INFLUENCE OF THE HIGH-SPEED MILLING STRATEGY ON 3D SURFACE ROUGHNESS PARAMETERS

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Abstract: High-speed machining is an effective modern machining method used in die-cast material processing, to increase the efficiency, quality and accuracy of the machined surface and to reduce costs and machining time. The aim of this research is to explore the technological strategy and influence of the processed materials on the 3D surface roughness parameters and provide recommendations for manufacturers on how to obtain the prescribed surface roughness parameters. This paper covers analysis of the following factors: feed rate, manufacturing strategy, overlap and material influences on the most characteristic 3D surface parameters. The results are based on ANOVA—analysis of variance—where differences between groups of means are analysed using a collection of statistical models. This method enables the comparison of three or more group variables for statistical significance. The present paper provides analysis and relevant conclusions on the most significant impact factors: material and the high-speed milling manufacturing strategy.

Key words: high-speed milling, 3D surface roughness, technological milling strategy, ANOVA, analysis of variance

1. INTRODUCTION

Up until recently, the 2D surface roughness standard ISO 4287:1998 was used in manufacturing. However, this has now been replaced by the 3D surface roughness standard ISO 25178: 2012 [1]. As yet, there is no reciprocal, correlative information regarding surface roughness and machining technology parameters for this standard. Given the changes in technological machining parameters and measured 3D surface roughness parameter variances, there is a need to draw conclusions and analytically describe certain relationships between the technological machining process parameters and surface roughness.

The overall aim of this research is to identify mathematically the most critical technological parameter influencing each specific 3D surface roughness parameter. At the end of this research, the authors prepared several recommendations for manufacturers on how to apply these technological parameters during the manufacturing process, in order to minimize surface roughness.

2. HIGH SPEED MACHINING

High-speed milling (HSM) is a modern technological manufacturing method, as compared to traditional machining with chip removing methods (turning, milling and grinding), which aims to increase manufacturing efficiency and improve surface quality, whilst at the same time reducing manufacturing time and costs. The high-speed milling method has many benefits compared with conventional milling. Very often, high-speed milling is considered merely as a way to improve productivity resulting from faster cutting speeds than those used conventionally. High-speed milling is widely used in
modern tool manufacturing and die-cast material machining, which has strict requirements for low surface roughness (e.g. [7]).

Based on this research in the Department of Mechanical and Materials Engineering at the Polytechnic University of Valencia, the most popular die-mould steel samples were machined using various combinations of cutting parameters (feed rate, strategy and overlap). Such cutting parameters as depth of cut and cutting speed were kept constant.

The Gentiger GT-66V-T16B high-speed milling machine was used for the experiment, which has a spindle speed of up to 16,000 min⁻¹. In addition, the machine power is sufficient to process highly durable materials operating at high-speed with a rapid feed rate. The machine spindle power can reach 26 kW, the rapid feed rate is 30 m/min and working feed rate is up to 20 m/min. The machine is equipped with a Siemens 840D NC controller and BT-40 cone-type spindle.

3. 3D SURFACE ROUGHNESS MEASUREMENTS

The actual surface of every existing object in real life is three dimensional (e.g. [1]). In order to successfully characterize the surface roughness, it is not enough to describe it with only a single parameter (e.g. Sa – the arithmetic mean height of the surface). Complex surface characterization is required, using parameter groups. Today the extensive review of surface roughness and numerical values provide us with 3D roughness measurement methods and a standard. The method is based on the measurement point determination, which is done using both random methods, through a graphical approximation and determining the number of points where the values of parameters are stabilizing. (e.g. [4])

The number of data points has to be optimal. Too few data points lead to inaccurate results and increased distribution amplitude; but too many data points substantially increase measuring time without broadening the range of fundamental information. (e.g. [4])

In this research, all machined samples were measured using the Taylor Hobson Form TalySurf Intra 50 measuring device with TalyMap Expert data software. All the measurements were taken in the Material Processing Technology Department at Riga Technical University.

4. APPROACH

Experiments were performed on 3 high-strength materials: two types of steel widely used in die mould manufacturing and titanium. The steel grades are 1.2312 (40CrMnMo58-6) and 1.1730 (C45W).

This research began in the Department of Mechanical and Materials Engineering at the Polytechnic University of Valencia and incorporates work at the Material Processing Technology Department of Riga Technical University, based on research into the impact of high-speed milling on 3D surface roughness parameters [1].

