Robust and Easy to Use Quality Control of Roughness on Milled Tool Steel Surfaces

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ABSTRACT

This study was an evaluation of measuring strategies using a handheld 2D profiler for quality control of finish milled tool steel with regard to surface roughness. A selection of ball nose end mills in combination with two different tool steels (hardness 39 and 47 HR C) were used to manufacture the surfaces that were to be measured. It was found that using an appropriate measuring strategy it is possible to measure the roughness of these relatively smooth surfaces (0.1<Ra<1µm) with satisfactory accuracy using a handheld profiler. However, it was also found that, in contrast to what is common practice, Ra is not a suitable parameter to use for evaluation. Instead, using Rz or Rp is suggested. To be able to control quality, the machining process (selection of cutting tool, cutting data, workpiece material etc) as well as limits for the evaluated parameters first have to be established.

1. INTRODUCTION

Many car models are introduced each year and to be able to produce each new model a new set of pressing dies has to be designed and manufactured. This is a process which consumes a lot of resources, both time and money. The manufacturing of pressing dies consists of several different stages of which milling and manual polishing contribute largely to the time and cost. The amount of polishing that has to be done is greatly influenced by the surface roughness after the finish milling stage [1]. Therefore, in manufacturing of pressing dies the surface roughness after finish milling stage is an important quality parameter. To monitor the quality it is a necessity to be able to make reliable measurements.

Surface roughness can be measured using many different techniques which all have their respective advantages and disadvantages. The most common types of measuring instruments can be divided into two categories, contacting and non-contacting instruments (typically stylus instruments and optical instruments respectively). In addition, there is currently a shift of paradigms in characterisation techniques, from profile to areal characterisation (from 2D to 3D) [2].

Previous studies have shown that 3D measurements are more appropriate than 2D measurements for characterisation of press die surfaces [1]. Also, efforts have been made to use data from 3D measurements to track wear of cutting tools [3]. However, 3D measurement equipment is usually more expensive and not very suitable to use in a workshop for quality control since they often are comparatively large and more difficult to handle. Instead, a common method used on the tool and die shop floor to evaluate surface after milling is visual inspection by an experienced machine operator and the use of a Ra-value from a surface profiler [1].

There are several handheld profilers available on the market today and these are commonly quite small, practical and easy to use. However, there is a lack of studies regarding their accuracy and consistency when measuring relatively smooth surfaces such as finish milled steel (0.1<Ra<1µm).

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The purpose of this study was to establish a practical, robust measuring strategy that is possible to use with a 2D profiler in a tool and die workshop and to study to what extent a handheld 2D profiler could give reliable results in this type of application.

2. Method and Material

2.1. Workpiece Material, Machine Tool and Cutting Tools

Two different tool steels from Uddeholm Tooling AB were used as workpiece materials. The materials were Nimax with a hardness of 39 HRC and Dievar, hardness 47 HRC.

The machine tool used in this study was a Hermle C40, 5 axis machining centre with a Capto C5 spindle interface and a spindle capable of 24000 RPM. Cutting data used for Nimax: Vc 385 m/min, fz 0.2 mm/tooth, ap 0.2 mm, ae 0.2 mm, n 10000 RPM. Cutting data used for Dievar: Vc 190 m/min, fz 0.2 mm/tooth, ap 0.2 mm, ae 0.2 mm, n 5000 RPM. The chosen tool path strategy was copy milling.

In the die and mould industry finish milling is primarily done by using ball nose end mills (BNE) [4]. In this study a selection of different BNEs were used since the different geometries of the cutting tools create somewhat different textures on the workpiece [5]. All BNEs used in the study have a diameter of 16 mm. Holding tool was a Capto integrated hydromechanical chuck.

2.2. Measurement Instruments and Methods

After each level was cut the machine operator made an optical inspection of the surface finish. This inspection was done to decide whether to keep on using the same tool to cut another level or to change tools. The same criteria as are used in the pressing die industry were used in this study. Measurements and images of the surface were made at two times for each tool, after the first level was cut and after the last. Measurements and images of the workpiece surface were made at three points, see Figure 1. The roughness parameters selected for evaluation, according to ISO 4287:1997 [6], are summarised in Table 1.

Table 1: Evaluated roughness parameters

<table>
<thead>
<tr>
<th>2D</th>
<th>3D</th>
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<tr>
<td>Ra</td>
<td>Average roughness</td>
</tr>
<tr>
<td>Rz</td>
<td>Mean roughness depth</td>
</tr>
<tr>
<td>Rp</td>
<td>Mean peak height</td>
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Figure 1: Workpiece and measurement points
The 2D measurements were made using a MarSurf PS1*, a handheld stylus type instrument with a 2µm diamond tip. Measurement length was 5.6 mm and the data was filtered using a Digital Gaussian filter [7] with cut-off 0.8 mm.

