

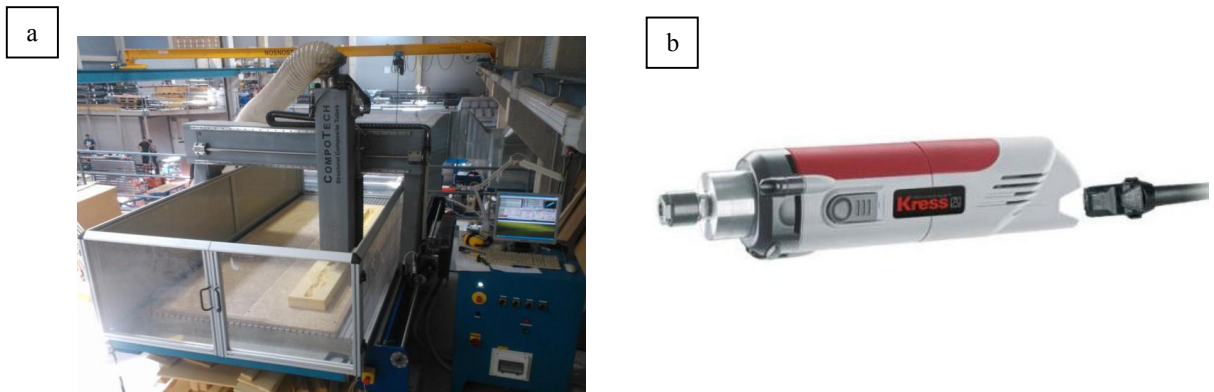


Fig. 4 (a) CNC machine; (b) Kress Spindle [5].

7. Evaluation

This section is focused on evaluation of the roughness and overall appearance of the machined surface. Fig. 5 (a) shows the dependence of roughness parameter Ra on the value of the feed speed. There is also divided value of Ra for climb milling and conventional milling. As can be seen, the smallest value of roughness parameter Ra is achieved when climb milling with a feed speed of 200 mm/min.

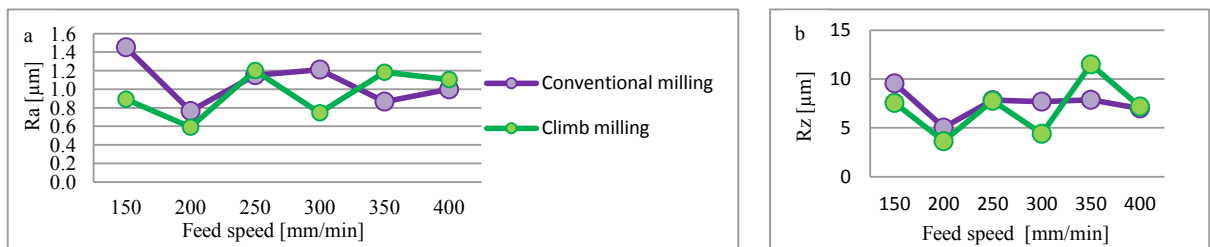


Fig. 5 (a) Influence of the feed speed on roughness Ra; (b) Influence of feed speed on Rz.

The same results are evident from Fig 5(b) and Fig 6 (a) where the dependence of roughness parameters Rz and Rt on feed speed is shown.



Fig. 6 (a) Influence of feed speed on roughness Rt; (b) Influence of feed speed on surface roughness RSm.

Fig. 6 (b) shows the dependence of surface roughness RSm on feed speed. Here is the lowest value of RSm for 400 mm / min for climb milling and for 250 mm / min in conventional milling.

The high value of parameter RSm for feed speed of 350 mm / min can be explained by the extreme increase in the delamination of the fibers at the place of measurement. Overall, it is surprising that climb milling shows better results than conventional milling.

