INFLUENCE OF FRICTION COEFFICIENT ON WORKPIECE ROUGHNESS IN RING UPSETTING PROCESS

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Abstract: In forming processes contact friction significantly influence metal flow, stress-strain state and process parameters. Furthermore, tribological conditions influence workpiece surface quality and its dimensional precision. This paper presents research results of the influence of contact friction coefficient on a workpiece surface quality in ring upsetting by flat plates. Workpiece surface roughness is measured using atomic force microscope. Ring upsetting experiments are conducted with ion implanted and nonimplanted dies.

Key words: ring upsetting, ion implantation, nanoroughness, AFM, friction coefficient

1. INTRODUCTION

Quality of a metal forming process is often controlled by the interfacial friction between the contacting die and workpiece surfaces. If the interfacial friction forces are large enough, the strain condition and formability of the workpiece may deteriorate and the energy required to form the part may be unacceptably high [1].

A basic premise of the theory of friction is that apparently flat, smooth surfaces are not so smooth when viewed on a microscopic scale. Surfaces of metals are actually rough, and asperities representing the roughness of the surface are present in surfaces of metals. Workpieces, dies and tools are characterized by surface roughness. Until all asperities are flattened, surface roughness has an influence on the friction properties of those surfaces, especially at the beginning of metal forming processes. During forming process asperities plough into each other, and thus a small sliding always exists. At the beginning of the process, since the tool is in contact just with the peaks of the asperities, the friction properties depend on the distribution of asperities, on their height and their deformation during the process, e.g. on the roughness of the contact surface. With the flattening of asperities the contact with the tool gets larger and this leads to varying friction properties [2, 3, 4, 5].

Such friction produces a tangential (shear) force at the interface between die and workpiece which restricts movement of the material and results in increased energy and press forces. The magnitude of the shear friction stress influences the deformation pattern, the temperature rise, the tool deflection and the total force in metal-forming [6]. The prediction of how quick the die will failure is an important objective to guarantee good output from a cold forging process. The failure of a tool does not only require it to be replaced but it also stops production, causes rejection of the workpieces, and requires new adjustment of the machine. The replacement of the dies planned according to a predictive maintenance program less affects productivity than unexpected stops [7].

2. FRICTION IN METAL FORMING PROCESS

During metal forming process working surface of the die is in continuous contact with the workpiece surface. In the contact between the die and workpiece high values of normal and tangential stresses are present together with the displacement and sliding of material. Contact surfaces of the die and workpiece have initial roughness which changes during metal forming process.

Contact friction corresponds to a resistance of relative movement between two bodies in contact, with normal stress present in between them (fig. 1).

![Fig. 1. Contact between workpiece and die](image)

In between those surfaces lubrication is present
which lowers contact friction. During metal forming process removal of workpiece’s material and wear process initiates on the surface of the die and workpiece, which modifies initial tribological conditions in forming process.

Since relative movement between die and workpiece is always present in metal forming process, friction is integral part of every metal forming process (with an exception of uniaxial tension). Contact friction is negative event since it causes an increase of required force and work, die wear and nonuniform deformation. Rolling process is exception, since friction is required for process to be carried out.

During metal forming process peaks of asperities found on workpiece and die are in contact, while other areas of the contact surface are separated by lubricant (fig. 2).

Composition of anti-friction material is changing during metal forming process, because friction generate workpiece and die wear, oxidation and corrosion of metal which affects friction and lubrication conditions. Surface roughness of tools and final parts is important for adequate lubrication and it also stands as a wear criterion in the metal forming process. Surface profile consists of many peaks and valleys that get deformed in the forming process. Those deformed peaks and valleys affect lubricant film sustainability and because of that surface topography affect the maintenance of lubricant film. For this reason, the surface topography is very important in metal forming processes.

According to [2] friction coefficient increases with surface roughness decrease except when samples were made of brass (tab. 1). For samples made of aluminum and steel, highest friction coefficient values are obtained in case of polished surface, while lowest values are obtained for machined only surface.

<table>
<thead>
<tr>
<th>Trial no.</th>
<th>Deformation ratio (%)</th>
<th>Pre-upsetting surface roughness of parts (Ra-µm)</th>
<th>Friction coefficient</th>
<th>µ</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>19.2</td>
<td>1.85</td>
<td>0.08</td>
<td>0.08</td>
</tr>
<tr>
<td>2</td>
<td>19.3</td>
<td>1.75</td>
<td>0.09</td>
<td>0.09</td>
</tr>
<tr>
<td>3</td>
<td>39.4</td>
<td>2.20</td>
<td>0.08</td>
<td>0.08</td>
</tr>
<tr>
<td>4</td>
<td>42.8</td>
<td>2.25</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td>5</td>
<td>58.0</td>
<td>2.05</td>
<td>0.13</td>
<td>0.13</td>
</tr>
<tr>
<td>6</td>
<td>59.0</td>
<td>2.09</td>
<td>0.12</td>
<td>0.12</td>
</tr>
</tbody>
</table>

Table 1. Friction coefficient and factor values [2]

Since the contact area between die and workpiece is smallest at machined samples, and highest for polished samples, the lowest friction coefficient values were obtained on samples whose surface is only machined. Various instruments are being used for measuring surface topography and for topography measurements in nano and micro scale atomic force microscopy can be successfully used. As universal method for friction coefficient measurement in bulk metal forming processes, ring upsetting by flat plates (dies) have been used [4, 7, 8].

3. RING UPSETTING EXPERIMENT

Fig. 3 shows contact friction coefficient determination by ring upsetting method.

Method consists of establishing the dependence between deformation of inner ring’s diameter and ring’s height. This dependence is taken into etalon chart and compared with existing within the chart.

