

Optimization of Cutting Parameter for Machining Ti-6Al-4V Titanium Alloy

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ABSTRACT – Titanium alloy Ti-6Al-4V, has been broadly used in industries, primarily medical manufacturing, and aerospace, due to their considerable mechanical properties. Aerospace structural components made of titanium alloy (Ti-6Al-4V) material, a difficult-to-machine material which results in massive cutting force, steep cutting temperature, and significant tool wear. In this research, carbide insert tool is used to cut a Ti-6Al-4V titanium block at constant depth of cut of 0.50 mm using the method of dry machining is investigated with the aim of estimating the effects of two manipulated cutting parameters, which are spindle speed (140 and 150 m/min), and feed rate (0.1 and 0.2). This was done to observe their effects on the tool wear of the insert. The objective of this study is to study the machinability performance of coated carbide insert tool under dry machining condition, and to optimize the cutting parameter to machine Ti-6Al-4V using dry machining method. It was found in this research that lowest valued parameter, Parameter 1 (140 m/min, 0.1 mm/rev) caused the most flank wear, and the roughest surface on the Ti-6Al-4V block. Lower speeds can possibly inflict higher shocking force, which leads to higher wear propagation.

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INTRODUCTION

Titanium alloys are materials made up of titanium and other chemical elements. Even at extreme temperatures, the tensile strength and toughness of such alloys are extremely high. They are lightweight and durable, have excellent corrosion resistance, and also can withstand high temperatures. That being said, due to the high cost of both raw materials and processing, they are only used for military purposes, spacecraft, aircraft, pharmaceuticals, jewellery, and highly stressed parts such as connecting rods in supercars, as well as some high-end sports gear and consumer electronics. The most common titanium alloy is Ti-6Al-4V, also known as Grade 5 titanium, not to be confused with Ti-6Al-4V-ELI (Grade 23). It is made up of 6% aluminium, 4% vanadium, 0.25% (maximum) iron, 0.2% (maximum) oxygen, and the rest is pure titanium [1]. While it has the same thermal properties and the same stiffness as commercially pure titanium (grades 1-4), it is substantially stronger [2]. Lately, dry machining has gained popularity as it contributes to a cleaner environment and lowers manufacturing costs [3,4]. The lack of cutting fluids, on the other hand, results in increased mechanical and thermal loads at the cutting tool-workpiece interface. This results in the deterioration of tool wear and alteration of surface integrity, such as surface roughness, microstructure, grain size and shape, residual stress, and hardness [5].

Generally, a liquid coolant, also known as cutting fluid, has been used to remove the heat generated during the machining process. Cutting fluids cool the tool and workpiece by dissipating some of the heat generated during the machining process [6]. However, after a certain period of use, cutting fluid formulations that are susceptible to the growth of bacteria and fungi, as well as contamination by metal particles and ions, must be discarded. Huge manufacturing industries must dispose of thousands of liters of waste cutting fluids, which, if not treated appropriately before disposal, can pose harmful environmental damage and contamination [7,8,9].

Aerospace structural components made of titanium alloy (Ti-6Al-4V) material require milling operations to achieve the required tolerance limits. Selection of optimal machining parameters to attain the desired surface quality and better tool life are the most critical task during the finish machining of titanium alloys under dry machining conditions. Usually, dry machining generates a very high cutting temperature and cutting force (feed force and tangential force) which affects the surface quality and tool life [10]. Titanium alloy Ti-6Al-4V is a difficult-to-machine material. This results in massive cutting force, steep cutting temperature, and significant tool wear [11,12]. But this research focuses on pushing the limit of cutting parameters of Ti-6Al-4V, in terms of spindle speed and feed rate, using only a traditional milling machine.

This research aims to optimize the machining parameters to machine Ti-6Al-4V titanium alloy under dry machining conditions. The objectives of this study are to study the machinability performance of coated carbide under dry machining conditions and to optimize the cutting parameter to machine Ti-6Al-4V using the dry machining method.

RELATED WORK

Theory of Metal Cutting

Metal cutting is one of the industrial processes where metal parts undergo the removal of undesired material to achieve their desired shape. Metal removal processes include abrasive processes; for instance, honing and grinding. In this process, small chips of the metal are produced because of the combination of cutting and mechanisms of friction. On the other hand, non-traditional machining processes include electrodischarge, ultrasonic, electrochemical, and laser machining. By such means of mechanical, thermal, electrical, or even chemical, the metal can be removed on a much smaller scale [13]. Due to some intrinsic properties of titanium and its alloys, its machinability is commonly known to be poor. Titanium is significantly reactive, at least chemically, and thus, during machining, it tends to weld to the cutting tool [14].

