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Survey and Study of Machinability for Titanium Alloy Ti-6Al-4V through Chip Formation in Milling Process

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Abstract
Most of the materials used in the industry of aero-engine components generally consist of titanium alloys. Advanced materials, because of their excellent combination of high specific strength, light weight and general corrosion resistance. In fact, chemical wear resistance of aero-engine alloy provides a serious challenge for cutting tool material during the machining process. The reduction in cutting temperature distributions leads to an increase in tool life and a decrease in wear rate. Hence, the chip morphology and segmentation play a predominant role in determining machinability and tool wear during the machining process. The result of low thermal conductivity and diffusivity of this alloy is in the concentration of high temperatures at the tool-work-piece and tool-chip interface. Consequently, the chip morphology is very important in the study of machinability of metals as well as the study of cutting tool wear. Otherwise, the result will be accelerating tool wear, increasing manufacturing cost and time consuming.

Keywords
Mach inability, Titanium alloy (Ti-6Al-4V), Chip formation, Milling process.

1. Introduction

Titanium has been recognized as an element (Symbol Ti, atomic number 22, atomic weight 47.9). In fact, Titanium was known as importance as a unique lightweight, high-strength alloyed, structurally efficient metal for critical, high-performance aircraft, such as jet engine and airframe components [1, 2].Titanium alloy is applied extensively in aero-engines and especially in gas turbines .

It was found in the navy ship components, armor plate applications, anodes, automotive components, food and pharmaceutical processing, recreation and sports equipment. Besides that, it is also observed in the medical implants and surgical devices.

Therefore, it can sum up the characteristics of titanium alloy as follows [2,3,4,5, 6, 7]:

1) Exceptional erosion and erosion corrosion resistance
2) High fatigue strength in air and chloride environments
3) Low modulus of elasticity
4) Low thermal expansion coefficient
5) High melting point
6) Essentially nonmagnetic
7) High intrinsic shock resistance

8) High ballistic resistance-to-density ratio
9) Very short radioactive half-life
10) Excellent cryogenic properties

1.1 Metal

Titanium alloy is work hardening material. The high pressure loads and high stress at the cutting edge when reducing the contact surface between the work-piece material and cutting tool are considered as the problem faced during the machining process of titanium alloy[8]. Therefore, careful machining practices are inevitable as shown in Figure 1.

Figure1. Titanium alloy is work hardening material

1.2 Machining Parameters

The chip morphology is considered as one of machin ability parameters of metals as well as an indicator cutting tool wear. The chip morphology and segmentation have been playing a dominant role to determine the tool wear and machinability during the machining process [9].

There are two theories about saw-tooth chip formation predominate. Firstly the thermoplastic instability. Secondly the initiation and propagation of cracks inside the primary shear zone of the work-piece material. Many researchers such as Shaw et al. [10], Komanduri and Turkovich [11] explain that the titanium chip morphology is due to a plastic instability during the cutting process resulting from the competition between the thermal softening and work hardening in the primary shear zone.

In order to ensure has a good tool life and avoid early tool failure as shown in Fig. 2. Ceramics have been recommended to machine materials such as Titanium alloy due to the hardness of Titanium alloy [12]. Ceramic such as Silicon Nitride, Cubic Boron Nitride, and hot-pressed Aluminum Oxides can able an increase in cutting speeds up to 300 m min-1, However, ceramics are low conductive materials [13], and the heat generated during the machining of Titanium alloy transfers very slowly through them. The accumulation of cutting heat on the cutting edges of ceramic tools causes many problems and sometime leads to early tool failure [14, 15]. Besides that, thermal shock is also considered another obstacle that restricts the machining of Titanium alloy.

The straight tungsten carbide (WC-Co) grade still remains the first choice in face milling for referring to (Ezugwu and Machado 1988) and turning (Hartung and Kramer 1982) of titanium alloy. However, the machining of titanium alloy is a major production problem, because of the frequent lower cutting speed. For instance, turning operations, the cutting speeds are limited to about 45 m /min when using straight-grade cemented carbide (WC-Co) (Jawaid et al. 1999).Otherwise, face milling operation, when coated carbide tools (PVD and CVD) were used. So, the best cutting condition with respect to the highest tool life of 30 min was achieved at cutting speed of 55m/min (Dearnly and Grearson 1986) [16].

