Recent Advances in the Hot Working of Titanium Alloys

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Abstract: *In this paper, recent advances in titanium alloy processing are reviewed. The casting, superplastic forming, friction stir welding and thermohydrogen processing of titanium alloys are developed. The great cost saving results from using casting comparing with the conventional machining for rings. The superplastic forming of titanium alloys is a feasible manufacturing technology for civil and military aircraft. The friction stir welding leds to the production of fully-formed, high quality friction stirwelds. In thermohydrogen processing, the high diffusivity of hydrogen in titanium is firstly used to add hydrogen to titanium alloys by controlled diffusion from a hydrogen environment, after thermohydrogen processing, to remove it by a controlled vacuum anneal so as to improve processing and mechanical properties.*

Key words: titanium alloy; casting; superplastic forming; friction stir welding; thermohydrogen processing

1 Introduction

Titanium alloys are used widely to critical aero-engine and airplane components, including discs, blades and structured components owing to their excellent combination of mechanical and physical properties, i. e., high specific strength, good corrosion resistance, oxidation resistance, creep resistance and fracture resistance characteristics. Over the past several decades, titanium alloys have met the stringent requirements of the aerospace industry through alloy chemistry development and microstructure control. With the development of advanced manufacturing, lightweight, complexity, high precision and high efficiency are paid much more attention to the hot forming of titanium alloys.

In the past years, my group researchers were devoted to the investigation of advance processing technologies of titanium alloys so as to realize the precision and the net shape manufacturing process with desired microstructure and reduced costs. The main objective in this paper is to review and introduce recent advances in titanium alloy processing.

2 Casting

The reactivity of titanium becomes most acute in casting. Not only does the process need to be carried out in a vacuum or an inert atmosphere, but also needs special melting facilities. Very few refractories are suitable for containing molten titanium, and those are either extremely expensive or very difficult to deal with in practice. The usual solution is to effectively use a titanium crucible in a method known as skull melting. At the DONCASTERS titanium foundry, SETTAS SA, deep pool electric arc melting is used as shown in Figure 1. The relatively low thermal conductivity of the solid titanium means that a large liquid mass can be produced with quite a thin solid ‘skull’, maintained by heat conduction into the water-cooled copper crucible.

The centrifugal casting arrangement is ideal for

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making near-axisymmetric shapes such as engine casings. An example is shown in Figure 2, which was cast into a ceramic shell mould. This type of component is conventionally fabricated from rings and extensively machined, and a great cost saving results from using a casting.

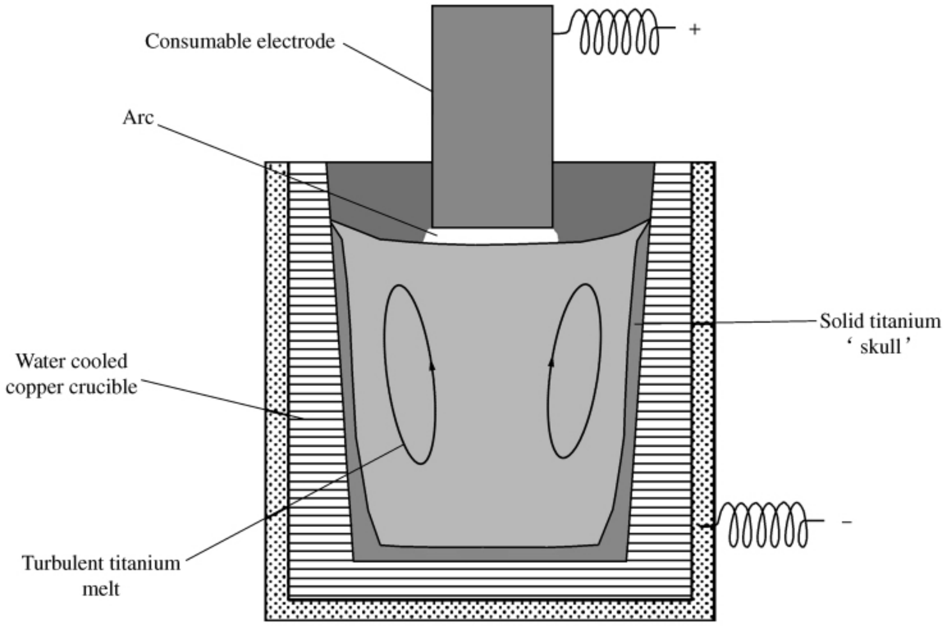

Figure 1 A schematic of the vacuum arc melting arrangement used for titanium casting

