Chapter 12

Tool Wear and Surface Integrity Analysis of Machined Heat Treated Selective Laser Melted Ti-6Al-4V

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ABSTRACT

In this study, the tool wear and surface integrity during machining of wrought and Selective Laser Melted (SLM) titanium alloy (after heat treatment) are studied. Face turning trails were carried out on both the materials at different cutting speeds of 60,120 and 180 m/min. Cutting tools and machined specimens collected are characterized using scanning electron microscope, surface profiler and optical microscope to study the tool wear, machined surface quality and machining induced microstructural alterations. It was found that high cutting speeds lead to rapid tool wear during machining of SLM Ti-6Al-4V materials. Rapid tool wear observed at high cutting speeds in machining SLM Ti-6Al-4V resulted in damaging the surface integrity by 1) Deposition of chip/work material on the machined surface giving rise to higher surface roughness and 2) Increasing the depth of plastic deformation on the machined sub surface.

1. INTRODUCTION

Additive manufacturing(AM) is gaining huge attention in the manufacturing industries due to its high productivity and freedom of design capabilities (Gibson, Rosen, & Stucker, 2010). Currently, titanium components are preferred to be manufactured using AM technology rather the conventional technology

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which is energy intensive and time consuming. However, AM components often requiring post machining operations for superior surface finish and improved product quality (Horn & Harrysson, 2012).

Speaking about the titanium alloys, it is regarded as one of the "difficult to machine" materials due to its several inherent properties. Low thermal conductivity and high chemical reactivity of this material often leads to high tool wear due to concentration of the heat in the deformation zones during machining. In addition, the high strength at elevated temperature, low modulus of elasticity and shear instability in chip formation further impairs its machinability (Davim, 2014). As titanium alloys are used for components requiring highest reliability, it is necessary to maintain the surface integrity. The surface integrity of the titanium alloys is easily affected because of the poor machinability of the titanium alloys. Heat generated during titanium machining acts as a major source of damage and results in surface and sub-surface alterations including plastic deformation, micro cracking, phase transformations and residual stress effects (Che-Haron, 2001; Che-Haron & Jawaid, 2005; Ginting & Nouari, 2009; Mantle & Aspinwall, 2001; Che-Haron, 2001; Mantle & Aspinwall, 2001). Having said these, there are not many literatures available, that discusses the machining of AM titanium components. However, some few literatures discuss the machinability and tool wear during machining of additive manufactured titanium alloys. A. a. b. u. i. Bordin, Bruschi, Ghiotti, Bucciotti, and Facchini (2014) (Bordin et al., 2014) compared the machinability characteristics of wrought and Electron Beam Melted (EBM) titanium alloys. They also studied and analyzed the tool wear in cryogenic machining of EBM Ti-6Al-4V (Bordin, Bruschi, Ghiotti, & Bariani, 2015). From their studies, it was found that adhesion was the main wear in semi finish turning of EBM Ti-6Al-4V using carbide tool.

This research has been undertaken by realizing the importance of tool wear, surface integrity and the lack of works related to effect of machining on surface integrity of additive manufactured titanium alloys. Face turning trails were carried out at different cutting speeds for specific number of machining passes and the tool wear, machined surface and machined sub-surface are analysed to study to the effect of machining on selective laser melted (SLM) Ti-6Al-4V.

2. EXPERIMENTAL PROCEDURE

Hollow cylindrical samples of wrought and additive manufactured Ti-6Al-4V were used as work materials in this research. A hollow cylindrical specimen of height 60 mm, outer diameter 50 mm and inner diameter 25 mm was fabricated using a SLM 125 metal additive manufacturing machine (as shown in Figure 1). Important process parameters such as meander build style, 0.2 mm laser focus diameter and 425 mm/s laser scan speed were used in fabricating this hollow cylinder. The sample was then heat treated in a vacuum furnace to 730^{o}C and cooled slowly to 1) relieve the residual stresses and 2) soften and improve the materials ductility. Face turning machining operation was then performed on the material in a Nakumara tome CNC machine. TiAlN+TiN PVD coated rhombic carbide tools with positive rake angle and a tool nose radius of 0.8 mm was used for the machining tests. The designation of the cutting tool used is DNMG 150608-TF.The material was machined at different cutting speeds of 60,120 and 180 m/min using a constant feed rate of 0.1 mm/rev and depth of cut of 0.5 mm respectively. The tool specimens and the machined surface were collected and preserved after specific number of machining passes to study the tool wear and surface integrity. The tool wear and surface characteristics was measured and characterized using optical and scanning electron microscope. The surface roughness was measured using Alicona Infinite Focus 3D optical surface profilometer.

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