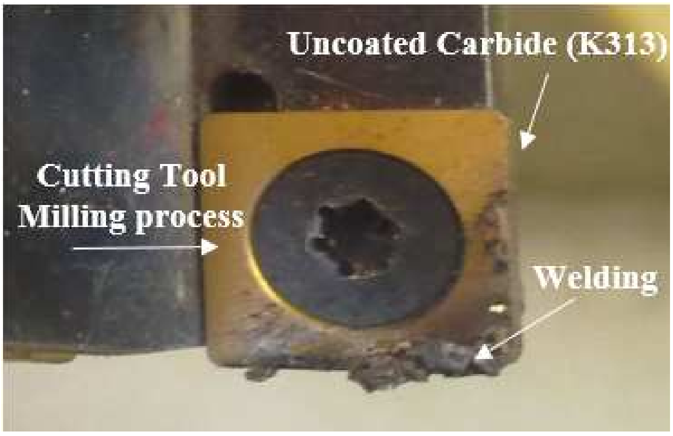

Figure2. Cutting tool during the milling process

2. Mach inability

The primary challenge when machining titanium alloy is overcoming the short tool life that typically prevents people from using high cutting speeds. The poor machinability of titanium alloy is because of their properties [17, 18].

The milling of titanium alloy is a more difficult operation than that of turning process. The cutter mills only part of each revolution and chips tend to adhere to the teeth during that portion of the revolution that each tooth does not cut. On the next contact, when the chip is knocked off, the tooth may be damaged. This problem can be alleviated to a great extent by employing climb milling, instead of conventional milling. In this type of milling, the cutter is in contact with the thinnest portion of the chip as it leaves the cut, minimizing chip “welding" [1] as shown in Figure 3.

Figure3. High thermal between cutting tool and work-piece surface leads welding

3. Titanium alloy (Ti-6Al-4V)

Titanium alloys are categorized based on the structure as alpha, alpha-beta, and beta alloys [2, 19].

Alpha Beta alloys are heat treatable and most are weld able. Typical properties include:

1) Strength levels are medium to high

2) High temperature creep strength is not a good as most alpha alloys
3) Cold forming may be limited but hot forming qualities are normally good
4) Many alloys can be super plastically formed

The most commonly used alpha beta alloy is Ti-6Al-4V, developed in many variations of the basic formulation for the widest possible choice of key properties. Titanium alloys such as Ti–6Al–4V offer high strength to weight ratio, high toughness, superb corrosion resistance, and biocompatibility and are increasingly used in aerospace and bio-medical applications. However, titanium alloys are difficult to machine due to their low thermal conductivity and diffusivity, high rigidity and low elasticity modulus and high chemical reactivity at elevated temperatures [20]. These alloys exhibits serrated and cyclical chip formation resulting in detrimental tool vibrations [21]. Titanium alloy machining performance can be increased by improving cutting tool materials and coatings [22, 23]. Cubic boron nitride (CBN) material offers outstanding properties such as high hardness and wear resistance. Even so, CBN material has the lower toughness and is unsuitable for forming inserts into complex shapes. Recently, CBN coatings have been explored by applying several deposition techniques. Among these, physical vapor deposition (PVD) has been preferred since thinner coatings can be deposited and sharp edges, and complex shapes can be easily coated at lower temperatures. On the other hand, coating applied affects the edge radius of the inserts and must be taking into consideration during tool performance analysis [23, 24].

The composition Ti- 6%Al- 4%V gives the commonest titanium alloy. Most of the other titanium alloys important in aerospace are essentially of the same type, although many have a greater level of α stabilizing element and some are heavily β stabilized [25].

4. Chip formation

4.1 Serrated chip formation

There are formed during the machining of semi-continuous material with zones of high and low shear strains. It normally occurs in metals where the strength decreases sharply with temperature. An example would be Titanium alloy [26].

