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Deformation properties and bending/diffusion bonding processing of a P/M Ti-22Al-25Nb alloy at elevated temperature

Kaifeng Zhang[a,] *, Yuanxin Wang[a], Jianbo Jia[a] & Baoyong Li[b]

[a]*School of Materials Science and Engineering, Harbin Institute of Technology, Harbin, 150001, China*
[b]*Beijing Hangxing Machinery Co. Ltd. Beijing, 100013, China*

Abstract

The multi layers structure made of Ti-Al intermetallic are meet the request both light weight and resistant to elevated temperatures in the aerospace vehicle. Powder metallurgy (P/M) Ti-22Al-25Nb alloy was prepared by hot pressed sintering at 1050 °C for 1h under a pressure of 35MPa. The flow behavior of a P/M Ti-22Al-25Nb alloy was evaluated by applying a series of compression tests with height reduction of 50% performed in a temperature range of 940-1070 °C and a strain rate range of 0.001-1s^{-1}. The hot deformation behavior of the P/M Ti-22Al-25Nb alloy was investigated by using the true stress-true strain behavior analysis, processing maps and the standard kinetic analysis. Processing maps at the strain of 0.4 and 0.6 were constructed on the basis of dynamic material model theory by applying the flow stress data obtained from isothermal compression tests. The Ti-22Al-25Nb sintered alloy was applied to manufacture three-layer structure part. The forming process was divided into hot bending and diffusion bonding. The hot bending of core sheet was performed at 1100 °C in a vacuum furnace. The diffusion bonding of three layers sheets was carried out at 1200 °C for 120 min and 10 MPa. The microstructures of the core sheet bending forming and bonding joint of three layers sheets was analyzed by SEM.

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Keywords: P/M Ti-22Al-25Nb alloy; Processing map; Bending/diffusion bonding; Multy layers structure

1. Introduction

* Corresponding author. Tel.: +86-451-86418763; fax: +86-451-86418763.
E-mail address: kfzhang@hit.edu.cn

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The Ti2AlNb-based alloys, based on the ordered orthorhombic (O (Cmcm)) phase, have drawn a number of applications in aerospace field due to their higher strength-density ratio, better creep resistance and better workability than conventional titanium aluminides such as TiAl-based and Ti3Al-based alloys (Banerjee et al., 1988). A Ti_2AlNb-based alloy with the composition of Ti-22Al-25Nb (at.%) is an important member of this alloy group with good mechanical properties both at room and elevated temperatures, which has excellent potential to be applied in engineering practice (Dey et al., 2010). The technique of processing map has been proven to be an available and effective tool to optimize hot processing parameters and understand the deformation mechanism for Ti and its alloys (Zeng et al., 2010). Based on the dynamic materials model (DMM), processing map is superimposed by an efficiency of power dissipation map and instability of deformation map at a constant strain value with temperature and strain rate variables. With the help of processing map, people can depict some typical deformation mechanisms, optimize hot deformation parameters and obtain favorable microstructures and properties. In fact, the microstructures and properties are significantly related with the processing parameters (deformation temperature, strain and strain rate). Therefore, in order to obtain the optimized hot processing parameters, the studies on the characterization of hot deformation for the microstructure evolution control during the hot forming are extremely significant and meaningful. Unfortunately, little research work was contributed to the hot deformation behavior of Ti-22Al-25Nb alloy using processing map, especially for the P/M Ti-22Al-25Nb alloy.

The multi layers structure made of Ti-Al intermetallics are meet the request in the aerospace vehicle both light weight and resistant to elevated temperature (Clemens et al., 2000). With the development of aeronautic and astronautic engineering, lower weight and higher efficiency had already been considered as a standard of structural components. Thus, light alloys, such as Ti, TiAl and Ti2AlNb alloys, had been widely developed and applied depending on its outstanding properties at elevated temperature. Especially, Ti2AlNb alloy as a promising structural material at elevated temperature, had been widely studied since it was found by Banerjee (1988). Moreover, as a structural part, multi-layer structure design had the advantages of lower weight, higher specific strength and good integrity.

