Influence of Thermo Mechanical Properties Parameters on Titanium Metal Matrix Composite and Ti-6Al-4V for Aerospace Applications

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Abstract: Ti-6Al-4V alloy is used mainly in aircraft industry due to its low density, excellent corrosion/oxidation resistance, and attractive combination of mechanical properties. This alloy has relatively low formability, so forming parts of complex geometries out of this alloy requires precisely controlled thermo mechanical processing parameters. In this respect, powder metallurgy methods are very promising, since the processing parameters in the case of P/M materials can be controlled more precisely. This work is aimed at the analysis of P/M Ti-6Al-4V alloy processing. The samples of Ti-6Al-4V alloy powder compacts, obtained from the blended mixtures of elemental powders, were subjected to plastometric tests under various temperature-strain-strain rate conditions. The microstructures of both Ti-6Al-4V alloy powder compacts and hot deformed in compression on Gleeble simulator P/M Ti-6Al-4V alloy samples were analyzed. Moreover, basing on the results of plastometric tests, thermo mechanical parameters of forging P/M Ti-6Al-4V alloy were determined. The investigated alloy was successfully forged in industrial conditions, what was also discussed in this study. The investigations showed a significant influence of processing parameters on development of the microstructure and mechanical behavior of P/M Ti-6Al-4V alloy.

Keywords: titanium alloy, metal Matrix Composite, Ti-6Al-4V, powder metallurgy, microstructure, temperature.

Introduction

Materials and materials processing have entered a new era. Where metals and alloys once dominated, advanced materials, such as polymers, ceramics, intermetallic compounds and composites with polymeric, metallic, ceramic and intermetallic matrices have entered to Extend applications. Titanium matrix composites (TMCs), such as the particle reinforced Ti6Al4V+10 wt. % Tic can be included in this new era opening new perspectives for applications such as sporting goods and aerospace structures. The use of advanced materials is very attractive to material scientists and high-technology industries, usually for specific Applications in which their special properties can be tailored and used to great advantage Exploiting the desirable properties and minimizing those less desirable features. Advanced materials require novel joining techniques; therefore, developments in new structural materials research should be conducted in parallel with that into weld ability aspects. Among the modern joining processes used in engineering, the solid-state techniques such as diffusion bonding and rotary friction welding are intensively used in materials sensitive to fusion welding processes. Solid-state joining processes operate without melting of the base metal, usually by the application of high pressure, thus limiting the extent of metallurgical reactions that may cause welding defects such as cracking, porosity or formation of intermetallic compounds. Bonding is achieved by the introduction of mechanical, electrical or thermal energy and/or diffusion. Nowadays these processes play an important role in key technology industries helping to develop complex structures such as airframes, offshore accommodation units, pipelines, among other components. Titanium is a low-density metallic element that is abundant and widely distributed

Titanium Matrix Composite - TMC (Ti6Al4V+10 wt. % of Tic)

The material used in this investigation was a Tic-particulate reinforced Ti6Al4V Composite. It was produced by the CHIP process, which is a P/M technique (blended elemental method – BE), comprising cold isocratic pressing of blended elemental powders (master alloy and Tic particles) in a reusable elastomeric mould, followed by vacuum sintering to achieve a closed porosity (94 to 98%) and hot isostatic pressing (HIP) at 899ºC for 2 hours at 103 MPa without need for additional expensive tooling achieving a final density of 99 to 100%. With this technique proper proportion of master alloy powders and reinforcement particles are blended to obtain a uniform distribution of the required chemical Composition. The Ti6Al4V+10 wt. % of Tic alloy was supplied by Dynamic Technology Inc. in the form of 50 mm diameter bars. The reinforcement of the Ti6Al4V alloy leads to several modifications in the mechanical and metallurgical properties changing the matrix alloy original characteristics. Basically, the most dramatically improvements in the composite are stiffness and high temperature tensile properties (10 to 15% higher). The material properties can be tailored to meet specific applications by increasing or decreasing the reinforcement level. The material has not been heat treated after fabrication and it was furnace cooled inside the HIP chamber under protective atmosphere. Such procedure allowed the formation of platelike α andintergranular β microstructures with Tic randomly distributed in the matrix alloy. The as-received Ti6Al4V/Tic-particulate reinforced chemical composition. A detailed description of the microstructure and properties of the base material

