The Impact of Changes in InFeed Rate on Surface Integrity after Chrome Plate Grinding by Silicon Carbide

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Grinding is a significant and very commonly used technology, allowing for important gains in surface integrity. The surface integrity quality after grinding is one of the most important parameters, which is prescribed on the production drawing. Chrome plating as protection against corrosion, erosion, abrasion and as a material for the overhaul of worn-out parts is used. This paper discusses the change of cutting conditions when samples were ground. The surface of all samples was preserved with galvanically applied chrome. The values show which grade of surface roughness is attained when selecting different cutting conditions. The results of surface integrity after grinding were evaluated depending on the comparison of the parameters of roughness. The input parameters of cutting conditions were chosen based on the experience, which was implemented.

Keywords: grinding, hard chrome plate, surface integrity, cutting conditions

1 Introduction

The grinding is a finishing operation, where using abrasive wheels, which is a compound of abrasive grains. These grains are bonded in a matrix. The grinding is a cutting process, where cutting edges are irregularly shaped and randomly spaced. Due to the randomly shaped and irregularly shaped grains, the grinding process is characterized by large amounts of heat, high values of cutting speeds, irregular cutting geometry, irregular removal of chips, a self-sharpening grinding wheel and a small cross-section of the chips. Figure 1 shows how abrasive grains are removing material from the workpiece. [1, 2, 3, 11, 12, 13]

![Fig. 1 Mechanism of grinding process](image)

The integrity of the surface is derived from surface roughness and its profile, geometric accuracy, the hardness of the surface and the surface layer, the residual stress, changes of microstructure, thermal changes – burn-offs and cracks. The integrity of the surface is a set of all properties which define a new surface. The surface integrity is evaluated and measured according to CSN EN ISO standards. [4, 5, 6, 14]

Hard chrome plating is based on galvanic coating and is a widely used technology in manufacturing. Hard chrome plating is an electrochemical process during which a layer of chromium is applied to the base material. It is used to reduce wear and increase the life of parts, tools and gauges. Excluded chromium coating has a hardness of 800 to 1200 HV. The thickness of the chromium coating ranges is from 5 microns up to about 1 mm. One of the benefits of hard chrome plating is an option to apply layers and is therefore often used for renovation of worn parts. [7, 8, 9, 10]

The purpose of this research was to compare the used SiC (silicon carbon) grinding wheel when grinding the galvanically applied chrome coating after changing cutting conditions. This experiment was in cooperation with Solar Turbines EAME L.t.d. The main consideration in measurement and evaluation was choosing components of surface integrity - the roughness of the surface and its profile and circularity.

2 Plan of experiment

The aim of the experiment was grinding samples, which are shown in Fig. 2, where the base material was chromic-molybdate steel (shaft), which corresponds with AMS 6415 standards and the coating material was Chrom (Cr).

![Fig. 2 Example of pattern](image)

On the outer surface of the samples a galvanic chrome coating which had 0.390 mm thickness was applied. Fig. 3 show 10x measurements of chrome plated layer.
3 The cutting conditions

In the process of grinding, Hakufluid 182 process fluid was chosen, which is specifically for machining. This liquid provides a cooling effect, has excellent lubricating ability, is odorless and improves the roughness of the machined surface. The grinding wheel was C49 150 J9V with a silicon carbide base, characterized by high hardness, moderate grain size, porous structure and a ceramic binder.

The experiment is based on the combination of cutting conditions, which are shown in Tab. 1. In my case, we changed the cutting speed of the grinding wheel from 30 m.s$^{-1}$ to 40 m.s$^{-1}$ and the infeed rate from 0,13 mm.min$^{-1}$ to 0,64 mm.min$^{-1}$. For both cutting speeds 5 different infeed rates were chosen. The depth removal rate was 0,05 mm. The grinding was done by grooving manner on a BU16 grinder.