Figure 2 Titanium engine casing centrifugally cast into a shell ceramic mould

3 Superplastic forming

Since the early 1970´s, superplastic forming of titanium alloys became a feasible manufacturing technology for military aircraft in the USA and also for the Concorde supersonic civil aircraft in European. Today, SPF/DB parts are used not only for simple static fabrications but also for complex rotating parts in most of the new military and commercial engines.

Figure 3 shows different engine parts where superplastic forming and diffusion bonding techniques can be used in aero-engine for civil and military aircraft. Titanium alloys such as Ti6Al4V alloy and Ti6Al2Sn4Zr2Mo alloy and other titanium alloys are the most employed material in SPF formed parts. It is mainly used to casings and hot parts around engines, ducts handling hot air, exhaust nozzles and engine components in fans, compressors and auxiliary systems.

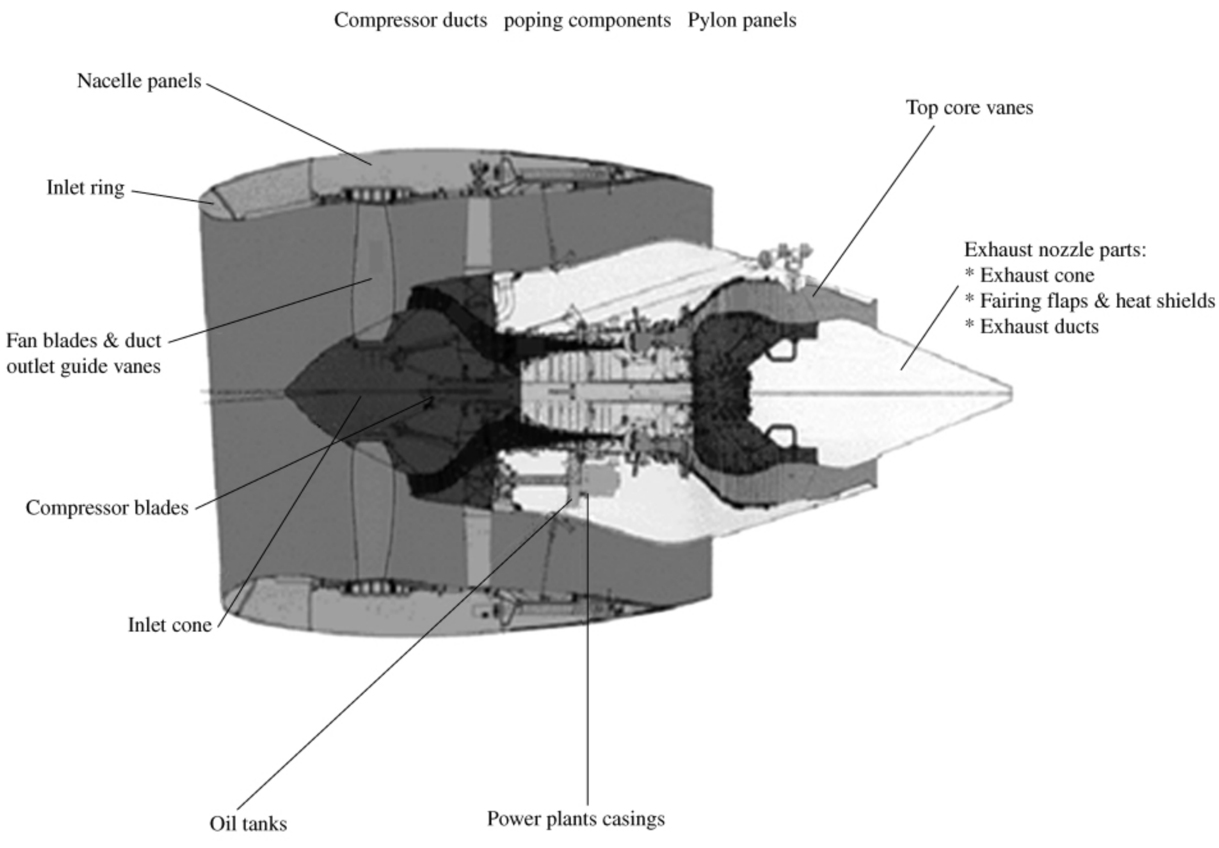

Figure 3 Possible SPF parts in aero-engines

Figure 4 shows some exhaust nozzle parts such as exhaust cone (Dolsig R&D European programme RR BR715), fairing flaps and heat shields (P&W F100, EJ-200), exhaust ducts and noise attenuators. Figure 5 shows a few engine components such as fan blades (RR Trent 900, RR Trent 1000, IAE V2500), fan duct outlet guide vanes, compressor blades, piping components and fuel and oil drain tanks (RR-BR725, EJ-200).