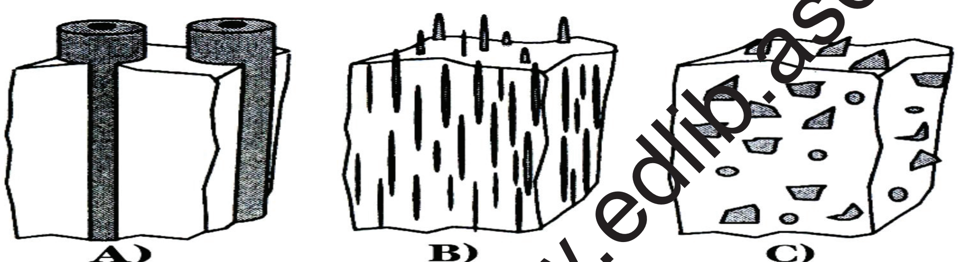

Figure 2.1 - Examples of reinforcements in composites: (a) Continuous reinforcement (fibres). (b) Discontinuous reinforcement (whiskers). (c) Discontinuous reinforcement (particulate

Alpha Alloys

Titanium and its alloys with α stabilizer either single or in combination are hcp at ordinary temperatures and are classified as α alloy. Satisfactory strength, toughness, creep resistance and weld ability characterize these alloys. Furthermore, the absence of ductile brittle transformation renders the α alloys suitable for cryogenic applications. Generally they have creep resistance superior to β alloys and are preferred for high temperature applications. Extra low-interstitial (ELI) grades retain ductility and toughness at cryogenic temperatures. Unlike α-β and β alloys, α alloy cannot be strengthened by heat treatment. Strengthening Mechanisms are cold work, cold work and anneal to control α grain size as well as solute additions for solid solution strengthening. Alloys that contain small additions of stabilizers (Ti8Al1Mo1V or Ti3Al2.5V) have been classified as near-α alloy. Although they contain some retained β phase, these alloys consist primarily of α and behave more like conventional α alloys than α-β alloys. An example of α alloy is Ti5Al2.5Sn.

Alpha-Beta Alloys

α-β alloys are such that at equilibrium, usually at room temperature, they support a mixture of α and β phases (10 to 50% of β)]. Although many binary β-stabilized alloys in thermodynamic equilibrium are two-phase, in practice α-β alloys usually contain mixtures of both α and β stabilizers. They retain more β phase after the final heat treatment than do near-α alloys (specific amount depending on quantity of β stabilizers present and on heat treatment). It can be strengthened by solution treating and aging. Solution treating usually is done at a temperature high in the two-phase α+β field and followed by quenching. As a result of it, the β phase present at the solution treating temperature may be retained or partly transformed during cooling by either martens tic transformation or nucleation and growth. The specific response depends on the alloy composition, section size, cooling rate and solution-treating temperature. It is followed by aging to precipitate α and produce a fine mixture of α and β in retained or transformed β. Examples of α-β alloys are Ti6Al4V and Ti6Al6V2Sn.

Beta Alloys

Titanium can be made to exist entirely in the β phase at room temperature. Alloy additions inhibit the β-to-α transformation (β stabilizers) with the β phase completely retained. They are characterized by high harden ability, excellent forge ability and good cold formability in the solution treated condition. The disadvantages of the β alloys in comparison with the α-β alloys are higher density, lower creep strength and lower ductility in the aged condition. Although the ductility is lower, the fracture toughness of an aged β alloy generally is higher than that of an aged α-β alloy of comparable yield strength. In the solution treated condition (100% retained β), the β alloys have good ductility and toughness, relatively low strength and excellent formability. They are prone to ductile-brittle transformation; therefore unsuitable for low-temperature applications. Some examples of β alloys are Ti10V2Fe3Aland Ti15V3Cr3Al3Sn.

