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Research Article

COMPARATIVE STUDY IN THE PASSIVE FORCE AND CUTTING TORQUE IN THE MILLING PROCESS OF POLYMER MATRIX COMPOSITES AND ALUMINUM ALLOYS

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ABSTRACT
This paper presents the results of a study undertaken to investigate the passive force and cutting torque during the milling of carbon fiber reinforced plastics saturated with epoxy resin and two aluminum alloys: AlSi21CuNi (AK 20) and 7075 (PA 9). The milling process was conducted using end mills with diamond inserts. The machining parameters were changed equally for each material as a result of which the passive force and cutting torque during the milling of these materials could be compared.

Keywords: polymer composites, silumin, duralumin, passive force, cutting torque.

INTRODUCTION

Polymer matrix composites have been of interest to engineers and scientists for decades. They are used in aviation, shipbuilding, automotive industry, sports and medicine. Their machining, that is cutting, turning, milling and drilling, is conducted using tools which have appropriate geometry and are made of wear-resistant materials. For each machining type, it is therefore necessary to know the "phenomena" that occur in the processing area. The relationships between variable machining parameters and values of cutting forces and cutting torques are of vital importance here.

There are numerous studies devoted to polymer composites, a new type of construction materials. The studies mainly focus on the description of their surface quality after machining operations such as turning, drilling or milling. Also, the studies discuss cutting forces and cutting torques.

One of the works on polymer matrix composites which analyzes the forces in milling is [1], written by D. Kalla, J. Sheikh-Ahmad and J. Twomey, in which cutting force values in the end milling of unidirectional and multidirectional composites are predicted. The predicted force values and the measured force results are then compared. Finally, the authors demonstrate the possibility to predict forces in the milling of polymer composites using the method employed. The authors of [2] describe the research undertaken to develop a new analytical method based on the energy method to predict forces that occur during the processing of polymer matrix composites with different fiber orientation (90° to 180°). The authors of [3] investigate cutting forces during milling grooves in a carbon composite, using two types of diamond cutters, in order to find the most favorable fiber orientation depending on the cutting force values. It has been found that the optimum conditions for machining composites occur with the fibers oriented at an angle of 45°/135°, which requires the lowest cutting force values. In [4], R. Teti offers a general description of polymer matrix composites, metal matrix composites and ceramic matrix composites. The turning, cutting, drilling and milling of each of these materials are described. The effect of tool wear on cutting forces in the machining of polymer composites with glass fibers is described in [5]. It has been found that the tool wear increases the cutting force values. In [6] and [7], methods for producing composites as well as the way of forming them are discussed.

The aim of this study is to investigate the effect of the cutting parameters, such as cutting speed and feed rate, on the passive forces and cutting torques during the milling of carbon fiber reinforced plastics (CFRP). Additionally, the results of milling silumin and duralumin are presented for comparative purposes. These materials have a low specific gravity and relatively high strength. Aluminum alloys exhibit a good resistance to corrosion, while the composites are characterized by a high corrosion resistance.

TEST STAND AND TOOLS

The carbon fiber reinforced plastics and aluminum alloy machining was conducted on a vertical machining center, Avila - VMC 800 HS. The samples were mounted on a milling table with dimensions of 1000 mm by 540 mm and displacement in three axes: X (800 mm), Y (540 mm), and Z (620 mm). A vice is mounted on the table, and to the vice the samples of the composite and aluminum alloys are attached in the working space during the milling operation. In the machine spindle, a Kistler dynamometer, model 9125A11A2, is mounted. It is used to measure the cutting torque and passive (vertical) force. A general view of the test stand is shown in Figure 1.

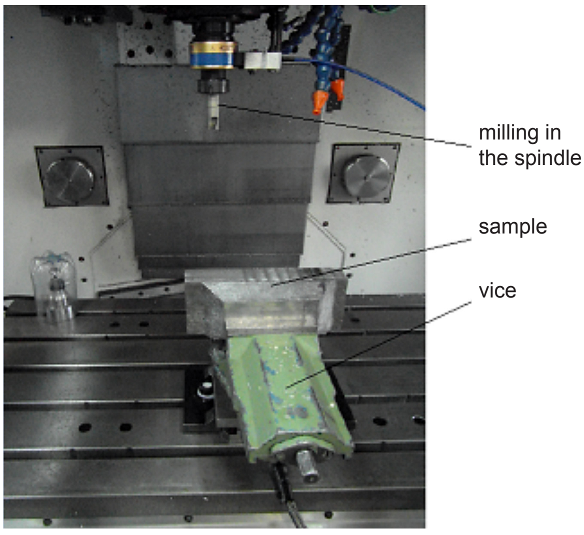

Fig. 1. Test stand

The testing tools (shown in Figure 2) were Iscar-manufactured cutters with diamond inserts (PCD), marketed under the symbol APKW 100304 PDR ID5 with radiused corners of 0.4 mm.

