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Microstructure and fracture behaviour of Ti_3Al/TC4 dissimilar materials joints welded by electron beam

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Abstract. **Electron beam was used to join TC4 alloy to Ti_3Al-based alloy. The composition of the weld was analysed by XRD and TEM and the results showed that the weld mainly composed of α' martensites. The change of heat input had little influence on the composition of the weld but can make the grain size increasing. The fracture path of the joints was mainly decided by the microstructure of the weld and started from coarse grain zone to HAZ and base metal of Ti_3Al alloy.**

Keywords. **Microstructure; dissimilar materials joint; electron beam welding; fracture behaviour.**

1. Introduction

Joining dissimilar materials became a focus because the composite structure can exploit the special advantages of two different materials. Titanium alloy TC4 (Ti–6Al–4V) and Ti_3Al-based alloy are widely used in aerospace and military industries for their remarkable strengths, weight ratio, and resistance to high temperature creep (Kestner-Weykamp *et al* 1989; Yu *et al* 1997; Boyce and Ritchie 2001; Shademan *et al* 2004). Many studies have been done to investigate the weldability of homogeneous material joint of the two materials (Barreda *et al* 2001; Casalino *et al* 2005; Saresh *et al* 2007; Prasad *et al* 2008). However, there are only a few reports on the dissimilar materials joint between titanium alloy TC4 (Ti–6Al–4V) and Ti_3Al-based alloy. The two materials have a high melting point and weak oxidation resistance, so it is difficult to join the two materials by conventional welding methods such as TIG and MIG. As to electron beam welding, it is carried out in the vacuum environment to avoid oxidation and has high energy density to melt refractory metals easily (Ferro *et al* 2005; Kim and Kawamura 2007).

In the present study, electron beam was used to join TC4 alloy and Ti_3Al alloy. The microstructure and phase composition of weld were analysed by OM, TEM and XRD. The fracture behaviour of the joints during tensile tests was also discussed according to the fracture surface and fracture path.

2. Experimental

The two alloys used for electron beam welding are all hot-rolled sheet materials, with a thickness of 3·1 mm. The microstructure of the Ti_3Al-based alloy is composed of $\alpha2+$ $B2+o$ three-phase equiaxial grains. The TC4 alloy is composed of typical biphase $\alpha+\beta$. The chemical compositions of two base metals are listed in tables 1 and 2.

All experiments were conducted using TECHMETA MEDARD 45 model pulsed electron beam welding machine with an accelerating voltage of 55 kV, and welding speed of 400 mm/min, and electron beam current from 9–18 mA, corresponding to heat input range from 90·75–148·5 J/mm for full penetration of butt welding.

The welded samples were sectioned into metallographic specimens. After the specimens were etched by a solution (10 ml HF, 20 ml HNO_3, 30 ml $C_3H_8O_3$), microstructural characterization was performed using light microscopy. A slice was also cut from fusion zone, and then thinned by plasma-pump to observe with transmission electron microscopy (TEM). X-ray diffraction (XRD) was used for primary phase identification of the fusion zone. The welded samples were also sectioned into definite size to measure tensile properties of the joints at a tensile speed of 0·5 mm/min.

3. Results and discussion

3.1 *Appearance and transverse pattern of dissimilar materials joint*

Figure 1 shows appearances of the joints made by different electron beam currents. Full penetration butt weld could be obtained by EBW with two different welding parameters. An asymmetric funnel-like joint can be seen from figure 2 due to the different thermophysical parameters of two different base metals. The front widths, surface indentations

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Table 1. Chemical composition of TC4 alloy (wt%).

Elements	Ti	Al	V	Fe	C	N	H	O
wt%	Bal.	5·82	3·99	<0·05	0·019	0·0032	0·0007	0·063

Table 2. Chemical composition of Ti_3Al-based alloy (wt%).