Alpha + Beta Alloy Ti6Al4V

The α+β Ti6Al4V alloy is the most widely used titanium alloy among all others. It contains 6% of aluminum and 4% of vanadium (weight percentage) and it has an excellent combination of specific strength and toughness as well as good stability at temperatures up to 400ºC. The Ti6Al4V modulus (100 to 130 GPA) is about midrange for the titanium alloys but relatively low compared to other high-strength materials. In general, it has been found that the α-stabilizing solutes increase modulus, whereas the β-stabilizing solutes decrease it . Room-temperature tensile properties are affected by heat treatment, composition and Texture. It is well established that the fracture toughness of titanium alloys strongly depends on micro structural parameters, which depend on both processing history and heat treatment. The micro structural parameters can strongly affect the fracture toughness behavior in two different ways: through direct influence on the material fracture properties and through influence on the crack front geometry. In general, the fracture toughness increases as amount of transformed β structure increases, with β annealing providing the highest fracture toughness . The best combination of micro structural parameters to improve the fracture Toughness value (KIC) is coarse grain size and lamellar microstructure, low age-hardening and low oxygen content. affirm that it is clear the superiority of microstructures that contain large acicular α percentage due to their high aspect ratio that provides extended α-β interfaces for preferential crack propagation resulting in greater energy consumption. The grain size also plays an important role (increasing the grain size increases the KIC) since the crack front is much smoother for the fine grained compared to the coarse grained material. The smoother the crack path is; the lower is the KIC value since a more irregular fracture path (crack direction changes) leads to a greater dissipation of work per unit crack extension distance in the direction normal to the loading direction resulting in higher\ KIC. The geometry of α+β structures also plays an important role in the KIC behavior; fine lamellar structure exhibits a much smoother crack path compared to serrated crack growth in coarse lamellar structure (higher KIC). When comparing equaled and lamellar structures, the equaled structure exhibits a smoother crack path than their lamellar counterparts. Also, the KIC of bimodal structures decreased with decreasing primary α volume fraction approaching the KIC of fine lamellar structure. Table 2.1 presents the mechanical properties of Ti6Al4V according to various micro structural condition resulted from different heat treatments and mechanical processing.

Advanced Titanium Alloys

Since the monolithic alloys have inherent performance limitations, the development of materials independent of equilibrium or met stable structures have been investigated leading to the development of MMCs where a metal or alloy is combined with a nonequilibriumdispersed phase - generally nonmetallic. Due to their unique properties, titanium alloys were among this initial MMC development, leading to the obtention of TMCs with boron fibers and later on with other kind of reinforcements (whisker or particulate). During the past decade, an extensive effort has been devoted in order to develop and increase the performance of advanced titanium alloys such as TMCs. These alloys have unique properties such as excellent high temperature performance (oxidation, fatigue and creep resistances) as a result of their high specific modulus, high recrystallisation temperature and low self diffusion. Much effort is currently being

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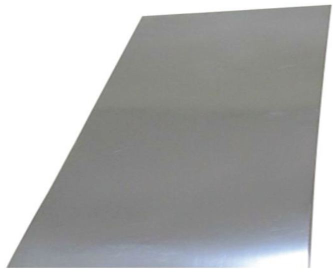
made to use TMCs for high performance industrial applications such as automotive and aeronautic components



Advantages of Titanium

- Good corrosion resistance in seawater applications
- Low density/ high strength-to-weight ratio
- Low modulus of elasticity
- Low thermal expansion
- Non-magnetic
- Good fatigue resistance
- Good high temperature mechanical properties

Applications

- Blades, Rings, and Discs
- Sporting Equipment
- Aircraft Structural Components
- Hand Tools
- Airframes
- Fasteners, Components
- Vessels, Cases, Hubs, Forgings
  Biomedical Implants

Aerospace applications

Dynamet has produced and supplied its PM processed Ti-6Al-4V alloy mate- rials to a commercial aerospace Manufacture for extensive property analysis. Results of thousands of data points generated to date show that the static properties of CIP-Sinter and CHIP prod- uct data are consistently above the mini- mum allowable developed for wrought Ti-6Al-4V. Additional information and data was presented at the AeroMat2011Conference [5]. It is anticipated that this work will soon lead to Dynamet's PM titanium products being used to substi- tute for wrought titanium airframe com- ponents for commercial aircraft. This is expected to significantly increase the volume of PM titanium product and provide a major breakthrough at the intersection of the titanium industry, the aerospace industry and the powder metal industry.