Each sample is named according to table 1, where there is 10 sample “Bx”, and each one is subject to certain cutting conditions by which the sample was ground. Each grinding operation was repeated twice on a new sample under the same cutting conditions, Bx_1 or Bx2.

### Tab. 1 Cutting Condition

| Material       | Grinding wheel | Cutting conditions | No. sample |
|----------------|----------------|-------------------|------------|
| Chrome plate   | C49 150 J9V    | 15 m.min$^{-1}$   | 30 m.s$^{-1}$ | 0.13 mm.min$^{-1}$ | B1 |
|                |                |                   |            | 0.17 mm.min$^{-1}$ | B2 |
|                |                |                   |            | 0.26 mm.min$^{-1}$ | B3 |
|                |                |                   |            | 0.41 mm.min$^{-1}$ | B4 |
|                |                |                   |            | 0.64 mm.min$^{-1}$ | B5 |
|                |                |                   |            | 0.13 mm.min$^{-1}$ | B6 |
|                |                |                   |            | 0.17 mm.min$^{-1}$ | B7 |
|                |                |                   |            | 0.26 mm.min$^{-1}$ | B8 |
|                |                |                   |            | 0.41 mm.min$^{-1}$ | B9 |
|                |                |                   |            | 0.64 mm.min$^{-1}$ | B10 |
|                |                | 40 m.s$^{-1}$     |            |                   |    |

4 Surface roughness and profile and circularity using SiC grinding wheel

I was dealing with the measurement of surface roughness, where I was following Ra, Rt, Rz, Rq, Rmax, Rvk and Rp$k$ parameters. Also, I was focusing on circularity which is marked ,,E,,. For the measurement of the surface roughness a Profilometr Hommel Tester T8000 device (Fig. 4) was used and for the measurement of circularity a Hommel Tester Form T4004 device (Fig. 5) was used. Measurement of surface roughness was performed 12 times at 30° and measurement of circularity was conducted at 3 specific points from the outer diameter. Arithmetic mean and standard deviation was calculated from the measurement of roughness and circularity. The results of surface roughness and circularity are shown in Tab. 2 and Tab.3.

![Fig. 4 Profilometr Hommel Tester T8000](image-url)
### Tab. 2 Average Values of Surface Roughness

| No sample | Arithmetic Average | Standart Deviation |
|-----------|--------------------|--------------------|
| B1_1      | 0.194 1.418 1.730 1.664 0.213 0.335 0.245 | 0.007 0.061 0.138 0.163 0.024 0.026 0.009 |
| B1_2      | 0.176 1.287 1.618 1.537 0.198 0.267 0.220 | 0.011 0.085 0.248 0.231 0.018 0.020 0.013 |
| B2_1      | 0.236 1.657 2.077 2.037 0.271 0.346 0.296 | 0.010 0.096 0.209 0.173 0.029 0.028 0.013 |
| B2_2      | 0.238 1.603 1.963 1.920 0.258 0.313 0.295 | 0.007 0.071 0.198 0.229 0.023 0.046 0.008 |
| B3_1      | 0.258 1.791 2.273 2.138 0.275 0.378 0.323 | 0.006 0.056 0.182 0.140 0.048 0.033 0.008 |
| B3_2      | 0.274 1.939 2.363 2.218 0.339 0.371 0.344 | 0.007 0.116 0.231 0.169 0.018 0.025 0.008 |
| B4_1      | 0.297 2.050 2.520 2.382 0.334 0.427 0.373 | 0.011 0.165 0.351 0.215 0.046 0.056 0.016 |
| B4_2      | 0.297 2.187 2.641 2.503 0.363 0.486 0.378 | 0.010 0.125 0.262 0.229 0.051 0.052 0.015 |
| B5_1      | 0.337 2.392 2.943 2.825 0.401 0.519 0.424 | 0.015 0.132 0.225 0.169 0.031 0.045 0.017 |
| B5_2      | 0.331 2.368 2.864 2.731 0.400 0.506 0.417 | 0.010 0.135 0.244 0.206 0.043 0.062 0.014 |
| B6_1      | 0.271 1.811 2.152 2.077 0.262 0.417 0.336 | 0.009 0.086 0.230 0.173 0.026 0.046 0.011 |
| B6_2      | 0.268 1.952 2.387 2.297 0.307 0.440 0.339 | 0.015 0.183 0.259 0.231 0.031 0.073 0.020 |
| B7_1      | 0.292 2.021 2.435 2.297 0.341 0.379 0.365 | 0.008 0.124 0.306 0.320 0.039 0.045 0.012 |
| B7_2      | 0.298 2.075 2.486 2.395 0.322 0.543 0.377 | 0.008 0.092 0.163 0.144 0.020 0.052 0.009 |
| B8_1      | 0.301 1.986 2.354 2.255 0.321 0.487 0.377 | 0.011 0.090 0.127 0.157 0.034 0.076 0.013 |
| B8_2      | 0.304 2.143 2.584 2.505 0.376 0.432 0.383 | 0.006 0.080 0.235 0.223 0.042 0.025 0.007 |
| B9_1      | 0.323 2.167 2.598 2.475 0.289 0.524 0.402 | 0.008 0.115 0.227 0.166 0.032 0.061 0.009 |
| B9_2      | 0.315 2.401 3.099 2.920 0.384 0.555 0.402 | 0.020 0.130 0.292 0.296 0.054 0.079 0.027 |
| B10_1     | 0.361 2.517 2.997 2.877 0.443 0.533 0.453 | 0.011 0.127 0.190 0.235 0.035 0.051 0.014 |
| B10_2     | 0.363 2.481 3.140 3.079 0.385 0.552 0.454 | 0.015 0.148 0.365 0.400 0.043 0.105 0.019 |

