Three-layer structure hot bending/diffusion bonding process of reactive sintering Ti-22Al-25Nb alloy and its load response at high temperature

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Abstract Three-layer structure part as a ideal structure part, that had light weight and enough strength to be widely used, was prepared combining hot bending and diffusion bonding processes in this paper. The Ti-22Al-25Nb sintered alloy that owned better using temperature was applied to manufacture three-layer structure part. The forming processes of manufacturing three-layer structure was divided into hot bending forming of the core sheet and diffusion bonding of three layers sheets. Firstly, the hot bending of core sheet was performed at 1423K for 10MPa in a vacuum furnace. Secondly, the diffusion bonding of three layers sheets was carried out at 1473K for 120min and 10MPa. Furthermore, in order to evaluate the quality and performances of three-layer structure, the microstructure of bonding joint of three layers sheets was analyzed by SEM, and the properties of three-layer structure part were tested at 1073K by compressing test and three-point bending test. Compressing load and compressing strength were 9014N and 10MPa, respectively. Bending strength was up to 54MPa. In addition, the experimental results also indicated that three-layer structure that prepared using the Ti-22Al-25Nb sintered alloy owned good properties.

1. Introduction
With the development of aeronautic and astronatic engineering, lower weight and higher efficiency had been already 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[1-3]. Especially, Ti2AlNb alloy, as a promising structural material at elevated temperature, had been widely studied since it was found by Banerjee D[4]. It had been regarded as a promising candidate of a structural material substituting for Ni-based alloy, which was expected to apply for higher temperature than that of Ti-based alloy. Moreover, as an excellent structural part, multi-layer structure design had the advantages of lower weight, higher specific strength and good integrity[5,6]. At present, however, the studies on Ti2AlNb-based alloys mainly focused on the microstructures and basic mechanical properties[7-11]. As to the applications of Ti2AlNb alloy serving as structural parts, it rarely reported. So, in this paper, the Ti22Al-25Nb alloy was prepared by reactive sintering with element powders, and then three-layer structure had been fabricated with the Ti-22Al-25Nb sintered alloy. Combining with their respective advantages, it expected to obtain the structural component in order to meet better requirements.
2. Material and experimental procedure

The as-received material was prepared by step reactive sintering with element powders. And then sheets to be forming were grinded and polished prior to forming. The forming process of three-layer structure was divided into two stages: bending forming of the core sheet and diffusion bonding of three layers sheets. Firstly, bending forming of the core sheet was carried out at 1423K in vacuum furnace. Secondly, diffusion bonding of three layers sheets was implemented at 1473K, holding 10MPa for 120min in order to ensure to obtain good diffusion joint. The forming molds were manufactured with graphite. The microstructure of diffusion bonding joint of as-received three-layer structure were observed by SEM(with BSE). In addition, the microstructures of the as-received material in pre-forming and post-forming were analyzed. In order to estimate the basic properties of three-layer structure during using temperature, compressing test and three-point bending test were conducted at 1073K on Instron 5500R with a high temperature furnace, the rate was used at 1mm/min.

3. Results and discussion

3.1. The as-sintered alloy and its microstructure analysis

Fig.1 showed the sintered alloy and its microstructure at sintered state. It was observed in Fig.1 that the as-sintered alloy owned good quality( the final density was 5.218g.cm\(^{-3}\), closing to the density of 5.3g.cm\(^{-3}\) in as-casted alloy)[12]. The microstructure of the sintered alloy indicated that no obvious holes were observed. The laths of O phases(the grey represented O phase) uniform dispersed in B2(the white indicated B2 phase) matrix ( phases identification by XRD in previous experiments by authors). Despite of ideal phases of O and B2 phases in the as-sintered alloy, it was found that the microstructure of the sintered alloy seem to be different from the literatures reported which mentioned and described the acicular O phases in B2 substrates. The reason that led to the coarse laths of O phases could be cooling condition after sintering. In addition, the reactive mechanism and diffusion condition during reactive sintering course were also different from that of as-casted alloy. On the other hand, O phase owning better strength(as orthorhombic structure) and B2 phase having better ductility(that owned b.c.c structure) had been studied by many researchers[13]. Therefore, lots of O phases crisscross distributing in B2 matrix would benefit the forming property and further contribute to the followed fabrication of three-layer structure.

![Figure 1 The sintered alloy and its microstructure at sintered state](image)

3.2. The forming process of three-layer structure

Fig.2 showed bending mold and bonding schematics. As can be seen from Fig.2, the forming process of three-layer structure was divided into two stages. Firstly, the bending formation of the core sheet was performed at 1423K in a vacuum furnace, holding 10min and 10MPa. Secondly, the forming process of three-layer structure, that is, diffusion bonding was carried out at 1473K between top-face sheet and core sheet and bottom-face sheet, holding 120min and 10MPa. Graphite foils were selected as separation between sheets and cushion blocks in order that it was easy to demould after post-forming.

