BÁNKI KÖZLEMÉNYEK
1. ÉVFOLYAM 3. SZÁM

Analysis of uncut fibres at machined holes in carbon fibre-reinforced plastics (CFRP) using digital image processing

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***Abstract* — Unlike metals, carbon fibre-reinforced plastics (CFRP) have anisotropic and inhomogeneous structure, in addition the reinforcements have strong wear-effect. Therefore those are difficult-to-cut materials. The main aim of this research is to find relation between the cutting tool diameter and the quality of the machined holes in CFRP. Milling experiments were designed using the full factorial design of experiments method. The experiments were conducted on a Kondia B640 machining centre. The machined surfaces were scanned with a digital microscope; the collected data were evaluated by digital image processing (DIP) techniques. The influence of tool-diameter and feed rate were examined and discussed in order to optimise the hole-machining process in CFRP.**

Keywords: Carbon fibre-reinforced polymers, CFRP; machinability; digital image processing; uncut fibres

1 INTRODUCTION

Nowadays, in the high-tech industries, the use of carbon fibre-reinforced polymers (CFRP) is increasing, as it is shown in Fig.1. due to its good specific mechanical properties. Since the production technology of CFRP is often inaccurate or simply doesn't make it possible to produce any hole, their machining is necessary and essential in order to reach any required geometry. To minimize, or avoid any failure during machining special tools were designed, such as compression end mills or twist drills with special tip geometry. Although these tools are more suitable for machining CFRP materials compared to conventional tools, they cost often more. Hence this engineers often choose a cheaper conventional cutting tool. The main question is whether it worth to avoid buying special tools.

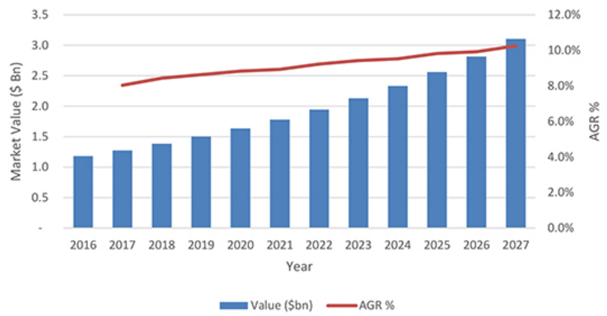


Fig.1 CFRP usage forecast in part of Europe [1] -$ Bn: billion dollar, AGR%: annual growth rate

1.1 PRELIMINARY KNOWLEDGE

Numerous earlier studies showed it is possible to machine hole in CFRP without special twist drill. One of these was written by *Geier and Szalay* [2]. *Sadek et al* [3] even proved it is possible to mill holes without any failure by using orbital drilling. These and several other researches assessed the fact, that feed rate has the most significant effect on the quality of the machined surface: regarding the average surface roughness, pulled out and uncut fibres (see Fig.3). Several article mention the so called „burr area" (see Fig.3) around 45° angle compared to the direction of the reinforce fibres, as can be seen in the Fig.2. Although delamination is also a known failure mode, during our experiments we did not take it into consideration.

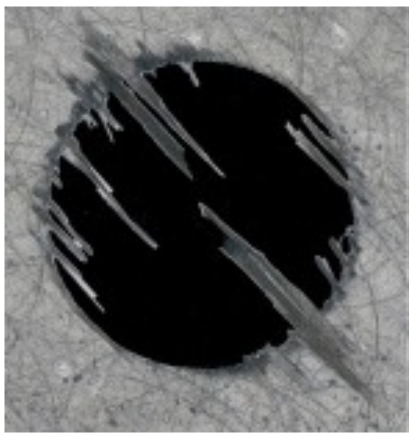


Fig.2 Uncut fibres [4]

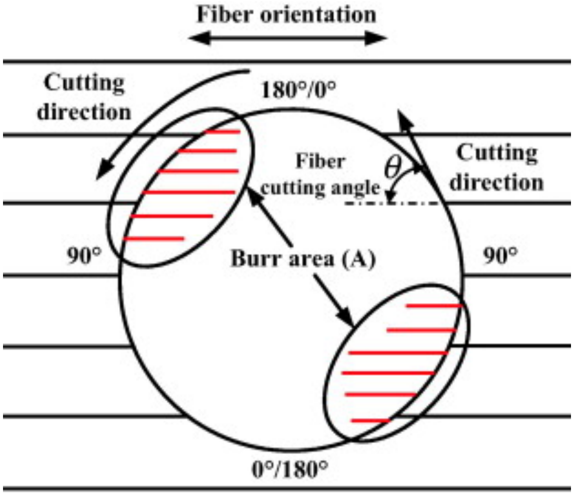


Fig.3 Burr area[5]

2 EXPERIMENT

2.1 DESIGN OF EXPERIMENT

2.1.1 APPLIED METHOD

The examined parameters (factors) were the tool diameter (D) and feed per tooth (fz) in this experiment. The values were chosen based on the recommendations of the tool manufacturer and preliminary knowledge. The factor levels can be seen bellow in Table 1. Since the number of the combination of the chosen values is few, it is possible to carry out full factorial experiments. This way experimental data loss can be decreased.

