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Influence of finish machining on the surface integrity of Ti6Al4V produced by Selective Laser Melting

Samuel Milton[a,b,*], Antoine Morandeau[a], Florent Chalon[b], Rene Leroy[b]

[a]*Sandvik Tooling France - Division Coromant, Rue Henri Garih,37230 Fondettes, France*
[b]*Laboratoire Mécanique et Rhéologie (LMR) – Centre d'Etude et de Recherche sur les Outils Coupants (CEROC), University of Tours, 7, Avenue Marcel Dassault 37004 Tours , France*

* Corresponding author. Tel.: +33 (0)2 47 62 52 59; *E-mail address:* samuel.milton@sandvik.com

Abstract

Selective Laser Melting (SLM) is a direct manufacturing technique that allows objects to be built by selectively melting successive layers of metal powder. There is an additional finish machining step that is required to achieve close tolerances and control the surface integrity of the final surface. This paper mainly deals with studying the influence of the finish machining step on the surface integrity of Ti6Al4V parts produced by SLM technique. Three different building directions are considered. Changes in roughness, hardness of the machined surface and sub-surfaces are evaluated and compared with those of conventional hot rolled alloy. Cutting forces were also measured during milling process to study the influence of machining the SLM samples on the components of force in the three orthogonal directions. It is observed that the SLM samples show higher surface hardening behavior after machining and exert 22% greater axial force during the machining when compared to the conventional alloy.

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Keywords: Selective laser melting; Surface-integrity; Milling; Ti6Al4V

1. Introduction

Titanium alloys have gained a lot of attention in the recent years with additive manufacturing (AM) technologies. Ti6Al4V being the most commonly used titanium alloy with its wide spread applications across aerospace, aeronautical, medical and other industries is now being developed to fit into mainstream through AM. Mainly because of its superior properties like high strength to weigh ratio, corrosion resistance and good performance at elevated temperatures [1], it is now being used to make functional parts with AM technologies. Selective Laser Melting (SLM) is one of the AM techniques adapted to make metallic parts in which parts can be created directly by selectively melting several layers of metal powder [2]. However in the view of surface quality and the manufacturing tolerances' required, these parts require finish machining (a post processing step) to produce the final functional surface. The surface integrity characteristics of the machined surface and the subsurface control the functional performance of a component to a large extent [3]. Some studies have been done on the conventional titanium alloys [4, 5, 6, 7] to understand machining induced surface integrity, whereas very little knowledge is available for parts produced by AM techniques.

In order to understand the influence of this post processing machining step on SLM parts, in this study, a face milling operation was performed and the final surface roughness and the sub-surface hardness was compared with the conventional hot rolled Ti6Al4V alloy. The cutting forces generated during the milling process were also compared. The SLM parts are built in three orthogonal orientations as it would help in understanding the influence of direction of the build process on this post processing step (Fig 1).

2. Materials and methods

The conventional sample which was used as a reference in this study was manufactured by a hot rolled process and then annealed at 750°C. .It was an α-β titanium alloy provided by TIMET.

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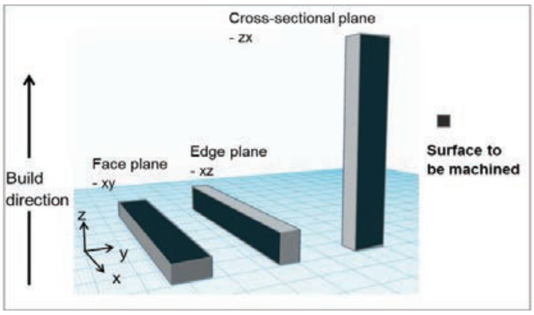

Fig. 1. SLM samples built in three different orientations.