Affordability and enhanced properties by PM will increase titanium's competitive position versus other materials, expand the use of titanium and provide a new supply base to meet customers' increasing demands for titanium product at lower
cost and shorter lead-times.

Physical Properties

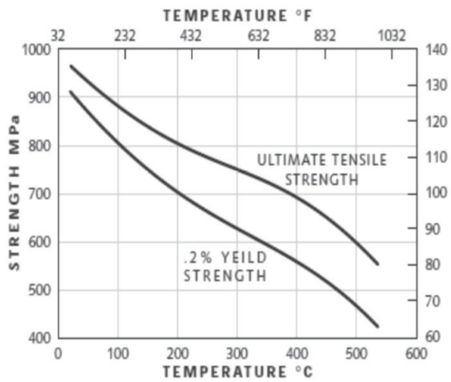
Melting Range: 2,800-3,000°F (1,538 - 1,649°C)

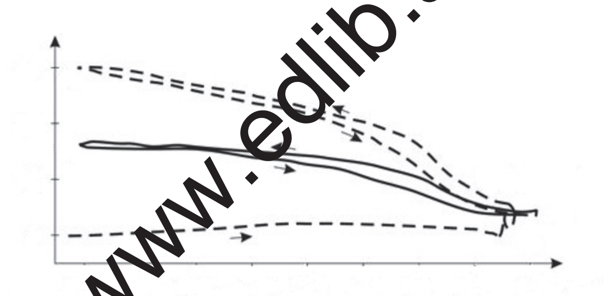
Density: 0.160 lbs/cu. in.(4.47 gm/cc) Beta Transus , Temperature: 1830°F (± 25°); 999°C (± 14°)

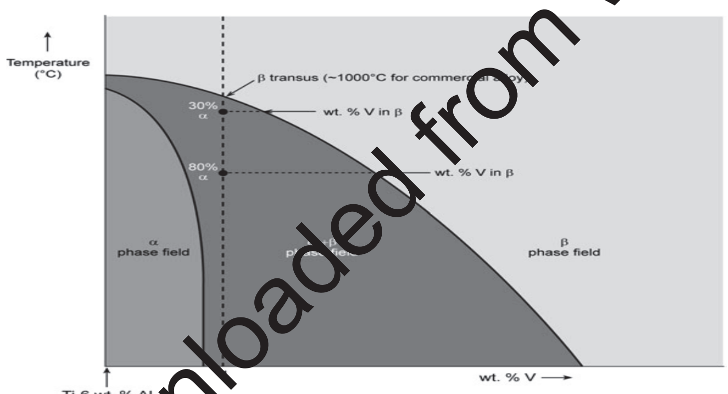
Mechanical Properties

Typical Mechanical Properties Annealed Condition (min)		
	MPa	Ksi
Yield Strength (0.2%)	828	120
Tensile Strength	895	130
Elongation (%)	10	
Reduction in Area (%)	25	
Hardness	Rc 30-34	

Note: Variations in mechanical properties are dependent on size/condition/heat treatment

