Journal of Manufacturing Processes 22 (2016) 7–20

Contents lists available at ScienceDirect

Journal of Manufacturing Processes

journal homepage: www.elsevier.com/locate/manpro

Technical Paper

Experimental analysis of axial and torsional vibrations assisted tapping of titanium alloy

Swapnil Pawar[a,b], Suhas S. Joshi[a,*]

[a] Department of Mechanical Engineering, Indian Institute of Technology Bombay, Powai, Mumbai 400076, India
[b] Kalyani Centre for Technology and Innovation, Bharat Forge Ltd. Pune, Pune 411036, India

ARTICLE INFO

Article history:
Received 22 June 2015
Received in revised form 10 January 2016
Accepted 16 January 2016
Available online 10 February 2016

Keywords:
Titanium alloys
Vibration-assisted tapping
Thrust
Torque
Surface quality
Microstructure

ABSTRACT

Sudden breakage of a tap is frequently encountered during tapping small diameter internal threads on titanium alloys. This work therefore presents an extensive experimentation to investigate mechanism and performance of tapping in titanium alloys in the presence of axial and, axial and torsional vibration-assisted tapping (AVAT and ATVAT). Tapping cycles based on the variation in thrust and torque in tapping have been established, which illustrate subtle differences in the tapping phenomena as a consequence of vibrations. AVAT and ATVAT were found to reduce tapping torque, axial force and temperature over that of the conventional tapping (CT) without compromising the thread quality. Between ATVAT and AVAT, ATVAT gives improved performance. The ATVAT and AVAT processes generate elastic recovery-free superior surfaces as against the heavily recovered surfaces in CT. Microstructure of the tapped surfaces shows a reduction in tapping affected zone in ATVAT and AVAT than that of in CT.

1. Introduction

A large number of tapped holes with high accuracy, over large depths and small diameters are required in automobile as well as aerospace industries [1,2]. However, sudden breakage of a tap is the most undesirable event frequently encountered during tapping on titanium alloys primarily due to excessive torque. The low elastic modulus and thermal conductivity of titanium alloys generate a large spring back from finished surfaces and also cause a thermal gradient at tap cutting edges. This results in galling and seizing around the cutting edges [3,4]. The consequent relief face friction causes locking and subsequent breaking of rotating taps in the drilled hole [5]. As tapping is one of the final operations performed on a component, the tap breakage at this stage is always costly [6]. Therefore, it is necessary to study the tapping process and evolve alternatives to overcome these limitations.

Based on the past research, it is realized that ultrasonic vibrations help improve machinability of 'difficult-to-cut' material. About 25 years ago, Kumabe et al. [7] showed that, the vibrations provided significant reduction in cutting forces and increase tool life in machining of ceramics. Thoe et al. [8] found that ultrasonic vibrations to the cutting tools during machining of brittle and non-conductive materials reduce tool-workpiece interference temperature, residual stresses, tool wear rate and improve the machining accuracy. Zhang et al. [9] showed that in tapping on titanium alloys, a large relief face friction due to spring back from work surfaces causes excessive torque. Kuo [10,11] shown that adding a controlled axial vibration in a tapping reduces tapping torque by 25–30% without causing any undesirable effect on the thread profile. Zhang et al. [12] found that adding axial vibrations is more beneficial for smaller size taps as they show a greater degree of reduction in tapping torque. The authors also found that square wave vibrations are more effective than a sine wave in reducing the tapping torque. Takeshi et al. [13] found that application of metalworking fluids becomes more effective with controlled axial vibrations. Kostek [14] and Adachi et al. [15] found the axial harmonic vibrations reduce average coefficient of friction and contact pressure. Han et al. [16] showed that the peak torque of torsional vibration-assisted tapping is about 30% lower than that of the conventional tapping. Yang et al. [17] found that an optimal ratio of backward to forward angular movements for reducing the tapping torque is 1.5. Yin et al. [18] observed an increase in the tap life with a decrease in the ratio. Guangjun et al. [19] shown that controlled torsional vibrations enhance the thread quality and prolongs the tap life. Wanga et al. [20] found torsional vibrations improve the chip breakability. Lu et al. [21] reported that too low or too large spindle speed could increase the tapping torque and cause breaking of taps inside a hole. Patil et al. [22] shown that 40–45% reduction in cutting forces and about 48% reduction in the cutting temperature occurs when controlled vibrations are imparted to during machining. They

* Corresponding author. Tel.: +91 22 2576 7527.
E-mail address: ssjoshi@iitb.ac.in (S.S. Joshi).

http://dx.doi.org/10.1016/j.jmapro.2016.01.006

also found that the controlled vibrations improve machined surface quality and reduce shear band formation in chips.

It is understood from the state of research on vibration-assisted tapping that the vibrations assistance in tapping gives definite advantages in terms of reduction in tapping thrust and torque, and eventually improves the tap life. Most of findings employ torsional vibrations and concentrate on measuring tapping torque. However, the effect of vibration parameters like frequency, amplitude and wave function has not been adequately addressed. At the same time, the effect of vibrations on the quality of threaded surfaces, thread accuracy and their correlation to the vibration characteristics, and chip formation mechanism in tapping have also not be an addressed adequately so far.

