Microstructural and Mechanical Properties of Nano Structural Titanium Alloys Processed by Ball Milling

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Abstract— Titanium alloys are characterized by high specific strength, low density, high strength to weight ratio, low thermal conductivity and corrosion resistance are used successfully in various branches of industry, such as, aerospace, automotive, power and chemical machine-building, ship building, production of medical and sportive equipment etc. This paper presents a brief review on titanium alloys, giving especial attention to Ti- 6Al-4Nb. In order to better understand the relationship of processing, structure and mechanical properties of Ti– 6Al–4Nb alloy fabricated by elemental powder metallurgy (EPM), the effects of sintering parameters on the microstructure and mechanical properties like hardness of the Ti–6Al–4Nb alloy were investigated by SEM and Vickers hardness test. The best microstructure was obtained when blended powders with a nominal composition of Ti–6Al–4Nb (at %) was ball milled for 10 hours. The results also show that hardness remarkably increased when the alloy was sintered at 950ºC followed by furnace cooling.
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Index Terms—Ti-6Al-4Nb,Powder metallurgy, Nano powders, Titanium alloys, Ball milling, Sintering, Microstructure, Mechanical properties

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1 Introduction

The most urgent problem of engineering and its advanced branches like aerospace engineering, automotive engineering, biomedicals is the efficient use of materials and increased service life. Creation of aircraft engines of new generation requires the development of absolutely new technological processes for producing articles characterized by increased reliability and service life providing high metal utilization. In this respect, titanium alloys, due to their high specific strength and corrosion resistance, are the most widely used structural materials, especially in such branches of engineering where material savings play a dominating role, In particular, aircraft engine, ship-building and medicine.

The aerospace industry faces challenges related to increasing operating temperatures and the development of polymer-based composites, innovative solutions, including metal matrix composites and titanium aluminides provide pathways for future development. Furthermore, improvements in extractive metallurgy and processing methods have made titanium-based alloys more accessible to alternative industries. Industries currently utilizing these materials include the sports, biomedical, and marine sectors. The alloy Ti-6Al-4Nb, due to its biocompatibility coupled with good combination of mechanical and corrosive properties is experimented in this paper for the best results.

The use of titanium alloys in aero-engines represents are remarkable synergistic relationship between the titanium supply chain and the gas turbine industry that has allowed progressive increase in titanium alloy use temperature. This has a direct weight reduction benefit for the engine since it is mostly relatively dense Ni alloys that are being replaced. As we know, powder metallurgy (PM) process, especially the elemental powder metallurgy process, is an economical fabrication process owning to cheap raw materials and low process cost.

In recent years, several studies on the fabrication of high strength and ductility titanium alloys with nanostructured and ultrafine grained microstructure have been reported. The process employed to achieve this microstructure consists of the preparation of NS or UFG powder by ball milling and the consolidation of the powder into dense compacts by PM methods such as Hydraulic pressing and Sintering

The industry of titanium alloys seems to be mature, but new technology and applications for these alloys continue to grow. Regardless of the usefulness of titanium alloys, the number of available articles addressing the subject has been limited. The aim of this paper is to perform a review on titanium alloys. The core subjects are properties and microstructure with special focus on Ti-6Al-4Nb. Additional descriptions on elemental titanium, alloying elements, chemical composition, and classification are also provided.

The structural titanium alloys are classified into three categories:

1. Alpha phase (α) alloys: The alpha-phase alloys of titanium, which is categorized as commercially pure titanium, is relatively weak in strength but offers a combination of good corrosion resistance, good weldability, creep resistance, receptive to heat treatment coupled with ease of processing and fabrication.
2. The Beta phase (β) alloys: are receptive to forging while also offering excellent fracture toughness.
3. The dual phase (α +β alloys) alloys: offer a combination of excellent ductility and strength when proper heat treatment is given, which makes them stronger than the other two
.

The Elemental Powder Metallurgy process has been utilized to prepare Ti–Al intermetallics. Ti–6Al–4Nb– alloy is fabricated by hydraulic pressing (HP) of blended powders, and the mechanism of this alloy was studied using microstructure examination and calculations. It is certainly important and worthful to systematically investigate how the sintering parameters effect on the microstructure and mechanical properties of Ti-6Al–4Nb alloys. Ti–6Al-4Nb alloys were prepared by PM with different sintering temperature and holding time. The influence of sintering parameters on the microstructure evolution and mechanical properties of Ti-6Al–4Nb alloys were also investigated.

