Drillability of Titanium 6246 Alloy

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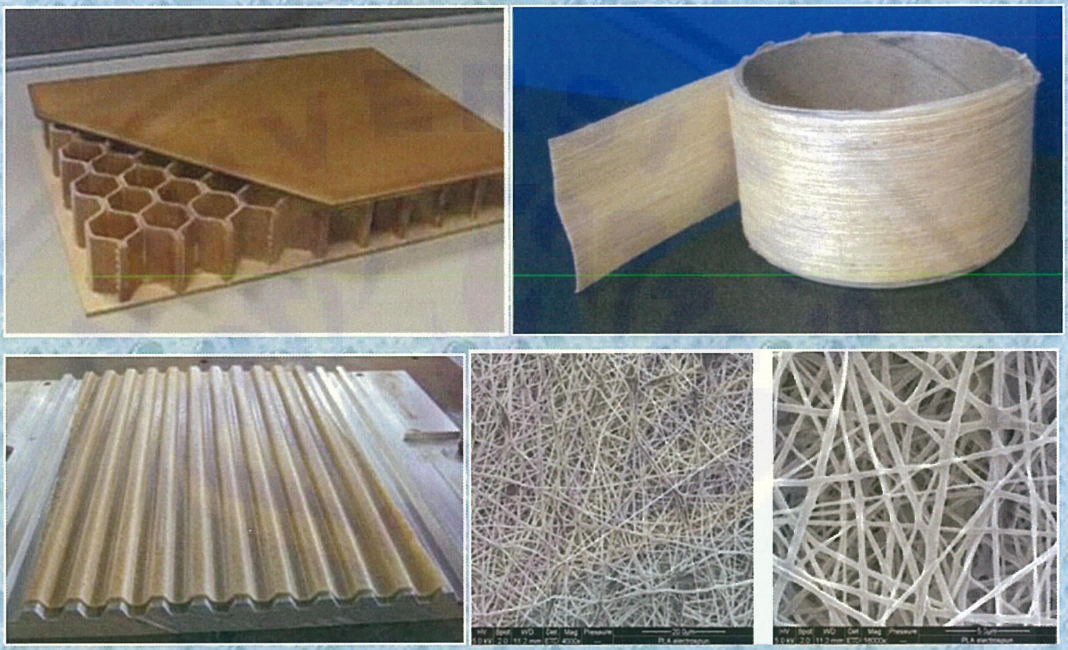
Processing and Fabrication of Advanced Materials-XXV



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Drillability of Titanium 6246 Alloy

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Abstract

This article describes the chips formation during drilling of Ti-6246 titanium alloy using TiAlN coating carbide insert drill. At the early stage of drilling, the chips had a conical spiral shapes regardless the parameters used and heat treatment conditions. However, as the depth increases different types of chips were observed depending on the parameters used. Drilling with high feed rates, lower cutting speed and with coolant resulted in segmented-type. On the contrary, low feed rate and high cutting speed result in long-curly chips. Furthermore, when the depth of drilling was around 10 mm or deeper, a zigzag form of chips was observed regardless the machining parameters applied. Though the chips forms were different, cross sectional observation using optical microscopy and scanning electron microscopy shows that all the chips had a serrated type. These chips experienced microstructural elongation at the shear band area. Micro Vickers hardness tests showed that the hardness of the chips was higher compared to the hardness of the original material prior to drilling.

Keywords: Ti-6246, drilling, chips formation

Introduction

Titanium alloys have advantages such as high strength to weigh ratio, and high heat and corrosion resistance. Therefore, they are widely used for airplane components. Titanium is among the hard-to-machine metals. One of the reasons is low heat conductivity, therefore the heat produced during machining was mainly absorbed by the tool then soften it [1]. In machining, some researchers have worked to find the best parameters in machining Ti-6246 such as milling [2], turning [3], wire-EDM [4] and ultrasonic assisted machining (UAT) [5]. Armendia et al. [6] had carried out annealing on three α+β titanium alloys to increase their machinability. They concluded that machinability of Ti-6246 was poorer than that of Ti-64. Ideally, machinability can be improved by softening the material through heat treatment together with selecting the most suitable machining parameters. To the extent of our knowledge, there is no published articles on drilling

Ti-6246. Understanding the chips formation will help to study better of drillability of this alloy.