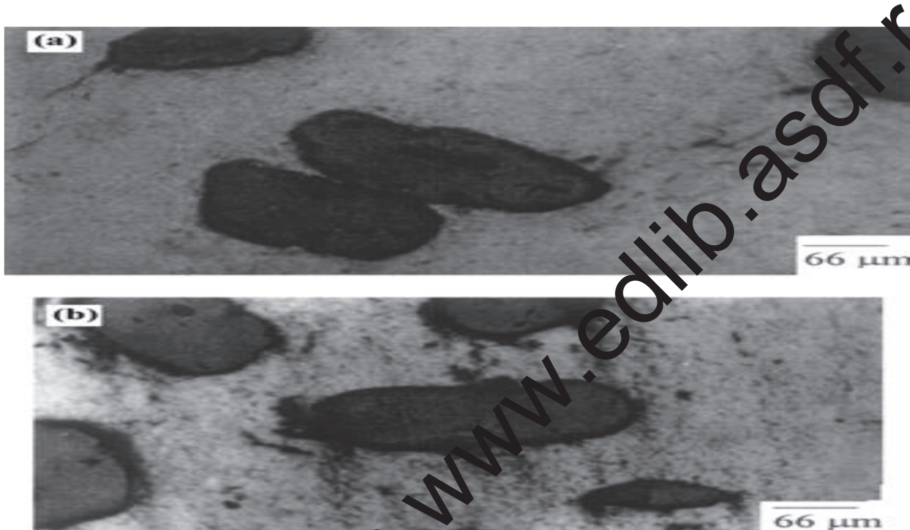






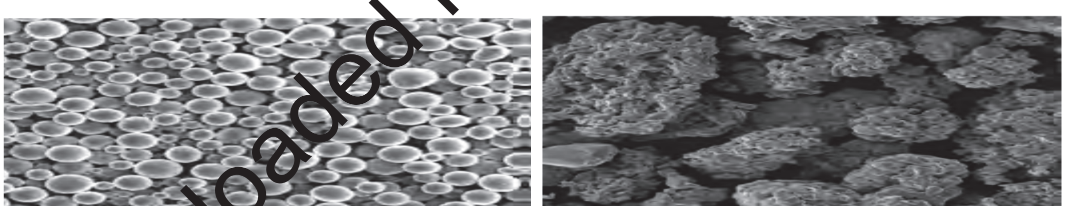
Pseudo-binary equilibrium phase diagram (schematic) for Ti-6Al-4V. The relative amounts of a at the two indicated temperatures are derived from the metallurgical phase diagram lever rule.

The General Metallurgy of Titanium Alloys Unalloyed titanium has two allotropic forms. The low temperature form, a, exists as an hexagonal-close-packed (hcp) crystal structure up to 882_C, above which it transforms to b, which has a body-centred-cubic (bcc) crystal structure. The alloying behavior of elements with titanium is defined by their effects on a and b. Element additions that increase or maintain the temperature range of stability of the a phase are called a-stabilizers. The most important of these are aluminium, tin and zirconium. Element additions that stabilize the b phase are called b-stabilizers. These include molybdenum, vanadium and iron. There are also important impurity elements, namely oxygen, hydrogen, nitrogen and carbon. Oxygen and hydrogen are the two most important impurities: oxygen is an a-stabilizer and hydrogen is a b-stabilizer. These four elements are also referred to as interstitial elements. This is because their atomic sizes are much less than those of the metallic alloying elements and they fit in the spaces (interstices) between the crystallographic positions of the metal atoms in the a and b phases. Titanium alloys can be classified in four categories: (1) a alloys Examples are commercially pure grades of Ti, containing welldefined amounts of oxygen, and Ti-2.5Cu and Ti-5Al-2.5Sn. (2) Near-a alloys These contain only a small amount of b phase. They are heattreatable and stronger than a alloys. Early examples are Ti-6Al-2Sn-4Zr-2Mo and Ti-8Al-1Mo-1V. More complex alloys have been developed for improved creep resistance. These include TiAlZrMoSiFe and TiAlZrSnNb(Mo,Si) alloys.These variables are controlled by processing and heat treatment. Examples are Ti-6Al-4V and Ti-6Al-2Sn-4Zr-6Mo. b alloys These have sufficiently high b-stabilizer contents that commercially useful microstructures are predominantly b phase. They have been developed mainly because of excellent formability (e.g. cold-rolling) and very good response to heat treatment. Examples are Ti-15Mo-3Nb-3Al-0.2Si and Ti-10V-2Fe-3Al.