4.2 Continuous chip

This type is usually formed while machining ductile material as shown in Fig. 4. It is creating at high cutting speed and/or high rakes angles. The chips deformation takes place along a narrow shear zone and the primary shear zone, which are caused by friction. The chips develop secondary shear zone at the tool-chip interface. The secondary zone becomes deeper as tool-chip friction increase. Although they generally produce good surface finish, but continuous chips formation should be avoided because it is disturbing the machining process. This problem can be overcome by the use of chip-breaker which is a device clamped to the top of the tool that encourages the chip to curl more tightly, hitting the work piece and breaking off [26].

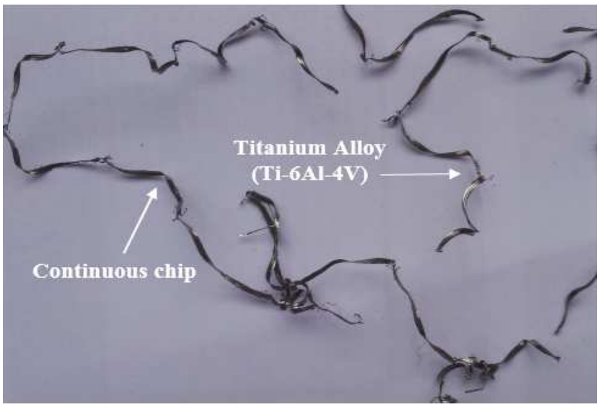

Figure4. Continuous chip formation during milling process

4.3 Discontinuous chip

This type is normally occurred during the machining of brittle work material such as glass and silicon. This type of chips also occurs when machining using cutting tools with small rake angles, coarse machining feeds (large depth of cut), low cutting speeds and lack of lubricant or cutting fluid as shown in Fig. 5. The factors for discontinuous chip formation are [27]:

1) Large depth of cut.
2) Low rakes angles.
3) Lack of an effective cutting fluid.
4) Low stiffness of the machine tool

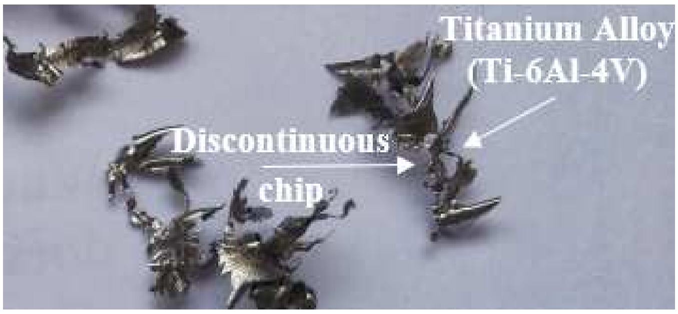

Figure5. Discontinuous chip formation during milling process

4.4 Continuous with Built-up Edge

Built-up edge (BUE) is basically the same as continuous chips. However, during the former chip formation, as the metal flows up the chip-tool zone, small particles of the metal begin to adhere or weld themselves to the edge of the cutting tool. There are many conditions for BUE formation [27]:

1) Mating metals must be mixable with each other
2) Metallic bonding.
3) High temperature.
4) Ductile materials and high stresses.
5) Velocity must be low.
6) Decreasing the depth of cut.
7) Increasing the rake angle.
8) Using a sharp cutting tool.

9) Using an effective cutting tool.

5. Conclusion

In conclusion, researchers seek on the application of titanium alloy such asTi-6Al-4V by using the special industries for instance the aerospace and gas turbine. Alpha beta alloyparticles made the alloys becomes stronger and more abrasive, thus more difficult to machine. Besides that, many titanium alloyis age hardenable. It is meaning that the hardness of the alloys increases dramatically upon heat treatment. The chip morphology and segmentation play a predominant role in determining machinability and tool wear during the machining process. Therefore, the machining parameter such as chip morphology is very important to study machinability of metals and cutting tool wear. It is led for reducing the cost of manufacturing in terms of prolongs the cutting tool life as well surface finish.

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