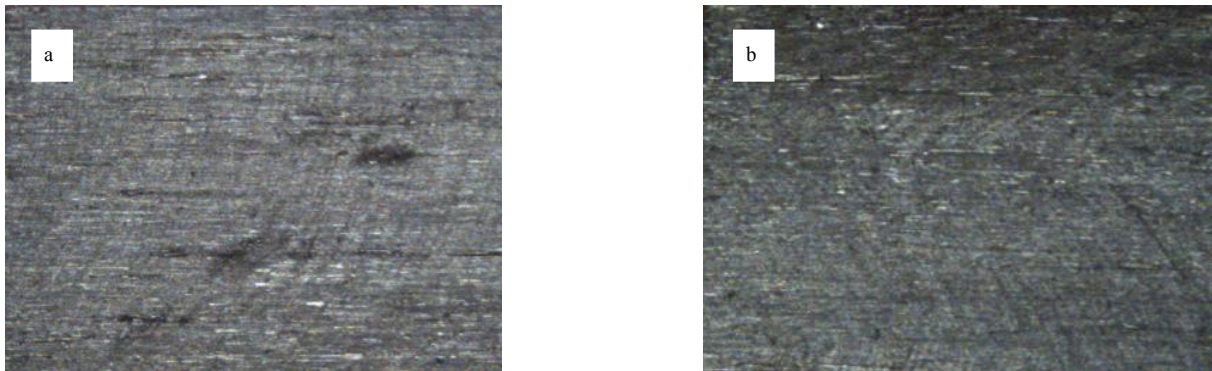


Fig. 7 (a) Climb milling workpiece surface; (b) Conventional milling workpiece surface.

Fig. 7 (b) shows the surface after conventional milling with feed speed 200 mm / min and Fig. 7 (a) after climb milling. Despite the fact that better surface quality was achieved in terms of roughness for climb milling at the feed speed 200 mm/ min, local delamination of fiber can be seen in Fig. 7 (a). When conventional milling was used the machined surface was generally cleaner.

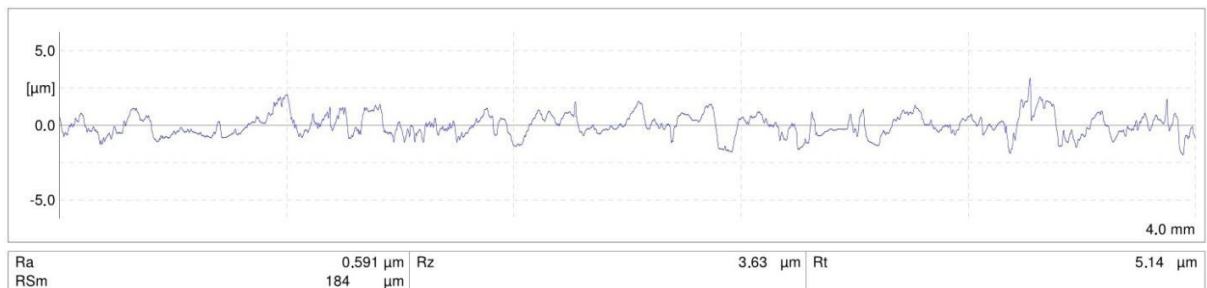


Fig. 8. Surface profile curve with the lowest values of roughness parameters.

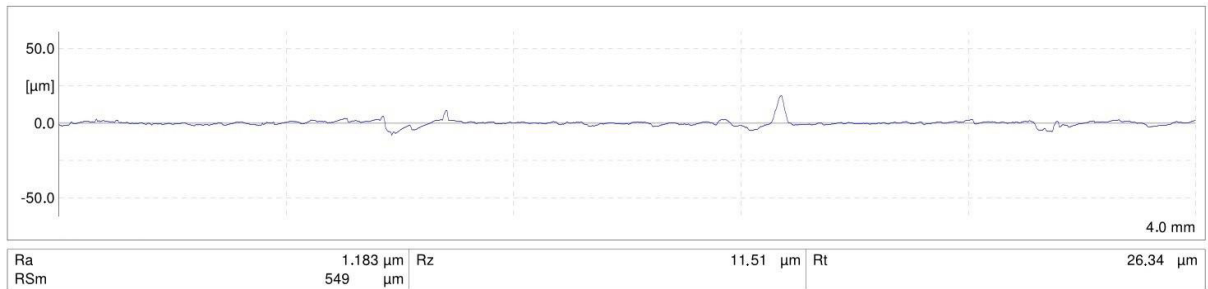


Fig. 9. Surface profile curve with the highest values of roughness parameters.

Fig. 8 and 9 show the best and the worst profiles of the variant feed speed – 200 mm/min and 350 mm/min in terms of the parameters of roughness. Fig. 8 shows the profile of the best option cutting conditions which were used. As can be seen, the scale is ten times smaller than in Fig. 9 for the worst surface quality.