Materials and Methods

Ti-6246 samples were prepared in a block shape with a size of 25 mm x 25 mm and vary in height. Prior to drilling a block was clamped in a fixture which is mounted on a Kistler dynamometer to measure the forces worked during drilling. The dynamometer is connected to a PC outside the CNC machine to monitor the process. The tool used were 10 mm insert type of TiAlN PVD coated carbide with included angle 140° as shown at Fig 1a. The parameters are given below

Cutting speed: 27, 35 and 50 m/min

Feed rate: 0.08, 0.11 and 0.15 mm/min

Material condition: (1) as received, (2) heat treated at 870°C for three hours followed by two different cooling, one was (2a) air cooled (AC) and another by (2b) water quenching (WQ). In the rest of paper these three conditions will be referred to as AR, HT1 and HT2.

The chips were collected after various depth of drilling. They were prepared metallographically and observed using optical and scanning electron microscope (SEM). Vickers micro hardness with load of 25g was used to measure the hardness of the chips. Whereas, hardness of the block samples were measured using Rockwell hardness machine with a load of 150 kg. Then the hardness values were converted to Vickers.

Results and Discussion

Chips formed from many single cones as effect of different cutting side of the drill bit and different cutting speed along the cutting blades. The peripheral chip is result of outer blade cutter, whereas central chips is cut by inner blade (Fig 1a). Longitudinal view with SEM shows that the segment chips are different at outer, inner and mid (Fig 1b&c).

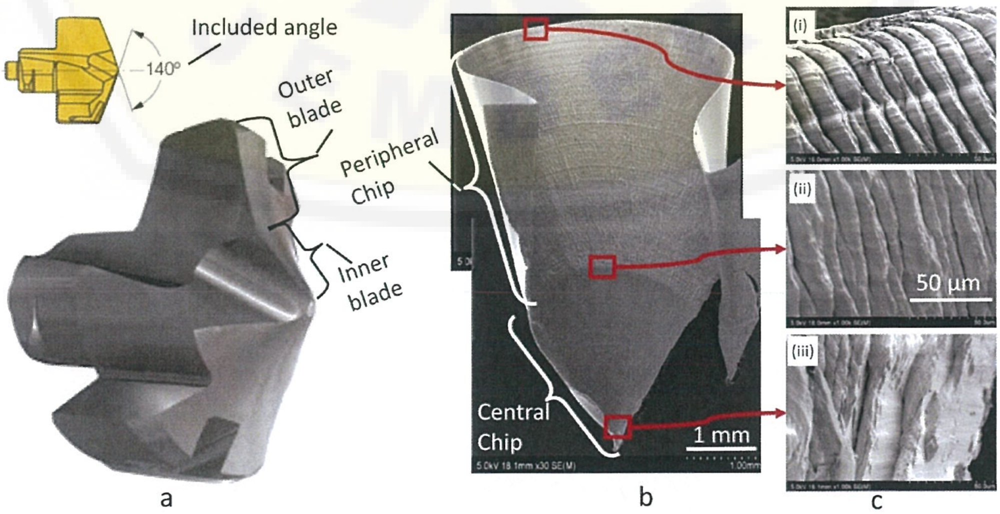

Fig 1. Illustration of a drill head with two blades (a), a single chip (b), SEM of chips pattern at different places (c).