Table 1.Used parameters

D (mm)	4	6	8
f_z (mm/tooth)	0.01	0.04	0.07

2.1.2 MANUFACTURING STRATEGY

Previous researches proved, the climb milling results better surface, than conventional milling. Considering this fact, climb milling was used to machine holes Fig.4(b). The effect of lead-in Fig.4(a) and stand-off Fig4(c) strategy is excluded from the discussion of this experiment, so they are simple radial one, as can be seen in the Fig. 4.

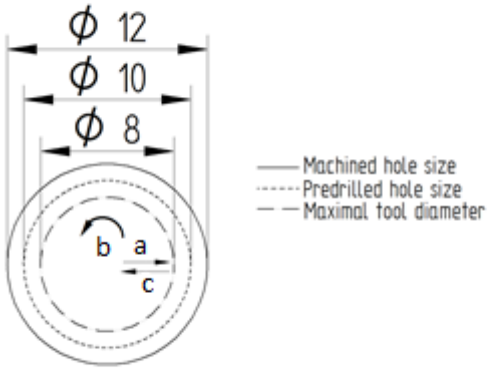


Fig. 4 Used manufacturing strategy. (a) movement is lead in, (b) is climb milling with feed rate and (c) is stand-off movement

2.1.3 EXPERIMENTAL SETUP

The experiments were carried out on a Kondia B640 machining centre. The tools were cemented carbide flute mills with one cutting edge, made by TIVOLY (ALU VHM P297), clamped in collet. For this experiment series a unique fixture was designed and manufactured, which ensure optimal material requirement and provides appropriate support resulting minimal delamination (laminated layer separation). In order to avoid the abrasive effect of carbon chips a Nilfisk GB 733 industrial vacuum cleaner was applied to remove them.

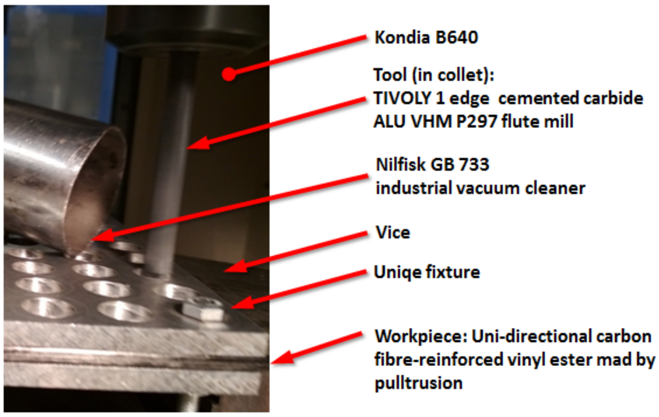


Fig. 5 Experimental setup

2.2 DATA COLLECTION

After machining, images were taken of the exit side of each hole, using Dino-Lite AD7013MZT digital microscope. These images were the base of the evaluation (explained below). Since the material was black, a white background was applied in order to increase the contrast of the images, thus increasing the accuracy of the evaluation process. The digital microscope station can be seen in the Fig.6.

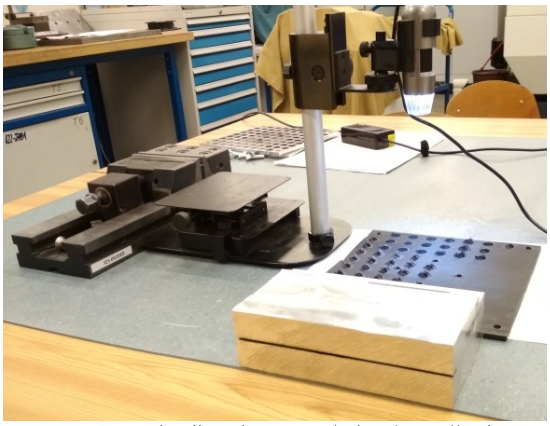


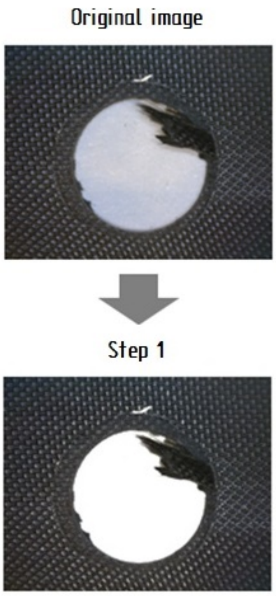
Fig. 6 Dino lite microscope during data collection

3 EVALUATION

3.1 USED METHOD

Digital image processing (DIP) was used to evaluate characteristics of uncut fibres. The images were binarized in three steps based on the picture's grey-scale histogram, as can be seen in the Fig. 7. In the first step was the white replacement, then the black replacement. The final step was removing the excess white pixels. During the image process the white pixels were counted. A reference value was measured on a computer drawn image. A see-through index ($\underline{I}$) was determined as the ratio of the number of the white pixels on the picture (n_{pic}) and the reference number (n_{ref}). This is very similar to other commonly used area based method – for instance the one used for classifying delamination as *Faraz et al.* [6] did.