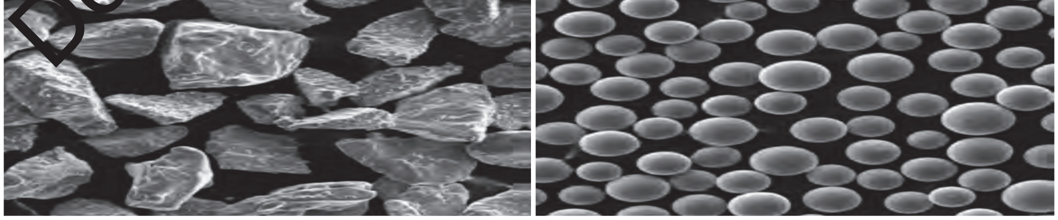


Optical micrograph of **Ti6Al4V+10 wt. % of TiC** composite:
(**a**) Hot rolled and (**b**) cold rolled

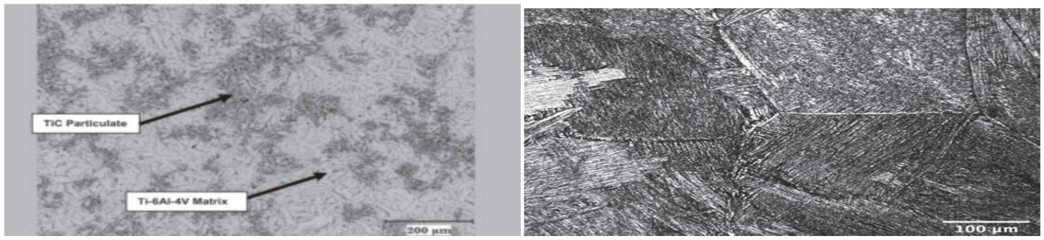
Thermo Mechanical Properties & SEM photomicrograph



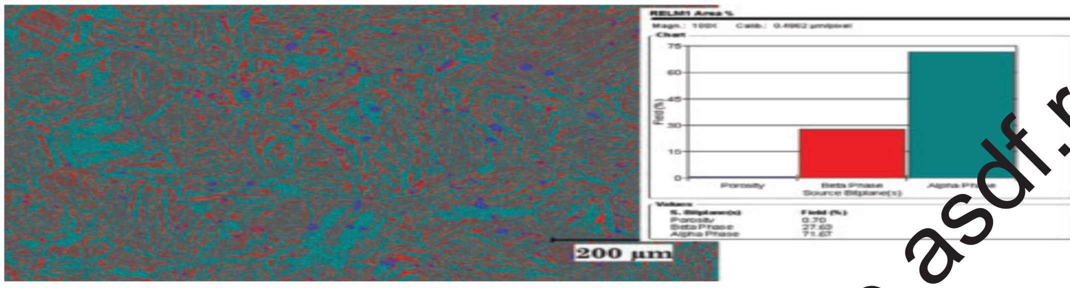
(a)SEM photomicrograph of gas-atomized prealloyed spherical Ti-6Al-4V
(b) SEM photomicrograph of sponge fines produced by the Kroll process



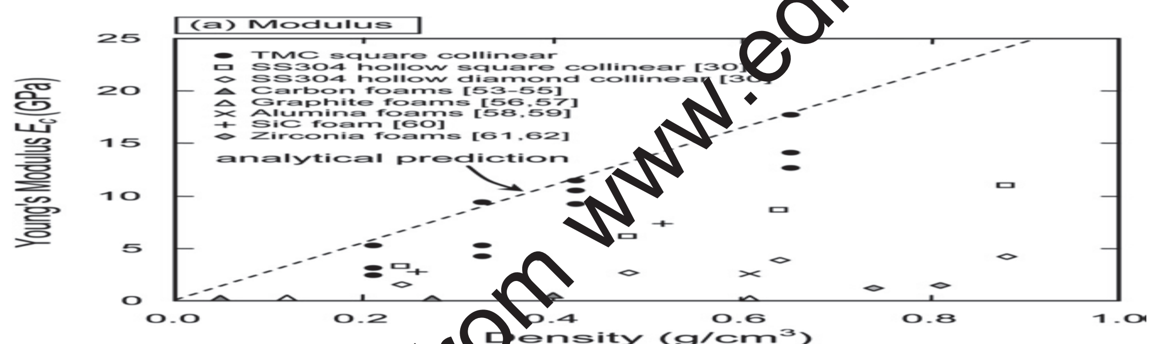
(c)SEM photomicrograph of angular HDH titanium powder; (d)SEM Photomicrograph of spherical powder produced by processing angular HDH titanium to a spherical morphology using the Tekna technique