### Tab. 3 Average Values of Circularity E

| No sample | Arithmetic Average | Standart Deviation |
|-----------|--------------------|--------------------|
| B1_1      | 1.037 1.363 1.890 | 0.214 0.057 0.255 |
| B2_1      | 1.227 1.837 1.907 | 0.285 0.163 0.158 |
4.1 Average arithmetic deviation analysis – Ra

In the ensuing graph is described the dependence of the roughness Ra on the infeed rate. The light blue and light green show the first grinding. The dark blue and dark green show the second grinding to verify the grinding process. When focusing on the graph, it can be seen that the second grinding process confirms the values of the Ra parameter during the first grinding process. By growing the infeed rate of the grinding wheel (0.13; 0.17; 0.26; 0.41; 0.64), it was clearly visible that there was an increased roughness of the surface. The lowest value 0.176 µm was achieved with a cutting speed of 40 m.s⁻¹ and infeed rate of 0.13 mm.min⁻¹. The highest value 0.363 µm was achieved using a cutting speed of 40 m.s⁻¹ and infeed rate of 0.64 mm.min⁻¹. The second grinding with different infeed rates, the same surface roughness values were achieved. In the graph is seen a value of reliability called R². This value for parameter Ra where the cutting speed was 30 m.s⁻¹ is 0.9938 and when the cutting speed was 40 m.s⁻¹ is 0.9824. That means reliability of 99.3 % and 98.2%.

4.2 Average arithmetic deviation analysis – Rz

The graph in Fig 7. has similar dependence as parameter Ra. The parameter Rz is typical for the minimum and maximum height of valleys in the measured length. The lowest value 1.287 µm was achieved using a cutting speed of 40 m.s⁻¹ and infeed rate of 0.13 mm.min⁻¹ (samle B6). The highest value 2.517 µm was achieved with a cutting speed of 30 m.s⁻¹ and infeed rate of 0.64 mm.min⁻¹ (samle B5). With increasing infeed rate and cutting speed, the roughness values are higher. From a reliability point of view, values are very reliable, 99.1% and 92.6%. Lower reliability for cutting speed 40 m.s⁻¹ caused a slight value decrease in infeed rate of 0.26 mm.min⁻¹.
4.3 Average arithmetic deviation analysis – Rt

The Rt parameter represents the maximum height of the profile in surface roughness. Like previous graphs, this graph shows a relationship of Rz parameter and increasing the infeed rate speed of the grinding wheel. Each value is supplemented by standard deviation, where the values are in tab. 2 and results are around 10%. For example, sample B7_1 2.297 ± 0.320 µm was achieved. At the lowest infeed rate and highest infeed rate, the values increased by almost 58%.

