Experimental study of fiber-glass plastic work pieces contour milling

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Abstract. The article represents the results of study of cut and feed speed influence on wear of monolithic hard alloy end milling cutter during cutting of foiled fiber-glass plastic sheets, used for printed-circuit boards’ production. The peculiarities and problems of cutting layered materials are described. The most effective feed and cut speed values are determined by cutter wear analysis.

1. Introduction
Tooling back up of the machine-building production is an important element of the engineering process. Efficient supply of metal-cutting technological systems with tools and production recommendations is one of the most important conditions of durable operation of machine building enterprises in the market economy [1].

A printed-circuit board (pc board) is one of the main elements of communication electronics equipment. It is traditionally made of foiled fiber-glass plastic [2-5]. One stage of a printed-circuit board production is mechanical processing. PC board contour milling in complicated forms with end milling cutters is rather cheap and commonly used method of processing. Milling operation is optimal for experimental, singular and limited production of PC boards. In fiber-glass plastic milling commercial processing accuracy should be within IT10 – IT12 limits [6].

Milling of composite non-metal materials has several peculiarities in comparison with that of metals. They are determined by characteristics and structure of the materials, that is why the process of metal milling cannot be applied directly to non-metals. Peculiar characteristics of composite non-metal materials cause difficulties in product manufacturing process, because it requires higher wear resistance of the tool cutting end. Currently applied tools and operation modes do not provide the required quality of goods. The researches in the fields of cutting processes and cutting tools for composite non-metal materials treatment do not give a solution to the problem [7-9].

2. Materials and methods
In comparison with forming and drilling, the process of milling is discrete. Due to this there is a high probability of chopping the material off at the cutting edges of a mill cutter. That is why, while milling fiber-glass plastic it is recommended to observe the following rules:

1) the workpiece should be pressed tightly to the mountain elements of the lathe table;
2) due to the layered structure of the material it is necessary to use an incidental milling scheme to avoid delaminating of a pc-board;
3) the machined part of the workpiece must be tightly pressed to the supporting (base) surface of the lathe.
Foiled fiber-glass plastic STEF-1 (GOST 12652-74) is used as construction material for PC boards production in Russian industry. In our experiments we used fiber-glass plastic 1 mm thick. High-speed steel tools were not used during milling of fiber-glass plastics due to their low wear resistance. Milling cutters of hard alloys from tungsten-cobalt groups or synthetic diamonds were used. The milling cutters were chosen from the catalogue of Russian company “Ostec Group” (http://ostec-st.ru). For milling foiled fiber-glass plastic we chose two types of monolithic end cutters made of hard alloys: milling cutters RCD with diamond machining of the cutting edges and milling cutters CBD with screwed crushing cutting edges. The milling cutters are shown in pictures 1 and 2.

![Picture 1. Milling cutter RCD](image1.png)

![Picture 2. Milling cutter CBD](image2.png)

Swarf removal from the milled area is very important for the surface quality of pc-board and service life of a milling cutter, as the process of fiber-glass plastic is done without coolant-cutting lubricant. During the milling the cooling is done with two air flows. The first air flow rotates the spindle; the second air flow removes fine chips. The foil layer provides additional dissipation of heat from the surface of pc-board.

The crucial defects in fiber-glass plastic milling for pc-boards are cratering when the cutter touches the workpiece for the first time, damages of a current-conductive layer by the lathe clamp gear and working surface, layering and cracking of the fiber-glass plastic. In order to avoid these defects several layers of workpieces are mounted at the auxiliary table of the lathe. Main kinds of defects on the cross-cut ends occurring after machining of pc-boards by end-milling cutters are shown in pictures 3-6.

![Picture 3. Thermal damage occurrence](image3.png)

![Picture 4. Breaking out of grains](image4.png)

![Picture 5. Surface smoothing](image5.png)

![Picture 6. Layering of the material](image6.png)

It is necessary to choose optimal feeding speed during milling fiber-glass plastic: if the speed is too low separate cutting edges cannot penetrate deep enough into the material, it results in smoothing the
surface instead of cutting. In this case the material is overheated in the cut zone and the quench layer is formed on the cutting edges. If the feeding speed is too high then the hardness of the cutter is lessened and the probability of the cutter’s breakage increases.

In order to increase the durability of the milling cutters and to avoid material layering at the beginning of the contour it is necessary to drill a hole, equal in the diameter to a milling cutter diameter. In some cases a bottom crosspiece with milled gauge is used in the bundle of stock, that allows bettering cooling of a tool and swarf removal.

The quality of milled surface also depends on the direction of the milling cut. It is recommended to cut the outer contours counterclockwise and inner contours – clockwise.

3. Preparation and experimental milling

Preparation and experimental milling of fiber-glass plastic in manufacturing environment included the following steps. In the article [7] it is recommended to machine fiber-, glass-, asbestos fiber-, or carbon fiber- reinforced laminates with milling cutters containing hard alloys laminas at the cutting speed from 125 to 300 m/min and feeding from 0.1 to 0.3 mm/tooth. In the article [7] it is recommended to set the cutting conditions according to the required quality and productivity in the following limits: feed per tooth from 0.15 to 0.17 mm/tooth, cut speed from 45 to 48 m/min and cut depth from 0.3 to 0.6 mm. Relying on these recommendations initial values were calculated for the experiments: spindle rotational speed (min⁻¹) and moment cutter feed speed (m/min) according to basic formulas (1) and (2):

\[
 n = \frac{1000V}{\pi D},
\]

where \( n \) - spindle rotational speed, \( V \) - cut speed, \( D \) - cutter diameter (mm);

\[
 S_m = S_z n,
\]

where \( S_m \) - moment cutter feed speed, \( S_z \) - feed per hob tooth (mm/tooth), \( n \) - spindle rotational speed, \( z \) - cutter teeth number.