Chips Pattern. At the early stage of drilling, the chips were conical spiral in shape regardless of the parameters used in drilling. Different shapes were then formed as the drilling continues depending on the drilling parameters (Fig 2). Most of high feed rate (0.15m/min) result in segmented, a conical spiral chips that is broken just before the chips grow into long-pitch shape by the wall of the drilled hole due to its insufficient ductility. Moreover, by applying cutting fluid these segments become shorter. The low feed rate (0.08 m/min), in the contrary, resulted in long and barely unbreakable chips during drilling. At high cutting speed the chips forms were helical spiral. With high feed rate the chips were thicker but the helical spiral shaped was still obvious. The deeper the drilling the more tendency to form zigzag chips, that is buckled and densely folded because they may be hard to find the way out through the flutes. This tendency can be found on drilling of 10 mm depth only when the chips were long and not broken, which is the last one third of whole long chips. On deeper drilling the zigzag chips were denser. On the contrary, the zigzag chip was not form in drilling 10 mm depth when applying feed rate 0.15 mm/rev with coolant.

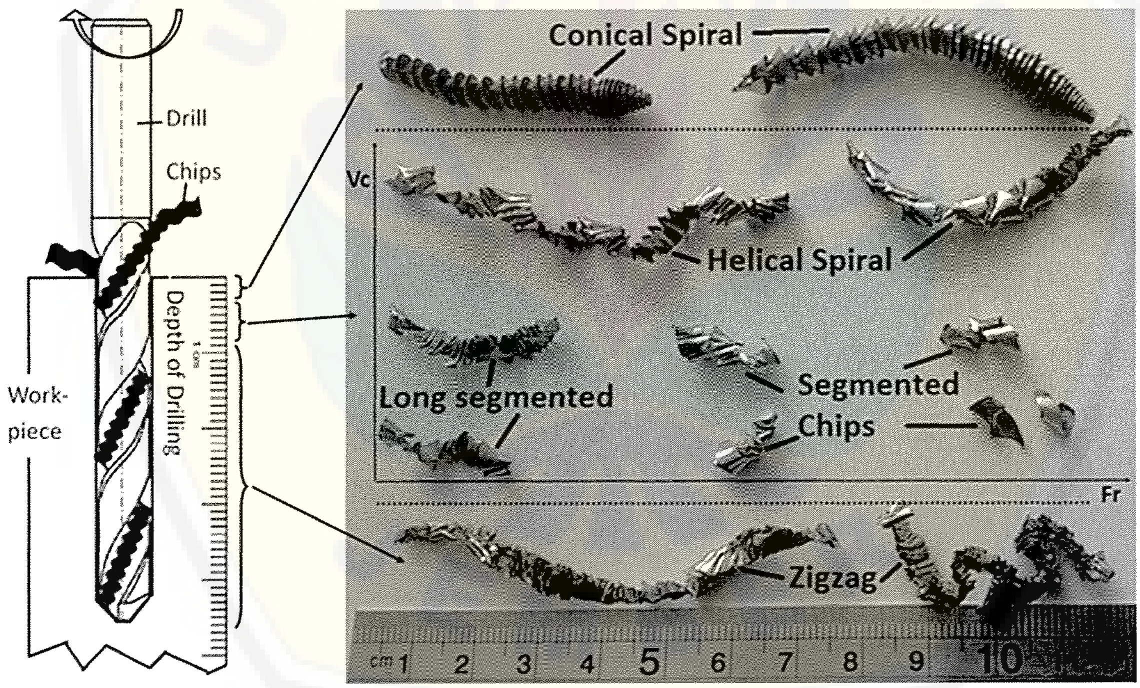

Fig 2. Form of chips from different stage of drilling.

Further observation on these chips using optical microscope shows that although there were different forms, their microscopic patterns were mostly the same, i.e. serrated (or saw tooth or segmented), as can be seen at Fig 3 and 4. Chips consist of segments between shear bands. Variation of drilling parameter, heat treatments and application of coolant will cause different size of each segment. The results were identical to what was reported by Ostroushko et al. [8]. They found that most of the chosen combination of cutting speed and feed rate resulted in segmented chips. Continuous chips, as exception, were found when machining with low cutting speed and low depth of cut (in case of drilling DoC = Fr/2). The microscopically continuous chips were not found in our experiments result. It may due to the applied parameters (Vc and Fr) are between the recommended value by the drill bit manufacturer.