![Figure 2 The forming process of three-layer structure](image)
Fig. 3 showed the products pictures of the core sheet after bending forming and as-fabricated three-layer structure part. The bending forming object of the core sheet was presented in Fig. 3(a). Good quality surface and precise shape were obtained in the bending forming. The bending forming of core sheet was performed at 1423K in a vacuum furnace. After bending forming, the core sheet was ground and polished for followed diffusion bonding meeting good effect. Diffusion bonding of three-layer structure was a crucial process, so, the temperature of diffusion bonding was set at 1473K in order to have enough diffusing time, higher than that of bending forming of the core sheet. The more appropriate process parameters were selected by means of previous optimization experiments of diffusion bonding at different conditions by authors. Therefore, diffusion bonding between top-face sheet and core sheet and bottom-face sheet was conducted at 1473K in a vacuum furnace, the bonding positions were held by pressure of 8MPa for 2h. As can be seen in Fig. 3(b), three-layer structure part was successfully fabricated. Its shape and size met design requirements. Next, as to its bonding qualities and mechanical properties during the range of using temperature, the microstructure of bonding joint was analyzed, moreover, the compressive strength and flexural strength were tested.

Fig. 4 showed the cross-sectional microstructures of diffusion bonding joint and non-bonding position. Diffusion bonding had a key effect on three-layer structure. In addition, quality of bonding joint would make sure if three-layer structure meeting good standard and owning quality qualified was fabricated. That is, quality of diffusion bonding is a key factor on evaluating properties of three-layer structure. In Fig. 4(a), the microstructure of diffusion bonding joint was observed. It was found that bonding interface of three-layer structure presented good bonding quality and homogeneity, the phases in two different sheets seemed to be full contact and growth until full fusion. The flaw between two layers sheets was hardly observed. But, the presence of bonding interface seemed to be observed by means of the
directions of O phases in two different sheets. From the morphology of the bonding joint, it indicated that the Ti-22Al-25Nb sintered alloy had good diffusion bonding ability, even if there no filler metal in the boundary of bonding joint. Thus, no differences between the microstructures of bonding joint and substrates would contribute to homogeneity and compatibility in the whole part.

In addition, it can be seen in Fig.4(b) that the microstructure of O phases of non-bonding positions became coarser than that of bonding joint in three-layer structure. The positions of bonding joint under pressure bore biaxial compressive stress could result in restricting precipitation and growth of O phases. However, non-bonding positions was at free condition, and the final forming temperature was up to 1473K, moreover, a slower cooling after forming also provided more time for the growth of O phases. All these during forming course would lead to precipitation and growth of O phases having conditions. Meanwhile, compared to the microstructure of the as-sintered alloy, it seemed that there no obvious difference between the two. The reason that could undergo the almost same environmental conditions gave rise to no obvious difference in the final morphologies.

![Cross-sectional microstructures of diffusion bonding joint(a) and non-bonding position(b)](image)

Figure 4 Cross-sectional microstructures of diffusion bonding joint(a) and non-bonding position(b)

3.3. Compression test and three-point bending test
As a structural part, the basic mechanical performances of three-layer structure during using temperature range would verify its applicability. So, compressing test and three-point bending test were conducted in order to evaluate the basic properties of three-layer structure part. The three-layer structure parts were machined with a length of 35mm and a width of 35mm and a height of 6.6mm.

Fig.5 showed schematic of compression test(a) and compression curve of three-layer structure at 1073K(b).
Compression test schematic was given in Fig.5(a). Compressing test was performed at 1073K with the rate of 1mm/min. The load increased with displacement increasing. The maximum load was 9014N while failure behavior of three-layer structure part occurred. From compression curve of three-layer structure at 1073K in Fig.5(b), no obvious plastic deformation behavior occurred. The compressing strength was up to 10MPa (the effective area is projected area of the core sheet). The compressing strain was 22.63% until three-layer structure broken. The three-layer structure part had no obvious deformation due to the sintered alloy owning poor plasticity, even if the temperature was kept 1073K. Moreover, three-point bending test was conducted at the same conditions. The maximum load was up to 1800N. The maximum bending strength was up to 54.8MPa before brittle failure.

4. Conclusions
In this paper, three-layer structure was successful fabricated by the processes of bending forming and diffusion bonding, using the Ti-22Al-25Nb sintered alloy which was prepared by reactive sintering with element powders. The qualities of bending and diffusion bonding were examined, and then the microstructures of the three-layer structure were observed and analyzed, compared to the microstructure of the as-sintered alloy. Furthermore, in order to evaluate the property and homogeneity for applications, the compressing testing and three points bending testing were performed at 1073K. The maximum compressive load and compressive strength of 10MPa were obtained. And the bending strength was up to 54MPa. From the experimental results, it was found that the sintered Ti22Al25Nb alloy owned good shaping ability and bonding ability for its applications at elevated temperature. Especially, three-layer structure that was fabricated with the Ti-22Al-25Nb sintered alloy, still owned good resistances of compression and bending by the tests of compression and three-point bending at high temperature.

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