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Phase distribution of friction welded Ti6Al4V/γ-TAB

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Abstract. A Ti-6Al-4V rod and a γ-TAB rod 24.5mm in diameter and 100mm length were joined by friction welding. Quantitative phase analysis was carried out by high energy synchrotron radiation with a local resolution of 1mm over the welding seam. Rietveld calculations were done by MAUD using complete Debye-Scherrer cones to avoid the influence of crystallographic textures. The base material Ti-6Al-4V consists of hexagonal α-Ti and of cubic β-Ti and γ –TAB consists of tetragonal γ-TiAl and of hexagonal α_2-Ti_3Al. New intermetallic compounds were not found.

Introduction

Titanium alloys are widely used for structural applications, especially where high specific stiffness is required at elevated temperature. One of the standard Ti-alloys is Ti-6Al-4V which belongs to the group of α + β alloys, is relatively cheap compared to titaniumaluminide alloys but is limited in high temperature application up to 550°C. Ti-6Al-4V presently is the most widely used titanium alloy, accounting for more than 50% of all titanium tonnage in world. The aerospace industry accounts for more than 80% of this usage. Automotive, marine, and chemical industries also use small amount of Ti-6Al-4V. In contrast, titaniumaluminide alloys have a relatively high melting temperature, a good oxidation resistance and good strength at high temperatures. Friction welding is one of the joining techniques which is able to weld dissimilar materials such as steel with Al-alloys or Ti alloys with Al-alloys. In our case joining takes place during high speed rotation of the Ti-6Al-4V rod and some seconds compression of the Ti-6Al-4V rod against the γ-TAB rod with high pressure. Variation of process parameters like rotation speed, pressure power and temperature influence the quality of the weld. The advantages of friction welding are material savings and the possibility of material substitution, rationalization and automation possibility in fabrication, low specific energy requirement, favourable possibilities of quality assurance, no

need for filler metals or shielding gases and the lack of spatter, fumes or radiation during welding [1].
High energy synchrotron radiation is known for its high penetration power, which is in the same order than thermal neutrons [2], so that rods of 24mm can be investigated in a non-destructive way. This is necessary to analyze phase composition, local textures and strains on identical samples. In the present investigation the quantitative phase analysis of friction welded Ti-6Al-4V and γ-TAB is described.

Materials and experiments

The base materials for the friction welding were two rods of 24.5mm diameter and 100mm length. Table 1 gives the chemical composition of the base materials. γ-TAB is a titanium-aluminid alloy of the second generation consisting of tetragonal γ-TiAl as majority phase and hexagonal α_2-Ti_3Al. The present γ-TAB rod was cut from an ingot with relatively coarse grains. The Ti-alloy Ti-6Al-4V consists of hexagonal α-Ti and cubic β-Ti.

Table 1 Chemical composition of the γ-TAB and Ti6Al4V titanium alloys used. (wt. %)

Alloy	Al	Mn+Cr+Nb	B+Si	V	Ti	Fe	O	N	C	H
γ-TAB	47.0	3.5	0.8		Balance					
Ti6Al4V	6.21			4.07	Balance	0.18	0.17	0.01	0.02	0.005

Local measurements were carried out at the high energy beam line BW5 at the Doris storage ring (HASYLAB at DESY, Hamburg, Germany). Due to the used wavelength of 0.1039Å the scattering angles were very low compared to conventional Cu-Kα X-rays. Thus, a MAR345 image plate detector allows the collection of a set of complete Debye-Scherrer cones simultaneously. The beam line and the use for texture analysis were already described by Wcislak et al. [3]. In addition, the global texture of the base materials was measured at the neutron texture diffractometer TEX-2 [4] at the FRG-1 (GKSS-Research Center Geesthacht, Germany). Figure 1 shows the γ-TiAl texture of the γ-TAB rod (neutron diffraction) and an image plate picture (synchrotron diffraction).

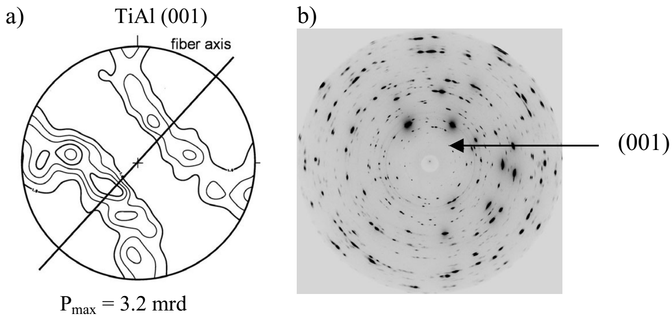

Figure 1 γ-TiAl texture of the γ-TAB rod a)TiAl (001) pole figure with 3.2 mrd b) image plate picture taken in 1 sec.