4.4 Average arithmetic deviation analysis – Rpk and Rvk

The parameters Rpk and Rvk express the highest peak and highest valley. The next graph on figure 9 are values of parameter Rpk and Rvk. These values are only for cutting speeds of 30 m.s⁻¹ and 40 m.s⁻¹ and the corresponding infeed rate per Table 1. In the graph on Figure 9 it can be seen the surface has bigger valleys than peaks. By increasing the infeed rate, the values are increased. It can be
said that all infeed rates result in valleys that are 50-75% larger than the peaks. All values of peaks and valleys were increased. Only using a cutting speed of 40 m.s\(^{-1}\) decreased the peaks, but the final infeed rate increased again as the other values.

4.5 Analysis of surface profile – Material ratio curve

The uniqueness of the surface is given by the tool, the cutting conditions and the technology. For each technology, the surface profile is a set of specific properties. Figures 10 and 11 show the graphs and the material share of the surface. Figure 10 shows a cutting speed of 30 m.s\(^{-1}\) and Figure 11 shows a cutting speed of 40 m.s\(^{-1}\) with the corresponding infeed rates as shown in Table 1. Looking at the first figure, it is seen that the blue-colored part occupies rather the projections on the surface. With increasing infeed speed, the peaks decrease, although their values increase according to Table 2 (parameter Rpk, Rvk). Figure 11 shows an even lower profile of the surface, i.e. rather valleys in the material profile. The surface profile with an increasing feed rate has an almost steady shape.

Fig. 9 The average value Rpk and Rvk

Fig. 10 The surface profile 30 m.s\(^{-1}\)

Fig. 11 The surface profile 40 m.s\(^{-1}\)
4.6 Analysis of circularity

Figure 12 shows the circularity values that are complemented by a standard deviation. The values can also be read from Table 3. It can be seen from the chart that the greatest deviations are at a cutting speed of 30 and 40 m.s\(^{-1}\) with a feed rate of 0.64 mm.min\(^{-1}\). For the feed rate, 0.17 mm.min\(^{-1}\) and 0.26 mm.min\(^{-1}\) the values are at the same level. From the point of view of the accuracy of production, the values show good results.

5 Summary

For this experiment 20 samples were tested, where 10 samples were used for the first measurement and the second 10 samples for repeated cycles under the same cutting conditions. All parameters for this experiment were set to indicate the dependence of changing the cutting conditions on surface roughness and circularity.

Surface roughness at a cutting speed of 30 m.s\(^{-1}\) and infeed rate of 0.13 m.min\(^{-1}\) achieved Ra 0.194 ± 0.007 µm. When changing the infeed rate to the highest value which was 0.64 m.min\(^{-1}\) Ra 0.337 ± 0.015 µm was achieved. When changing the infeed rate and the same cutting speed, the increase was approximately 42%. Surface roughness at a cutting speed of 40 m.s\(^{-1}\) and infeed rate of 0.13 m.min\(^{-1}\) Ra 0.271 ± 0.009 µm was reached. When changing the infeed rate to the highest values, the value of 0.64 m.min\(^{-1}\) was achieved Ra 0.361 ± 0.11 µm. When changing the feed rate and the same cutting speed, the increase was approximately 25%. Looking at standard deviations shows accurate values were achieved.

The material ratio curve is good in looking at possible...
peaks and valleys in the profile of material. By maintaining a cutting speed of 30 m.s\(^{-1}\) and increasing infeed rate results in decreasing the region of the profile, with decreasing peaks in the surface profile.

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