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Cyclical Chips Formation during Machining of Titanium and Titanium Alloys

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A B S T R A C T

Turning of titanium alloys which is characterized with low cutting speeds and high tool wear, poses considerable problems due to the poor machinability of titanium. In this work, the process of cyclical chip formation during machining of titanium and titanium alloys was studied and analysed. Titanium alloys of BT1.00, BT3-1 and BT-5.1, of diameter 100 – 200 mm and length 600 – 800 mm, was used as the work piece. Experimental results show that the width of chip formation zone during cutting of titanium alloys is very minimal. As a result of this, increasing the plasticity (elasticity) properties of volumes of titanium alloys lead to the ceasing of the formation of cyclical chips. This study has however analysed and pointed out that the best wear resistant cemented carbide tool was BK6 and cemented carbide tool BK8 was only 75 - 80% as good. At a cutting speed V = 60 m/min, a durability of S30 minutes was attained. The durability increased to 45 – 50 minutes when the cutting speed was reduced to V = 50 m/min and a stable wear of 0.30 - 0.35 min was maintained for about 70% of the working period. Majority of the chip elements increased in the width of localized shear plane and the contact layer with increase in cutting speeds.

1. Introduction

Titanium and its alloys are used extensively in aerospace because of their excellent combination of high specific strength (strength-to-weight ratio) which is maintained at elevated temperature, their fracture resistant, characteristics, and their exceptional resistance to corrosion. They are also increasingly (or being considered for use) in other industrial and commercial applications, such as petroleum refining, chemical processing, surgical implantation, pulp and paper, pollution control, nuclear waste storage, food processing, electrochemical (including cathodic protection and extractive metallurgy) and marine applications. They have become established engineering materials available in a range of alloys and in all the wrought forms, such as billet, bar, plate, sheet, strip, hollows, extrusions, wire, etc. (Ezugwu et al. 1995). Chip formation and its morphology are important features of metal machining and yield important information on the cutting process itself. In titanium alloy machining, cyclical chip formation involves localized shearing which is associated .with the generation of cyclic forces and acoustic emission..

The frequency of the cyclic strain, load sensor and acoustic emission signals is found to correspond to the frequency of chip segmentation (Sun et al., 2009). Titanium alloy machining performance can be increased by improving cutting tool materials and coatings. Cubic boron nitride (CBN) material offers outstanding properties such as high hardness and wear resistance (Ozel et al., 2010). The growing popularity of titanium is today rousing a lot of interest in the research circles. Titanium and its alloys are expected to push stainless steel to the second position in the rating of the most used or useful metals soon because of its extremely favourable properties .

Titanium poses considerable problems in its manufacturing due to its poor machinability. Cutting of titanium alloys is characterized by low cutting speeds and high tool wear. Up to the present moment, the rough turning process of titanium alloys, where the determining factor of the tool life is the mechanical characteristics of the tool, is well studied unlike the semi-finished turning of the alloys, especially α-titanium alloy. The machinability of titanium and its alloys is generally considered to be poor owing to several inherent properties of the materials. Titanium is very chemically reactive and, therefore, has a tendency to weld to the cutting tool during machining, thus leading to

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chipping and premature tool failure. Its low thermal conductivity increases the temperature at the tool/workpiece inter- face, which affects the tool life adversely. Additionally, its high strength maintained at elevated temperature and its low modulus of elasticity further impairs its machinability. In 1955, Siekmann pointed out that "machining of titanium and its alloys would always be a problem, no matter what techniques are employed to transform this metal into chips". The poor machinability of titanium and its alloys have led many large companies (for example Rolls-Royce and General Electrics) to invest large sums of money in developing techniques to minimise machining cost. Reasonable production rates and excellent surface quality can be achieved with conventional machining methods if the unique characteristics of the metal and its alloys are taken into account (Awopetu et al., 1995).

Researchers have worked on machining titanium and its alloys in the past. Awopetu et al., (1995), worked on the selection of cutting tools for turning α-titanium alloy BT-5, Ezugwu et al., (1997), Veiga et al., (2013) and Gao et al., (2016) reviewed titanium alloys and their machinability, Sun et al., (2009), worked and analysed the characteristics of cutting forces and chip formation in machining of titanium alloys; Srivastava et al., (2001), carried out an investigations on turning Ti-6Al-4V titanium alloy using super-finished tool edge geometry generated by micro-machining process (MMP). There is no available report on the formation of cyclical chips. This work therefore is aimed at studying and analysing the process of cyclical chip formation during machining of titanium and titanium alloys.