Elements	Ti	Al	Nb	Fe	Mo	Cr	Si	Cu	Mn	C
wt%	Bal.	9·83	26·10	0·07	0·07	0·09	0·07	0·02	0·02	–

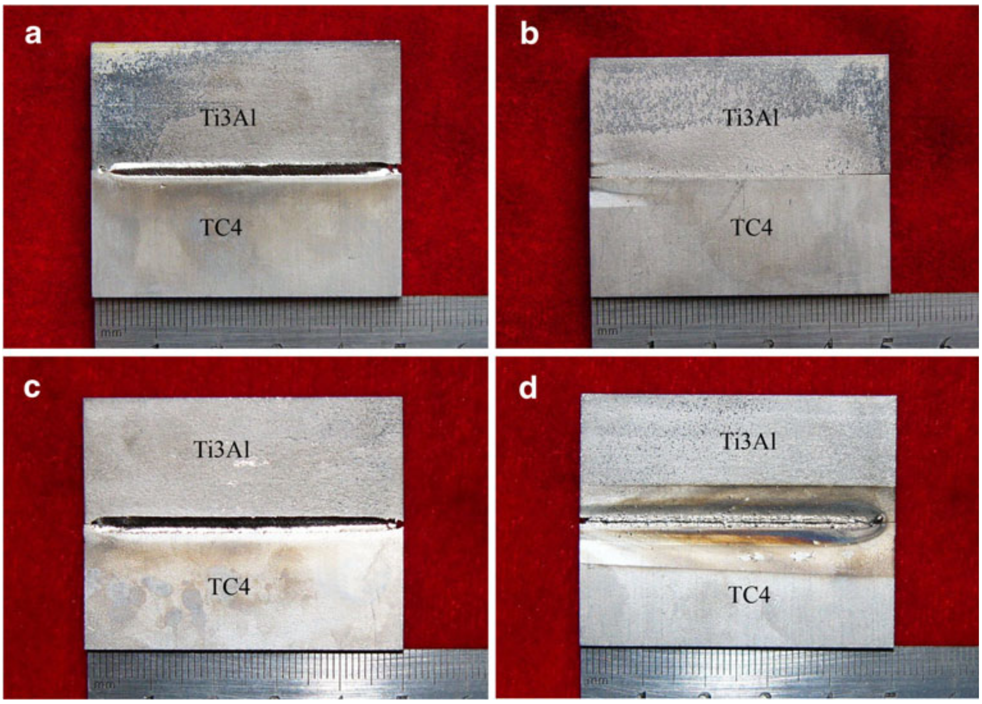

Figure 1. Appearances of welds made by different electron beam currents: (**a**) front face (beam current, 9 mA), (**b**) back face (beam current, 9 mA), (**c**) front face (beam current, 18 mA) and (**d**) back face (beam current, 18 mA).

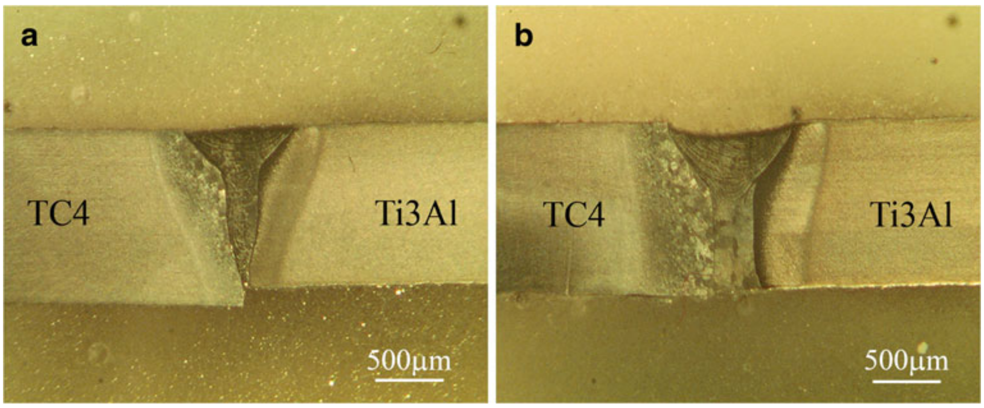

Figure 2. Transverse patterns of joints with different beam currents: (**a**) beam current, 9 mA and (**b**) beam current, 18 mA.