For reference, 3D measurements were made using a white light interferometer. The instrument used was a Wyko RST Plus† at magnification 2.5x giving a measurement area of 1.84 mm (x) * 2.48 mm (y). For practical reasons the 3D measurements could not be made directly on the workpiece. Instead, a replica technique‡, that has previously been shown to work well, was used [8].

Images of the machined surface were made using a microscope at 40x magnification with a digital camera.

3. RESULTS AND DISCUSSIONS

3.1 MEASURING STRATEGIES

A large number (100) of 2D measurements were made at one time in measurement point A to evaluate the distribution of the measured values. These measurements were made at approximately mid-life of one of the tools. There was a detectable wear on the tool, however, the surface finish was still considered to be good. Mean values and standard deviations were calculated. As can bee seen in Table 2 the standard deviations were quite large for all parameters. There are several factors which could explain this. First of all, since the 2D profiler was handheld the operator probably was responsible for some measurement errors through accidental movement of the profiler during the measurement or by not being able to position the device perfectly (the measurements are supposed to be made perpendicular to the feed direction). Secondly, as the tool was worn the surface texture became less homogenous, as will be shown in more detail later.

<table>
<thead>
<tr>
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<th>Ra (µm)</th>
<th>Rz (µm)</th>
<th>Rp (µm)</th>
</tr>
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<tbody>
<tr>
<td>Mean</td>
<td>0.512</td>
<td>2.430</td>
<td>1.384</td>
</tr>
<tr>
<td>StDev</td>
<td>0.154</td>
<td>0.555</td>
<td>0.410</td>
</tr>
<tr>
<td>StDev/Mean</td>
<td>30%</td>
<td>22%</td>
<td>30%</td>
</tr>
</tbody>
</table>

It was desired to develop a measuring strategy that gave reliable results and at the same time did not require a large number of measurements. From the collection of 100 measurements different sets of values were randomly picked to simulate different measuring strategies. The different strategies were: 3, 5, 5-2, 7, 7-2, 7-4, 10, 10-2, 10-4 and 10-6 (where "5" means: one set consists of five randomly picked values, and "5-2" means: one set consists of five randomly picked values with the highest and lowest values excluded). A large number of sets using each strategy were collected and mean values and standard deviations were calculated for each new set. These mean values were compared to the mean value for all 100 measurements. The average deviations of the mean values and the average standard deviations for each strategy are shown in Figure 2. Strategy "5-2" was considered to be a good compromise between reliability and ease of use.

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† Veeco Instruments, www.veeco.com
3.2 Tool Wear and Impact on Surface Roughness

When comparing all measurements and images there was a consistent and obvious difference between the surfaces cut with a new tool and the ones cut with a worn tool. An example of this can be seen below in Figure 3 and Figure 4 which show a surface (measurement point C) cut with the same tool. Feed direction is horizontal in the figures.
In the surfaces cut with new tools a recognisable texture could typically be seen. This was the pattern created when the material was cut. This pattern is very much in line with the ideas presented by Chen et al. in [9]. In the surfaces cut with a worn tool there was still a discernable pattern, though not at all as obvious. The feed direction could be seen but in general it looked as if the material had not been cleanly cut. A probable explanation for this is that as the tool was worn the cutting edge became less sharp and rubbing between the cutting tool and workpiece took place, as shown by Zeng et al. using artificial tool wear in [3]. However, there are many factors in the machining process which can influence the surface roughness of which tool wear is one of them [10].

In all three measurement points there were generally a considerable increase in the evaluated 2D roughness parameters. This was also the case in the 3D measurements made for reference with only a few exceptions in measurement point B. A summary of the average change in the 2D parameters can be seen in Figure 5.

![Average difference](image)

**Figure 5: Average change in 2D surface parameters**

Although there was an increase of the average value of Ra, in some cases the Ra value did not change much at all during machining. This indicates that the Ra parameter might not be a very good parameter to use for evaluation of surfaces. Instead Rz or Rp is suggested to be used since an increase of those parameters showed a more consistent relation to the deterioration of surface finish appearance as the cutting tools were worn.

Ra is the average deviation from the mean line of each and every point along the measured profile. The base of calculation for Rz, on the other hand, is only the very highest and lowest points. Rp is calculated from the measurement points which are considered to be the peaks of the profile [11]. The result of this is that Rz and Rp are much more sensitive than Ra.

4. **Conclusions**

- Using a single Ra value to determine if a surface is good or bad is very uncertain. First of all, a surface judged as good by an experienced machine operator can have the same Ra value as a surface judged as bad. Secondly, using a handheld profiler, as the one used in this study, a set of several measurements has to be made to reduce the impact of measurement error and to get a more reliable result. Using Rz or Rp is better than using Ra if surface finish appearance is to be assessed.

- It is possible to use a handheld 2D profiler to evaluate the quality of a finish milled steel surface, in regard to roughness, if certain conditions are met. An appropriate measuring strategy must be used, for example the strategy "5-2" discussed previously. Furthermore, limits for the evaluated parameters must first be established for each combination of cutting tools, cutting data, workpiece material etc.

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REFERENCES


