INFLUENCE OF MATERIAL PROPERTIES ON THE MACHINABILITY IN FACE MILLING

A workpiece material and its mechanical properties, chemical composition and microstructure have a significant influence on the material machinability in machining, i.e., on the machining-process output properties: productivity, machined surface quality and machining accuracy. Machinability improves when equal conditions are achieved: long tool life, increased productivity, better machined surface quality, lower forces and cutting temperatures, as well as favourable chip type. Cutting-process planning requires reliable cutting-force estimates, which can be currently obtained only from process-dependent machinability databases. This paper described research in the field of cutting forces in the face milling of eight different materials: steels C45 and C60, gray irons GJL150 and GJL200, silumine AlSi12Cu.00, copper EK2-Cu.00, bronze CuSn12.01 and brass CuZn40Pb.05. The results showed that the hardness, tensile-strength values, chemical composition and microstructure of a workpiece material have a significant influence on the main cutting force, and thereby on the cutting energy in machining.

Keywords: material machinability, the main cutting force, face milling

1 INTRODUCTION

Material machinability in machining is the key issue in the cutting-process technology, considering the fact that there is a large number of parameters influencing it (workpiece material, tool material and geometry, cutting fluid, machining-system stability, machining types, cutting conditions). The technological properties of a process, like the economy, accuracy and machined surface quality, are largely dependent on the efficiency in solving the problem of material machinability. There are several criteria for evaluating the machinability and the most used ones are the following: tool life (influencing the machining time and the production costs), cutting forces (influencing energy consumption), cutting temperatures (influencing tool wear), machined surface quality and chip shape. In practise, no two materials that are subject to machining can behave alike when being cut with the same tool, at the same cutting speed and feed rates, using the same machine, and working under similar conditions. In machining, diverse materials under constant machining conditions and diverse cutting forces owe their origins to the different physical and chemical properties of a workpiece material. The properties of workpiece materials that may affect machinability are: microstructure, grain size, heat treatment, chemical composition, fabrication, hardness, yield strength and tensile strength as well as physical properties such as the modulus of elasticity, thermal conductivity, thermal expansion, and work hardening.

The criteria for a machinability evaluation (output machining-process properties) can be expressed in the functions that provide the connections among these criteria and influencing parameters. These functions are known as material-machinability functions and are determined experimentally. Cutting force is one of several parameters to be considered for a full assessment of the machinability of a workpiece material. Since the face-milling process is one of the most utilized and most efficient processes, the largest number of papers and researches are about this process. The specific characteris-
tics of the face-milling process, like a large number of teeth simultaneously cutting a material and the changeability of the cross-sectional area of a cut, have influenced the development of a large number of models for calculating the cutting-force components. In this paper, the machinability of eight different materials was evaluated through the main cutting force in face milling. The results of testing the material machinability allow an effective and reliable management of the machining process for these materials, the modelling of the cutting forces, and a creation of a database for calculating the cutting forces.

2 EXPERIMENTAL WORK

2.1 Cutting-force measurement

In face milling, the cutting forces exerted by the face-milling cutter tooth on a workpiece are changeable in time and space. Figure 1 presents the cutting-force scheme in the one-tooth face milling (the shaded area is a chip removed by one tooth per revolution).

The main cutting force $F_v$ can be calculated on the basis of the measured cutting forces in the $x$ and $y$ directions using the following equation:

$$F_v = - \sin \phi \cos \phi \begin{bmatrix} F_x \\ F_y \end{bmatrix}$$

During the experiments, the cutting forces were measured using a three-force-component Kistler dynamometer (model 9257A) and also a PC-based data-acquisition system with the LabVIEW software. The experimental work was carried out at the Department of Production Engineering, the Faculty of Technical Sciences in Novi Sad. The machining was conducted on a vertical-spindle milling machine (Prvomajska FSS-GVK-3). A face-milling cutter with a $\Phi 80$-mm diameter (Jugoalat G.707.1), cemented carbide inserts (the Sintal type P25 and type K10), the tool cutting-edge angle of $\beta = 75^\circ$ and the rake angle of $\gamma = 0^\circ$ was used as a tool. All of the experiments were conducted with one insert without a coolant, except for the machining silumine where, due to the chip particles getting stuck in the cutting-edge area, petroleum was used.

A typical cutting-force signal acting on the cutter in the $x$, $y$ and $z$ directions during the face milling is presented in Figure 2. The average value of the cutting forces $F_x$ and $F_y$ was obtained with the cutting forces for five revolutions of the cutter.

2.2 Materials and cutting conditions

Eight different machinability materials have been used as workpiece materials, Table 1. The chemical testing of the steels and silumin were made in the factory Motins in Novi Sad; gray irons were tested in Livnica in Prijepolje; copper, bronze and brass were tested in the company Novkabel from Novi Sad.

The chemical compositions of the investigated materials are shown in Table 1. Experiment conditions and research into the mechanical properties of the materials are summarized in Table 2. The selection of the cutting conditions are closely connected to the cutting tool and workpiece materials ($s_1$ – feed per tooth, $a$ – depth of a cut and $v$ – cutting speed).

Metallographic and mechanical tests were performed at the Laboratory for Material Testing, the Department of Production Engineering, the Faculty of Technical Sciences. Figures 3 to 10 show the microstructures of the tested materials.

Using metallographic researches it was determined that the steels C45 and C60 had a ferrite/perlite structure with clearly defined perlite lamellas, Figures 3 and 4.
All steel was handed out in normalized condition. The microstructure of gray iron GJL150 consisted of perlite and lamellar graphite, type A (according to ASTM), class 1 (>100 mm), equally spread all over the whole section, Figure 5. The test showed that the microstructure of gray iron GJL200 consisted of perlite, phosphide eutectic and lamellar graphite, type C (according to ASTM), class 1 (>100 mm), Figure 6.