Fig. 2. End mill with diamond inserts

PREPARATION OF SAMPLES

The creation of the composite samples with dimensions of 200 by 200 by 10 mm consisted of the supersaturation of carbon fiber mats with epoxy resin, traded under name GR / EP 985-GF-3070, and positioning them in a 0–90 configuration. For a sample with a thickness of 10 mm there were about 50 pieces of mat. The temperature, humidity, and the amount of impurities in the controlled room were maintained at a preset level, namely at a temperature range of 18–30 °C, humidity up to 60%, and the amount of impurities not exceeding 10 000 particles per 1 m^3.

After positioning each fabric, the samples were put into a furnace and soaked for 120 minutes at the temperature of 177 °C and under the pressure of 0.3 MPa. After their removal from the furnace, the samples were left to cool and then the resin was cut.

The second material to be tested was silumin AlSi21CuNi, a casting aluminum alloy. The chemical composition of the alloy is listed in Table 1.

Table 1. The chemical composition of the alloy AlSi21CuNi

Chemical element	Si	Fe	Cu	Zn	Ti	Mn	P	Ni	Pb	Cr	Mg	Al
Percentage	21.92	0.40	1.27	0.02	0.004	0.14	0.007	0.91	0.004	0.006	0.47	rest

Table 2. The chemical composition of the alloy 7075

Chemical element	Si	Fe	Cu	Zn	Ti	Mn	Cr	Mg	Al
Percentage	0.40	0.50	2.00	6.10	0.20	0.30	0.28	2.90	rest

The third tested material was duralumin 7075. The chemical composition of the alloy is listed in Table 2.

THE EXPERIMENT

In the experiments, the effect of the feed rate and cutting speed on the passive force and cutting torque in milling carbon fiber reinforced plastics as well as silumin AlSi21CuNi and duralumin 7075 were investigated. The machining was performed using a 20 mm diameter end mill with diamond inserts (PCD ID5). The feed varied in the range from 0.04 mm/tooth to 0.28 mm/tooth. The cutting speed ranged from 100 m/min to 340 m/min. Both parameters were changed at a constant depth of cut equal to 1 mm. Each experiment was repeated 6 times.

The passive force and cutting torque were measured using the dynamometer mounted in the spindle of the machining center. The force and torque values were measured over the entire passage length. More than 10 000 measurements were obtained. 10 highest and 10 lowest results for the passive force and cutting torque were filtered out. Mean values of the maximum and minimum cutting force and cutting torque were calculated. The amplitude of the passive force and cutting torque was determined by subtracting the mean maximum value from the minimum value. An example of the passive force distribution over time is shown in Figure 3. Each measurement was made of six samples, which allowed for determining a standard deviation.

RESULTS

Investigating the passive forces, it can be observed that the maximum forces increase with increasing the feed at a constant cutting speed. This dependence applies to the composite as well as to silumin and duralumin (Figure 4). In the case of duralumin, the passive force values are the highest and they vary from 400 N to 900 N. In case of polymer composite, the force values are approximately three times lower. The standard deviation for the maximum forces is in the range from 25 N to 80 N.

The dependence of the passive force amplitude on the feed is shown in Figure 5. Both the force and its amplitude increase with increasing the feed.

In case of duralumin, a change in the cutting speed at a constant feed value results in a decrease in the passive forces. In case of silumin and the composite, the effect of the cutting speed on the passive force is not as considerable it as can be seen in Figure 6.

Figure 7 shows the dependence of the passive cutting force amplitude on the cutting speed. The

