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Experimental design and performance analysis of TiN-coated carbide tool in face milling stainless steel

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Abstract

A preliminary experiment and performance analysis of a TiN-coated carbide tool in the face milling of stainless steel is given first. Then, the experimental design of using the Taguchi method is employed to optimize the cutting parameters. An orthogonal array, the signal-to-noise (*S*/*N*) ratio, and the analysis of variance (ANOVA) are employed to study the performance characteristics in face milling operations. Through this study, not only can the range of cutting parameters for face milling stainless steel be obtained, but also the optimal cutting parameters can be found.

Keywords: Experimental design; Taguchi method; Signal-to-noise ratio; Analysis of variance

1. Introduction

The face milling process is used frequently in industrial machining to machine large, flat surfaces in a very fast and precise way. D'Errico and Guglielmi [1] presented the influence of physical vapor deposition (PVD) coatings on the flank wear of a cermet tool when milling a normalized carbon steel. Gu et al. [2] employed three types of coatings, TiN, TiALN and ZrN, coated by the PVD process face, in the milling of 4140 preheat treated steel, the wear mechanisms of attrition, abrasion, mechanical fatigue, and thermal fracture being identified and represented by wear maps. Diniz and Filho [3] reported the influence of the relative positions of the tool and the workpiece on the tool life and surface finish of the AISI 1045 steel in the process of the face milling of a flat surface. Su et al. [4] used the Taguchi method to analyze and optimize titanium carbonitride films on a cemented carbide indexable milling cutter when machining AISI 1045 medium carbon steel. Narutaki et al. [5] used a zirconia toughness alumina ceramic tool for the high speed face milling of plain carbon steel, S45C.

Stainless steel materials play an extremely important role in the engineering industry, in the manufacturing of medical materials and in other high-corrosion applications. The machining of stainless steel materials generally gives short tool lives, a limited metal removal rate, large cutting forces and high power consumption. This is due to their high temperature strength, rapid work-hardening during machining and reactivity with most tool materials at high cutting speed. Sun et al. [6] described the interface adhesion behavior between the cutter and the workpiece when austenitic stainless steel is milled by a cemented carbide cutter. It was shown that: (1) at medium cutting speed, an adhesive layer is formed between the rake face and the chip; (2) at low cutting speed, no adhesive layer exists on the rake face; (3) at high speed, a crater is formed on the rake face, and adhesion does not occur. Balazinski and Ennajimi [7] presented the results of their experimental studies on the influence of feed variation on tool wear during the face milling of stainless steel. Their experimental results show that it is possible to substantially increase the tool life with proper variation of the cutting feed rate throughout the cutting process.

Almost all machining processes are similar in producing common-burrs. The burr phenomenon is very serious, especially in the machining of difficult-to-cut materials. Stein and Dornfeld [8] reported the burr height, thickness and geometry in the drilling of 0.91 mm diameter holes in stainless steel 304L. Dornfeld et al. [9] investigated four distinct burr types when drilling titanium alloy plates. This paper is organized in the following manner. A preliminary experiment and performance analysis is given first. Then, the experimental design of using Taguchi method [10] is described. The optimal cutting parameters with regard to performance indexes such as tool life and burr height are considered. Finally, the paper concludes with a summary of the study.

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2. Preliminary experiment and analysis

Face milling experiments were performed on a vertical milling machine having a spindle speed of $n = 40$–1750 rpm. In order to simplify the tool life and burr formation analysis, only one insert was used in the milling cutter. Rectangular blocks of 150 mm length, 100 mm width and 30 mm thickness of stainless steel were used for the cutting tests. The cutting tool used was a commercial carbide-grade SEMN 1203AZ (ISO grade P30, M20) with a PVD TiN coating. For the milling of stainless steel, chipping was of prime concern; therefore, the tool life (or removed volume) is defined as the period of the cutting time at which the maximum chipping width is equal to 0.3 mm (see Fig. 1). Analyzing the milling system, it was found that the variables (cutting speed, feed rate and depth of cut) are not known for the cutting-limited region of the new TiN-coated carbide tool in the face milling of stainless steel. However, in a preliminary study, the cutting-limited region and the performance analysis of the three variables could be obtained. Fig. 2 shows the burr height versus removed volume at different cutting speeds. It is clearly seen that the cutting speed of $V = 330$ m/min is the maximum cutting-limited value. Fig. 2 shows the two variations of the burr height with the cutting process: the burr height increases with cutting process at low cutting speed ($V = 85$ m/min), and the burr height is transitional at medium or high cutting speed. This is because the burr breaks away at the medium or high cutting speed. Fig. 3 shows that the burr height increases with the progress of the cutting process regardless of the feed rates. It is noted that the