2. Materials and Experimental Procedures

The work pieces used for this research work are Titanium alloys of BT1.00, BT3-1 and BT-5.1, in the state in which it was supplied, because they are now the leading alloys of titanium in use today. They are of diameter 100 – 200 mm and length 600 – 800 mm. The machining experiment was carried out on an industrial lathe machine model IM63 with a 7.2KVA motor. Majority of the experiments on the characteristics of cutting processes are carried out using the following cemented carbide tools BK8, BK60M, BK6, BK100M, BK10X0M, BK10XTM, T5K10 and T15K6. The cemented carbide tools come under the Russian standard (GOST) 2209-69 as insert forms 0227A which are bolted (fixed) mechanically on the tool body.

The inserts have the following geometry, clearance angle, α, 15o, rake angle, γ, 0o. Sharpening of the insets was carried out on a universal tool grinding machine with abrasive disc AYK-ACP100/80.51.100. Since the properties of the cemented carbide tools (inserts) are not homogenous, the inserts to be used are chosen to be having the same thermal electromotive force (emf) after such tests have been performed on all the acquired inserts.

Component cutting forces are registered on an apparatus YDM-600. The dynamometer YDM-600 comes as a complete set consisting of dynamometer sensor, four channel amplifier TA-5, oscilograph H-700, the power block and the voltage stabilizer. The signals of the changes of the component force was fixed on the Oscilograph. The speed of pulling of the signal photo paper, covered with ultraviolet film, for instant analysis of results of experiment, equals 5000 mm/sec with time indication marks at every 0.002 sec. The frequency of the cyclical chip formation was checked both by calculating the chip elements on a unit length as well as speed of the chip movement. Chip shrinkage is defined as the relationship between width of cut and the average width of chip based on the study of the chip root on optical microscope NIOFOT.

The temperature during cutting was measured with the aid of thermal EMF by the natural thermal couple method. The tool wear was observed on an instrumental microscope. Micro metallographic specimen guarantees the best and authentic information about the contact process during cutting and tool wear. The chip root, consisting of the chip and a break-off of the tool, was contained in the micro metallographic specimen and a typical cyclical chip was produced as shown in Fig.1. A micro metallographic specimen of this type of alloys, during the study of the mechanism of the contact relationship, in any pre-determined section, in the particular way they have been even during cutting process. The mathematical statistics method was adopted in compiling the results of the experiments.

3. Results and Discussion

Dynamic part of the component cutting forces Px and Py is obtained to be 30 – 40% of the static part. This percentage has a good correlation with changes in area of shear plane of chip element and is not subjected to fall in stress in the localized share plane. Results showed that cemented carbide tool BK6 is the best wear resistant while cemented carbide tool BK8 is only 75 – 80% good. Using the recommended geometry, the chips are easily breakable. From the results obtained, the durability of S30 minutes is obtained in a semi-finished operation when cutting at a speed of 60 m/min. It was noted from the experiment that the durability increased to 45-50 minutes when the cutting speed, V was reduced to 50 m/min and a stable wear of 0.30-0.35 min is maintained for about 70% of the working period.

Awopetu O.O. / FUTAJEET 10 (1) (2016) (41-44)