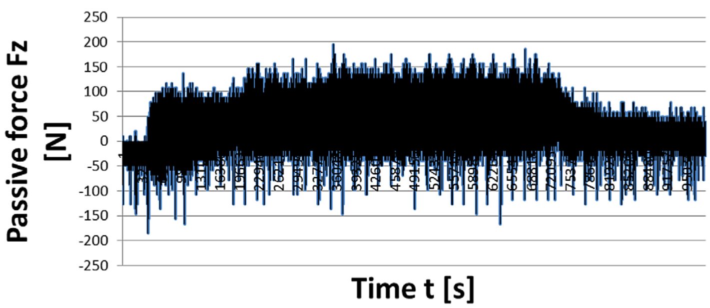

Fig. 3. Distribution of passive force during milling

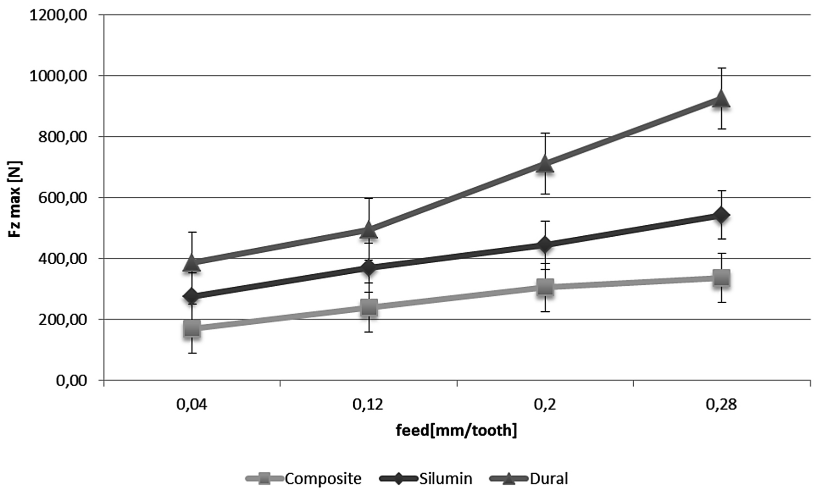

Fig. 4. Dependence of passive forces on feed

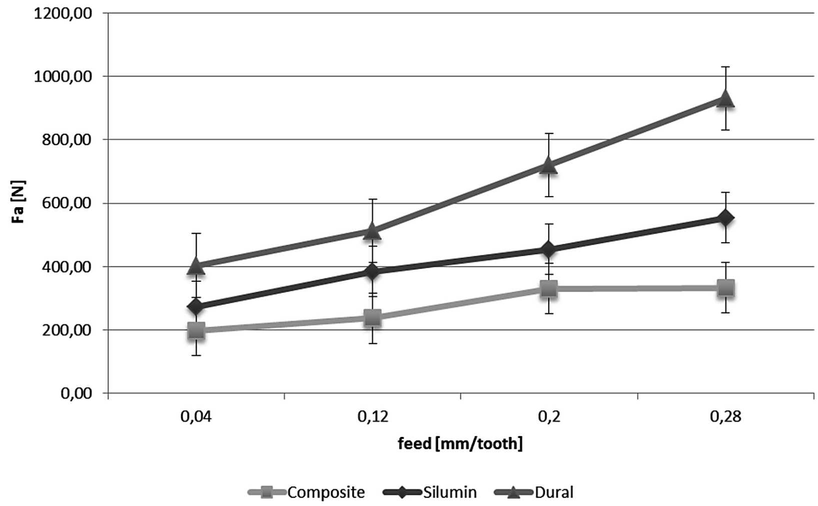

Fig. 5. Dependence of passive force amplitude on feed

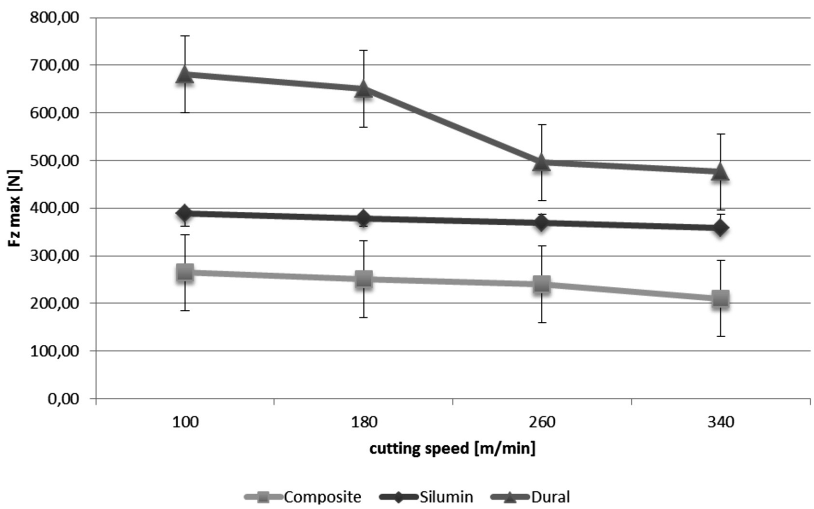

Fig. 6. Dependence of passive forces on cutting speed

graph clearly illustrates a decrease in the forces for duralumin. In case of the composite and siluminthis effect is smaller.