This paper therefore focuses on understanding the mechanism of vibration-assisted tapping and its correlation with tapping torque, and quality of thread surfaces. Accordingly, an elaborate experimentation on tapping of titanium alloy was undertaken. The details of this work are presented in the following sections of this paper.

2. Experimental details

2.1. Theme of the experiment

The theme of the experiments involved understanding the effect of (i) axial vibration-assisted tapping (AVAT), where vibrations are imparted to the work specimen in the direction of feed and, (ii) axial and torsional vibration-assisted tapping (ATVAT), in which vibrations are imparted to the work specimen in the feed as well as in the angular directions. To understand the effect of axial and torsional vibrations on tapping torques and subsequently on the machinability of titanium alloy in tapping, various experiments were undertaken; see Fig. 1 for theme of experimentation. The experimental work initially focused on the design of an experimental setup to provide axial and torsional vibrations during tapping. Experiments were performed to analyze the tapping torque, force and temperature. In the post tapping analysis, accuracy of taped holes, quality of threaded surfaces, microstructure of the thread profiles and morphology of chips generated during tapping have been analyzed. The data obtained from this analysis has been used to correlate the effect of processing parameters on the machinability of titanium alloys in tapping.

2.2. Experimental set up

An elaborate experimental set up was developed to impart vibrations in tapping of Ti-6Al-4V. Fig. 2a shows a block diagram of the ultrasonic vibration-assisted tapping system designed and developed for this work. It consisted of three units; one for measuring thrust and torque, second for imparting ultrasonic axial vibrations to work specimens, and third for imparting torsional vibrations to taps. The entire assembly of the first two units is mounted on worktable of a CNC machining center, see Fig. 2b. The amplitude and frequency of the axial vibrations is regulated by a generator. The spindle speed and the ratio of backward to forward movements of the tap were imparted by preparing CNC programs. It may be noted that ultrasonic vibration device mounted on the dynamometer did not interface with the measurement of thrust and tapping torque. This is because the ultrasonic vibration frequency is 10 times higher than the natural frequency of the dynamometer.

Fig. 2c shows the vibrating work assembly which consists of an assembly of transducer, booster, flange and work specimen holder or horn. The ultrasonic work assembly consists of (i) a piezoelectric transducer to convert electrical signals from generator to mechanical vibrations, and (ii) a booster which boosts these vibrations as the amplitude of vibrations would be very low at the face of the transducer. The vibrations were carried to the work specimens using a

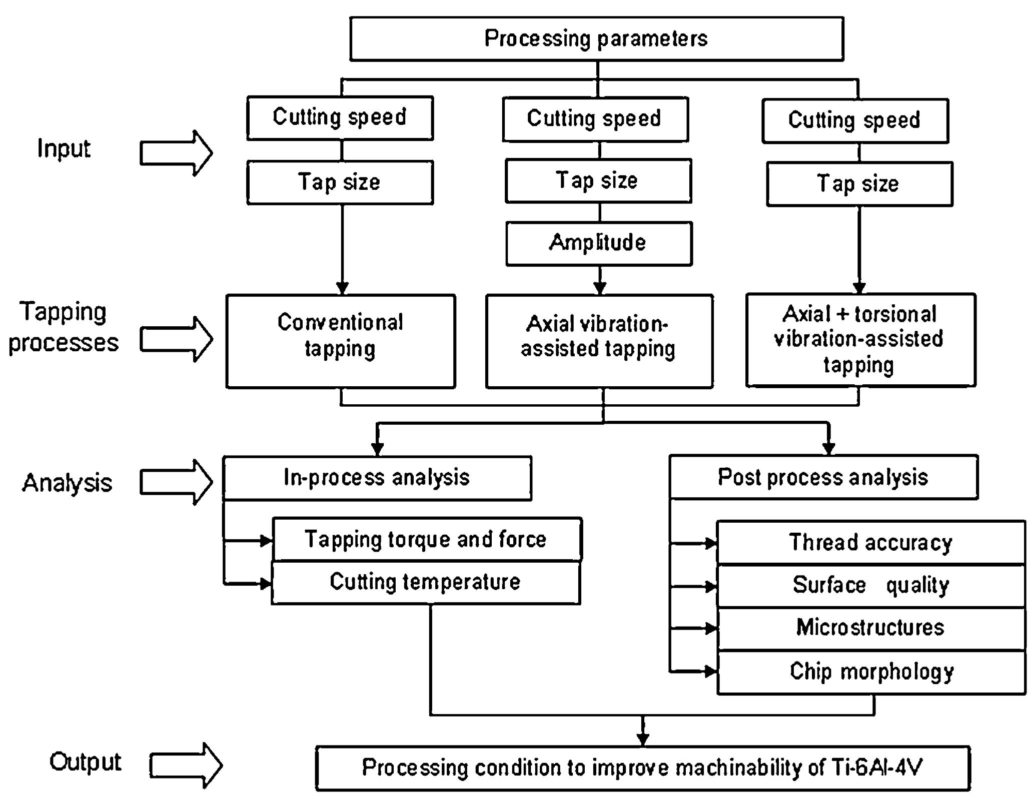

Fig. 1. Theme of the experiments.