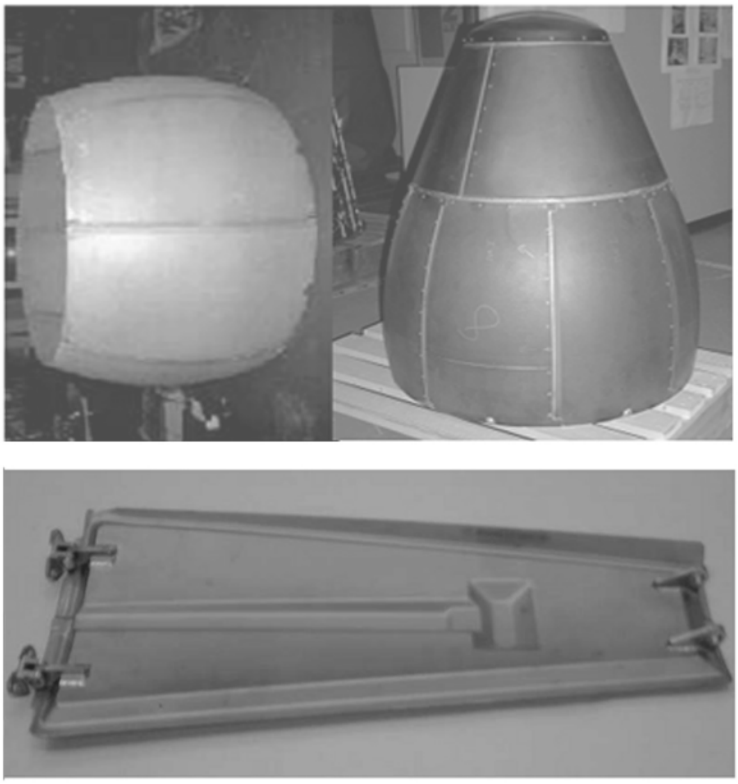

Figure 4 TiAl exhaust cone and fairing flap

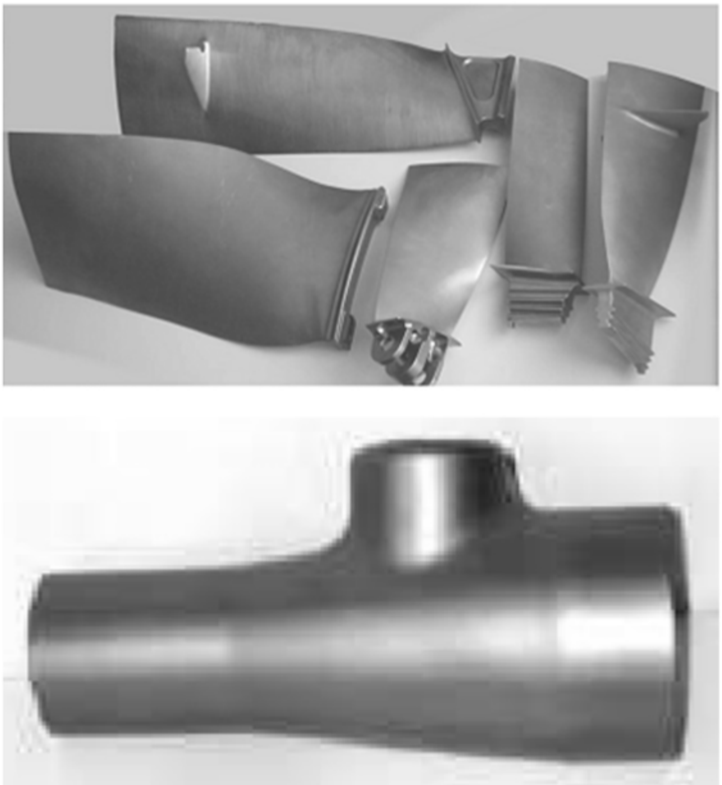

Figure 5 Fan blade and piping

4 Friction stir welding

Friction stir welding is an important new non-fusion technique for joining sheet and plate material. Friction stir welding was invented by TWI in 1991, and was a TWI licensed technology. The basic form of the process used a cylindrical (non-consumable) tool, consisting of a flat circular shoulder with a smaller probe protruding from its centre. The tool was rotated and plunged into the joint line (between two rigidly clamped plates) so that the shoulder sits on the plate surface and the probe was buried in the work-piece as shown in Figure 6.