A variable combination of feed rate, strategy and overlap factors was selected. Such cutting parameters as depth of cut and cutting speed were kept constant. One of the most potentially significant factors affecting the cutting quality and manufacturing speed is the feed level. The cut feed level is determined taking into account recommendations from tool manufacturers, as specified in the cutting tool catalogue. Also, machining may be repeated in different directions by different paths or cutting strategies. The overlap influences the processing time, costs and roughness. Likewise materials with different mechanical properties have differing impacts on the machining results. Each material sample was divided into 16 subsamples, eight per side, cf. Fig.1.
After all of the samples were machined, 3D roughness measurements were taken. Several photographs were also taken of the surface using a microscope, in order to compare the images with the images provided by the Talymap Expert software for the surface roughness measurement. For each of the 3 materials, 16 surface roughness measurements were taken. The results were initially sorted by the groups they belonged to and the most significant parameters were chosen using the correlation matrix in the Rcommander software. By preparing the correlation matrix of \( n \) random variables and including a set of 3D roughness parameters, we obtained the most significant, distinctive parameters for each group. They are \( S_a \) – the arithmetical mean height of the surface, \( S_{ku} \) – the kurtosis of the scale limited surface, \( S_{tp} \) – the height of the bearing area ratio curve, \( S_{tr} \) – the texture aspect ratio and \( S_{vi} \) – the valley fluid retention index.

5. ANALYSIS

The chosen 3D roughness parameters were collated in spreadsheets, to prepare graphs illustrating the roughness parameter changes affected by feed level, overlap and strategy type. Fig. 4. and Fig. 5. show the differences between the surface roughness parameters applying the linear pattern (LP) and circular pattern (CP) in the machining process, where overlap and feed levels are kept constant. Multiway ANOVA data analysis software, such as Rcommander, with libraries of statistics provides more extensive information about the influences of technological parameters on roughness.

As can be seen from the retrieved data, their value is similar to that shown by the mathematical regression, although the overall surface roughness is slightly lower using a circular milling pattern. This is also seen in the surface images (Fig.4.and Fig.5.)
The polynomial regression trend line equation with argument x for the first example with a linear pattern shows that one of the technological parameters has a major influence; in this case, it is the feed level:

$$y = -31.818x^2 + 14.568x - 0.4076 \quad (5.1)$$

The same situation occurs with the second, circular pattern. However the equation ratios confirm that differences between feed levels are lower:

$$y = -13.84x^2 + 6.29x - 0.01 \quad (5.2)$$

The situation is slightly different in the case of a linear cutting pattern, where the cutter overlap is 0.1mm. This situation is described below and shown in Figures 6. and 7. Here the roughness parameter Sa increases together with the feed level. This is also shown by the difference between the equation ratios:

$$y = -8.14x^2 + 6.27x - 0.13 \quad (5.3)$$

For material type 1.2312 (40CrMnMo58-6), the situations in terms of the graph lines are comparable. The surface roughness distribution for samples such as LP 0.05 and CP 0.05 are similar and differences between surface roughness for different feed levels are almost imperceptible. The roughness distribution of feed level for samples with LP 0.1 is different. As we can see from Fig. 8., with a low feed level (0.07) the roughness parameter Sa is lower and at a medium feed level it is highest, but at the high feed level the parameter decreases again.
The influence of the linear pattern strategy type and 0.1 mm overlap on the Sa parameter (material 1.2312)

Equation with ratios for this polynomial line:

\[ y = -16.795x^2 + 8.6273x + 0.3863 \]  (5.4)

The R commander mathematical analysis software was used to validate this schedule, replacing all technological parameters with factors. ANOVA analysis between pairs of technological parameters is done firstly for all material types. The pairings that cross-reference the parameters are: feed level–strategy type, feed level–cutting direction, strategy type–cutting direction, feed level–overlap and overlap–cutting direction. A similar correlation was also conducted previously for each of the chosen roughness parameters, in order to compare their influence on each of the chosen parameters.

The use of the condition of cutting direction for example is not objective for analysis where one cutting direction is advantageous for only a few samples, rather than all. It thus had to be abandoned. Finally, pairs of all of the technological parameters were correlated, resulting in only two different technological parameters, which had the most significant impact, and all 3 kinds of materials. Final analysis between these parameters and the materials was then conducted for each chosen roughness parameter, to identify the most significant parameter. For parameters Sa and Svi, the most significant factor is strategy type (the significant ratio is respectively 0.002 and 0.04). For parameters Sku and Stp, the most significant factor is material type (0.01 and 0.03). For the roughness parameter Str, the most significant factor is feed level (0.001), with the second most significant factor being material type (0.09).

6. SIMULATION

A simulation was also undertaken with the developed application, coded using software called Python, to capture the cutters’ cutting edge behaviour on the material surface. It is based on actual surface pictures taken by the camera from sample no. 18 (1.2312, LP 0.1, Feed 0.2 mm⁻¹) and the technological parameters used during the sample machining process, cf. fig. 9. The simulation shows the movement of the cutting edge over the material, cutting edge velocity vectors and surface texture changes.

7. CONCLUSIONS

The greatest influence among the selected technological parameters is the material or the influence of the material’s mechanical properties. The material influence is reflected in two parameters: Sku and StP. Materials with the highest hardness affect the distribution of “peaks” over the surface. Other mechanical properties affect the bearing ratio index. It is possible to determine whether the surface has peaks of several different heights, or whether their height is evenly distributed (Fig.10).
Titanium cannot be processed with the same technological parameters as those used to process die mould materials. Titanium has a different distribution of surface roughness parameter values compared with die mould manufacturing steels.

The research will be continued and further experiments will be conducted during our future work.

1. REFERENCES