2 EXPERIMENTAL PROCEDURE

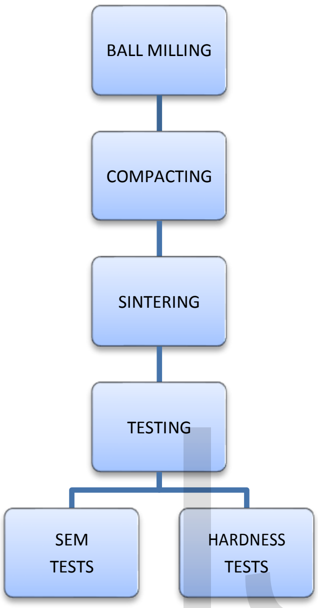

Fig.1: Steps in processing of Ti-6Al-4Nb powder

2.1 Ball Milling

Elemental powders of purity and size of Ti (99.99%, <45μm), Al (99.99%, <20μm) and Nb (99.95%, <35μm) were selected as the starting materials. Ti, Al, Nb powders were then ball milled in the mass ratio of 90:6:4 as shown in Fig.2 (a) for different times of 5, 10, 15 and 20 hours. Fig2 (b) shows that 2 balls of diameter 10 mm were used and the ball to powder weight ratio was kept 2:1 throughout the process.

Fig.2 (a): SPEX shaker mill Fig.2 (b): 2 balls of ϕ10mm each

This process of ball milling not only helped in reduction of particle size from microns to nano but also in the mixing of all the three materials perfectly.

2.2 Palletization or compacting

It is the process of compressing and moulding the metal powder into the shape of a pellet. A manual hydraulic laboratory pellet press was used along with a die, punch and plunger to obtain the required pallet shape and size (shown in fig.3(a)).

Fig.3(a): Hydraulic press Fig.3(b): Pellets obtained

High pressure of 2000 psi (around 13 MPa) was applied with a holding time of 5mins and hence the desired pellets were obtained as shown in Fig.3(b)

2.3 Sintering

Sintering is a heat treatment applied to a powder compact in order to impart strength and integrity. The temperature used for sintering is below the melting point of the major constituent of the powder metallurgy material. The type of sintering that was carried out is:

2.3.1 Conventional Sintering: Conventional, free or pressure less sintering is the simplest technique which involves heating of a powder compact, previously prepared at ambient temperatures, without applying any external pressure. Sintering is carried out at 950ºc, 1050ºc, 1150ºc and 1250ºc respectively with a holding time of 2 hours.

After removing the surface layer from the sintering disks by grinding, the mechanical and wear tests are carried out.

2.4 Testing

Testing was done on the powdered metal after ball milling and also on the pellets after HP and sintering. Two types of tests were conducted:

2.4.1 Scanning Electron Microscope

The surface, topography and texture of the sample observed by using the Scanning Electron Microscope. SEM is a powerful tool for examining and interpreting the microstructures of materials and is widely used in the field of material science. The principle of SEM is based on the interaction of an incident electron beam and the solid specimen. SEM images were used for the evaluation of the morphology of material.

Fig.4. Scanning electron microscope

2.4.2 Vickers Hardness Test

The Vickers hardness measurement is performed on the surface of specimen after polishing it with emery papers. The corresponding diagonals of the indentation and crack sizes are measured using the low magnification optical microscope .Hardness is the measure of resistance offered by the material for the local compressive load. The indenter used here is diamond indenter with a square-base pyramidal geometry with an included angle of 136º.

3 RESULT AND DISCUSSION

The morphology changes of the ball-milled Ti–6Al–4Nb alloy powder with the BM time are displayed in Fig.4. After 5 hours of BM, the powder particles still maintained the spherical shape (Fig.4a). The dendritic cellular network was continuously broken by collisions and finally disappeared. After the ball-milling for 10 hours, the powder particles changed from spherical shape to flake-like shape (Fig. 4b). This is because the powder particles underwent severe plastic deformation generated by the collisions between ball/ball or ball/vial.