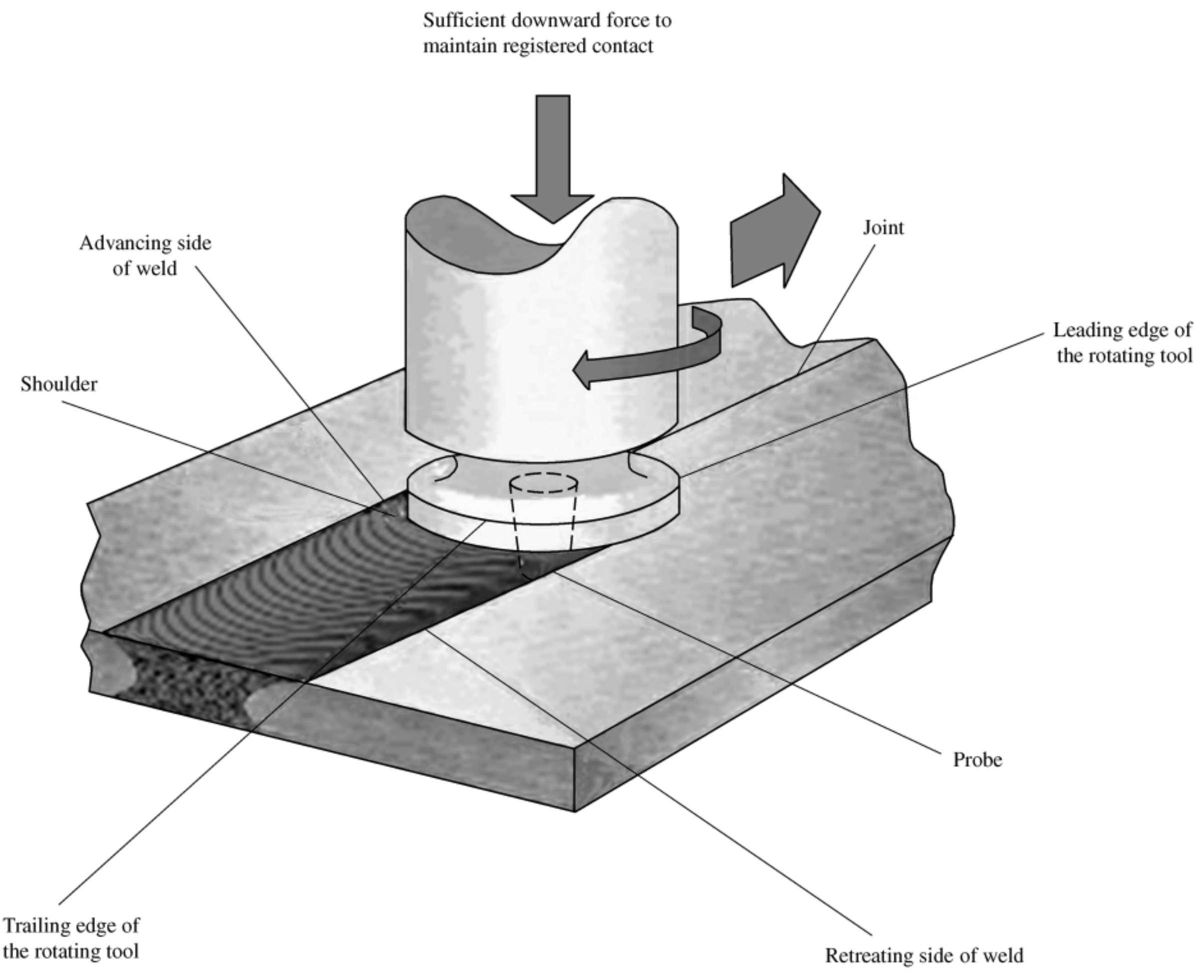

Figure 6 The schematic of friction stir welding

The majority of the work during TWI's group sponsored project on the friction stir welding of titanium alloys was carried out on a Ti-6Al-4V plate of 6.35 mm (1/4 inch) thickness. Following the identification of a suitable tool material, an extensive programme of welding trials were carried out to develop effective tool designs and processing conditions for the friction stir welding of the 6.35 mm thickness Ti-6Al-4V plate. This ultimately leds to the production of