Silumine AlSi12Cu.00 was unmodified and consisted of differentiated needle-shaped eutectic and large needles of Al2Cu, with large moulding porosity, Figure 7. The structure of electrolytic copper consisted of polygonal copper grains and a large number of annealing doubles, Figure 8. The inhomogeneous microstructure α of a tough solution where the isles of eutectoid (α+δ) were present, was determined with the metallographic researches of tin bronze. The porosity of the structure was noticeable, as well as its dendrite orientation, indicating that it had been obtained by casting, Figure 9.

Brass had a microstructure αβ containing lead (light fields indicate α brass, dark fields indicate β brass), Figure 10.

<table>
<thead>
<tr>
<th>Material Code in EN</th>
<th>Chemical composition, w/%</th>
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</thead>
<tbody>
<tr>
<td>C45</td>
<td>0.46</td>
</tr>
<tr>
<td>C60</td>
<td>0.57</td>
</tr>
<tr>
<td>GJL150</td>
<td>2.94</td>
</tr>
<tr>
<td>GJL200</td>
<td>3.40</td>
</tr>
<tr>
<td>AlSi12Cu.00</td>
<td>10.86</td>
</tr>
<tr>
<td>CuSn12.01</td>
<td>–</td>
</tr>
<tr>
<td>CuZn40Pb.05</td>
<td>–</td>
</tr>
</tbody>
</table>

Table 1: Chemical compositions of the materials used during the machinability test in mass fractions, w/%

Table 2: Experiment conditions and mechanical properties of the materials used during the machinability test
3 RESULTS AND DISCUSSION

Figures 11 to 18 present diagrams of variations in orthogonal cutting forces and the main cutting force derived from equation (1) for the face milling of the tested materials.
The results of measuring the cutting forces during the face-milling process showed that a workpiece material, with its mechanical, chemical and metallographic features, has a significant influence on their values. Mechanical characteristics (tensile strength $R_m$ and hardness HB) have a dominant influence on the value of the main cutting force. For example, the cutting force needed to machine silumine is much lower than the force required for steels or gray mouldings.

The structure of a workpiece material also had a big influence on the value of the measured cutting forces, as well as on the result dissipation. During the cutting of steels, orthogonal forces $F_x$ and $F_y$ had a small dissipation, Figures 11 and 12. The structure of these materials was very homogenized without any noticeable micro holes and other impacts. Figure 11 shows that the steels with a smaller percentage of sulphur (C45) are harder to be machined (a larger main cutting force is required) than the steels with a larger sulphur content (C60). This can be explained with the fact that a larger sulphur content enables the appearance of a larger number of the MnS particles that are plastically deformed during the process of the cutting machining, unlike the fragile cementite tiles in perlite. In addition to this, the presence of MnS particles shortens the contact length on the front surface of the cutting tile. The shorter contact length results in thinner chipping and a weaker cutting force.

The records of the cutting forces during the machining processes for gray tin GJL150 and GJL 200 shows a large dissipation of the experimental points, Figures 13 and 14. This can be explained with the presence of a large quantity of lamellar graphite in both materials (more in GJL150). The chipping is extremely short, sometimes even in the form of dust, and in that way its contact with the front surface of the cutting tile is also short, influencing the cutting forces that have smaller values than the forces required for steel machining. The
fact that graphite lamellas are weak, makes the cutting forces smaller, too.

During the machining process of silumine AlSi12Cu.00 small cutting forces have been measured. A large tin porosity as well as the micro holes were noticed in the material structure, and, as a result, the cutting forces did not have a continuous flow. A big problem during the experiment with this material was caused by the sticking of the chippings onto the cutting-tool edge. That is why petroleum, which disables the sticking, was used during the machining process.

The main cutting force during the process of brass machining was relatively high. This can be explained with a big contact surface between the workpiece and tool because of the high plastic brass features. For this reason the chipping was thick and during the machining process the tool not only cut but also plastically deformed the working piece. Although the records from the literature say that the occurrence of the layers on the cutting-tool edge during the process of brass machining was reduced with an increase in the cutting speed to over 30 m/min, our experiment has showed something different.

It is known that brass machinability is improved with alloying. This has been proven by measuring the forces during the process of bronze and brass machining. Figures 17 and 18. In this case the measured cutting forces are much smaller than during the machining of pure copper, especially during the brass machining. Because of the inhomogeneous and porous bronze structure, there is a significant dissipation of the experimental points. The biphasic brass structure (α+β) also has a tendency to produce layers on the cutting-tool edge at the reduced cutting speeds.

4 CONCLUSION

This paper has discussed the dependence of material machinability on the mechanical properties, microstructure and chemical composition of a workpiece material. According to the experimental results it can be established that:

- Regarding low cutting forces, low values of hardness and tensile strength usually provide better machinability.
- Sulphur forms inclusions in steels, acting as stress raisers in the chip-formation zone and thus increasing machinability.
- Gray cast irons are frequently characterized in the literature as easily machined materials. However, the machinability of gray irons is influenced by a complex interplay of the graphite and its surrounding matrix structure, which is not well understood. The machinability of gray iron primarily depends on its composition.
- Silumine is an easy-to-cut material except for an intensive adhesion of the chip for the insert.
- Copper and copper-based alloys are easier to machine than steels. Copper is more difficult to machine than bronze, but bronze is more difficult to machine than brass.

5 REFERENCES

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