Therefore, in the present work, the P/M Ti-22Al-25Nb alloy is subjected to study the hot deformation behavior and obtain the optimized hot processing parameters by referring to the microstructure features, the processing map and the kinetic analysis. And three-layer structure had been fabricated with the as-sintered Ti-22Al-25Nb alloy. Combining with their respective advantages, it expected to obtain the structural component in order to meet better requirements.

2. Experimental procedure

The experimental material in this research was determined to be a P/M Ti-22Al-25Nb alloy billet, which was prepared with a nominal composition of Ti-22Al-25Nb (at.%) obtained by argon atomization, and then fabricated by hot pressing at 1050℃ and a pressure of 35MPa for 1h followed by furnace cooling. The initial microstructure and phases determinated by XRD are shown in Figs. 1 and 2, respectively. It is revealed that the microstructure of the P/M Ti-22Al-25Nb alloy is composed of large B2 grains with about grain size of 100-300μm, lamellar O with 1-12μm length and 0.2-1 μm in thickness inside the B2 grain, and little α_2 (Ti_3Al) along the B2 grain boundaries. The cylindrical specimens, with the size of Ø6×9mm for the isothermal compression tests, were prepared by electro-discharge wire cutting. Both the ends and the cylindrical surface of specimens were polished before compression testing. A special high temperature lubricant was coated on the two ends of specimen, and tantalum chip was placed between die surface and specimens to prevent cementation. Compression tests were conducted on a computer controlled Gleeble-1500D thermal simulator at the deformation temperatures range of 950-1070 °C with 30 °C intervals, strain rate of 0.001, 0.01, 0.1 and 1 s^{-1} and the height reduction of 50%. All the specimens were heated to the desired temperature and kept for 180 s before thermal compression. Deformed specimens were water quenched to maintain the deformed microstructure. True stress-true strain data was automatically recorded in the thermal compression process. To observe the microstructure evolution, the deformed specimens were sectioned in the center along the compression axis and the cut surface of the half specimen was prepared for microstructure examination using standard procedures.

The forming process of three-layer structure was divided into two stages: the core sheet bending forming and three layers sheets diffusion forming. Bending forming was carried out at 1100 °C in vacuum furnace. Diffusion bonding of three layers sheets was implemented at 1200 °C, holding 10 MPa for 120 min in order to ensure good diffusion. The forming mold was manufactured with graphite. The microstructures of the bending core sheet and diffusion bonding joint of three layers sheets were observed by SEM. In addition, the microstructures of the as-received material in pre-forming and post-forming were analyzed.

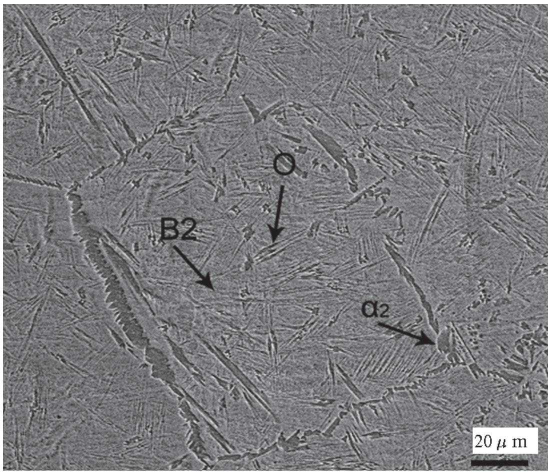


Fig. 1. Initial microstructure of the P/M Ti-22Al-25Nb alloy.

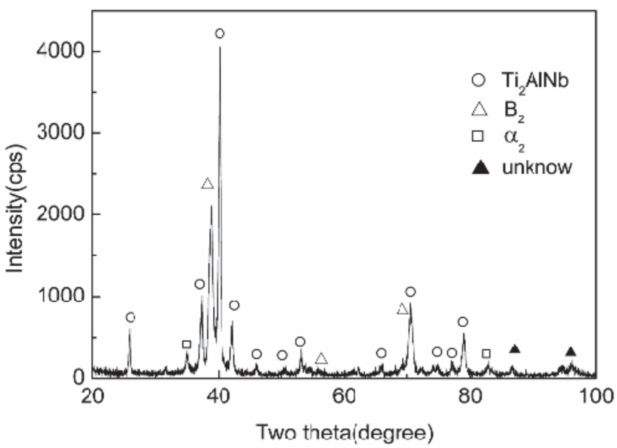


Fig. 2. XRD patterns of the P/M Ti-22Al-25Nb alloy.