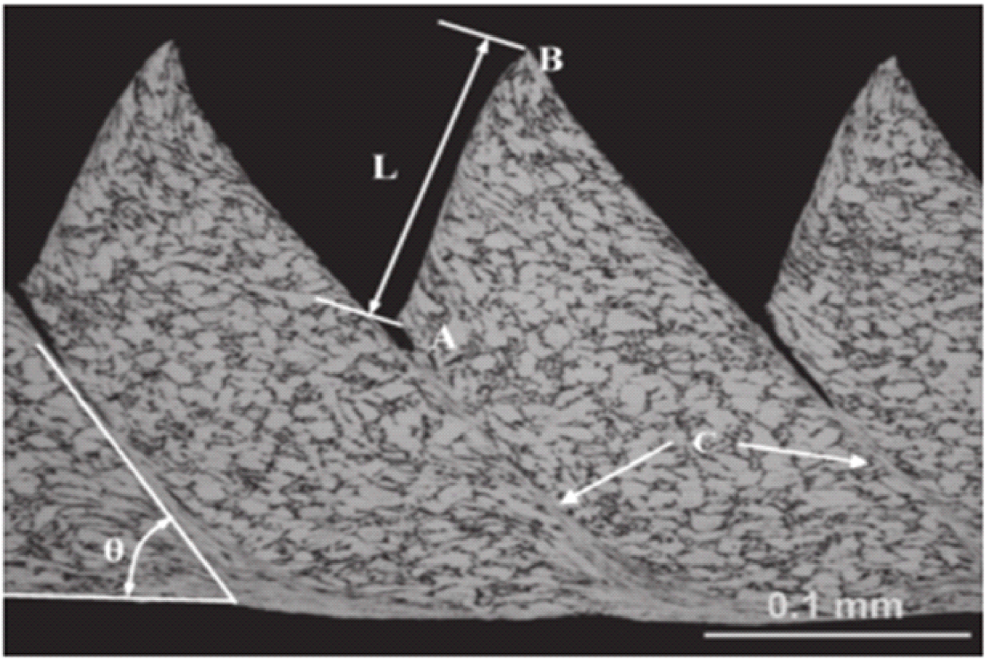

Fig. 1: Cross-section of a typical cyclical chip in machining of BT1.00 titanium alloy.

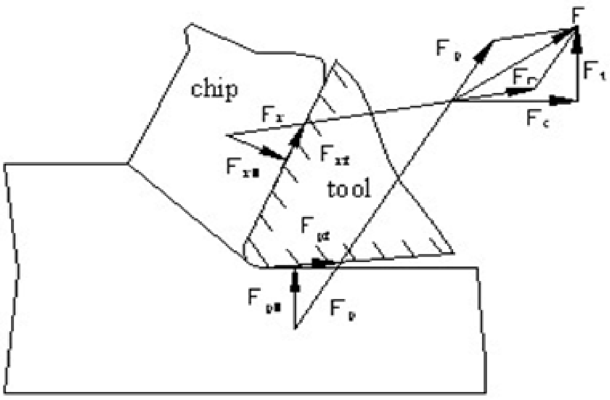

Fig.2: Merchant model with tool edge showing force acting on the cutting tool.

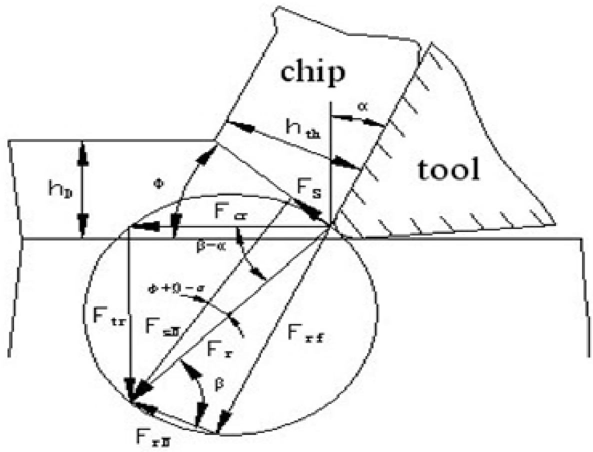

Fig.3: Merchant model with tool edge showing force acting on the chip.

Forces acting on the chip and tool are analyzed in Figs. 2 and 3, in which:

Fc and Ft are corresponding to the measured cutting force and thrust force;

Fr is the resultant force of the component Fcr in the cutting direction and the component Ftr along the feed direction;

Fr is also the resultant of normal friction force Frf and normal force FrN acting on rake face;

Fp is the resultant of normal force FpN and friction force Frf acting on tool flank;

F is the resultant of Fr and Fp as shown in Fig. 3.

The resultant force Fr of Frf and FrN forces acting on rake face is also a resultant force of normal force FsN and shear force Fs acting on the shear plane.

4. Conclusion

The aim of this work is to study the process of cyclical chip formation during machining of titanium and titanium alloys. From the results obtained, the considerably effect on the process of cyclical chip formation has the structural build-up of titanium alloys. The crystals (structural blocks) are equal to the cutting zone in which the microstructures of the block in the cutting zone, has different orientations in relation to the shear plane. This is responsible for the formation of cyclical chip with different element sizes which accelerates the negative effects of fluctuating force and heat stress on the tool.

Experimental results show that, the structural block boundaries in respect to elastic (plastic) deformation are the weakest and they predetermine the emergence of the process of localized shear of theformed chip element in most cases. It is therefore necessary to reduce the amplitude of fluctuation of both force and heat stress in order to have titanium alloy with fine grain structure.

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