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Sustainable turning of the Ti-6Al-4V alloy at low feed rates: surface quality assessment

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Abstract

Titanium alloys are widely used in the aeronautic industry in which repair and maintenance operations are usually required. Because titanium is a difficult-to-machine material, it is recommended the use of cutting fluids to achieve good results. However, the cost and environmental impact of cutting fluids encourages the use of sustainable alternatives. The present study analyses the use of dry machining and cold-compressed air for turning Ti-6Al-4V bars. Surface quality was analyzed evaluating the use of low feed rates and different types of tools and tool holders. As main conclusion, it can be affirmed that the feed rate is the most influential factor on the surface roughness (*Ra* and *Rz*). The surface roughness decreases at the higher feed rate until a certain machining time; afterwards, it increases with the increase of the feed rate.

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*Keywords:*aeronautic; cold-compressed air; dry machining; surface quality; titanium.

1. Introduction

Titanium alloys are widely used in the aeronautic industry and other sectors such as automotive, chemical, medical, oil and gas, sports and power plants [1]. Titanium presents advantages such as high strength to weight ratios, good temperature and chemical resistance, and low density [2]. In aeronautics, maintenance operations of aircrafts are important because both cost and safety reasons [3]. Thus, it is usual to perform repair and maintenance

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operations of titanium parts. Titanium is considered to be a difficult-to-machine material due to certain aspects such as its chemical reactivity with tool materials [4]. Moreover, the temperature during machining can reach high values due to its low thermal conductivity [5]. So, it is usually recommended to use cutting fluids to cool down the workpiece [6]. However, the use of cutting fluids has some drawbacks such as cost and environmental impact [7].

Surface quality for applications in the aeronautical sector is a demanding requirement. For instance, a usual range for the arithmetic average of the roughness profile (*Ra*) is 0.8 – 1.6 µm [8]. Although several studies have addressed the use of sustainable cooling/lubrication systems in the machining of titanium, the analysis of repair and maintenance operations still requires new specific experimental studies.

In the present study, the results of repair and maintenance turning operations of Ti-6Al-4V bars using dry machining and cold-compressed air are shown. The quality of the machined surface is assessed in terms of the surface roughness evaluating the influence of different machining conditions.

2. Material and methods

The workpieces were cylindrical bars of the Ti-6Al-4V titanium alloy: Ti (87.725-91%), Al (5.5-6.75%), V (3.5-4.5%). The geometry of the bars was: diameter of 50 mm and useful length of 400 mm. To perform the turning tests a parallel lathe (PINACHO model L- 1/200) was used. One external cooling/lubrication system was mounted on the lathe. Namely, a cold-compressed air system (CCA): Cold Air Gun Vortec system based on vortex tube technology was used (Fig. 1). Thus, both dry machining and CCA conditions were evaluated.

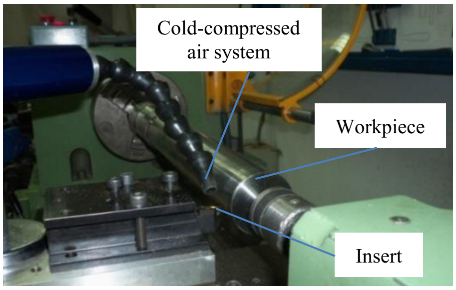

Fig. 1. Set-up used for the tests with the cold-compressed air.

Theoretical equations are useful to predict the surface roughness. For instance, Equation (1) can be used to calculate the theoretical *Ra* [9], considering as influential factors the feed rate (f) and tool nose radius (R_h).

$$Ra = \frac{1}{32}\frac{f^2}{R_h} \quad (1)$$

To carry out the experiments, two different DCMT 11T308-F2 tools from SECO manufacturer were used. The tools had the same geometry but different coatings, concretely: TiN (TP100) and TiCN/Al_2O_3/TiCN/TiN (TP1000). The nose radius of the tools was 0.8 mm. So, to reach an adequate surface roughness according to the theoretical equation, the feed rate was fixed at 0.051 and 0.10 mm/rev, theoretical *Ra* surface roughness of 0.10 and 0.39 µm, respectively. Moreover, two different tool holders with different inclination angles, 0º and 45º, h1 (SDNCN1616H11) and h2 (STDPDJNR1616H11), respectively, were used.

The cutting speed selected is fixed at a low level. Ezugwu *et al*. [10] tested cutting speeds of 175-250 m/min with high-pressure cooling. Authors affirmed that the use of the high-pressure cooling allows increasing the cutting speed up to 35%. So, in the present study, cutting speeds lower than 150 m/min (spindle speed of 925 rpm) are selected. Moreover, the depth of cut was fixed at 0.25 mm that is adequate for finishing operations.

The turning process was analyzed using a full factorial design of 4 factors of 2 levels: type of tool, T, type of cooling system, Q, feed rate, f, and tool holder, h. So, 32 tests were planned, including one repetition. Surface roughness was evaluated using a Mitutoyo Surftest SJ 401 tester. Four measurements were taken at 30, 150, 275 and 400 mm from the end of the workpiece. The surface roughness was measured using the arithmetic average (*Ra*) and average maximum height (*Rz*) parameters.