Influence of grinding parameters on the surface roughness of steel 1.0562 in the softened state

Wpływ parametrów szlifowania na chropowatość powierzchni stali 1.0562 w stanie zmiękczonym

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PIOTR WASZCZUR
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Results from testing the grinding process of structural elements made of alloy steel 1.0562 in the softened state are presented. Influence of the grinding depth $a_b$ and the longitudinal feedrate of the workpiece $v_f$ on the surface roughness is analyzed. Roughness values of $Ra$, $Rz$ and $Rt$ were considered available to obtain under accepted test conditions. KEYWORDS: surface grinding, feed speed, depth of grinding, surface roughness parameters

The correct course of the grinding process is related to the appropriate selection of technological parameters, which allows to meet certain construction requirements, mainly to obtain high dimensional accuracy and shape of the required surface geometry (WW) and achieve the desired condition of the workpiece (PO) [2, 5]. In addition to the low surface roughness and high grinding efficiency [1], the research also reduces the process energy consumption and carbon dioxide emissions [6]. The grinding wheel and its conditioning parameters also have a significant influence on the process and technological effects [3]. Proper selection of machining parameters with correct delivery of cooling-lubricating fluid (CCS) avoids damage in the form of micro-cracks and cures in WW-PO [4] and prolongs the service life of the workpieces, e.g. railway rails [5].

The results of the study along with the assessment of the effect of grinding depth $a_b$ and the longitudinal feedrate of the object $v_f$ on the values of surface roughness parameters of structural elements made of 1.0562 steel in the softened state, were presented. Obtaining $Ra$ roughness value below 0.1 μm was one of the basic design requirements for plates (fig. 1), which is a research hydraulic device.

Test conditions

Grinding tests were performed on a CNC grinding machine for SPG 25X60 planes with horizontal spindle axis. The panels of 256×68×28 mm dimensions (fig. 1) made of 1.0562 steel with hardness of 220 HB, tensile strength $Rm = 490$÷$630$ MPa and yield strength $Re = 335$ MPa, were machined. By default, the components of this material are heat treated to increase their hardness and wear resistance. In the research carried out for the purpose of the hydraulic equipment, in accordance with the requirements of the constructor, the plates were softened. The treatment was carried out with Norton Grinding Wheels at 38A60LVS and dimensions $(D \times T \times H)$ 250×25×76.2 mm.

The grinding was performed at constant wheel circumferential speed $V_C = 25$ m/s, using coolant. The transverse feedrate of the grinding wheel followed the grinding wheel along the grinding surface and was 15 mm (60% of the grinding wheel). Prior to each test, the grinding wheel was conditioned with a diamond dresser with the following parameters set in the control program:

- depth $a_b$ at one passage – 0.01 mm,
- number of crossing passages – 4,
- abrasive wheel circumferential velocity – $v_f = 23$ m/s,
- transverse feedrate of abrasive wheel – $f_t = 0.2$ mm/rev.

<table>
<thead>
<tr>
<th>Number of sample</th>
<th>Levels of initial parameters</th>
<th>Values of parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Feedrate $v_f$</td>
<td>Grinding depth $a_b$</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>2</td>
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<td>6</td>
<td>2</td>
<td>3</td>
</tr>
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<td>7</td>
<td>3</td>
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<td>8</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

Statistically determined complete 3-value study plan – PS/DK-3² was adopted. Each grinding test (Table I) was repeated.

Less velocity of the longitudinal feedrate $v_f$ than the recommended ones [2] was assumed, because at higher velocities, the roughness and the waviness of the surface of the PO increased with visible inequalities in the form of bands. After each grinding and repetition test, 4 surface

Fig. 1. Plate with holes after grinding

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roughness measurements were taken – a total of 8 measurements. For this purpose, the contact profilometer HOMMEL TESTER T1000 was used. Measurements were made for an elementary section of 0.8 mm.

Test results

Fig. 2 and Fig. 3 show mean values of roughness parameters from individual grinding tests (Table I), and as a measure of spread, the standard deviation was assumed. The highest values of roughness parameters, irrespective of the grinding depth, were obtained after samples 7–9 with the highest feedrate of \( v_l = 1.8 \) m/min. The lowest – values of roughness parameters such as \( Ra \), \( Rz \) and \( Rt \) were obtained after grinding with \( v_l = 0.9 \) m/min and \( a_e = 0.004 \) mm.

![Fig. 2. Average values of surface roughness parameters \( Ra \) and \( Rq \) obtained after subsequent grinding tests](image1)

![Fig. 3. Average values of surface roughness parameters \( Rz \), \( Rt \) and \( Rp \) obtained after subsequent grinding tests](image2)

### TABLE II. ANOVA analysis for parameter \( Ra \)

<table>
<thead>
<tr>
<th>Variance source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>( F )</th>
<th>( p )</th>
<th>( F_{test} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( v_l )</td>
<td>0.038</td>
<td>2</td>
<td>0.019</td>
<td>129.805</td>
<td>0.000</td>
<td>3.143</td>
</tr>
<tr>
<td>( a_e )</td>
<td>0.007</td>
<td>2</td>
<td>0.003</td>
<td>23.804</td>
<td>0.000</td>
<td>3.143</td>
</tr>
<tr>
<td>( v_l \cdot a_e )</td>
<td>0.005</td>
<td>4</td>
<td>0.001</td>
<td>8.297</td>
<td>0.000</td>
<td>2.518</td>
</tr>
<tr>
<td>Error</td>
<td>0.009</td>
<td>63</td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>0.00875</td>
<td>71</td>
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</tr>
</tbody>
</table>

Legend: SS – sum of squares of deviations; df – number of degrees of freedom; MS – average square of deviations; \( F \) – calculated value of \( F \) statistics; \( p \) – probability; \( F_{test} \) – critical value read at significance level \( \alpha = 0.05 \).