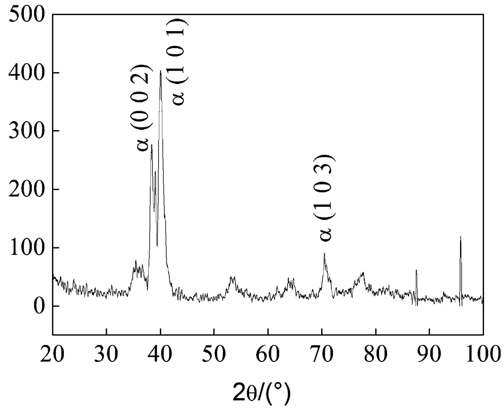

Figure 3. XRD spectra of weld metal.

and penetration degree of the joints increased distinctly with the rising of beam current.

3.2 *Phase composition of weld metal*

XRD was utilized to determine the phase that developed in fusion zone microstructure. Figure 3 shows that the weld is mainly composed of α phase and a little residual β phase. But when joining homogeneous materials joint of Ti_3Al-based alloy β phase was found as a predominant phase in the weld as previously described by Feng *et al* (2005). For joining Ti_3Al-based alloy separately, metastable β(B2) phase was predominant in the weld as the concentration of Nb element in the

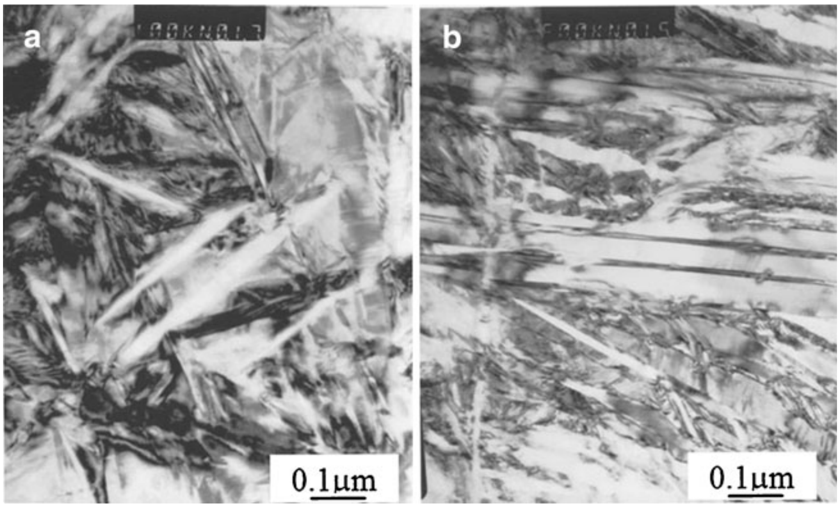

Figure 4. Martensites form in the weld: (**a**) needle-like martensites and (**b**) lath-like martensites.