Experimental machining was done on the lathe Schmoll MX, with numerical control system CNC-7 of Exellon company.

Table 1 shows the machining parameters received at the end of the experiment. In the trial cuts a monolithic hard alloy end milling cutter of CBD type, 2.5 mm in diameter was used, the total thickness of the processed bundle of stock was 5 mm (three machined workpieces and two additional crosspieces as top and bottom plating were used).

| №  | Milling cutter rotational speed, min⁻¹ | Feed, m/min | Time of processing, min | Tool wear, mkm |
|----|--------------------------------------|-------------|-------------------------|---------------|
| 1  | 6 000                                | 2.04        | 1                       | 40            |
| 2  | 15 000                               | 3           | 5                       | 34            |
| 3  | 20 000                               | 3           | 5                       | 31            |
| 4  | 25 000                               | 6           | 5                       | 33            |
| 5  | 30 000                               | 3           | 5                       | 40            |
| 6  | 35 000                               | 16          | 1                       | 50            |
| 7  | 38 000                               | 22.8        | 1                       | milling cutter breakage |
| 8  | 30 000                               | 2.04        | 10                      | 4             |
| 9  | 30 000                               | 1.4         | 10                      | 2             |
| 10 | 30 000                               | 1           | 10                      | 4             |
| 11 | 30 000                               | 1.4         | 46                      | 10            |
Table 2 shows processing conditions with the use of milling cutters RCD type. The cutter diameter and the thickness of the processed bundle of stock – 2.5 mm and 5 mm accordingly.

| №  | Milling cutter rotational speed, min⁻¹ | Feed, m/min | Time of processing, min | Tool wear, mkm |
|----|--------------------------------------|-------------|-------------------------|---------------|
| 1  | 30 000                               | 1.2         | 10                      | 5             |
| 2  | 30 000                               | 2.04        | 10                      | 4             |
| 3  | 30 000                               | 1.4         | 10                      | 3             |
| 4  | 30 000                               | 1           | 10                      | 4             |
| 5  | 25 000                               | 1.4         | 10                      | 7             |
| 6  | 35 000                               | 1.4         | 10                      | 5             |
| 7  | 32 000                               | 1.4         | 10                      | 2             |
| 8  | 33 000                               | 1.4         | 10                      | 4             |
| 9  | 32 000                               | 1.4         | 46                      | 9             |

At low cutting speeds grain tearing and fast wear of the cutters occur; at high cutting speeds the processed surface of the fiber-glass plastic is smoothed. At slow feeding speeds surface smoothing occurs and at fast feeding speed the tool is damaged.

Table 3 shows the information about possible defects of pc-boards and the probability of their occurrence depending on the chosen mill conditions. The probability of their occurrence is based on the experience. Whereby the probability of the material splitting is always present and is equal to 1% with observing all recommendations described above. To avoid splitting the material it is necessary to lead smoothly to the starting point of the instrument move. But even in this case there is a probability of splitting because of the faulty adhesion of the fiber-glass material.

| №  | Milling cutter rotational speed, min⁻¹ | Feed, m/min | Defect type        | Defect probability, % |
|----|--------------------------------------|-------------|--------------------|-----------------------|
| 1  | 6 000                                | 2.04        | Smoothing          | 20                    |
| 2  | 15 000                               | 3           | Thermal damage     | 24                    |
| 3  | 20 000                               | 3           | Thermal damage     | 31                    |
| 4  | 25 000                               | 6           | Smoothing          | 48                    |
| 5  | 30 000                               | 3           | Thermal damage     | 42                    |
| 6  | 35 000                               | 16          | Grain tearing      | 50                    |
| 7  | 38 000                               | 22.8        | Grain tearing      | 73                    |
| 8  | 30 000                               | 2.04        | No                 | 4                     |
| 9  | 30 000                               | 1.4         | No                 | 2                     |
| 10 | 30 000                               | 1           | No                 | 4                     |
| 11 | 30 000                               | 1.4         | No                 | 10                    |

Instrumental measurement of the worn part of the milling cutter showed that minimal wear was 10 mkm. The wear of the cutting part of the first and the fourth tooth is a little bit more intensive then of the third and the forth teeth, which processed the workpiece directly.

4. Conclusion
The results of the experiment show, that the optimal cutting speed for hard alloy milling cutters 2.5 mm in diameter is 235 m/min for CBD type and 250 m/min for RCD type at the feed 1.4 m/min, processing width 3 mm and cutting depth 2.5 mm. According to the Russian branch standard OST 3-1291-82 maximal roughness value $R_d$ should be within 50 to 25 mkm. The determined cutting
conditions provide roughness $R_d = 40 \text{ mkm}$, which corresponds to the recommendations of this Standard.

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