$$\underline{I} = \frac{n_{pic}}{n_{ref}} \tag{1}$$



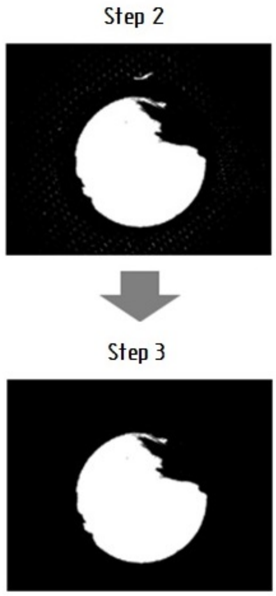


Fig. 7 Image processing of uncut fibres at the edge of drilled holes in CFRP

3.2 RESULTS

The method described above in was executed using Matlab and Mathematica software. Although both execute the same steps, the method used by them is different. As a result of this the returned values was different, but coherent. It means the returned value was not same for the same image, but since the reference value was also different it resulted only marginal differences in see-through index.

By analysing the indexes it became clear, the special drill is not necessary to make a good quality hole. It can be clearly seen in Fig. 9. This result confirmed our visual examination. This means it is possible to use general purpose conventional tool instead of special tool for CFRP manufacturing. Of course the machining parameters ought to be chosen carefully in this case, because of increased risk of causing failure in the material. With the proper settings the frequent defects can be avoided and the quality of the geometry will be also acceptable.

A chart is shown in Fig. 8 about see-through index of 22 holes made by the same drill under the same condition. After calculating the average value and the standard distribution (σ) of the given indexes we had to admit, the distribution is too big to consider these results exact, although the see-through index of manufactured holes reflects clear tendency.

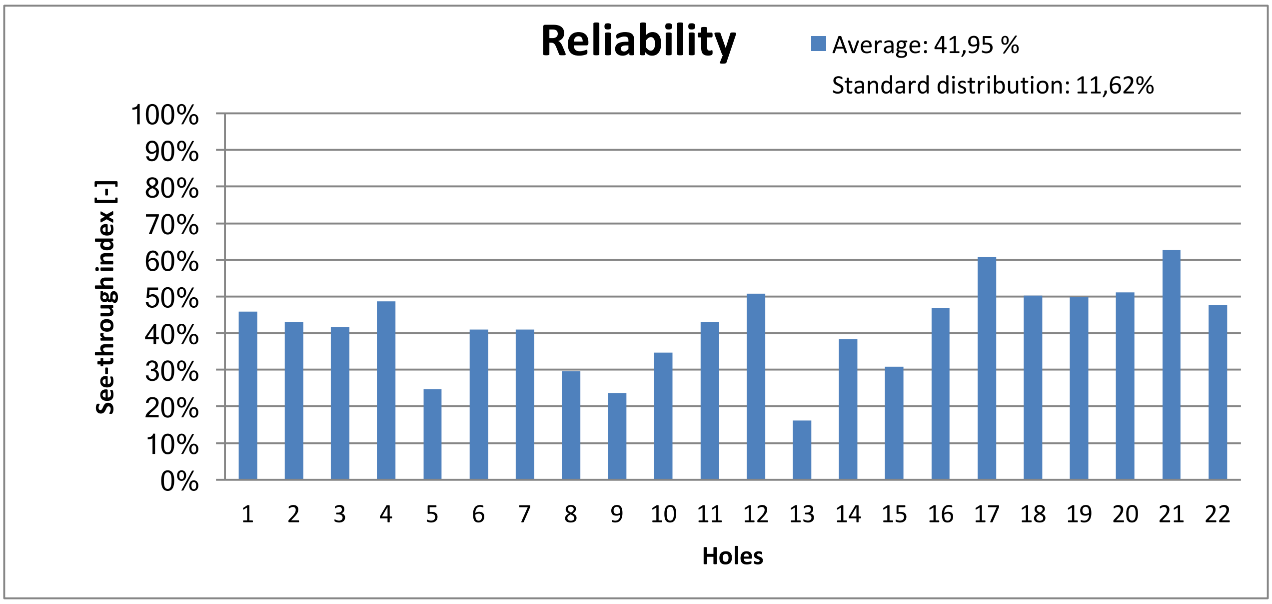


Fig. 8 Reliability of the processing

Fig. 9 Quality of holes –I: average see-through index, σ: standard distribution

4 Summary

In conclusion the experiments confirmed our preliminary knowledge regarding the place of "burr area". Furthermore at low feed rate burning of the matrix polymer was noticeable. Some instance of fibre pull-out was also noticeable.

All in all in our opinion due to the inaccuracy (σ=11.62%) of the measurement no optimum can be settled, but it can be concluded, using a general purpose flute mill is also possible for machining good-quality holes in CFRP. Further analysis of the manufactured holes with more accurate devices or methods may reveal more specific relations.

5 References

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