TITANIUM (TI-6AL-4V) ALLOYS STRUCTURE AND ITS PROPERTIES

By Name

Course

Instructor

Institution

Location

Date

Introduction

This project is about the various aspects of the parts of Titanium microstructure which are constructed using varied manufacturing parameter of additive metals. Among the unique properties of titanium alloy include light weight, high strength, high resistance to corrosion as well as high Young's modulus. These properties make titanium be a good ingredient in aeroscopes applications and the involved ranges. The development of titanium, alloys has been motivated by the need for affordability and higher structural efficiency in the aircraft technology. Titanium alloys are found to be excellent motivators that enhance improvements in this technology (Bartolo 2015, p. 454).

Titanium finds its applications in such areas as biomedical, aeroscope as well as chemical industries. This is due to its admirable mechanical properties, low density besides the ability to withstand both high temperatures i.e. temperatures above 773K and sub-ambient. Abrasive wear and oxidation at high temperature are some of the properties that limit the applications of titanium and its alloys. The mainly studied manufacturing process involving titanium and its alloys include scanning electron microscope, electron beam melting, 3-d printing, selective laser melting and laser cutting among other applications. In these applications, a study the change in the way of manufacture of alloys or metals is done. The latest developed metal AM technology is powder-bed fusion which has created opportunities for the manufacture of complex components of metal with excellent dimensional accuracy controls and high resolutions (Welsch 2013, p. 369). From this technology, it was determined that titanium ingots are about fifty times steel and ten times aluminum as far as cost is concerned. The cost of using titanium was also found to be increased as a result of the complicated manufacturing process.

The cost barrier forms one of the greatest concerns of using titanium. Institutions and industries across the globe have converged to get a better approach in handling this menace. The cost issues are addressed at the extraction, synthesis and process stages of titanium. One of such approaches is using powder metallurgy in the solid state as well as taking advantage of the cost-effectiveness of processing in the form of powder metallurgy. From this approach, the costs of processing titanium powder have recorded significant drops thereby reducing the cost of feedstock material. This is a cheaper cost compared with processing through the Kroll process. A disadvantage associated with this production technology is its ability to produce components which are large enough to inject a transport cost into the industry. The new technology also possesses the preferred chemical homogeneity, microstructure, and high density.

In case titanium and its alloys find their application in the automotive industry, they would be used in varying sizes ranging from millimeters to a few meters in varied forms and shapes. Still, the metallic coatings or bulk forms produced by the thermal processes are characterized by high levels of oxidation, porosity as well as high thermal residual stresses (Joshi 2011, p. 457). These properties may have an effect on the chemical properties of the material as they would degrade them resulting into ineffective service life of aeroscope components repaired with them. This study aims at:

- Developing a physically based strength model which incorporates microstructure and composition
- Developing a model used in the prediction of a microstructure using thermal history and starting local composition
- Developing stochastic models to explain the reason for variations in natural probability as exhibited by each of the materials

- Developing a process model to help in the prediction of the local thermal histories as well as composition of materials

One of the most important characteristics of titanium alloys is the tailoring microstructural features ability to obtain a range of combinations of properties. This property is achieved through that treatment (Dunbar 2016, p. 230). Ti-64 is heat treatment material used in this process. Through the properly established heat treatment, such objectives as increasing strength, relieving residual stress during the fabrication process, production of optimum combinations for ductility-machinability as well as structural stability can be achieved. Still, optimization of such special properties as creep strength, fatigue strength, and fracture toughness can as well be achieved through well-established heat treatment.

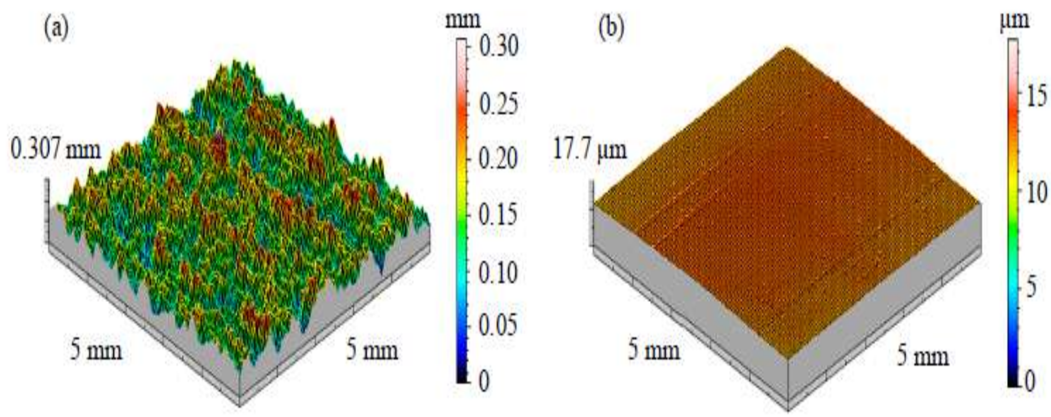
It should not, however, be forgotten that titanium and its alloys have such technicalities as wear properties which must be considered in some categorical applications under friction and wear conditions. An example is Ti-64 which is very poor in resting wear under dry sliding conditions due to the low protection on the surface exerted by tribo-oxides formed on the surface. From this study, a designer will be equipped with the skills that he can use to study the properties of titanium under varying parameters as well as understand the influence of the variations in the performance of titanium. From this approach, the designer will be able to design and maximize the visible approaches to manufacturing (Donachie 2010, p. 457).