The SLM samples tested here were built using MLab Cusing machine from CONCEPT LASER, with 100W ytterbium (Yb) fiber laser. Ti6Al4V powder according to ASTM F136-02a (ELI Grade 23) was used as the initial powder material to make the samples. The chemical composition of the conventional and SLM samples are compared in the Table 1. Optimized process parameters used for making the SLM parts are listed in Table2. Lower laser scan velocity of 400 mm/sec was used for the contours in order to have a better surface finish of the final part [8]. Simple straight line scans were used for melting each layer. The samples were built in a protective argon atmosphere on secondary support structures that help us to detach the samples from the build platform after the part is completed. The geometry of all the samples was a cuboid with dimensions of 70mm x 10mm x 6mm.

Table 1. Chemical composition of Conventional and SLM parts

Element	SLM parts Vol(%)	Conventional Vol(%)
Ti	88	89.14
Al	6.5	6.47
V	4.5	4.05
Fe	0.25	0.15
C	0.8	0.01
O	0.13	0.17
N	0.05	0.0045
H	0.012	0.0035

The samples were built with three different orientations as described in ASTM F2921, along the face plane - XY, edge plane - XZ and cross-sectional (vertical) plane ZX (Fig 1).

Once the samples were built they were removed from the build plate without any post processing heat treatment so as to study the samples in as-built condition.

As expected, the samples built on the face plane and edge plane showed some degree of deformation while the sample built on the cross-sectional plane had no observable deformation. This is attributed to excessive thermal stress produced by rapid melting and cooling during the SLM process. Though the supports help in conducting the heat away from the sample, the orientation of the sample determines the final part accuracy and quality [9].

The as-built samples were cut along the cross-section to do a micro-structure analysis which will allow us to know the orientation and the size of the grains and to compare it with the conventional hot rolled alloy. The cut samples were mechanically polished up to 1µm finish with diamond suspension and then etched with the Kroll's reagent to observe the micro-structure.

Table 2. Process parameters used for building SLM parts.

Process parameter	
Laser power (W)	95
Scanning speed (mm/sec)	900
Layer thickness (µm)	30
Diameter of laser (µm)	40

Only the side with dimensions of Length L= 70mm and width W= 10m (Fig 1) was to be machined in each of these samples. Surface roughness of the samples was measured on this side in as built condition which is shown in Table 3. Optical profilometer based on interferometry which uses white light scanning for non-contact measurements was used to measure the average roughness, Ra of the samples. Ra values of the surfaces was also measured after face milling the samples.

Table 3. As-built roughness of SLM samples on the surface to be machined

Sample orientation	Ra (µm)
Face plane	12.75
Edge plane	14.02
Cross-sectional plane	8.24

Face milling was done on the SLM samples and the conventional alloy with cutting parameters recommended for finishing operations with radial depth of cut a_p = 0.5 mm, feed rate f_z= 0.08 mm/tooth and cutting speed V_c= 55 m/min. Radial engagement of the tool was the sample width and the mill was in a central position. Coromill R300 milling cutter with AlTiN - PVD coated carbide insert grade from Sandvik Coromant was used. Dedicated round inserts were used for machining each sample to avoid the influence of the edge radius, ER wear on the force measurements. Milling was done under dry condition. The samples were mounted on a specially designed fixture that could be mounted on a KISTLER dynamometer table (type 9255B) which was used to measure the forces in the three orthogonal directions Fx, Fy and Fz. These forces correspond to the force in feed direction, cutting direction and the axial direction respectively during the face milling process (Fig 2).

To measure the machined surface hardness and hardness in the subsurface, series of indentations were performed using Nano indenter equipment from Micro Materials, UK. Berkovich indenter tip and a load of 150mN were used to make the indentations.

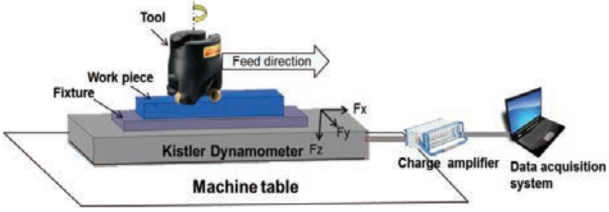

Fig. 2. Cutting force measurement setup.