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A geometrical model for surface roughness prediction when face milling Al 7075-T7351 with square insert tools

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ABSTRACT

Surface quality is important in engineering and a vital aspect of it is surface roughness, since it plays an important role in wear resistance, ductility, tensile, and fatigue strength for machined parts. This paper reports on a research study on the development of a geometrical model for surface roughness prediction when face milling with square inserts. The model is based on a geometrical analysis of the recreation of the tool trail left on the machined surface. The model has been validated with experimental data obtained for high speed milling of aluminum alloy (Al 7075-T7351) when using a wide range of cutting speed, feed per tooth, axial depth of cut and different values of tool nose radius (0.8 mm and 2.5 mm), using the Taguchi method as the design of experiments. The experimental roughness was obtained by measuring the surface roughness of the milled surfaces with a non-contact profilometer. The developed model can be used for any combination of material workpiece and tool, when tool flank wear is not considered and is suitable for using any tool diameter with any number of teeth and tool nose radius. The results show that the developed model achieved an excellent performance with almost 98% accuracy in terms of predicting the surface roughness when compared to the experimental data.

1. Introduction

Product quality has always been one of the most important elements in manufacturing operations. In view of the present global economy and competition, continuous improvement in quality has become a major priority, particularly for major corporations in industrialized countries, such as USA, UK, Germany, Japan, etc. The range of technologies involved in the manufacturing sector continues to grow with the introduction of improved equipment and tools in order to produce high quality final products, with specific characteristics, such as: dimensional accuracy, surface roughness, etc. Machining processes require specific attention to guarantee the quality of a final product against certain manufacturing specifications. Besides the obvious problems related to correct dimensions, one of the biggest problems is achieving the appropriate finish or surface smoothness on the workpiece. Surfaces are commercially and technologically important for a number of reasons. Few reasons are: (1) esthetic; a smooth and free of scratches surface is more likely to give a favorable impression to costumer, (2) surfaces affect safety, (3) surfaces interact with its environment, due to its influence on mechanical properties such as: wear, corrosion and lubrication [1–5].

General defects caused by and produced during component manufacturing can be responsible for inadequate surface integrity. These defects are usually caused by a combination of factors, such as defects in the original material, the method by which the surface is produced, and lack or proper control of process parameters that can result in excessive stresses and temperature. For example, roughness is a measure of the texture of a surface and is a consequence of the cutting parameters, tool geometry, etc. used during the machining process. Depending on how rough the surface is (deepness of the grooves left by the tool on the machined surface) a piece can wear more quickly and have higher friction coefficients than a smoother surface [6].

One of the most promising advanced manufacturing technologies in the last decade is the high speed cutting, due to its potential for faster production rates, shorter lead times, reduced costs and improved part quality, since the technique combines high spindle speeds with increased feed rates [7]. This results in a high chip-forming rate and lower milling forces, producing an improved surface quality and tighter tolerances. However, appropriate tools and cutting parameters should be used in order to complete the machining process without damaging the cutting tool. This is the

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Nomenclature

a_p	axial depth of cut (mm)
ε_a	axial run out (mm)
ε_r	radial run out (mm)
f_z	feed per tooth (mm/rev * tooth)
HBN	Brinell hardness number
i	tooth number
n	peak number of the surface roughness profile
r	tool nose radius (mm)
R_a	experimental surface roughness (μm)
R_{a_p}	predicted surface roughness (μm)
%RE	relative error (%)
S_u	maximum strength (MPa)
S_y	yield strength (MPa)
V	cutting speed (m/min)

main factor of why the prediction and control of the surface roughness and the tool wear are challenges to researchers.

In recent years there have been several proposals regarding different models for surface roughness predictions during a milling process.

Baek et al. [8] analyzed the effects of the insert run out errors and the variation of the feed rate on the surface roughness operations using a surface roughness model. The experiments were conducted in AISI 1041 ductile steel.

In 2004, Wang [9] analyzed the influence of cutting conditions and tool geometry on the surface roughness when slot end milling aluminum alloy 2014-T6. The developed surface roughness models for both dry cutting and coolant conditions were built using a response surface methodology (RSM). The results showed that the dry-cut roughness was reduced by applying cutting fluid.

The research made by Franco et al. [10], contributes on the development of a numerical model for surface roughness profile prediction when using round inserts. The model relates the feed, the cutting tool geometry and the tool errors, incorporating an algorithm that makes possible the variation of the surface roughness from the values that can be adopted by the tool errors.