3. Results and discussion

3.1 True stress-true strain curves of tensile for the P/M Ti-22Al-25Nb alloy

The typical true stress-true strain curves obtained under various compression deformation conditions are shown in Fig. 3(a) and (b). The curves obtained at different strain rates and test temperatures of 980°C and 1040°C, which represent typical behavior at lower and higher temperatures, respectively. At the lower temperatures in the α_2 $+\beta/B_2$+O phase field (≤1010 °C), the material exhibits severe hardening followed by continuous flow softening, and the softening tendency presents more obviously at higher strain rate. However, at the higher temperatures in the α_2+B_2 phase field (≥1040 °C), the curves are of steady-state type in which the true stress remains constantly with increasing of strain, indicating the mechanism of softening are sufficiently fast to balance the rate of work-hardening and mechanisms like dynamic recovery or DRX are suggested. Moreover, the true stress-true strain curves display oscillation at higher strain rates (＞0.01 s^{-1}) in both the $\alpha_2+\beta/B_2$+O phase field and the α_2+B_2 phase field which is an indication of DRX, unstable deformation, or cracking.

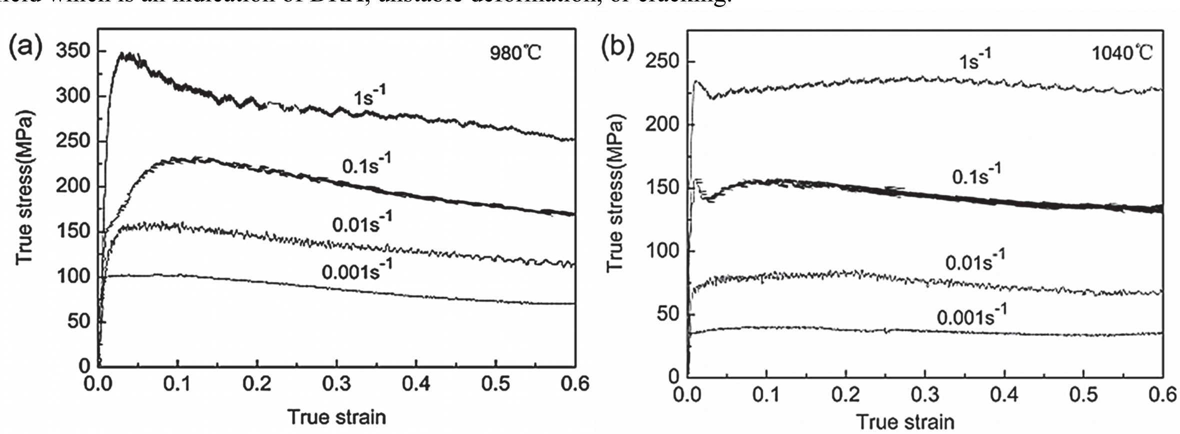


Fig. 3. True stress-true stain curves for the P/M Ti-22Al-25Nb alloy at different deformation temperatures: (a) 980°C and (b) 1040°C.

It should be noted that several similar flow behaviors may result in different deformation mechanisms during the hot working. So, it is difficult to predict the deformation mechanisms by relying on the shapes of true stress-true strain curves only. For instance, the flow softening may indicate DRX, lamellar globularization or adiabatic heating, etc. Similarly, the steady-state type flow behavior has been observed during the dynamic recovery as well as superplasticity. Therefore, further analysis of flow stress behavior will be conducted in the following sections by processing maps.