Conclusion

The main task of this paper is finding of the usable cutting conditions for milling in terms of the machined surface quality. There are also information about the cutting tools and the factors which have great effect on the milling process. The usable cutting conditions were determined by the experiment. According to the results of the experiment the appropriate feed rate for the given cutting speed can be determined as 200 mm / min. As can be seen, these materials could be machined with good surface quality. It should be assumed that better combinations of feed rate and cutting speed exist. The main problem is that the cutting speed was constant, but for a rough draft it is sufficient. It would be useful to examine the dependence of mechanical properties on the maximum temperature at the cutting edge - mainly due to the low temperature of glass transition of the polymer matrix. When this temperature is exceeded the mechanical properties are changed. Reduction of the strength and hardness of the composite can be expected. This phenomenon can be observed mainly with thin workpieces.

Acknowledgements

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References

- [1] R. Teti, Machining of Composite Materials, CIRP Annals - Manufacturing Technology, Volume 51, Issue 2, 2002, Pages 611-634, ISSN 0007-8506, [http://dx.doi.org/10.1016/S0007-8506\(07\)61703-X](http://dx.doi.org/10.1016/S0007-8506(07)61703-X). (<http://www.sciencedirect.com/science/article/pii/S000785060761703X>) [20.8. 2014].
- [2] Y. Karpat, O. Bahtiyar, B. Değer, Mechanistic force modelling for milling of unidirectional carbon fiber reinforced polymer laminates, International Journal of Machine Tools and Manufacture, Volume 56, May 2012, Pages 79-93, ISSN 0890-6955, <http://dx.doi.org/10.1016/j.ijmachtools.2012.01.001>.
- [3] Sheikh-Ahmad, Jamal Y. Machining of Polymer Composites. The Petroleum Institute, Department of Mechanical Engineering Abu Dhabi, United Arab Emirates : Springer Science + Business Media, LLC, 2009. ISBN: 0387355391, 9780387355399.
- [4] K. Bill. Super tools. Cutting Tool Engineering plus - http://www.ctemag.com/aa_pages/2010/100601_SuperTools.html [25. 8. 2014].
- [5] CNCSHOP.cz. CNC & automatizace - <http://www.cncshop.cz/kress-fme1050-1-vysokootackova-frezka-1050w> [14. 8. 2014].
- [6] Shandilya, P.; Jain, P. K. & Jain N.K.: Wire Electric Discharge Machining of Metal Matrix Composite Materials, Vol. 10, ISSN 1726-9687, ISBN 978-3-901509-84-1, Editor: B. Katalinic, hard cover, Publisher DAAAM International Vienna, Vienna, 2011.

- [7] GmbH Hufschmied Zerspanungssysteme, HUFSCHMIED - http://pdf.directindustry.com/pdf/hufschmied-zerspanungssysteme/catalogue-part-1/38670-242917-_72.html [19. 8. 2014].
- [8] H. Hocheng, H.Y. Puw, Y. Huang, Preliminary study on milling of unidirectional carbon fibre-reinforced plastics, *Composites Manufacturing*, Volume 4, Issue 2, June 1993, Pages 103-108, ISSN 0956-7143, [http://dx.doi.org/10.1016/0956-7143\(93\)90077-L](http://dx.doi.org/10.1016/0956-7143(93)90077-L).
- [9] O. Pecat, R. Rentsch, E. Brinksmeier, Influence of Milling Process Parameters on the Surface Integrity of CFRP, *Procedia CIRP*, Volume 1, 2012, Pages 466-470, ISSN 2212-8271, <http://dx.doi.org/10.1016/j.procir.2012.04.083>. [21.10. 2014].
- [10] Stoica, M.; Anania, F. - D.; Bisu, C. F. & Zapciu, M. (2010). Research Concerning the Machinability of a Fiber Glass Composite Material, *Annals of DAAAM for 2010 & Proceedings of the 21st International DAAAM Symposium, 20-23rd October 2010, Zadar, Croatia*, ISSN 1726-9679, ISBN 978-3-901509-73-5, Katalinic, B. (Ed.), pp. 0803-0804, Published by DAAAM International Vienna, Vienna.