Researcher, Oktema et al. [11], predicted the surface roughness by using RSM (response surface methodology) coupled with GA (genetic algorithms). The studies were made in Al 7075-T6.

In 2005, Reddy et al. [12] studied the effect of tool geometry (radial rake angle and tool nose radius) and cutting conditions (cutting speed and feed rate) on the machining performance during end milling of medium carbon steel. First and second order mathematical models, in terms of machining parameters were developed for surface roughness prediction using RSM. The results showed that the cutting speed, the feed, the radial rake angle and the tool nose radius are the primary factors influencing the surface roughness of medium carbon steel during end milling processes.

The study of plane surface generation mechanism in flat end milling process was made by Ryua et al. [13]. They concluded that the bottom of a flat end milling has an end cutting edge angle that plays an important role in surface texture and that the surface texture is produced by superposition of conical surfaces generated by the end cutting edge rotation. The evaluation of the generated surface texture characteristic was done using RSM.

Also Ozcelik [14] in 2006, presented the development of a statistical model for surface roughness estimation in a high-speed flat end milling process, under wet cutting conditions, using machining variables such as spindle speed, feed rate, depth of cut and step over.

Researcher, Jesuthanam et al. [15], proposed the development of a novel hybrid neural network (NN) trained with genetic algorithm (GA) and particle swarm optimization (PSO) for the prediction of surface roughness. The proposed hybrid NN was found to be competent in terms of computational speed and efficiency over the NN model. In 2007, Zhang et al. [16] studied the Taguchi design application to optimize the surface quality of a face milling operation when using a CNC. The results verified that the Taguchi design was successfully in optimizing the milling parameters for surface roughness.

Bharathi and Baskar in 2012 [17] developed a generalized model based on particle swarm optimization (PSO) technique to achieve a desired surface roughness when face milling aluminum. The machining time was included as input parameter together with cutting speed, feed and depth of cut. They concluded that the use of optimization technique replaces the selection of cutting parameters by trial and error method.

Finally, Arrazola et al. in 2013 [18] compiled different advances in the modeling of machining processes. In its paper the advances in predictive, analytical, computational and empirical models among others for the prediction of variables such as surface roughness, cutting forces, stresses, chip formation, etc. are highlighted.

From analyzing all the literature, it has been observed that the proposed models are based on computational, numerical analysis and complex mathematical calculus and basically addresses the use of end milling processes for round inserts when using a face milling process with a specific number of teeth and tool diameter. Based on these findings, the aim of this research is to develop a model for surface roughness prediction based solely on geometry when face milling with square inserts. The model can be used for any tool geometry regarding tool nose radius, tool diameter and number of teeth, where also parameters such as the feed per tooth and tool run outs are considered. The validation of the model will be conducted by using experimental surface roughness data obtained when face milling aluminum alloy 7075-T7351 under specific cutting conditions.

This new contribution will represent a useful capability for researchers in the area since it will allow the prediction of roughness before conducting trial and error experiments, representing saving in cost and time.

2. Development of the geometrical model for surface roughness prediction

The proposed geometrical model is developed based on a geometrical analysis. In this case, a visual observation of the Al 7075-T7351 machined surface is conducted and a recreation of the tool trail left on the machined surface is analyzed. In this case the tool trail is developed considering the feed per tooth, the cutting tool nose radius and the tool run out errors. From previous research [8,10] it was noted the influence of the tool run out variable on the surface roughness and the importance of including this variable for the prediction of the surface roughness.

The tool run outs (axial (ε_a) and radial (ε_r) deviations of the tool) are defects that consist in small discrepancies in the relative position of the different cutting teeth. These discrepancies are obtained for many reasons such as: manufacturing tolerances of the cutting tool inserts and seats, inaccuracy in the fixture of the indexable inserts, uncertainty in the clamping force of the insert screws, imperfections in the machine tool axis movement, etc. [10].

Fig. 1 shows a schematic of the tool run outs and angle K_i and Fig. 2 shows the contribution of the tool run outs on the surface roughness profile.

When analyzing Fig. 2, it is observed that the axial tool deviation is the tool deviation that produces displacement of the surface roughness profile in an “up or down” direction (depending on the sign of the deviation), affecting the deepness of the profile and