Scope

This task aims at examining the impact of the processing parameters on the mechanical properties of models constructed by SLM using grade 1 pure titanium powder. To achieve this, a pulse Nd: YAG laser of 50 W maximum average power and 3 kW maximum peak power was used in the processing of the titanium powder (Kutz 2012, p. 379). Measurements including the density, torsional fatigue strength, hardness and Charpy impact energy are taken. Microstructure analysis is done using electronic and optical microscopes. It is observed that rapid prototyping as a direct method of fabrication of components of metal works well for a single lot or low volume production and small sized parts of complicated geometry. Fabrication of implants and prostheses are considered to be good candidates while titanium and its alloys are considered to be excellent materials for implants due to their biocompatibility besides the high weight to strength ratio.

A single powder component is melted and solidified by scanning of a CO2 or a Nd: YAG laser onto a powder bed during selective laser melting. This process is different from SLS in which combination of different metal powders of both low and high melting points and a polymer is used to encapsulate metal powder. Balling phenomenon occurs resulting in porosity in direct fabrication when a single powder metal component. The porosity achieved in this process has a negative influence on the mechanical properties and accuracy of the final product (Laboratory 2016, p. 243).

This raises the need for a second phase that allows for full densification. In this phase, titanium-based materials are once again deemed as the best metallic materials for use in different applications. This is due to their resistance to corrosion, good mechanical properties and as well as high biocompatibility. Powder-based fusion is the technology adopted in this process as it enhances good dimensional accuracy control design and manufacture of complex shapes of Ti parts with good qualities which are highly demanded in different applications. Selective laser melting can be used in producing large volumes of structural parts without geometric constraints. The paper aim at evaluating the work done on the importance of titanium materials, SLM manufacturing technology as well as SLM manufacturing of titanium materials which are used in different areas of applications. The resulting bulk parts include Ti-24, Ti-6Al-4V, Ti-TiC, Ti-TiB among other parts as well as porous structures produced in the SLM production process (Mishra 2010, p. 611). From this review, it is deducible that SLM produced titanium materials meet the mechanical and biocompatibility standards hence can be considered as candidates to be used in varied application areas.



Through the SLM process, the possibilities offered by intrinsic heat treatment induced by the scanning laser are explored. There is a widespread use of additive manufacturing technologies to produce functional or lightweight structures, for example, Ti6Al4V is a vital component of this manufacturing process. Parts are manufactured in a bid to characterize the mechanical properties of open porous structures as well as to generate scaffolds whose properties are aligned to the intended applications.

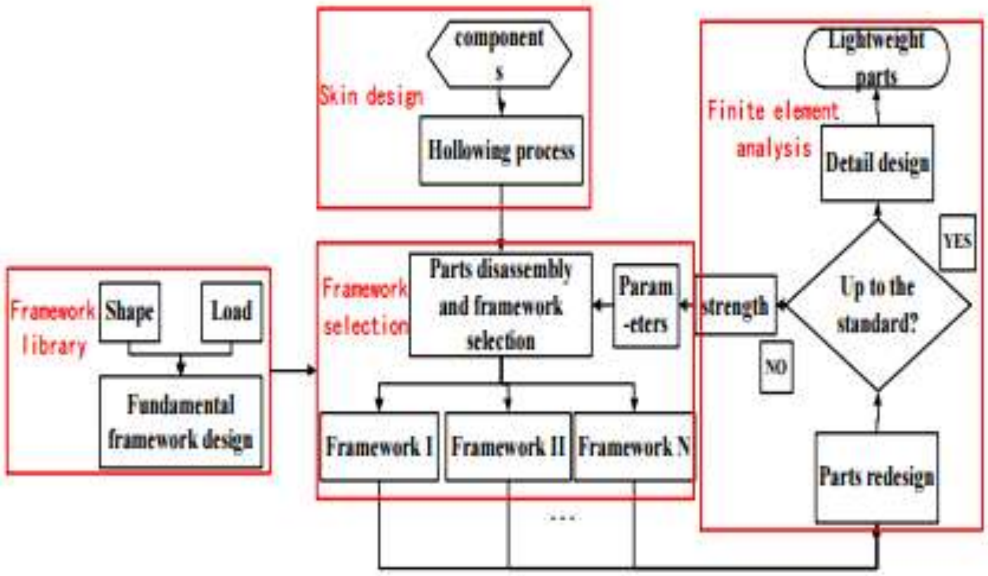
Table I. Descriptions of Typical Heat Treatments Used for Ti-64