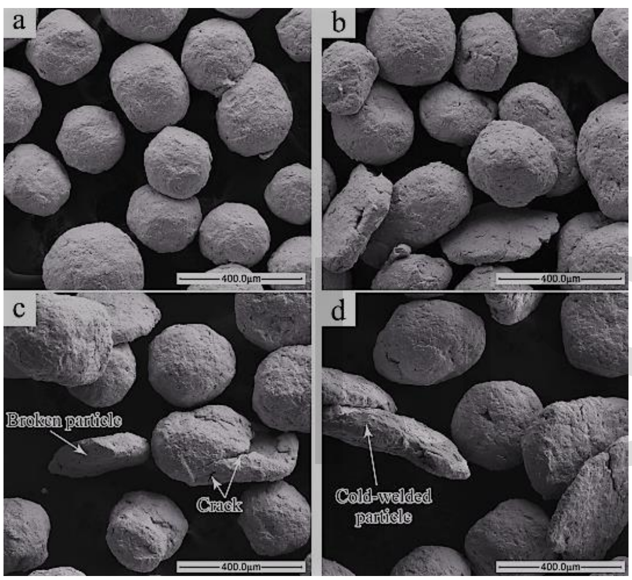

Fig.5: SEM images of Ti-6Al-4Nb powder after BM for different times (a)5hr,(b)10hr,(c)15hr and (d)20hr respectively.

As the BM time increases to 15 hours, the powder particles with coarse flake like shape were broken gradually into finer particles (Fig.4c). At this stage of BM, the strength and hardness of the powder particles obviously increase due to the multiplication of dislocations and other crystal defects. The powder particles become more and more brittle, making it difficult to produce the plastic deformation. Presence of a large number of defects in the coarse particle induces micro-cracks which are growing. As a result, the coarse particles were broken into finer particles to re-weld together, and it led to a particle agglomeration at 20 hours of BM (Fig.4d). Therefore, the particle size increased a little with the BM time.

Vickers hardness test was carried on two sample pellets S1 and S2 of ϕ13mm and height 5mm respectively. Pellet of commercially pure Ti powder was taken as S1 and that of Ti-6Al-4Nb sintered at 950ºC was taken as S2. The Vickers hardness number of S1 and S2 was found to be 340.32 and 322.45 VHN respectively. The Vickers hardness of S2 is remarkably greater than S1.This significantly increased the hardness of the material, possibly as a result of alterations in the microstructure. This shows the importance of sintering for achieving better microstructural and mechanical properties.

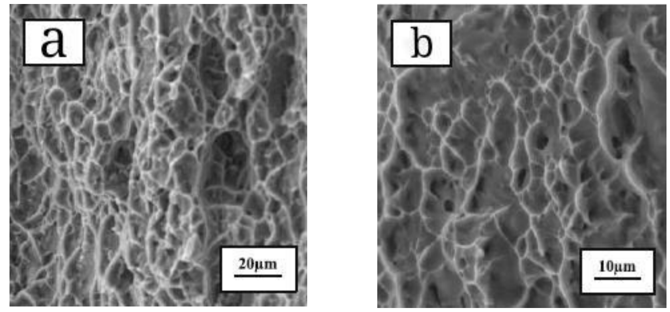

Fig: High magnification scanning electron micrograph of the Ti-6Al-4Nb alloy after BM for 10 hours followed by sintering at 950ºC.

An important aspect that might have contributed to the increased hardness of S2 is the cooling method used during sintering. In present study, the slow cooling method was employed (7ºC/min in furnace), which permits the formation of an ordered structure and a higher strength and hardness at room temperature.

4 CONCLUSIONS

In this paper, the nanostructural and mechanical properties of Ti-6Al-4Nb processed by ball milling and followed by sintering at 950ºC are investigated. The conclusions are drawn as follows:

1) The Ti-6Al-4Nb alloy ball milled for 10 hours exhibited the best microstructural and mechanical properties.

2) Reduction in in size of the alloy particles from microns to nano along with perfect blending of Ti, Al and Nb was achieved through ball milling.

3) Remarkably greater hardness was achieved after the experiment.

5 SCOPE FOR FUTURE WORK

Titanium is being increasingly used in the modern society due to its unique properties. Enlisted below are some of the areas for further study and research:

- Due to excellent resistance to seawater, it can be used in offshore rigs, propellers of the ships, rigging, and desalination plants.

- Apple computers recently put a titanium laptop computer on the market for its light weight.

- The spark plasma sintering method (SPS) is a modern method of rapid pressurized sintering of a broad group of materials, including materials classified as hard-sinterable. In this method, periodically repeated high-current impulses of direct current lasting up to several hundred milliseconds are used to heat compressed powder. The heat not only exceeds the melting temperature of the base material, but also helps the particles bond together.

- Titanium bicycle frames are widely considered to be the most durable. Compared to a steel frame, a titanium bicycle frame of the same dimensions would have a 'whippy' feel because it would be less stiff. This might be more noticeable in a bicycle carrying a heavy load. In addition to that squash racquet construction of a bicycle can make use of titanium alloy mesh. This gives the racquet its lightweight feel, durability and strength.

- The human body does not reject titanium, so it can be used for joint replacement and tooth implants.

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