Microstructure and Hardness Alteration. Microstructure and hardness of Ti-6246 as received (AR), after HT1 and HT2 are presented in Fig 3a, b, and c respectively. The AR is most likely in the forged condition according to its similarity to the one in ASM Metals Handbook volume 9 [9]. The hardness test on the chip were carried out after polishing and light etching. The hardness of AR and HT1 are the same of 288Hv, whereas after HT2 it is higher compared with the other conditions (335Hv). There is an increase in hardness of chips compare to their original condition except for the HT2.

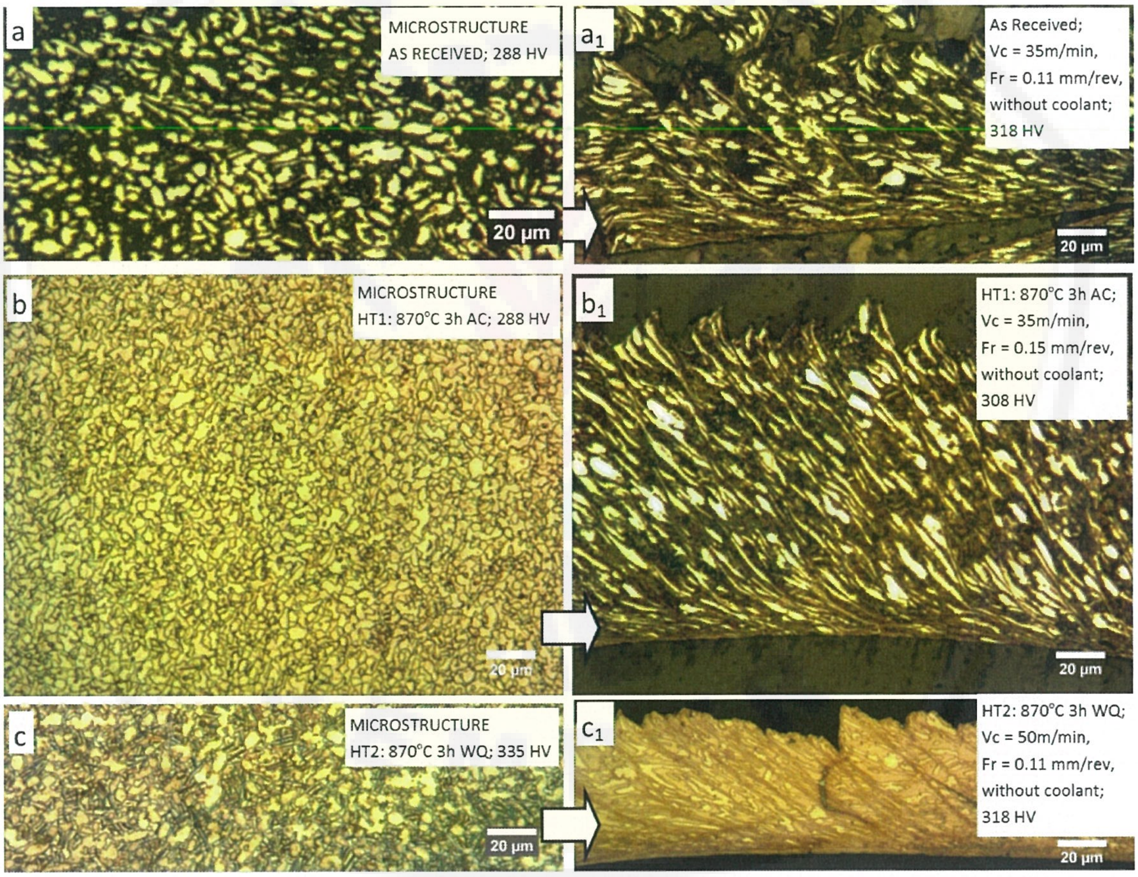

Fig 3. Microstructure and hardness alteration after drilling with different machining parameters.