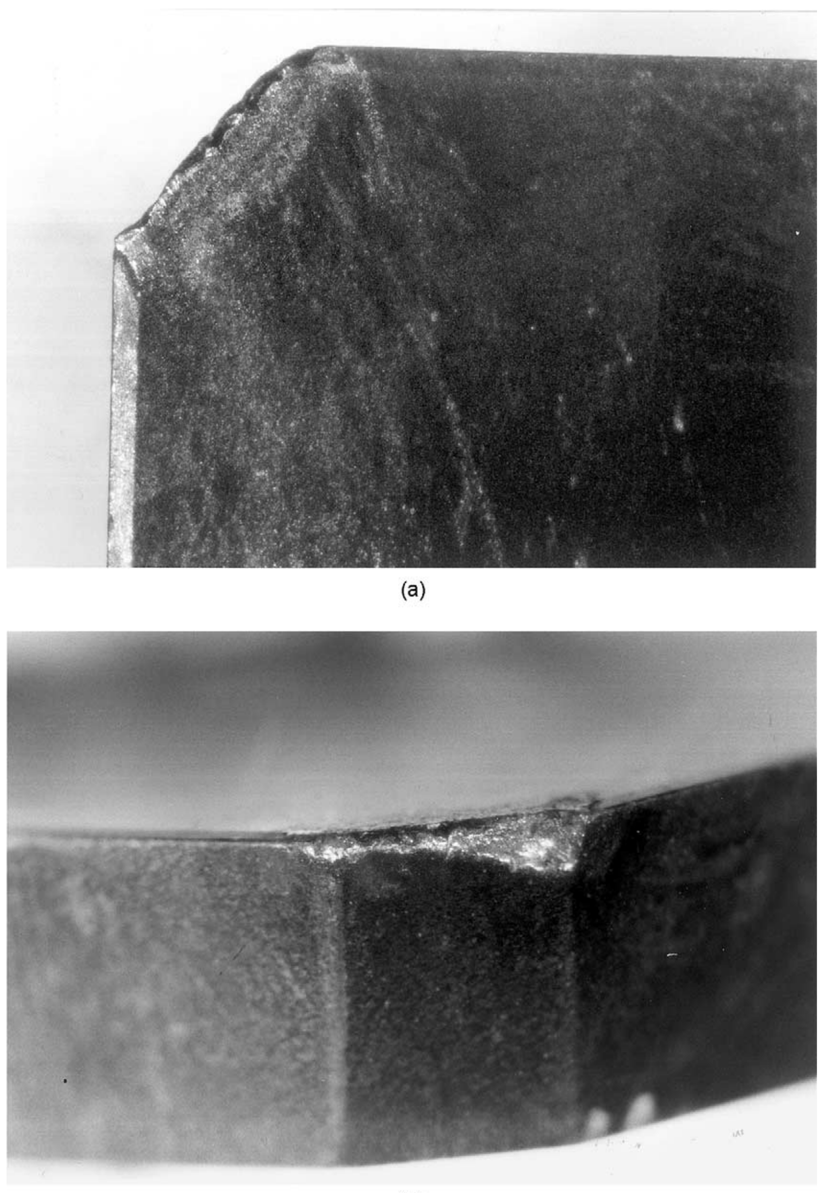

Fig. 1. Typical tool chipping in the face milling of stainless steel: (a) rake face; (b) side face.