![Fig. 4. Dependence of roughness parameters: a) \( Ra \), b) \( Rt \), c) \( Rz \) for ground surface on the longitudinal feedrate \( v_l \) and grinding depth \( a_e \)](image3)

### TABLE III. ANOVA analysis for parameter \( Rt \)

<table>
<thead>
<tr>
<th>Variance source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>( F )</th>
<th>( p )</th>
<th>( F_{test} )</th>
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<tbody>
<tr>
<td>( v_l )</td>
<td>33.952</td>
<td>2</td>
<td>16.976</td>
<td>19.754</td>
<td>0.000</td>
<td>3.143</td>
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<tr>
<td>( a_e )</td>
<td>0.623</td>
<td>2</td>
<td>0.311</td>
<td>0.362</td>
<td>0.697</td>
<td>3.143</td>
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<tr>
<td>( v_l \cdot a_e )</td>
<td>15.352</td>
<td>4</td>
<td>3.838</td>
<td>4.466</td>
<td>0.003</td>
<td>2.518</td>
</tr>
<tr>
<td>Error</td>
<td>54.140</td>
<td>63</td>
<td>0.859</td>
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<tr>
<td>Total</td>
<td>104.066</td>
<td>71</td>
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</table>

### TABLE IV. ANOVA analysis for parameter \( Rz \)

<table>
<thead>
<tr>
<th>Variance source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>( F )</th>
<th>( p )</th>
<th>( F_{test} )</th>
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<tbody>
<tr>
<td>( v_l )</td>
<td>12.871</td>
<td>2</td>
<td>6.435</td>
<td>58.958</td>
<td>0.000</td>
<td>3.143</td>
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<tr>
<td>( a_e )</td>
<td>0.543</td>
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<td>0.272</td>
<td>2.489</td>
<td>0.091</td>
<td>3.143</td>
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<tr>
<td>( v_l \cdot a_e )</td>
<td>1.147</td>
<td>4</td>
<td>0.287</td>
<td>2.628</td>
<td>0.043</td>
<td>2.518</td>
</tr>
<tr>
<td>Error</td>
<td>6.877</td>
<td>63</td>
<td>0.109</td>
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<td></td>
</tr>
<tr>
<td>Total</td>
<td>21.438</td>
<td>71</td>
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</tbody>
</table>

In the case of the roughness parameter \( Ra \), the \( v_l \) and \( a_e \) parameters as well as interaction between them were significantly affected. The parameter \( Rt \) was most influenced by velocity of the longitudinal feedrate of the object \( v_l \) and interaction of this parameter with the grinding depth \( a_e \). Similar results were obtained for \( Rz \) parameter.

Fig. 4 shows the values of roughness parameters \( Ra \), \( Rt \) and \( Rz \) obtained depending on the feedrate of the object and the depth of grinding. It can be seen that within the range of assumed values of \( v_l = 0.3 \) and 0.9 m/min, the \( Ra \) and \( Rz \) values were similarly independent of the grinding depth. Only for \( Rt \), significant values were recorded for the smallest longitudinal feedrate of the object \( v_l \) and grinding depth \( a_e = 0.004 \) mm.
Exemplary roughness profiles with material contribution curves and ordinate distributions are illustrated in figs. 5–7.

Fig. 5. Exemplary surface roughness profile obtained after grinding with parameters $v_f = 0.9 \text{ m/min}$ and $a_v = 0.004 \text{ mm}$

Fig. 6. Exemplary surface roughness profile obtained after grinding with parameters $v_f = 1.8 \text{ m/min}$ and $a_v = 0.006 \text{ mm}$

Fig. 7. Exemplary surface roughness profile obtained after grinding with parameters $v_f = 0.3 \text{ m/min}$ and $a_v = 0.004 \text{ mm}$

The most favorable surfaces were obtained after grinding the sample No. 5. An example of such surface area is shown in fig. 5. The surface profile after grinding with the highest values of parameters (sample No. 9) is shown in fig. 6. When comparing the profiles of fig. 5 and fig. 6, the differences can be seen due to the occurrence of scratches on the surface, which can be contributed to the small hardness of the workpiece. The scratches are also visible on the roughness profile of fig. 7 obtained after the grinding the sample No. 2. Their formation influenced the value of $R_t$ parameter.

Fig. 8 shows values of the asymmetry coefficient of the roughness profile $R_{sk}$ obtained after individual grinding tests. Negative values of this parameter indicate that the ground surfaces have a high bearing load.

Fig. 8. Average values of the asymmetry coefficient for the roughness profile $R_{sk}$ after subsequent grinding tests

Conclusions

Based on the grinding of 1.0562 steel in the softened state, it has been determined that the longitudinal feedrate $v_f$ has a greater effect on the surface roughness than the grinding depth $a_v$. The lowest surface roughness was reported for the grinding parameters No. 5. The smallest values of the $Ra$ roughness parameter – in the range of $0.06 \div 0.08 \mu m$ – appear to be the limiting values that can be achieved under the accepted conditions of grinding of low hardness objects. Increasing the $v_f$ speed over $1.8 \text{ m/min}$ resulted in an increased surface roughness. At the lowest accepted feedrate, the best results were also not obtained.

REFERENCES