Ring upsetting has been performed incrementally, with a height deformation around 10%. After each upsetting stage ring’s dimensions were measured. Incremental upsetting has been carried out until total deformation of the ring’s height has reach around 70%.

Once the ring upsetting has been completed, deformation of the ring’s inner diameter and deformation of the ring’s height has been calculated for each upsetting increment. By connecting all the pairs of height and inner diameter deformation curve was defined.

In order to find the friction factor for the completed upsetting process, it is necessary to compare the curve with an existing ones from the etalon diagram.

Ring upsetting has been carried out with two different pairs of dies. One pair of dies has been grinded, polished and ion implanted with 2·10^{17} N⁺ 50 keV, while another pair of dies has not been ion implanted. Dies were made of X210Cr12 cold work tool steel (Č.4150) with dimensions ø50×45 mm. Rings were made of Ck15 unalloyed carbon steel (Č.1221) with initial dimensions D₂:D₁:h=18:9:6 mm. Hardness of the dies was 58±2 HRC, while hardness of the ring upset with nonimplanted dies was 167 HV-10 and hardness of the ring upset with implanted dies was 161 HV-10. Upsetting was done without contact surface lubrication.
4. RESULTS

4.1 Ion implantation simulation by SRIM software

In order to ensure successful ion implantation into X210Cr12 steel, SRIM simulation software was used to evaluate the effect of $2 \times 10^{17}$ N⁺ 50 keV ion implantation into die’s surface. As it can be seen from fig. 4, ion implantation depth was around 100 nm. For the convenience, SRIM simulation on fig. 4 was completed with 10000 ions.

![SRIM simulation of ion implantation into steel](image)

Fig. 4. SRIM simulation of ion implantation into steel

Based on the results of simulation, ion implantation of the dies has been carried out in Institute of Nuclear Sciences “Vinča”.

4.2 Ring upsetting – contact friction coefficient

Fig. 5 shows comparison of friction factors obtained from a ring upsetting experiment while tab. 2 shows friction factors and friction coefficients values.

<table>
<thead>
<tr>
<th>Dies</th>
<th>Friction factor ($m$)</th>
<th>Friction coefficient ($\mu$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonimplanted</td>
<td>0.15</td>
<td>0.087</td>
</tr>
<tr>
<td>Implanted</td>
<td>0.11</td>
<td>0.064</td>
</tr>
</tbody>
</table>

Table 2. Friction factors and friction coefficients for rings upset with implanted (2) and nonimplanted dies (1)

![Comparison of friction factors for rings upset with implanted (2) and nonimplanted dies (1)](image)

Fig. 5. Comparison of friction factors for rings upset with implanted (2) and nonimplanted dies (1)

determine the influence of die’s surface ion implantation on friction and dimensional accuracy, i. e. workpiece surface quality at metal forming processes. By comparing the roughnesses between corresponding rings, influence of die’s surface ion implantation on ring’s quality and accuracy can be established.

Topography of the ring was measured with VEECO “di CP II” atomic force microscope.

To evaluate the effect of die surface ion implantation on ring’s surface roughness during upsetting, ring roughness has to be determined before upsetting was carried out. Fig. 6 displays topography of the ring that hasn’t been upset with dies and tab. 3 shows average roughness values of rings before upsetting.

![Topography of the ring’s surface before upsetting](image)

Fig. 6. Topography of the ring’s surface before upsetting

<table>
<thead>
<tr>
<th>Ring for upsetting with</th>
<th>$R_a$ [nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>ion implanted dies</td>
<td>126.75</td>
</tr>
<tr>
<td>nonimplanted dies</td>
<td>137.65</td>
</tr>
</tbody>
</table>

Table 3. Average values of $R_a$ for ring before upsetting

Fig. 7 shows measuring points where surface roughness was measured using atomic force microscopy, while tab. 4 shows average ring’s roughness values after upsetting. Distance between measuring points on the rings is approximately 1 mm.

![Measuring points on the ring upset with a) nonimplanted dies, b) implanted dies](image)

Fig. 7. Measuring points on the ring upset with a) nonimplanted dies, b) implanted dies

<table>
<thead>
<tr>
<th>Ring upset with</th>
<th>$R_a$ [nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>ion implanted dies</td>
<td>11.11</td>
</tr>
<tr>
<td>nonimplanted dies</td>
<td>23.79</td>
</tr>
</tbody>
</table>

Table 4. Average values of $R_a$ for ring before upsetting

Fig. 8 shows topography of the ring upset with nonimplanted dies at measuring point 7 (see fig. 7), while fig. 9 shows topography of the ring upset with
implanted dies also at measuring point 7.

Fig. 8. Topography of the ring upset with nonimplanted dies measured at point 7

Fig. 9. Topography of the ring upset with ion implanted dies measured at point 7

Fig. 10. shows roughness comparison between the rings upset with nonimplanted and ion implanted dies.

5. DISCUSSION

It is evident from diagram (fig. 5) that ion implantation has influence on friction coefficient in ring upsetting process, since friction coefficient is 1.36 times lower in case of upsetting with ion implanted dies. According to tab. 4 ring upset with ion implanted dies has average roughness (Ra) that is 2.14 times lower than ring upset with nonimplanted dies. Also, it is obvious from fig. 8 and 9 that rings upset with ion implanted dies has smoother surface compared to ring upset with nonimplanted dies. Diagram on fig. 10 shows that ring upset with ion implanted dies has roughness in narrower range compared to ring upset with nonimplanted dies.

6. CONCLUSION

Based on the results presented in this paper, it can be concluded that ion implantation can reduce the friction coefficient and improve surface roughness and quality at bulk forming process. AFM application is essential for researching surface nanomorphology in bulk forming processes. Results obtained in this paper contribute to development of ultraprecision engineering.

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7. REFERENCES


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