The investigation of the cutting torque has shown that the highest values is recorded when milling the composite (they are about 2 – 3 times

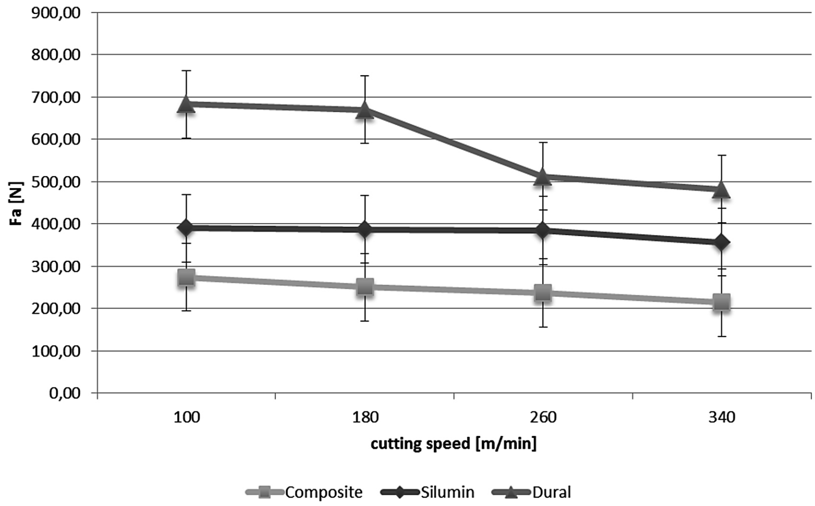

Fig. 7. Dependence of passive force amplitude on cutting speed

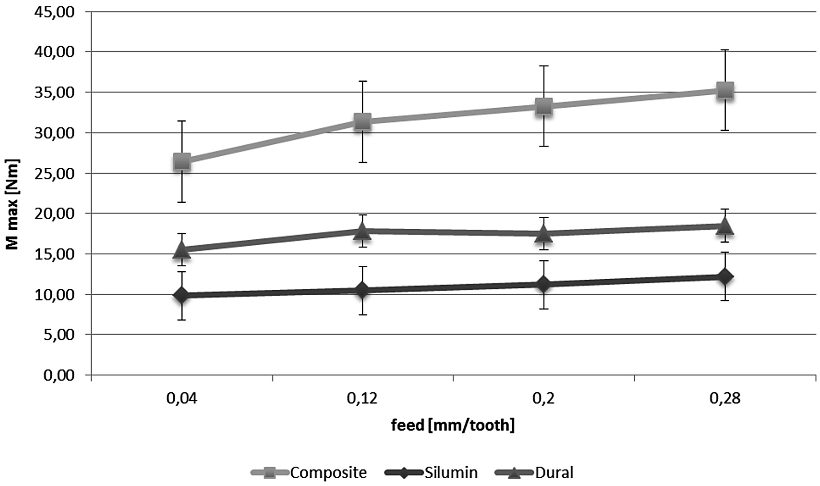

Fig. 8. Dependence of cutting torque on feed

higher compared to aluminum alloys). Increasing the feed causes a small increase in the maximum cutting torque (Figure 8). The maximum values of the cutting torque in the composite milling process vary in the range from 25 to 35 Nm. The standard deviation for the maximum cutting torque is from 2 Nm to 5 Nm. Figure 9 shows the dependence of the cutting torque amplitude on the feed. An increase in the cutting torque amplitude, especially for the polymer composite, is visible.

Investigating the relationship between the maximum cutting torque and the cutting speed, an interesting observation can be made. In case of silumin and duralumin, the cutting torque decreases with increasing the cutting speed, but the reverse is true for the polymer composite (Figure 10). Figure 11 shows the dependence of the cutting torque amplitude on the cutting speed. Analyzing this figure, another interesting observation can be made: the cutting torque amplitude increases for the composite, simultaneously decreasing for silumin and duralumin.

CONCLUSIONS

Summing up the results, it can be observed that increasing the feed rate at a constant cutting speed causes the increase in the passive forces and their amplitude. This dependence applies to all the investigated materials. With an increase in the cutting speed, the passive forces and their amplitude decrease, especially in case of duralumin. The maximum cutting torque increases with the increase in the feed for all the investigated materials. However, the increase in the cutting speed causes a decrease in the maximum cutting torque in case of aluminum alloys and an increase in the cutting torque when milling the composite. This may prove that the cutting edge has a different effect on such a complex material as the examined composite.