3.2. Processing maps of the P/M Ti-22Al-25Nb alloy

The relationship of $\ln\dot{\varepsilon} - \ln\sigma$ was analyzed by applying the peak flow stress data at different strain rates and temperatures. The linear correlation coefficient was calculated to be 0.979-0.998, which indicates that the DMM theory could be applied to construct the processing maps for the P/M Ti-22Al-25Nb alloy.

The processing maps of the P/M Ti-22Al-25Nb alloy at the true strain of 0.4 and 0.6 are shown in Fig. 4. On the processing map, the contour numbers represent the constant efficiency of power dissipation in percent, which indicate different dominant deformation mechanisms. The shaded areas represent the instability domains, and the thick dash curves of zero indicate the boundary between stability and instability domains. In generally, the efficiency of power dissipation increases with the decreasing of strain rate and increasing of strain, which is similar to other titanium alloy investigated by many researchers, as shown in Fig. 4. Only one instability domain can be found in the processing map at the strain rates higher than 0.1 s^{-1} and temperatures lower than 980 °C, increasing with the increasing of strain. Moreover, a domain with peak efficiency of 59% is observed at the strain of 0.6, occurring at 1070 °C/0.001 s^{-1}.

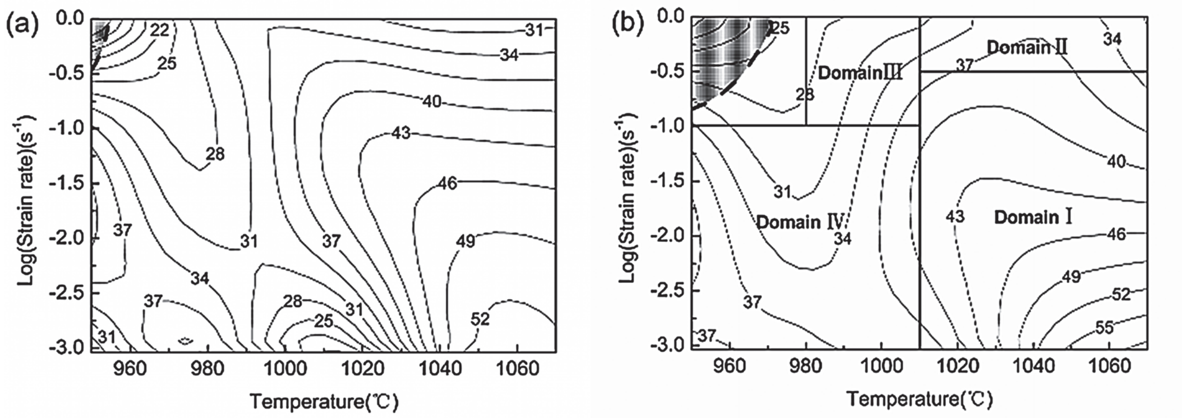


Fig. 4. Processing maps at various true strain: (a) 0.4 and (b) 0.6.

3.3. Bending/diffusion bonding processing of the P/M Ti-22Al-25Nb alloy sheet

Since the SPF/DB technology proposed by Rockwell at 1973, it was widely applied to titanium multi layer structures in aerospace vehicle. The SPF/DB structure have good performances both light weight and high strength. But, that technique is difficult to adopted for make Ti-Al intermetallics multi layer structure, because Ti-Al intermetallics have low superplasticity and diffusion bond ability than titanium alloy. So, Bending/diffusion bonding processing was adopted to manufacture of Ti-Al intermetallics multi layer structure. Fig.5 showed bending mold and bonding schematics. As can be seen from Fig.1, the forming process of three-layer structure was divided into two stages. Firstly, the bending formation of the core sheet was performed at 1373 K in a vacuum furnace, holding 10min and 10MPa. Secondly, the forming process of three-layer structure, that is, diffusion bonding was carried out at 1150 °C between top-face sheet and core sheet and down-face sheet, holding 120min and 10MPa. Graphite foils were selected as separation between sheets and blocks in order that it was easy to demould after post-forming.