The grains were elongated at the shear band area (Fig 3a1, b1, c1). Elongation of grains is also observed at the bottom of the chips, which is usually called secondary shear areas. In most cases, the chips experienced strain hardening, the hardening mechanism caused by dislocation movements and dislocation generation within the grains. The hardening usually happens on plastically deformed material below the recrystallization temperature. In case of this alloy that has been heat treated then followed by rapid cooling (water quenched/ HT2), alpha prime phase was formed [10], which is harder than the normal alpha plus beta form. The heat absorbed by the chip during drilling may lead to softening. Therefore, the HT2 resulted in softer chips.

Serrated Degree of Chips. For quantitative characterization of serrated chips, the serrated degree (Gs) of chips is defined by Liu et al. [7] as

$$Gs = \frac{H-h}{H} \quad (1)$$

Where, H and h are the height from the bottom of the chips to top and the bottom of segmentation, respectively, while D is chip segment thickness. There is a slightly different in chips formation between different cutting speed (comparison between Fig 4a & d). We found that serrated degree, Gs, is 0.17 of cutting speed 35 m/min compare to 0.22 of cutting speed 50 m/min. Higher cutting speed would slightly increase the serrated degree. Meanwhile, different feed rate has increased the serrated degree twice from 0.17 to 0.35 of feed rate 0.11 mm/rev and 0.15 mm/rev respectively (comparison of Fig 4a & b). The chips thickness (D) was also increased significantly from 18 to 43 μm. The highest serrated degree (0.34) and widest chip segment (43 μm) was achieved by applying Vc 35 m/min, Fr 0.15 mm/rev without coolant in drilling the AR block (Fig 4b). On the contrary, the same parameters would result in lowest serrated degree (0.09) and fair chip segment (around 20μm) when drilling HT1 block (Fig 3b1).

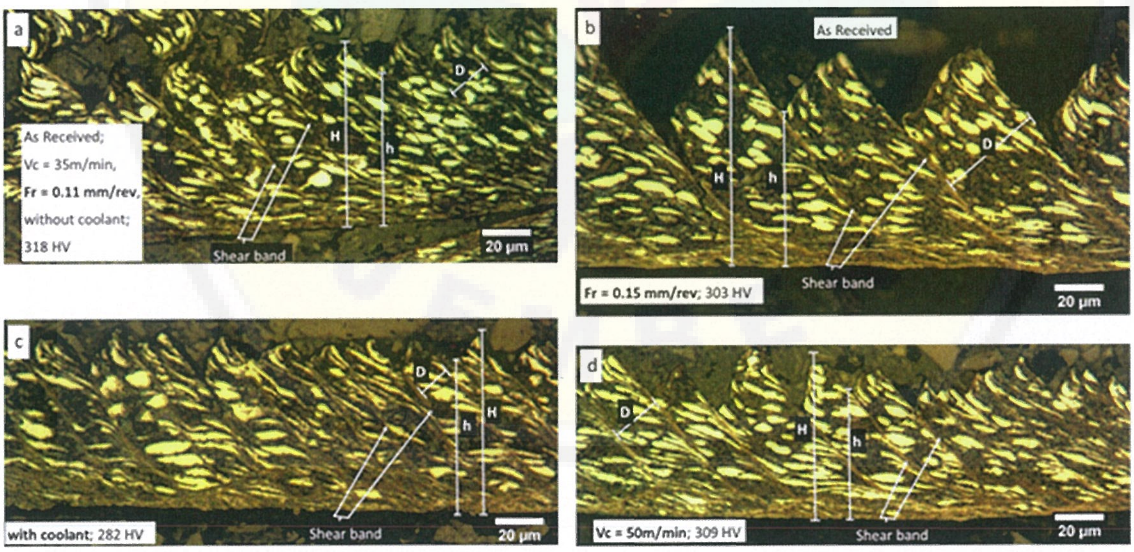

Fig 4. Chips from different drilling parameters

Mechanism of Chips Formation. There are two main forces work on the tool tip, thrust force (Fz) and torque (Mz) caused by feed rate (Fr) and linear cutting speed (Vc) applied on the drill (Fig 5a). Thrust force mainly (more than 50%) caused by works on chisel [11]. While torque is influenced by speed rotation and diameter of the drill. The chip formed due to shear force (τ

