Experimental Study of Nodular Cast Iron Alloys During Milling

Abstract: In the paper experimental investigations of cutting forces during face milling are presented. Investigations were provided during milling of two type of nodular cast iron alloyed with copper. In investigations was used virtual instrumentation projected for cutting forces measurement. During investigation orthogonal cutting forces components versus time were measured and relationships for cutting forces components versus cutting conditions were determined. The chip root specimens obtained by "quick-stop" method during face milling was prepared for microstructural analysis on light and scanning electron microscopy observation by standard metallographic technique.

Key words: Milling, Cutting forces, Data acquisition, Virtual instrumentation, Chip root, Nodular cast iron

1. INTRODUCTION

Cutting force (resistance) and their moments have great significance in engineering technology and general in the theory of material machining. They represent the basic categories of cutting mechanics, which means that the cutting force expresses one of the basic characteristics of the state and conduct of the process [1].

Research in the field of metal processing technology, chip removal, in most of the works, was focused on machinability of material. Machinability of material defines features of tool life, cutting forces, surface quality, cutting temperature and chip form. Having known these features, as well as important technological characteristics of the material, it is important to both the classical and the automated design of cutting process technology. In accordance with that was created a database of machinability and optimization of cutting parameters [2].

Nodular cast iron is the cast iron where the graphite during the process of casting aside in the form of nodules, i.e. spheres. This form of graphite is very favorable for cast iron and in relation to all other cast iron this type has higher strength and the highest ductility. Further thermal treatments (austempering or isothermal improvement) ductile cast iron can be obtained even better features, and the resulting material is due to its unique structure - ausferrite is called ADI (Austempered Ductile Iron). Parts made from ductile iron and ADI material are used for machines and devices that operate in extreme conditions. It is therefore necessary to know the behavior of ADI materials during various cutting conditions processing.

The microstructure of ductile cast iron (NL) and the ADI material in polished and bitten state are given in Figure 1 (a-c). Graphite nodule in live are spaced evenly with the degree of spheroidization over 90% and their density from 60 to 80 nodules/mm² and with average nodules size from 40 to 55 microns, Figure 1 (a). The microstructure of nodular cast iron metal base consists of ferrite and pearlite (mostly pearlit, with more than 90% pearlite), Figure 1 (b). The microstructure of ADI material obtained after austempering of nodular cast iron is ausferrite with metal base, composed of acicular ferrite and austenite left, Figure 1 (c). The amount of residual austenite in the ADI microstructure material is 16.56%.

Nodular cast iron and ADI mechanical properties are shown in Table 1. Austempering process improves all the mechanical properties of ductile cast iron, so it comes to enhancing the value of strength and hardness of 1.5 to 2 times. This increase in mechanical properties is caused by changing the microstructure of predominantly pearlite in the NL in ausferrite in ADI materials.

<table>
<thead>
<tr>
<th>Material</th>
<th>Tensile strength $R_m$ [MPa]</th>
<th>Yield strength $R_{0.2}$ [MPa]</th>
<th>Hardness $HV_{10}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>NL</td>
<td>771</td>
<td>510</td>
<td>270</td>
</tr>
<tr>
<td>ADI</td>
<td>1110</td>
<td>995</td>
<td>480</td>
</tr>
</tbody>
</table>

Table 1. Mechanical properties at room temperature

In Figure 2 are shown the orthogonal cutting forces in face milling process.

Face milling process like multi tooth simultaneously cutting and difference in the chip cross section that one tooth cut influenced development of variety of models for cutting force calculation. Variation in chip cross section gives difference in intensity of cutting forces and thermal load of single tooth [3].
2. EXPERIMENTAL RESEARCH

2.1. Face milling

The first objective of the experiment was to perform the measurement of cutting forces for different modes of ductile iron processing during face milling. In that order relationships for cutting forces and cutting conditions was determined.

Following materials was used:

- Nodular cast iron alloyed with 0.45% Cu (designated NL1)
- Nodular cast iron alloyed with 1.6% Cu and 1.5% Ni (labeled NL2)
- ADI material - where NL1 austenitized at 900 ° C/2h and austempered at 350 ° C/2h indicated (A1)
- ADI material - where the NL2 austenitized at 900 ° C/2h and austempered at 350 ° C/3h indicated by (A2)

2.1.1. Terms of the experimental study

a) Machine: The study was conducted on a vertical milling machine. This machine was chosen because it is rigid enough; it has sufficient strength and is available for testing.

b) Tool: The milling head was used for test with the insert of the HM P25. The experiment was carried out with a tooth and without cooling and lubrication agent.

In order to continuously and simultaneously measuring components of cutting force “Kistler” dynamometer type 9257 was used.

2.1.2. Acquisition system for the cutting force during face milling measurement

Figure 3 shows scheme of the acquisition system for the cutting force during face milling measurement.

From Figure 3 can be seen that the system consists of the following components:

- Machine Tool (vertical milling machines)
- Tools (milling head with interchangeable cutting inserts)
- Sensor measurement system (three component piezoelectric dynamometer - "Kistler"-9257A)
- Amplifier of measurement system (capacitive-amplifier "Kistler" - CA 500)
- Dial-up panel for connecting the module with the actual acquisition process (ED429-UP)
- Acquisition Module - A / D converter - ED428
- Computer System
- Program (software) support system
- VI for acquisition, display in real time, storing and processing data.