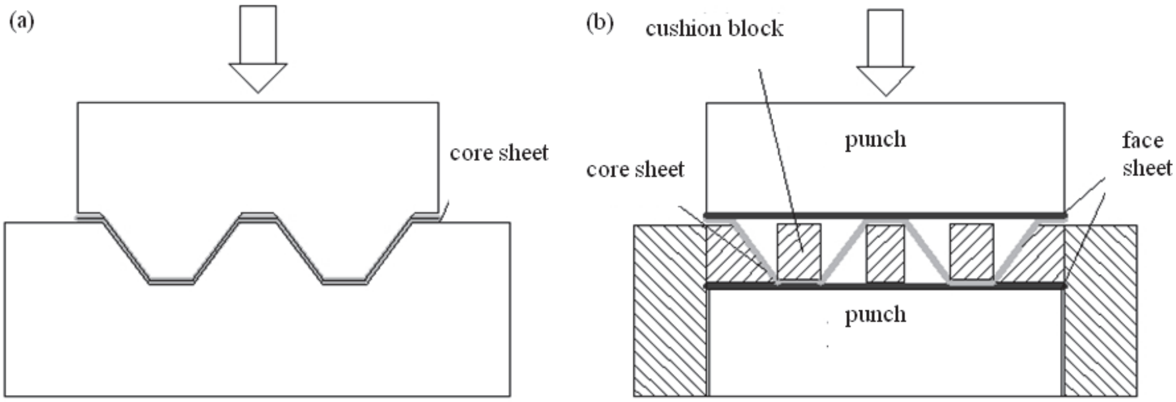
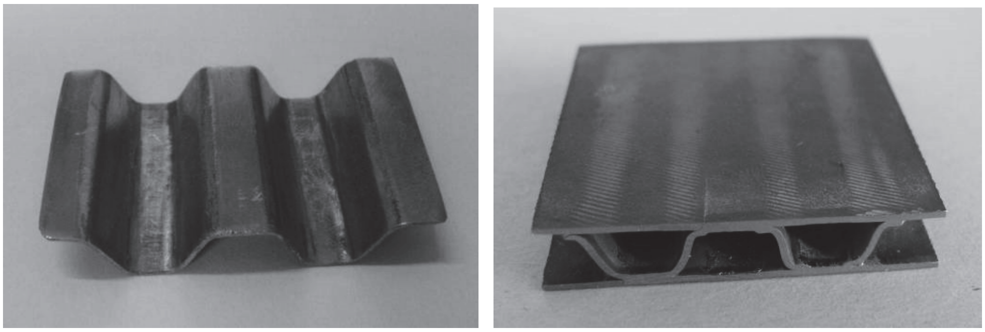


Fig. 5. (a) Bending forming and (b) diffusion bonding.

The bending forming object of the core sheet was presented in Fig. 6 (a). Good quality surface and precise shape were obtained in the bending forming. Diffusion bonding between top-face sheet and core sheet and bottom-face sheet Fig. 6(b).



(a) (b)

Fig. 6. Core sheet bending part (a) and three-layer structure part (b).

The microstructures of the bending core sheet and diffusion bonding joint of three layers sheets were observed by SEM (see Fig. 7), apparently the diffusion bonding joint at 1200 °C (b) is better than the one at 1150 °C (a).