cutting) that deform the material then separate it (Fig 5a). The serrated chips are caused by periodic thermoplastic shear instability happening within the primary shear zone. The shear instability happens when the rate of thermal softening exceeds the strain rate and strain hardening. Due to the shear process that takes place in very short time, the heat generated by severe plastic deformation in primary zone was not dissipated. Fig 5b shows clearly the primary shear zones (between chips segments) and the secondary shear zone at the bottom of the chip. The pattern of elongated grains clearly show that the chip experienced shear deformation.

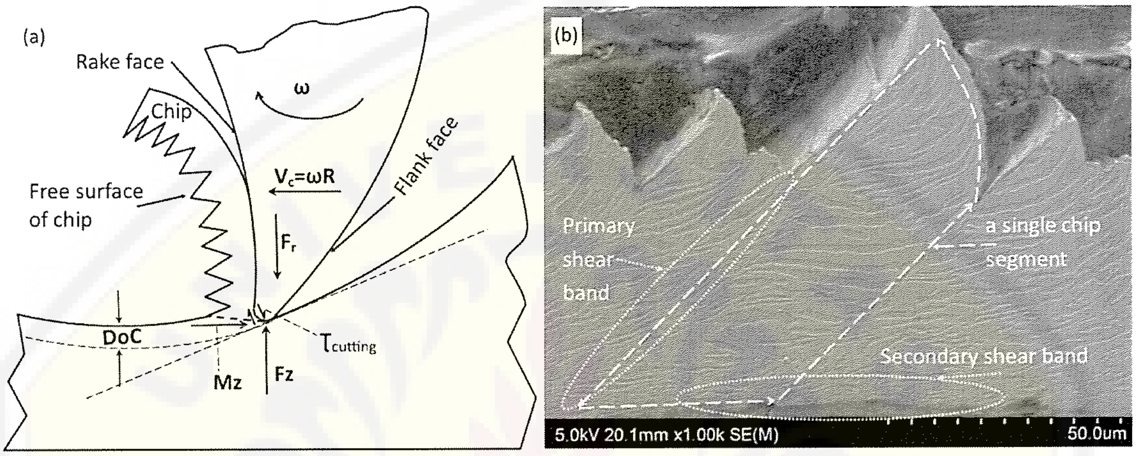

Fig 5. Mechanics of chip formation in drilling (a) and SEM photography of a serrated chip (b).

Torque and Force. High feed rate (0.15 mm/rev) results in both high torque (Fig 6a) as well as high axial force (Fig 6b). Torque at Fr 0.15 increased about 30% at the beginning of drilling compare to that of Fr 0.11 mm/rev. It increased sharply to about 300 N.cm after 10 seconds drilling until the tool was retreated. Increasing cutting speed from 35 to 50 m/min did not affect the torque. Of all parameters applied, the torque tends to increase as the depth increased. This may be caused by an additional effort to propel the chips out through the flutes. On the other hand, axial or thrust force was relatively stable during drilling (Fig 6b). The axial force was affected only by feed rate not by other machining parameters.

Increasing torque and axial force at feed rate of 0.15 mm/rev may relate to higher material removal rate (MRR) as both parameters are linearly connected in the following formula

$$MRR = \frac{\pi.Fr.D^2.N}{4} \quad \text{(2)}$$

MRR is an important parameter in machining processes. MRR is defined as a volume that has to be removed in a certain time (mm^3/s). The higher the MRR the more efficient the drilling is.

