Deformation Behaviour of Ti–8Ta–3Nb During Hot Forging

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Ti–8Ta–3Nb, as a new biomaterial, was prepared by cast and swaging process. Their deformation behavior of Ti–8Ta–3Nb alloy has been characterized on the basis of its flow stress variation obtained from the true strain rate compression testing in the temperature of 700–900°C and strain rate of 0.001–10 s⁻¹. At the strain rates lower than 0.1 s⁻¹ and the all temperature ranges which consist of two phase α+β as well as single β phase fields, the flow curves show a small degree of flow softening behavior. In contrast, the shapes of the flow curves at other strain rates indicate unstable behavior. The shapes of the flow curves were similar in both as-cast and swaged specimen as well as in both α+β phase and β phase. The flow stress data did not obey the kinetic rate equation over the entire regime of testing but a good fit has been obtained in the intermediate range of temperatures (750–850°C). In this range, a stress exponent value of about 7.7 in as-cast specimens and about 6.2 in swaged specimens with an apparent activation energy of about 300 kJ/mol and about 206 kJ/mol respectively have been evaluated.

Key Words: Deformation, Forging, Stress, Strain Rate

1. Introduction

Ti alloys are usually used in the space and chemical industries due to an excellent specific strength, corrosion resistance, biocompatibility and fracture characteristics.

Ti–8Ta–3Nb is developed as a candidate material for applications in the human body. Compared with conventional Ti alloys it offers an improved high biocompatibility.

For successful application of Ti alloy, it is necessary to develop suitable and economical processing techniques to produce the material with the desired shape without losing the low cost advantage. (Sundar et al., 2003)

Hot forging operations are advantageous in that the temperature is uniform and deformation tends to be homogeneous. For any forging operation, there is a limit to achievable deformation before failure is likely to occur. This forging limit depends, in addition to the shape change and process conditions, on the formability of the material, i.e. the material’s ability to deform without failure. To increase the achievable deformation for a particular process and to be able to model the process, it is essential to know the flow behavior of the material which is determined by
process factors, such as true strain ($\varepsilon$), strain rate ($\dot{\varepsilon}$), deformation temperature ($T$), and material factors, such as flow stress ($\sigma$), strain rate sensitivity ($n$), and deformation activation energy ($Q$) (Huang et al., 1996).

The objective of present work is to examine the forging flow behavior and then determine the deformation characteristics for different forging conditions during hot forging of Ti–8Ta–3Nb in order to provide some fundamental data for engineering processing.

2. Experimental

The Ti–8Ta–3Nb alloy was melted three times using and made into small rods using a non-consumed electrode. The as-cast specimens were made through the consumable VAR process. Re-melting was carried out in a furnace filled with Ar, to make uniform alloys with the electrode. Then cylindrical rods were made. The chemical composition of the alloy in wt.% was as follows: Ta–7.23, Nb–3.22, Ti-balance. The homogenizing treatment was carried out at 1050°C for 24 hours.

The cylindrical specimens of length 8.25 mm, and diameter 5.5 mm, were machined from a Ti–8Ta–3Nb alloy on which the homogenizing treatment was carried out. The Ti–8Ta–3Nb underwent two primary processes. The first, the swaging process, was at 950°C followed by a homogenizing treatment whereby same sized specimens were made, similar to the as-cast specimens.

The temperature of the specimen during compression tests was monitored with the aid of a thermocouple spot-welded on the surface at the height of the specimen. This thermocouple was also used to measure the adiabatic temperature rise in the specimen during deformation. A computer controlled servohydraulic testing machine (Thermecmaster_Z) was used for hot compression tests.

The machine was equipped with an exponentially decaying cross head speed, enabling constant true strain rates in the range 0.001–10 s$^{-1}$ to be imposed on the specimen. Isothermal tests were conducted by surrounding the specimen, platens and pushrods with a resistance furnace with a temperature control of ±2°C. The adiabatic temperature rise was also measured on the specimen using the spot-welded thermocouple and a recorder.

The tests were conducted over a temperature range of 650–900°C, at intervals of 50°C and in the strain rate range of 0.001–10 s$^{-1}$. In each test, the specimen was compressed to about half its original height and the stress–strain data were recorded.

3. Results and Discussion

Figure 1 shows the true stress–strain curves at forging temperatures and strain rates. In general, the stress increases rapidly with increasing strain to reach a maximum stress value. At the strain rate lower than 0.1 s$^{-1}$ and at all temperature range consisting of two phase $\alpha+\beta$ ($<880°C$, (Lee et al., 2004)) as well as single $\beta$ phase fields ($>880°C$, (Lee et al., 2004)), the flow curves show a small degree of flow-softening behavior. In contrast, the shapes of the flow curves at other strain rates indicate unstable behavior. The limited amount of flow softening in most test conditions may indicate that the hot deformation of Ti alloy is led mainly by dynamic recovery and not by dynamic recrystallization (Park et al., 2002). The limited amount of flow softening at slow strain rates can be attributed to the occurrence of dynamic spheroidization of the $\alpha$ grains or dynamic recovery. The variation of flow stress is less significant at low strain rates, which means that it is beneficial to process the alloy under these conditions.

At strain rate higher than 0.01 s$^{-1}$ in the $\alpha-\beta$ range, the flow stress is similar in comparison with that of other strain rates, while in the $\beta$ phase the flow stress is clearly higher according to increasing strain rate. At strain rate higher than 0.01 s$^{-1}$ in the $\alpha+\beta$ phase and $\beta$ phase fields, the flow stress of the swaged specimen is higher than that of the as-cast specimen. At other strain rates, the flow stress is similar in both as-cast and swaged specimen.

The shapes of the flow curves are similar in both as-cast and swaged specimen as well as in