Heat Treatment	Code	Process	Microstructure	Purpose
Mill anneal	MA	735 °C/2 h/AC*	incompletely recrystallized α with a small volume fraction of β particles	general purpose treatment given to all mill products; good overall property combinations.
Duplex anneal	DA	940 °C/10 min/AC plus 675 °C/4 h/AC	primary α plus Widmanstätten α-β colonies	to improve damage tolerance (maximized fracture toughness and minimized fatigue crack growth rate)
Solution treat plus age	STA	940 °C/10 min/WQ** plus 525 °C/4 h/AC	primary α plus tempered α′ (martensite) or α	highest strength condition but less ductility, fracture toughness, and stress corrosion resistance than annealed
Beta anneal	BA	1035 °C/30 min/AC plus 730 °C/2 h/AC	Widmanstätten α-β colonies	to maximize damage tolerance; slight reduction in ductility and significant debit in fatigue life
High-beta anneal	HBA	1200 °C/30 min/AC plus 730 °C/2 h/AC	coarse Widmanstätten α-β colonies	nonstandard treatment for Ti-64; higher damage tolerance

* AC = air cool.
** WQ = water quench.

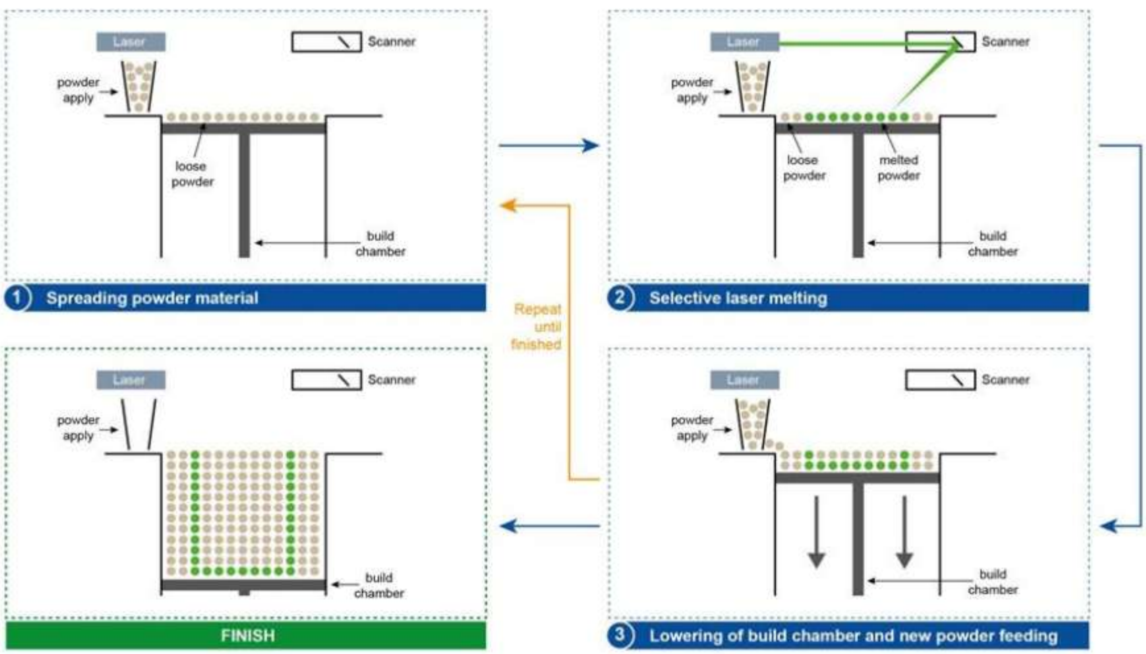
Multifarious properties of titanium and its alloys manufactured from additive manufacturing processes using Ti6Al4V has enabled it to be widely used in the medical technology (Joshi 2011, p. 266). The success and stability of the applications of mechanically optimized structures are dependent on their mechanical properties. Such applications include in biomedical fields e.g. being used as bone substitutes. Selective laser melting seems to be likely a successful additive manufacturing technique for titanium and its alloys.