Dry Machining

Dry machining produced better presentation results but was found to be less abrasive than wet machining [15]. Dry machining is an interesting approach in machining method science these days. As a result, discharge products are considered with caution. These advantages stem from lower costs for fluid procurement, pumping and cutting fluids, as well as solvent discharge and fluid disposal. It also aids in the development of heat transfer during the machining process. Dry machining has the disadvantage of causing tools to wear out speedier due to high thermal loads and friction between the instrument and the workpiece materials.

Carbide Tool

The purpose of the surface of the carbide being hardened is to extend the lifespan of the tool. The prime elements on the carbide coating of the tool are titanium carbide (TiC), titanium nitride (TiN), titanium nitride/ aluminium nitride (TiN/ AlN), hafnium nitride (HfN), chromium carbide (CrC), diamond-like 12 carbon (DLC), and diamond. It was also established that tools that are carbide coated suffer high levels of wear as well as delamination [16]. Cemented carbide stands as the most effective tool to aid in the process of machining, fabrication, as well as carving.

METHODOLOGY

Flow Process of Work

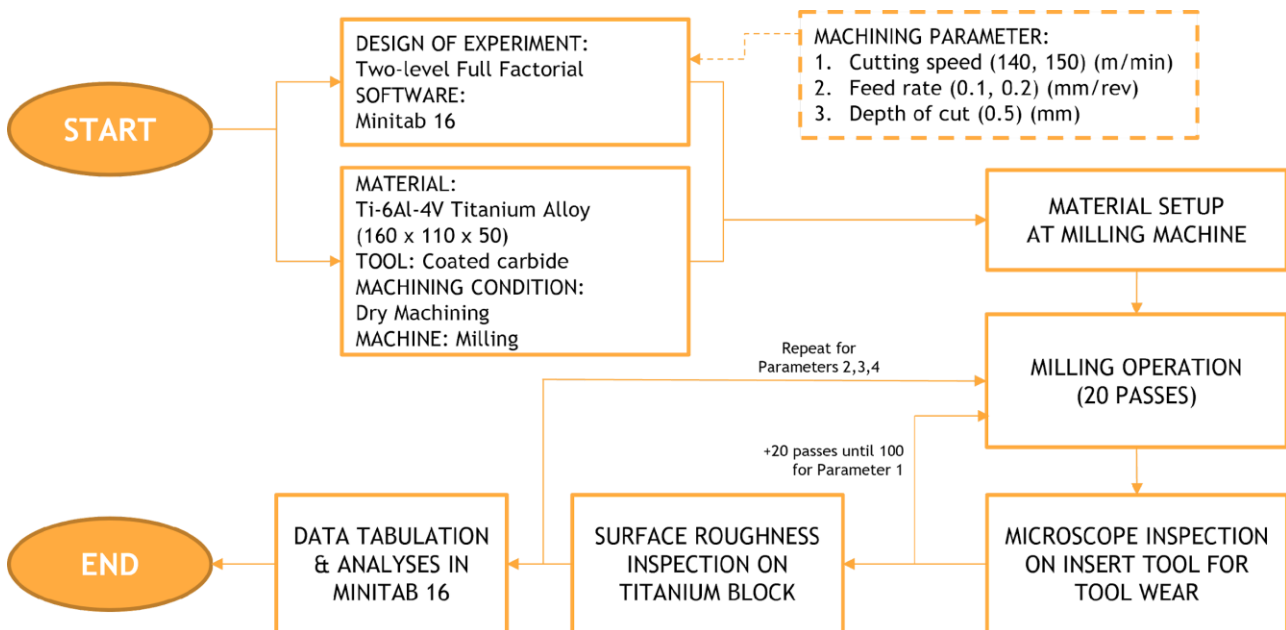


Figure 1. Flowchart of Experiment

Titanium Block

Milling tests are to be conducted on a cuboid titanium block of 160 mm long, 110 mm wide, with 50 mm thickness. The dimension and annotations of the parameters on the titanium alloy block are as shown in Figure 2.