fully-formed, high quality friction stirwelds in the Ti-6Al-4V alloy shown in Figure 7 and Figure 8.

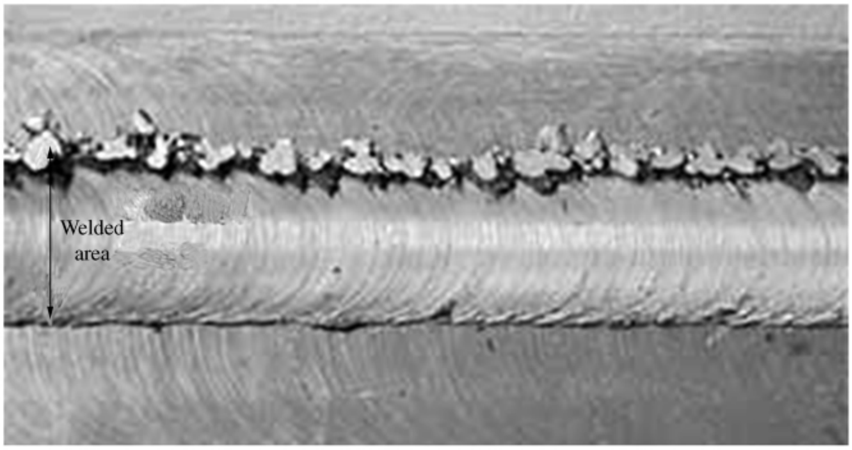

Figure 7 The surface appearance of friction stir welding for the Ti-6Al-4V alloy

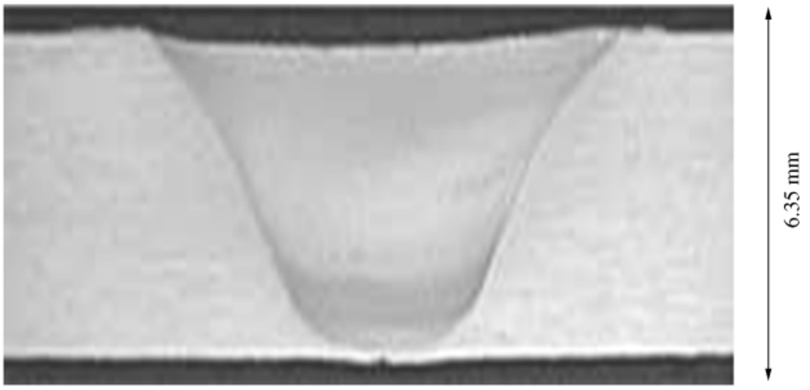

Figure 8 The section of friction stir welding for the Ti-6Al-4V alloy

5 Thermohydrogen processing

Thermohydrogen processing is based on the modifying effect of hydrogen as an alloying element on phase compositions, development of metastable phases and kinetics of phase transformations in titanium alloys.