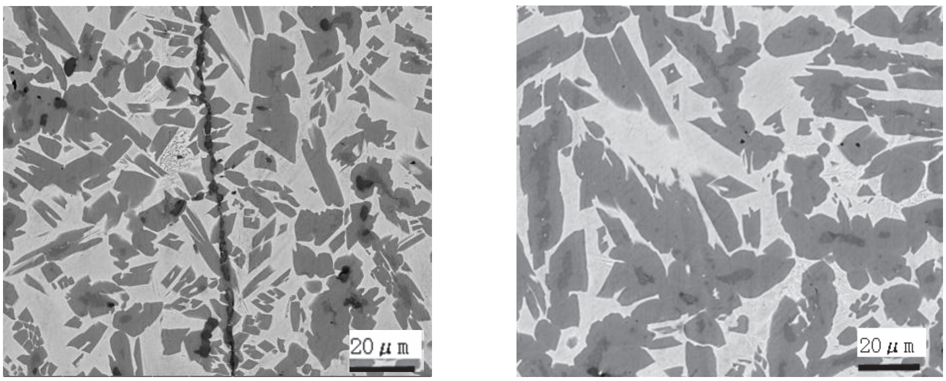
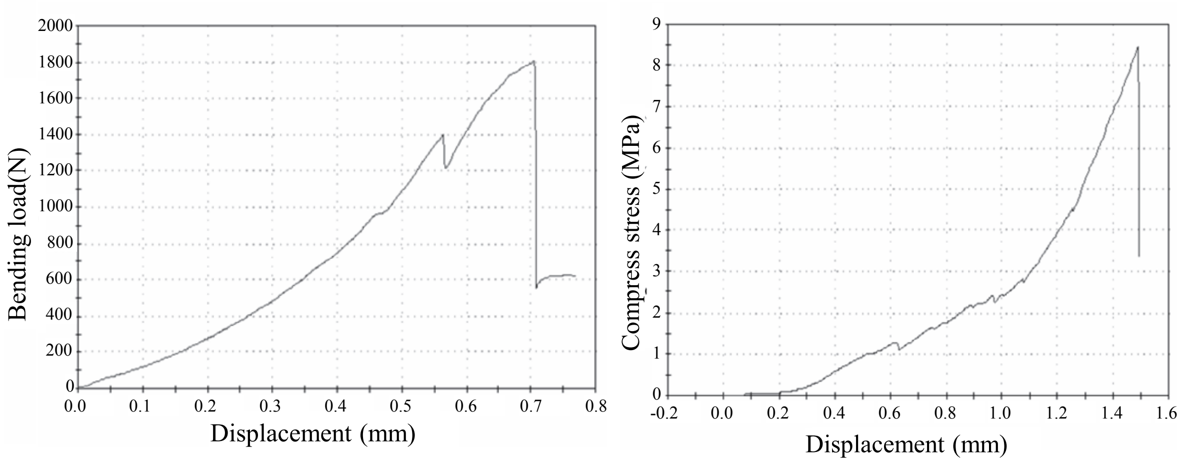


Fig. 7. Microstructure of joints diffusion bonded at (a) 1150°C and (b) 1200°C.

The compressing testing and three points bending testing were performed at 800 °C. The compressive strength and the bending strength were obtained, respectively (see Fig. 8). From the experimental results, it was found that the sintered Ti22Al25Nb alloy owned good shaping ability and bonding ability at elevated temperature.



(a) (b)

Fig. 8. Results of compressing testing (a) and three points bending testing (b).

4. Conclusions

The processing map (ε = 0.6) for the P/M Ti-22Al-25Nb alloy exhibits a workability domain (domain Ⅰ) of DRX in the form of fine equiaxed grains with serrated grain boundaries at the temperatures range of 1010-1070 °C and strain rates ranging from 0.001 to 0.3 s^{-1} with the power dissipation efficiency from 36% to 59%. Lamellar globularization occurs in the domains II, III and IV with the power dissipation efficiency ranging from 26.7% to 36%. Ti22Al25Nb alloy three-layer structure was successful fabricated by the processes of bending and diffusion bonding. The qualities of bending and diffusion bonding were examined, and then the microstructures of the three-layer structure were observed.

References

Banerjee, D., Gogia, A.K., Nandy, T.K., Joshi, V.A., 1988. A new ordered orthorhombic phase in a Ti_3Al Nb alloy. Acta Metallurgica, 36(4), 871-882.

Clemens, H., Kestler, H., 2000. Processing and applications of intermetallic γ-TiAl-based alloys. Advanced Engineering Materials, 2(9), 551-570.

Dey, S.R., Roy, S., Suwas, S., Fundenberger, J.J., Ray, R.K., 2010. Annealing response of the intermetallic alloy Ti–22Al–25Nb. Intermetallics, 18(6) 1122-1131.

Zeng, L.Y., Yang, G.J., Ge, P., Mao, X.N., Zhao, Y.Q., Zhou, L., 2010. Processing map of one kind of metastable β titanium alloy. Rare Metal Materials and Engineering 39(9), 1505-1508.