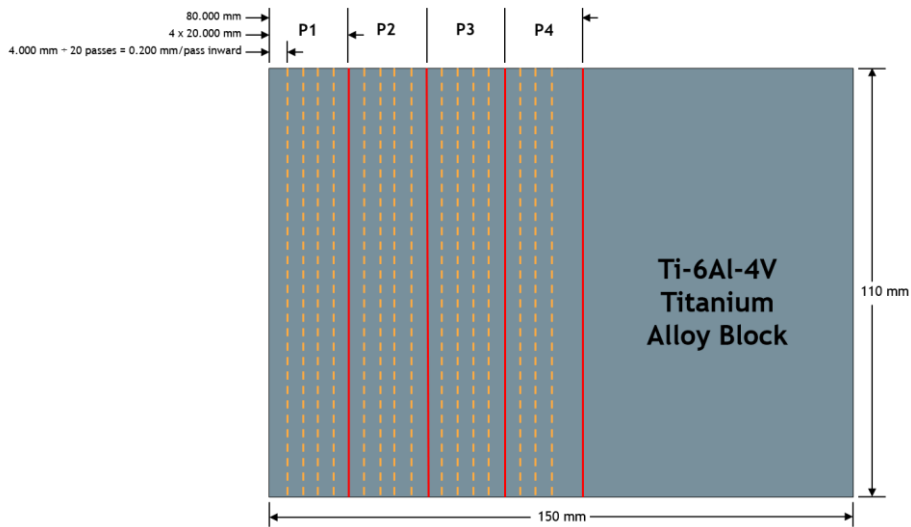


Figure 2. Ti-6Al-4V titanium alloy block dimension and parameters annotations

RESULTS AND DISCUSSION

This section displays the result of the experiments that have been carried out according to the parameters that have been studied. The manipulated variables are V_c (140 and 150 m/min), and f (0.1 and 0.2 mm/rev). On the other hand, the depth of the cut was maintained constant at 0.500 mm, and the travel distance for every pass is 0.200 mm.

Flank Wear

The type of wear that was observed using the 5x objective on the metallurgical microscope in this research is the flank wear (mm) of the tool insert, via the brightfield observation type. An example of the flank wear measurement is shown in Figure 3.

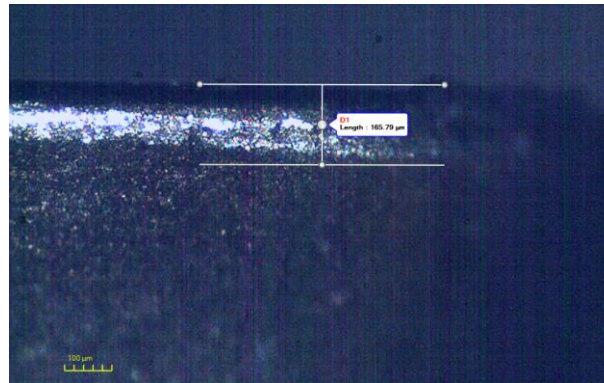


Figure 3. Example of flank wear after 60 passes from Parameter 3. Measurement: $165.79 \mu\text{m} = 0.166 \text{ mm}$

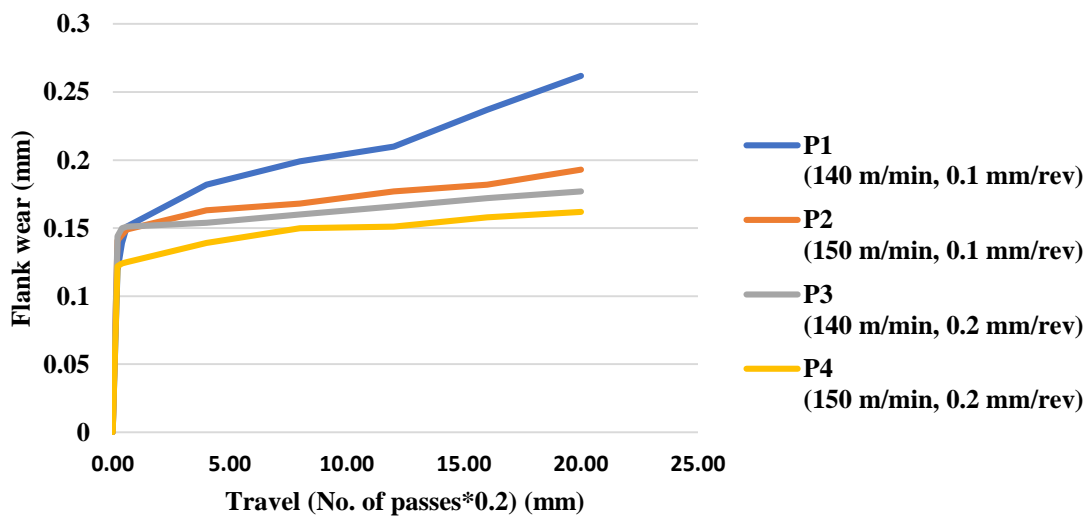


Figure 4. Graph of Flank wear (mm) against Travel (Number of passes \times 0.2 mm) (mm)