Hydrogen is a unique alloying element in titanium alloys because, unlike other elements, it can easily be added and removed without melting. Titanium and conventional titanium alloys have a high affinity for hydrogen, being capable of absorbing up to 60% hydrogen at 600 ℃, and even higher contents can be alloyed with titanium at lower temperatures. Since the beginning of the titanium industry in the late 1940s, a great deal of attention has been given to controlling the hydrogen content of titanium products as hydrogen levels above 0. 02 ppm can lead to a degradation in fracture-related mechanical properties. Fortunately, the reaction of hydrogen with titanium is reversible due to a positive enthalpy of the solution in titanium, allowing hydrogen to be easily removed by vacuum annealing. At sufficiently high hydrogen contents, room temperature embrittlement provides an economic method for production of titanium powder, with the hydrogen then removed by vacuum annealing.

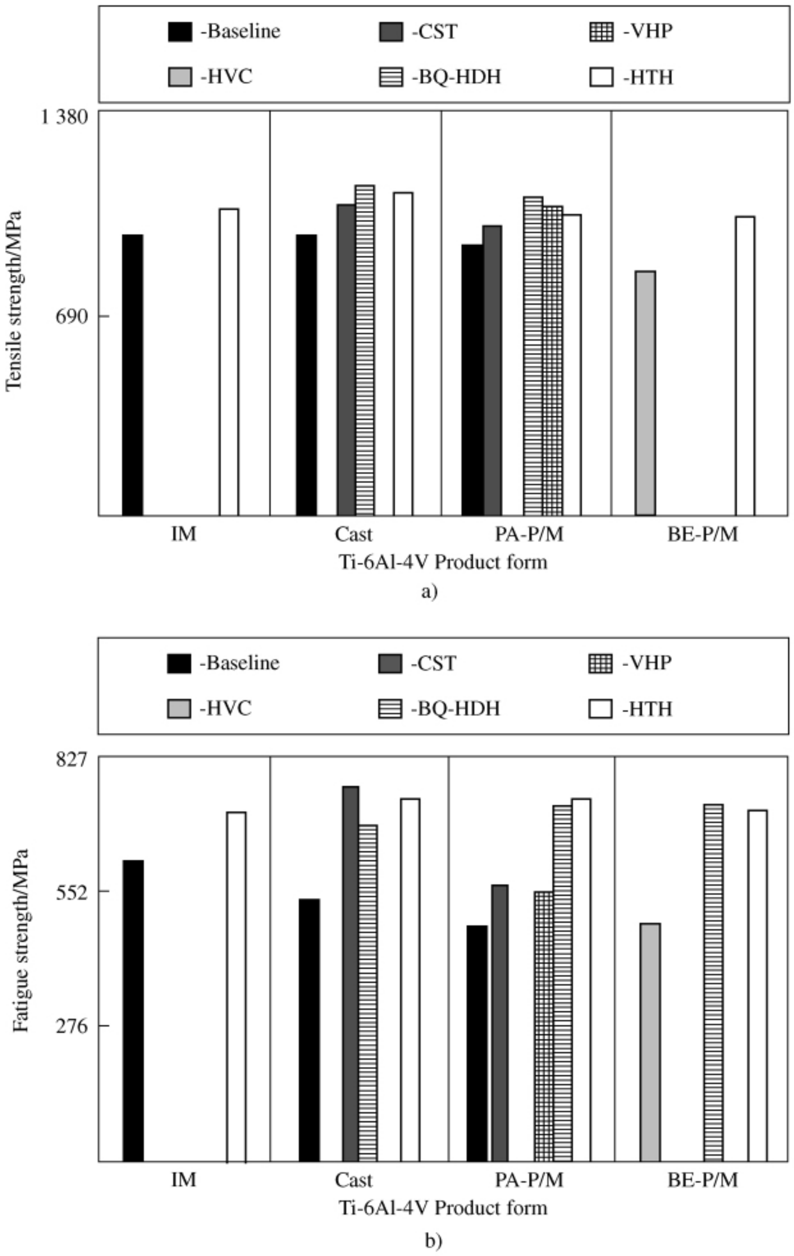

Figure 9 The comparison of tensile and fatigue data from the TCP and conventional Ti-6Al-4V alloy