Virtual instrument used for measuring the cutting force in face milling process was developed using graphical programming software Lab VIEW 8.0. VI is designed to allow easy monitoring of voltage with dynamometer, which correspond to the cutting forces during milling Fx, Fy and Fz, view, change the values in the form of diagrams and tables, and to display the maximal values of single measurement. [4]

2.2. Peripheral milling

Another objective of the experiment is to obtain samples of the chip roots in nodular cast iron and in the austempered state during up peripheral milling for different cutting conditions. To obtain samples of root chip used was a method of quick stopping cutting process based on programmed breaking of workpiece
materials. Thus obtained samples were used for metallographic analysis to study the process of chip formation.

2.2.1. Terms of the experimental study

a) Machine: vertical milling machine "PRVOMAJSKA" FSS GVK-3P, which was carried out and the first experimental surveys.

b) Tool: The survey was used peripheral milling cutter with screw teeth JAL 63x40x27 N made from high speed cutting steel with TiN coating.

c) Equipment for cooling and lubrication was not used.

For microstructural analysis, samples were prepared for light and scanning electron microscopy observation of the standard metallographic technique and were investigated by Leitz-Orthoplan light microscope (LM) and JEOL JSM 6460 LV scanning electron microscope (SEM) working at voltage of 25 kW.

4. RESULTS AND DISCUSSION

Measuring components of the resulting cutting force was adapted statistical methods three factorial design of the experiment, which in addition to savings in the tool, workpiece material and time trials, provide sufficient reliable dependence between input and output parameters of the process.

As experiments were done for 12 measurements and for the four types of workpiece material, it was found that the best was here to show the results of measurements of only two materials. The charts based on cutting force Fx, Fy and Fz measured in time, for different structures of nodular cast iron completely the same as shown diagrams, except that the value of the resulting components of cutting force for all the types of workpiece material at the same cutting conditions.

By observing the charts on which are shown the resulting components of cutting forces depending on the time, it can be noticed that the largest component is Fx, Fy is medium, and the lowest Fz.

**Figure 4 Orthogonal force patterns versus time for ADI material**

In Figure 4 and 5 are shown diagrams to illustrate the change of the orthogonal cutting force depending on the time with certain cutting conditions.

It can seen that the cutting forces under the same cutting regimes for these two materials are significantly different. Cutting forces of ADI materials are higher than the ductile cast iron. This can be attributed to the higher mechanical properties of ADI material in relation to the NL in cast condition.

In addition, the particular stands out and the appearance of the resulting inequality components of cutting force due to periodic entry or exit of cutter teeth from the material of workpiece. Since the values of components in the graphs shown periodically change from zero to a maximum value F_{max} follows that only one tool was in the milling operation.

The following chart shows the dependence force Fx, Fy, Fz versus the cutting speed v, feed s and the depth of cut a for NL1 ductile cast iron used in the experiment, Figure 6. (b). A similar diagram and the same dependence was obtained during varying of different ADI material. In order to obtain these diagrams elements of cutting conditions vary and the two are always left constant. In Figure 6. (a) chart shows the maximum force in the processing of ductile cast iron NL1. In Table 2 are values of maximal force.

**Figure 5 Orthogonal force patterns versus time for ductile iron**

**Figure 6 (a) Maximum cutting forces at a constant depth and feed for various cutting speeds (NL)**
Figure 6. (b) Dependence of force $F_x$, $F_y$, $F_z$ versus the cutting speed $v$ (NL).

Table 2. The values of maximum force

<table>
<thead>
<tr>
<th>$v$(m/min)</th>
<th>$F_x$</th>
<th>$F_y$</th>
<th>$F_z$</th>
</tr>
</thead>
<tbody>
<tr>
<td>44</td>
<td>387</td>
<td>99</td>
<td>132</td>
</tr>
<tr>
<td>55.2</td>
<td>422</td>
<td>159</td>
<td>141</td>
</tr>
<tr>
<td>71</td>
<td>616</td>
<td>235</td>
<td>169</td>
</tr>
</tbody>
</table>

Below are shown micrographs of chip root samples from which the values are the following:
- rake angle $\gamma$,
- shear angle $\Phi$,
- angle of the texture line $\Psi$ ($\Phi_1 = \Phi + \Psi$).

Figure 7. Chip root of ductile iron with 0.45% Cu ($v=44$ m/min, $V_p=630$ mm/min, $s_1=0.35$ mm/t, $a=0.2$ mm)

Figure 8. Chip root of ADI material with 0.45% Cu ($v=44$ m/min, $V_p=40$ mm/min, $s_1=0.35$ mm/t, $a=4$ mm)

The sample of chip root in Figure 8 was obtained nearly band chips and a good quality of the machined surface.

Figure 9 shows that the small built up edge is accumulated at the chip root and nodules are find on the machined surface.

The influence of workpiece material is great, because every material particular in its own way. In this paper, the ADI material is obtained a better surface, which can be attributed to higher hardness material, which amounts to 480 HV.

5. CONCLUSION

Investigation of cutting forces is a key part in the development of cutting technology itself. They are one of the main criteria for evaluating machinability of material and as such attract the attention of many researchers in this field. Exact knowledge of the characteristics and values of cutting force in the face milling is needed to study the dynamics of cutting process in interaction with the dynamics behavior of the structure of machine tools. Analysis of cutting force in milling is very complex due to the influence of a number of different phenomena. The work indicates the complexity of the processes that take place during cutting. The highest values of cutting force components have force $F_x$, medium $F_y$ and at least $F_z$.

Chips obtained during cutting of ductile iron and ADI material is in very suitable form, most often bent in the shape of roll with clearly expressed teeth on the outer surface of the chip, what is the result of relative sliding along rake face of tool.

6. REFERENCES


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