From this process, metallic components with uniform shapes can be produced with cost savings and high efficiency of resources. Due to the formation of brittle martensitic microstructures during selective laser melting, the component of Ti-6Al-4V is usually hindered (Bartolo 2015, p. 398). To divert this scenario, intrinsic heat treatment is adopted during the process of melting the alloy using a scanning strategy. The scanning strategy combines the porosity-optimized processing with a tight hatch distance. There are expected tremendous changes which are expected in the manufacturing industry as a result of the invented additive manufacturing methods including selective laser melting. Selective laser melting as an additive manufacturing technique allows the manufacturing of net-shade metallic components (Zardiackas 2009, p. 198). The ability to produce very complex geometries is a leading strength of selective laser melting.



Selective laser manufacturing is an example of this method of manufacturing. In this method, it is possible to generate complex components directly from powder metal on a CAD files base. The method is mostly used in the manufacturing of tools to be used in die casting and injection molding. From this method, it is also possible to generate filigree structures for human and dental implants. The applications extend to the paper industry where it is applied in rapid tooling, rapid prototyping as well as rapid manufacturing. About ten materials meet the qualification standards to be used as materials in the manufacturing process (Stucker 2014, p. 231).

These materials include titanium, aluminum, and nickel-based alloys. Others include high-quality steels. Additive manufacturing produces layers which are between 20 μm and 50 μm thick. Selective laser manufacturing process is dividing into three recurrent phases. In the first phase, the substrate plate is lower by one layer thickness while in the second phase a coater is used to apply a new layer on the substrate plate. In the third phase which is the final phase, scanning of the powder occurs by the use of a laser. The powder is fused at the scanned areas as result of the energy absorbed. The manufacturing procedure is repeated until the component Is fully manufactured as per the specifications (Ohji 2016, p. 201).



Additive manufacturing process can be summarized using a few points including:

- Conceptualization and computer-aided design (CAD)
- Conversion of the file to Stereolithography/ Additive Manufacturing file(AMF)
- Transfer to an AM machine and manipulation of the file

- Set up of the machine
- Removal and cleaning up
- Post processing
- Application (Additive Layer Manufacturing)

Powder Bed Fusion

In this method, layers are deposited which are then subsequently fused together by a source of energy thereby generating solid parts in a powder bed. The most commonly used methods in this technique include electron beam melting and selective laser sintering. Electron beam processes benefit from high energy from the source of heat and the flexibility which is capable of instantaneous movements with split beams. EBM builds are able to maintain a high temperature of the bed and create parts using a cast, low residual stress and low porosity microstructure (Myers 2016, p. 415).

EBM requires a conductive target material and vacuum chamber to manufacture thereby limiting their application. Selective laser sintering, on the other hand, is able to complete the manufacturing process of substances such as ceramics and polymers in a gaseous atmosphere. Even though PBF is a widely known technology, the availability od some open-source machines resulting from lapsing of major patents have led to the invention of non-engineering applications of this technology.

Materials Jetting

First used in the 1980s. Depended on heated waxy thermoplastics deposited by heads of ink printers hence lending themselves to investment casting and modeling manufacture. With recent developments and modifications, a focus has been on the deposition of acrylate photopolymers as liquid manometer droplets are formed and polymerization initiated by exposure to UV light (Joshi 2011, p. 237). This manufacturing technique works with massive machines as well as materials with multi-material capability by varying the composition of numerous photopolymers.

Efforts are in place to include non-photopolymers as part of the materials. Non-photopolymers under study include metals with low melting points and ceramic suspensions (Mani 2015, p. 256). The main challenge with the non-photopolymers is the formation of droplets and how to control deposition and solidification characteristics. Formation of droplets and heating incorporates fluid mechanics and hence an in-depth study on this is included in the process model for the process of materials jetting.

Binder Jetting

Abbreviated as BJ, these methods were developed in the 1990s at Massachusetts Institute of Technology with a powder bed that is more the same as the one used in the PBF process. The difference between this process and PBF is that an inkjet head is used to deposit a binder onto each layer in this process. This is constraining to the case of PBF in which a source of energy is used in fusing the materials together. The binder then forms agglomerates with the particles of powder and provides a bonding with the underneath layer. I this chapter, some of the commercially available materials are discussed at length and it is noted that most of the materials require post-processing in order to achieve the required strength (Sherby 2010, p. 589).

Post processing

More often than not, additive manufacturing is assumed to be a complete process that does not require post processing. Various types of support structures required for the maintenance and achievement of the needed complex geometric levels. Discussed in this part is the subsequent post-processing methods and considerations in design that would help in their removal upon completion of the manufacturing process (Mani 2015, p. 367). The surface finishing may also be needed depending on the application of the part. In case finishing is required, extra materials are supposed to be designed to be post-processed so as to ensure the specified and desired dimensions are maintained in the final product. The surface finishing should also be done in line with the required standards and specifications.

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