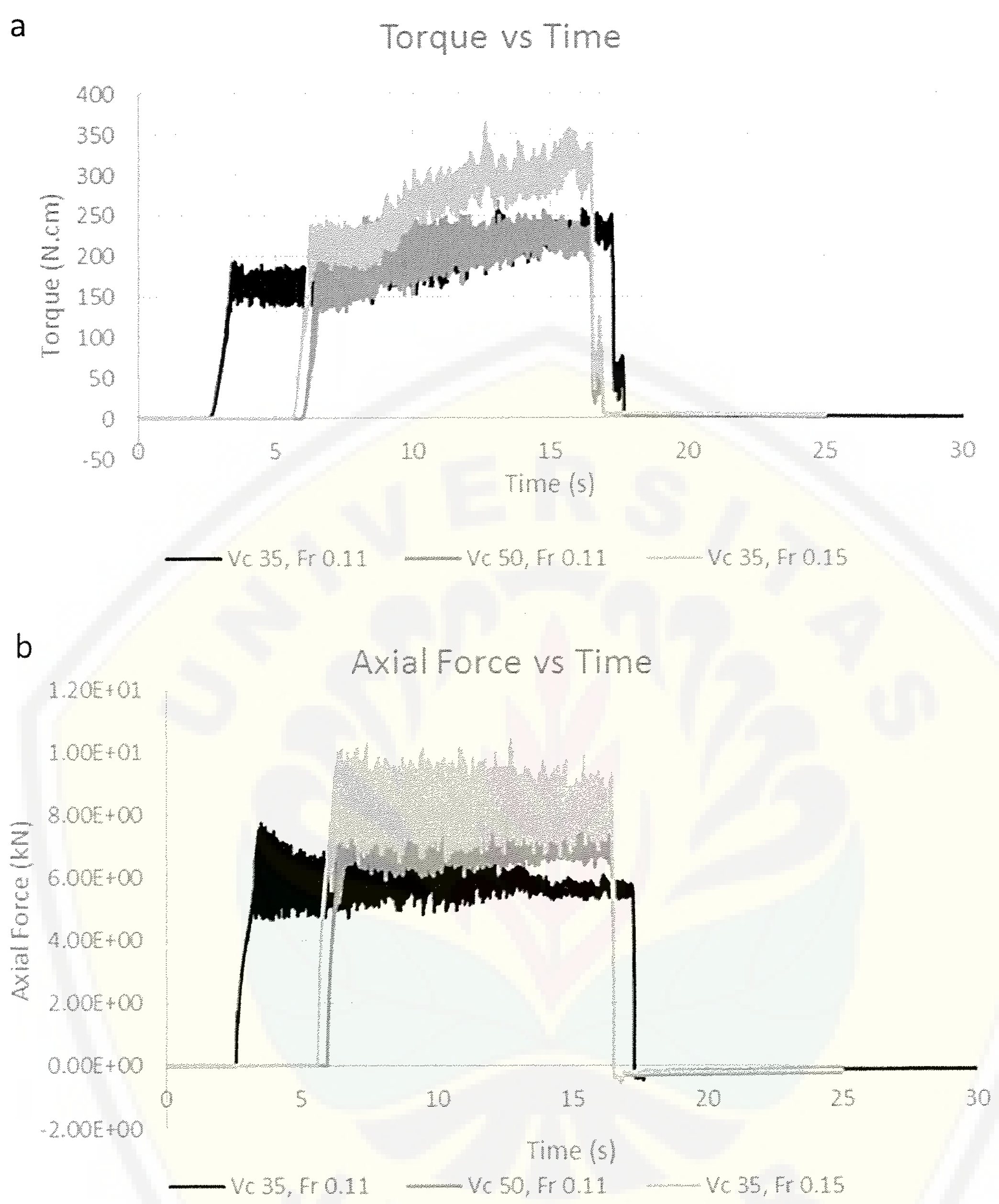

Fig 6. Torque (a) and Axial Force (b) as a function of time.

Conclusion

In this study we come to conclusion that keeping the Ti-6246 the as received condition (forged) and applying feed rate 0.15mm/rev will be the best for drilling of this alloy. This parameter results in segmented chips and high material removal rate.

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