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Optimization of the surface roughness in ball end milling of titanium alloy Ti-6Al-4V using the Taguchi Method

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Abstract

The aim of this work is to study the influence of some milling parameters (the cutting speed *Vc*, the radial depth of cut a_e and the feed per tooth f_z) on the 3D average surface roughness *Sa*. The Taguchi method was applied to find optimum process parameters in ball end milling of the titanium alloy Ti-6Al-4V with an inclined workpiece angle of 25°. An orthogonal array L_9 and a signal to noise ratio S/N were used to analyze the impact of each cutting parameter on the surface roughness *Sa* and to select the optimum levels of the machining parameters.

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Keywords: Ball end milling, 3D Surface roughness; Taguchi method; Signal to noise ratio S/N; Cutting speed

1. Introduction

High speed ball end milling of complex shaped parts become more and more common activities in aeronautic industries where the Titanium alloy Ti-6Al-4V has been used thanks to its high corrosion resistance, its low density and its high mechanical resistance [1] but it is very difficult to cut because of its poor machinability. Also the chemical reactivity of the Titanium leads to the early wear of the cutting tools and damages consequently the finish surface [2]. Hence, it's compulsory to optimize continuously the cutting parameters and to select the adequate machining strategy in high speed milling of Ti-6Al-4V in order to satisfy the surface integrity requirements and to increase the tool life.

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Many researchers have used the Taguchi method to optimize the machining parameters. In fact, Avinash (2013) [3] optimized the surface roughness while milling AISI 1040 MS material and he found that the most influencing parameter on surface roughness is the coolant flow. Hamdan et al. (2011) [4] applied the Taguchi method to optimize the high speed milling parameters of stainless steel using coated carbide tools and they found that the feed is the most influencing parameter on the surface roughness. Amal et al. (2015) [5] studied the machining parameters in end milling of Ti-6Al-4V and found that the feed rate is the most influencing parameter on surface roughness and on the cutting forces. Ashok Raj et al. (2013) [6] optimized the milling parameters of EN8 steel using the orthogonal array L_9 of Taguchi and found the cutting speed is the most influencing parameter on the surface roughness. Boujelbene et al. [7] and Choubey et al. [8] optimized the milling parameters of mild steel and they found that the spindle speed has the biggest influence on the surface roughness and that the feed rate is the most influencing parameter on the material removal rate MRR. Bouzid, et al. [9-10] used the L_{25} orthogonal array to optimize the surface roughness in high speed milling of duplex steel and carbon steel.

2. Problem definition

The aim of this work is to analyze the 3D average surface roughness *Sa* in ball end milling of Ti-6Al-4V with an inclined workpiece angle of 25° in relation with the cutting parameters using the Taguchi method.

In this paper, three milling parameters were studied and optimized, which are the cutting speed *Vc*, the radial depth of cut a_e and the feed per tooth f_z. Each factor took 3 levels as shown in table 1. The levels of the cutting speed and the feed per tooth were selected based on the recommendations given by the tool manufacturer's recommendation.

Table 1. Factors and levels.

Factors	Level 1	Level 2	Level 3
Vc (m/min)	50	100	150
fz (mm/tooth)	0.1	0.15	0.2
a_e (mm)	0.3	0.5	0.7

3. Method of analysis

3.1. Experimental procedure

The nine experiments were conducted under dry conditions on a Deckel Maho DMU 50 evolution 5-axis CNC milling machine with Siemens control 840D, a maximum spindle speed of 18000 rpm and a maximum power of 16kW (Fig. 1). The tool holder reference is R216F-16A16S-063 and the ball end mill is composed by two uncoated cemented tungsten carbide inserts (z=2) which are manufactured by Sandvik with the reference R216F-16 40 E-L P20A. The diameter of the tool is 16 mm and the axial depth of cut was 0.4 mm.

Fig. 1. Five-axis CNC milling machine