Recently, an increased understanding of titanium metallurgy has demonstrated that, when used correctly, hydrogen as a temporary alloying element can become a powerful tool in improving processing and microstructure/mechanical properties of titanium alloys. This so-called thermohydrogen processing was based on the modifying effect of hydrogen as an alloying element on phase compositions, development of metastable phases, and kinetics of phase transformations in titanium alloys. In Figure 8, the latter designations referred to various types of TCP treatments; HVC referred to a hydrogenation, beta solution treatment with water quenching, aging to form hydrides, and finally, dehydrogenation; BQ-HDH referred to a beta solution treatment with water quenching and hydrogenation and dehydrogenation below the eutecitoid temperature; HTH referred to hydrogenation in the beta region, cooling to room temperature and dehydrogenation below the normal eutectoid temperature.

In the thermohydrogen processing of titanium alloys, the high diffusivity of hydrogen in titanium was firstly used to add hydrogen to the alloy by controlled diffusion from a hydrogen environment, after processing, to remove it by a controlled vacuum anneal. With the hydrogen present, advantageous thermal or thermomechanical treatments and forming processes could be performed.

6 Conclusions

The casting, superplastic forming, friction stir welding and thermohydrogen processing of titanium alloys are presented in this paper. These studies establish a foundation for developing precision hot working technologies. The progress in these techniques will enlarge the application scope of titanium alloys and contribute to the development in many industry fields.

References

[1] Bridges P J, Magnus B, *Manufacture of titanium alloy components for aerospace and military applications*. In RTO-MP-069(II) , 2001

[2] Serra D, *Superplastic forming applications on aero engines*. A Review of ITP Manufacturing Processes. 6th EUROSPF Conference,2008

[3] Dawes C J, Thomas W M, *Friction stir welding*. Proceedings of 11th Annual North American Welding Research Conference, Columbus, OH, USA,1995

[4] Thomas W M, Nicholas E D, Needham J C, Murch M G, Temple-Smith P, Dawes C J, *Improvements relating to friction welding*. European Patent Specification 0 615 480 B1, 1991

[5] Senkov O N, Froes F H, *Thermohydrogen processing of titanium alloys*. International Journal of Hydrogen Energy,24(6) : 565 ~ 576,1999

[6] San-Martin Manchester F D, *The H-Ti (hydrogen-titanium) system*. Bulletin of Alloy Phase Diagrams,8(1) : 30 ~ 42,1987

[7] Lenning G A, Graighead C M, Jaffee R I, *Constitution and mechanical properties of titanium-hydrogen alloys*. Transaction of American Institute of Mining, Metallurgical and Petroleum Engineers,200: 367 ~ 376,1954

[8] Wipf editor H, Hydrogen in metals III. Springer,1997

[9] McQuillan A D, *An experimental and thermodynamic investigation of the hydrogen-titanium system*. Proceedings of Royal Society of London, Series A,204: 309 ~ 323,1951

[10] German R M, *Powder metallurgy science*. Princeton, NJ: Metal Powder Industries Federation,1994

[11] Froes F H, Eylon D, Suryanarayana C, *Thermochemical processing of titanium alloys*. Journal of the Minerals, Metals and Materials,42(3) : 26 ~ 29,1990

[12] Senkov O N, Jonas J J, Froes F H, *Recent advances in the thermohydrogen processing of titanium alloys-overview*. Journal of the Minerals, Metals and Materials,48(7) : 42 ~ 47, 1996

Brief Biography

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