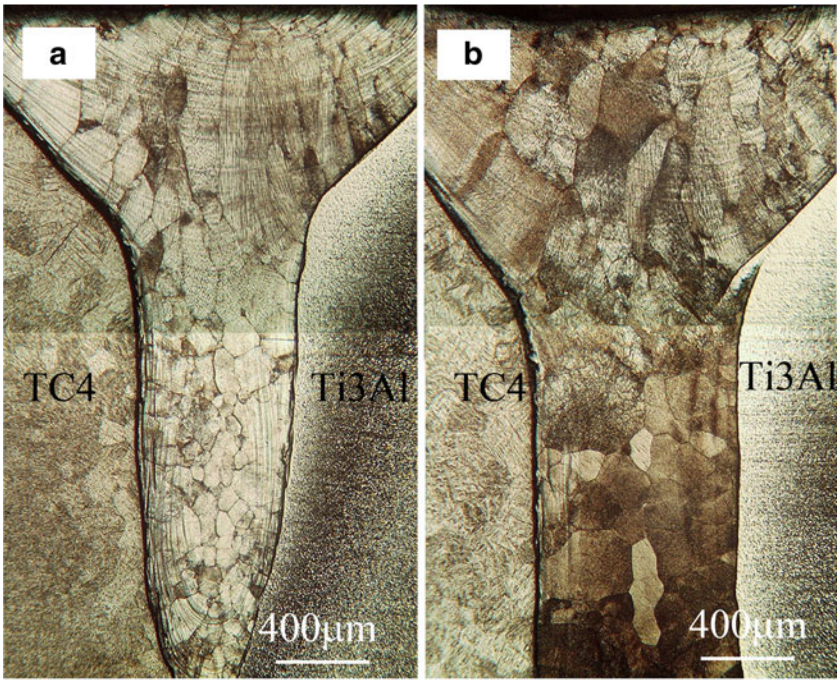

Figure 5. Optical microstructure of joints made with different heat inputs: (**a**) E= 90·75 J/mm and (**b**) E=148·5 J/mm.

fusion zone was high. But the concentration of Nb element which acted as β stabilizing element in the fusion zone was less for the mixture of the liquid Ti_3Al-based alloy and Ti–6Al–4V alloy and the Al element which acted as α stabilizing element was added in the fusion zone, the composition of the weld was changed to α phase when joining Ti_3Al-based alloy to Ti–6Al–4V alloy. TEM observation also confirmed that there were many α' martensites in the weld which presented needle-like and lath-like form as shown in figure 4. This weld zone α' martensites was also independent of the welding parameters.

3.3 *Effect of heat input on joint microstructure*

The welding beam current indicates the value of the heat input during welding. The welding heat input was calculated by the formula, $E = 60UI/v$, where E is the heat input, U the accelerating voltage, I the beam current and v the welding speed. In the experiments, the beam currents varied and the other process parameters were kept unchanged.

The beam currents had obvious effect on the microstructure of weld. The columnar grain at the top of the weld was fine when the heat input was low as shown in figure 5. As the beam current increased the size of column grain at the top of the weld and the equiaxed grain at the lower position of the weld all became more coarse.

The relationship between the equiaxed grain size at the lower position of the weld and heat input can be seen from figure 6. The grain size is mainly related with the welding temperature and the high temperature dwelling time of β phase. But the grain size increase became gradual when heat input exceeded 100 J/mm. This can be attributed to the change of the electron beam heating mode. When the beam current increases to a critical value, the penetration became excessive to make the heat run off along the depth direction. So the heat accumulation effect in the fused metal was weakened and the growth tendency of the weld grain was decreased.

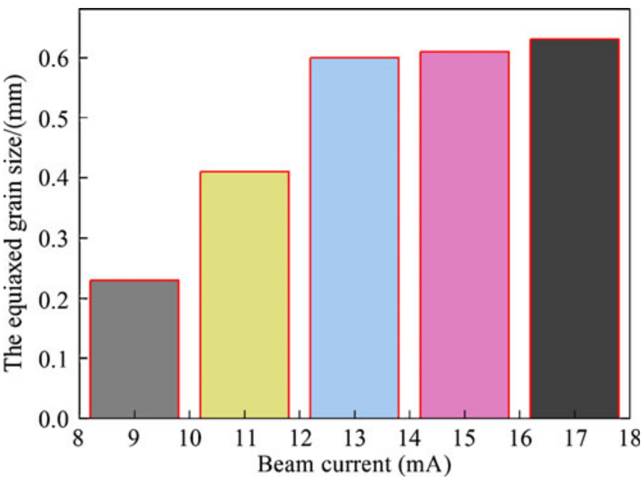

Figure 6. Grain size varying with beam currents.