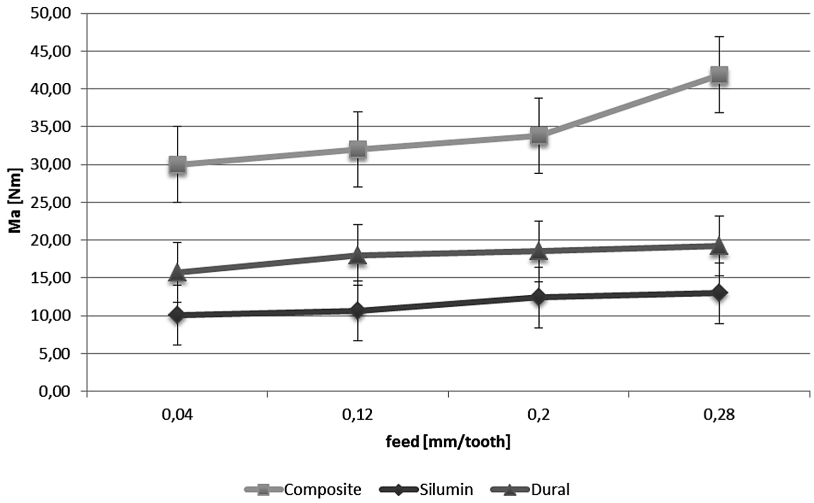

Fig. 9. Dependence of cutting torque amplitude on feed

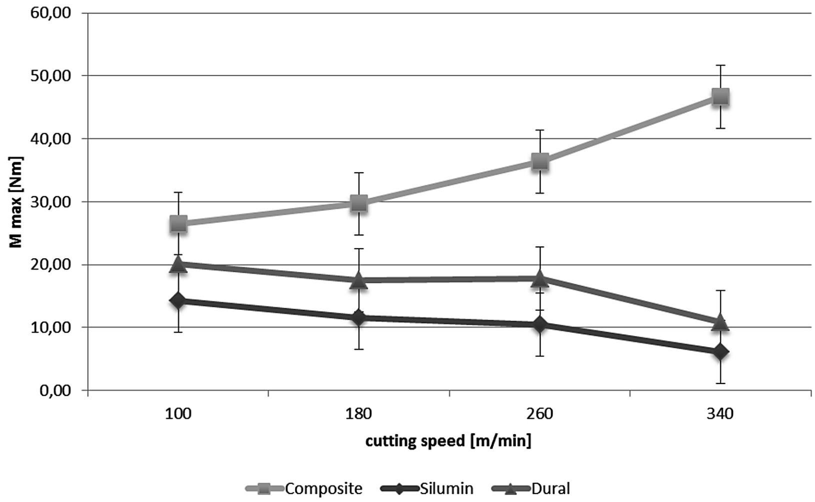

Fig. 10. Dependence of cutting torque on cutting speed

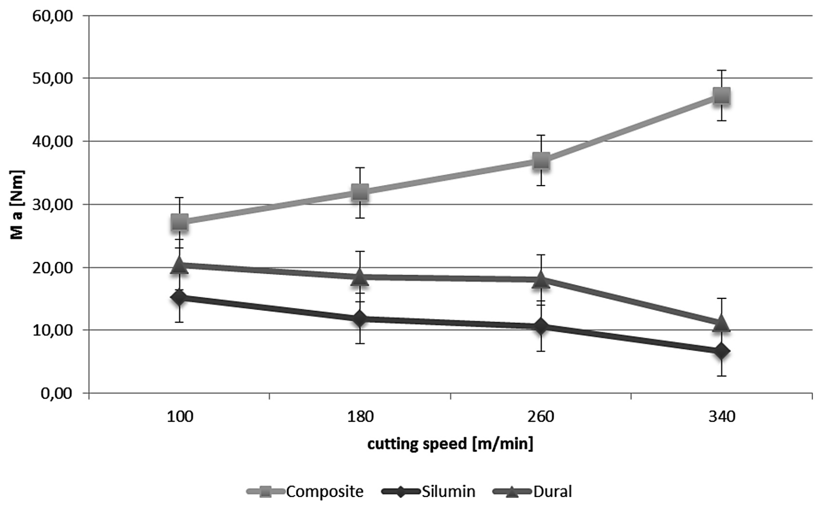

Fig. 11. Dependence of cutting torque amplitude on cutting speed

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