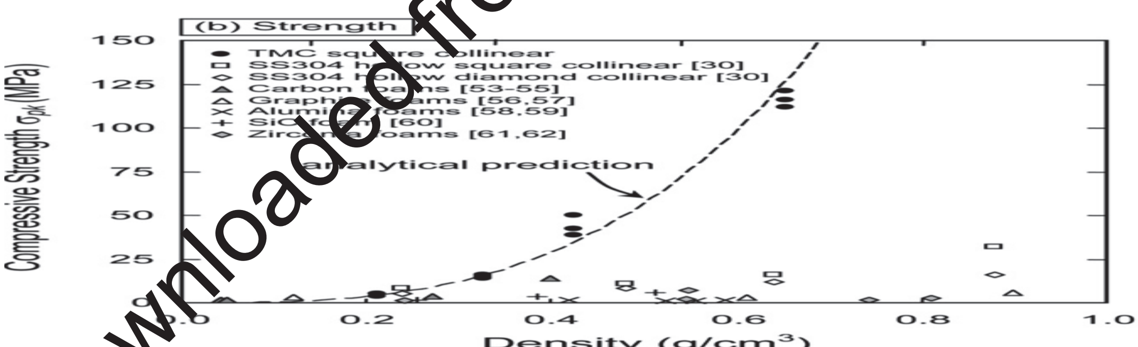


SEM micrographs of P&S samples sintered at 900 ºC (a) and 1300 ºC (b)



Mechanical Properties





Results

A comparison of the mechanical properties of fine Ti/TiC composite and conventional Ti-6Al-4V (Ti64) alloy .By adding a small percentage of carbon black particles, the yield stress and tensile strength of fine Ti/Tic increased, approaching the lower levels of the Ti64 alloy. At the same time, the elongation was much higher than that of Ti64. We would expect that fine Ti/carbon black composite. May replace the conventional Ti64 alloy in the near future Micro voids are observed in the particles enriched zone. A phase transformation has been observed during the resistivity and DSC measurements owing to the precipitation of TiAl3 phase. Cold and hot rolling of the composite is successfully carried out to 40% and 50% reduction, respectively. Hardness of the composite is greater than the base alloy, which can be attributed to the presence of higher dislocation density in the matrix due to the difference in thermal properties between the matrix and dispersions.

Conclusions

This study demonstrated that near net-shape, chemically-homogeneous and dense titanium products with properties similar to those of the wrought materials can be produced by means of powder metallurgy techniques, which should lower the production costs and, possibly, expand the employment of titanium in new industrial applications. Ti-6Al-4V/TiB composites were fabricated using a powder metallurgy route. Annealing studies of HIP'ed materials showed that increasing the anneal temperature accelerated the kinetics of the transformation of TiB2 particles to the stable TiB phase. Increasing the anneal temperature or duration led to more complete transformation, the formation of larger TiB whiskers, and a nearly complete elimination of densely-packed, fine TiB whisker aggregates which occurred in the vicinity of previous TiB2 clusters. Given the size of the TiB2 and Ti powders used in this study, a heat treatment of 1300 °C for 6 h was established to retain a fine matrix grain size and to provide a reasonably homogeneous distribution of distinctive whisker reinforcements. Composites reinforced with 20 and 40% by volume of axially aligned TiB whiskers were produced by blind die compaction and extrusion. The average elastic moduli of Ti-6Al-4V/TiB/20w/1D and Ti-6Al-4V/TiB/40w/1D composites tested along the extrusion axis are 169 and 205 GPa, respectively, representing increases of about 55 and 88% relative to the elastic modulus of the unreinforced Ti-6Al-4V matrix. TiB whiskers are

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