The γ-TiAl texture is typical for γ-TAB ingots with its <111> fiber [5]. The projection plane of the pole figure is parallel to the contact plane of the weld. γ-TAB ingots have relatively large grains which can be seen as spotty distributions along the individual Debye-Scherrer cones. In the case of local measurements this coarse grained microstructure had influenced the results due to the poor grain statistics.

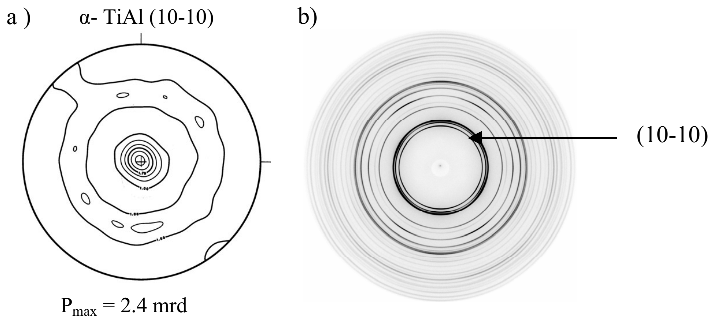

Figure 2. Texture of the Ti-6Al-4V rod a) α -Ti (10-10) pole figure with 2.4 mrd b) image plate picture taken in 1 sec.

Figure 2 shows the α-Ti texture with the (10-10) reflection as example. The <10-10> texture is typical for round extruded α-Ti but the texture sharpness is comparably low (2.4 mrd – multiple of random distribution). In this case the fiber axis of the α-Ti texture was perpendicular to the welding plane.

In order to study the phase composition over the weld a local resolution was obtained by an incoming slit of 1x1mm². A compromise had to be found between the right volume for a sufficient grain statistics and the necessary local resolution. It has to be noticed that the welded zone is only 0.5mm broad. A z-scan to take a set of image plate pictures over the weld in steps of 0.5 mm was performed. A typical counting time for an image plate picture at each z-position was taken in 1 second.

Results

Data analysis started with the calculation of the sum-diffraction pattern to integrate over the complete Debye-Scherrer cone. As an example figure 3 shows the image plate picture taken at the weld. Due to the small welded zone, the used local resolution of 1mm in z covers beside the weld also Ti-6Al-4V and γ-TAB. Sum-diffraction patterns are preferred because of integration over the texture. The presence of crystallographic texture can be seen by the intensity distribution along the Debye-Scherrer cones. Texture free materials have a unique homogenous intensity distribution while textured materials show intensity variations. It has to be noticed that one image plate picture gives only a small area of a complete pole figure [6]. Nevertheless, due to the comparably weak texture, the choice of a favorable sample orientation for the integration and the use of sum-diffraction patterns result in a sufficient texture averaging for quantitative phase analysis. Comparing figure 3a with figure 1b, one can see the change in grain size in γ-TiAl and in α_2-Ti_3Al. The Debye-Scherrer cone closest to the primary beam is the γ-TiAl reflection (100) with a mostly homogeneous intensity distribution in figure 3a and a spotty intensity distribution in figure 1b. Due to very similar crystal structures of the different phases (γ-TiAl P4/m2/m2/m, α_2-Ti_3Al $P6_3/m2/m2/c$, β-Ti I4/m-32/m and α-Ti $P6_3/m2/m2/c$) a number of overlaps were observed. Therefore, figure 4 shows two sections 2θ 1.0°-2.0° and 2θ 2.8°-3.8° to present the existing phases in the weld and in the base materials. Particular for the low volume fraction of α_2-Ti_3Al the low angle region is of great importance because of no overlapping.

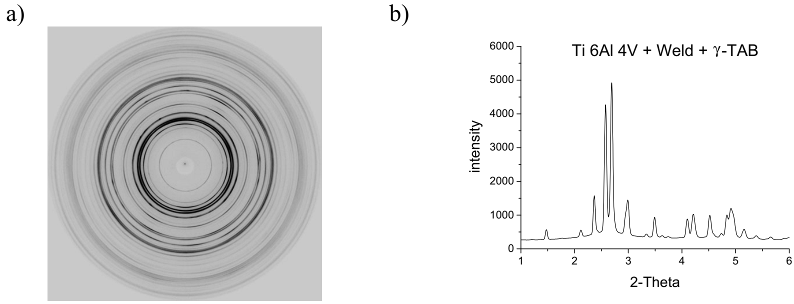

Figure 3. Image plate picture (a) and sum-diffraction pattern (b) of the welded zone

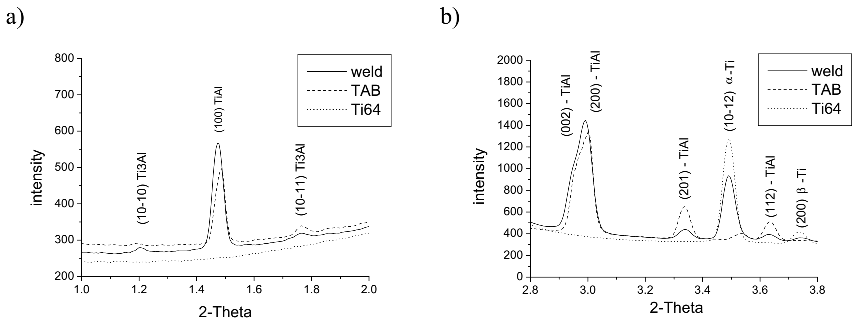

Figure 4. Sections from 2θ 2.8°-3.8°(a) and 2θ 2.8°-3.8° (b)