It can be seen from the graph in Figure 4 that Parameter 1 (blue) has the highest value of tool wear among the four parameters, followed by Parameter 2 (red), Parameter 3 (green), and finally Parameter 4 (purple).

Surface Roughness

Surface roughness, represented by R_a , the test was carried out on the Ti-6Al-4V titanium alloy after it undergo dry machining which involved 100 passes and microscopic inspection of the tool insert every 20 passes.

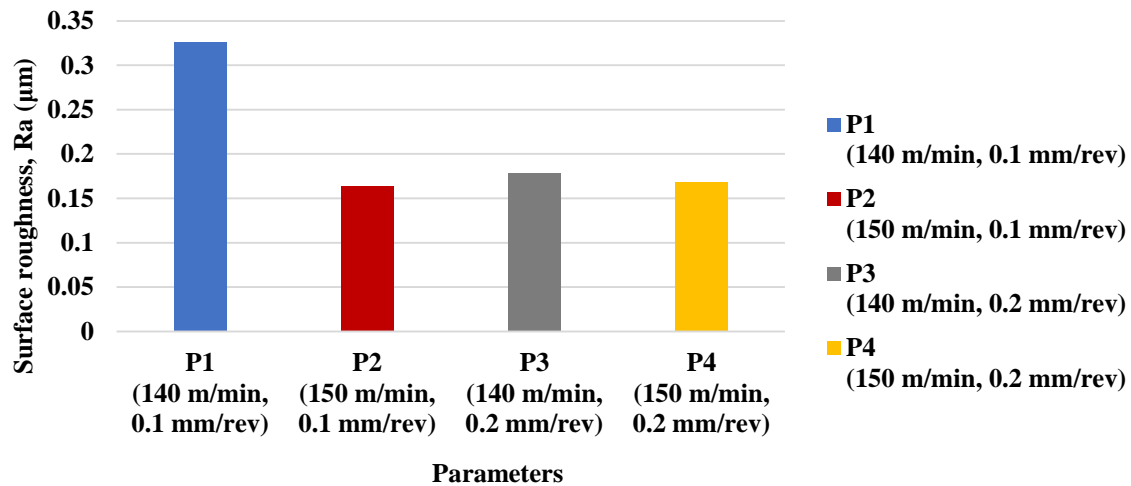


Figure 5. Graph of Surface roughness, R_a (μm) for each cutting parameter

As can be observed from Figure 5 shown, Parameter 1 ($V_c = 140$ m/min, $f = 0.1$ mm/rev) produce the roughest surface on the titanium block. Parameters 2, 3, and 4 are at about the same level of R_a . As the depth of cut and feed rate are fixed, increasing the cutting speed will decrease the surface roughness [17]. On the other hand, as the depth of cut and cutting speed is fixed, increasing the feed rate will decrease the surface roughness obtained from the machining process. However, as P2 and P4 are compared, as the depth of cut and cutting are fixed, increasing the feed rate will not show any surface roughness difference, only a slight increment. It can be understood that the force is distributed evenly along with the contact between tool and workpiece, generating constant chip thickness, thus, surface roughness is not affected.

CONCLUSION

Tool wear refers to the gradual deterioration of cutting tools as a result of continuous usage. Tipped tools, tool bits, and drill bits that have been used with machine tools are all susceptible. The type of wear investigated in this study was flank wear, which occurs when the tool section in contact with the finished part erodes. The flank wear analysis revealed that Parameter 1 (140 m/min, 0.1 mm/rev) contributes the most to the wearing of the tool insert after 100 passes. Within the limitation of the difference between two values of spindle speed (140 and 150 m/min), lower speeds can inflict higher shocking force, which leads to higher wear propagation. On the other hand, though, Parameter 1 also gave out the most surface roughness. Surface irregularities are caused by workpiece material breakup during metal cutting, and discrepancies in the machine tool itself, such as feed paths that are not straight.

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