3.4 *Fracture behaviour of joints during tensile tests*

The tensile strength mainly depended on the grain size in the weld, especially the grain at the top of the weld. The joint strength decreased obviously with increasing beam current. The highest tensile strength of the dissimilar materials joint can reach 831 MPa, which is about 92% of Ti_3Al-based alloy strength.

The fracture path was described in figure 7 and the fracture surface presents typical brittle fracture characteristic as shown in figure 8. The joint was cracked at the columnar grain zone at the top of the weld and then the crack propagated into the HAZ and base metal of Ti_3Al-based alloy during tensile tests.

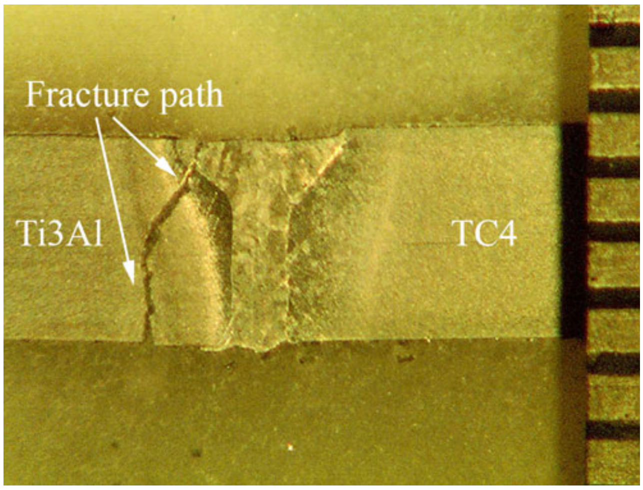

Figure 7. Fracture path of welded joint.

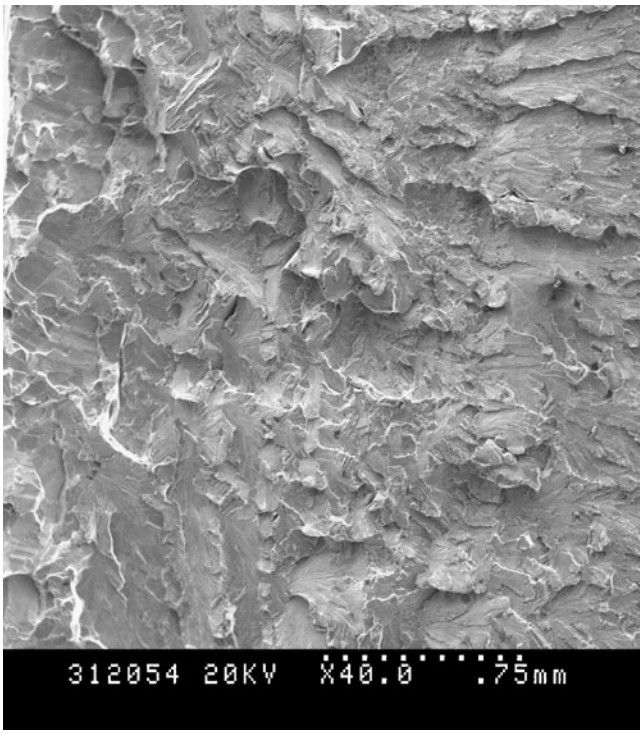

Figure 8. SEM photo of the joint fracture surface.

4. Conclusions

(I) EBW had better applicability to join TC4 alloy and Ti_3Al-based alloy and could obtain weld of two dissimilar materials.

(II) The weld zone is mainly composed of α' phase in the weld owing to the high cooling rate of the welding process and the decrease of the β phase stabilizing element(Nb) along with the increase of the α phase stabilizing element(Al) in the fusion zone. The heat input had distinct effect on the grain size rather than on the phase structure of the weld.

(III) The fracture of the joint started at columnar grain zone at the top of the weld and had brittle fracture characteristic. The highest tensile strength of the dissimilar metals joint could reach 831 MPa.

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