The quantitative phase analysis was carried out using MAUD (Materials Analysis Using Diffraction [7]) a program package which allows conventional Rietveld refinement and quantitative texture analysis. The present results deal only with the Rietveld refinement. Local texture measurements require at least 19 image plate pictures with a rotation around the sample axis of 5°. Sharp textures need much finer steps. The instrumental parameters for the refinement were obtained by an Al_2O_3-NIST standard. One example is shown for Ti-6Al-4V with its typical two phased composition. The position was 15mm outside the weld so that no influence of the joining process on the phase composition was expected. Rietveld refinement gives a composition of 80.5wt% of the α-phase and 19.5wt% of the β-phase. Table 2 collects the results of the major interesting part. As one can see there is no great influence of the composition till 1.0 mm to the weld. On the other side of the weld γ-TAB was calculated as two phased material with about 97.5wt% TiAl and 2.5wt% Ti_3Al. It can be seen that close to the weld an increase of Ti_3Al is observed but this can also be related to fine grained materials with less error in the calculation (grain statistics).

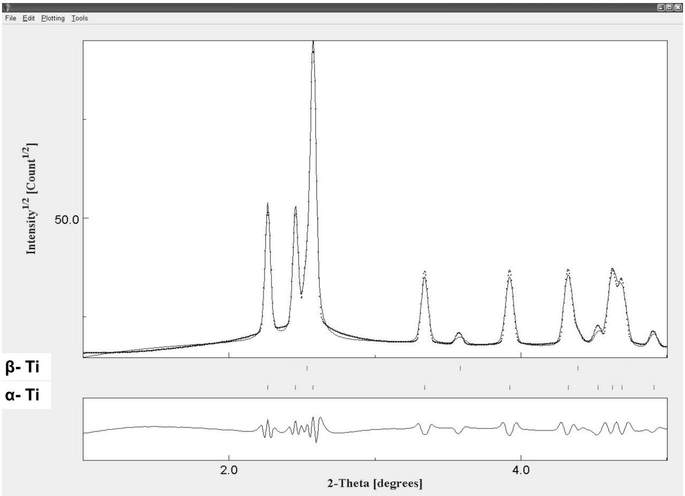

Figure 5. Rietveld fit of a sum diffraction pattern of Ti-6Al-4V (position +15mm)

Table 2 Phase analysis using Rietveld method (MAUD)

TAB-side	TiAl (wt.%)	Ti3Al (wt.%)	α-Ti (wt.%)	β-Ti (wt.%)	Ti64 side	TiAl (wt.%)	Ti3Al (wt.%)	α-Ti (wt.%)	β-Ti (wt.%)
+15.0 mm	97.2	2.8			-0.5 mm			84.8	15.2
+ 6.5 mm	97.9	2.1			-1.0 mm			80.6	19.4
+ 5.5 mm	97.9	2.1			-1.5 mm			79.2	20.7
+ 4.5 mm	97.6	2.4			-2.5 mm			78.9	21.1
+ 3.5 mm	97.4	2.6			-3.5 mm			78.9	21.1
2.5 (TiAl)	97.5	2.5			-4.5 mm			78.9	21.1
1.5 (TiAl)	96.4	3.6			-5.5 mm			79.3	20.7
1.0 (TiAl)	95.4	4.6			-6.5 mm			81.1	18.9
0.5 (TiAl)	92.7	2.1	5.1		-15 mm			80.5	19.5
weld	53.3	1.9	41.4	1.6					

The position named 'weld' includes the welded zone part of the zone with heavily plastic deformation due to the friction welding process. In these area all four components can be detected, the two minority phases with volume fractions between 1-2 wt%.

Both alloys (γ-TAB and Ti-6Al-4V) are two-phased alloys. The determined volume fractions are within the expected range. Next step in the investigations is to improve MAUD for grain size and microstrain analysis within the weld. Therefore, friction weld with different process parameters (temperature, pressure and rotation) are performed.

Concluding remarks

First of all one can recognize that high energy X-rays (50 keV – 200keV) are able to characterize the phase development in γ-TAB and Ti-6Al-4V with components having very similar volume fractions. Secondly, the high penetration power allows the investigation of large samples, rods of 24.5mm in diameter, in a non-destructive way to get local information. Friction welding is a process with a rather small welded zone, but with a strong change in the microstructure and the texture. Due to the process parameters these zones can be influenced, so that the heat affected zone can be very small. Qualitative phase analyses indicate no new intermetallic Ti-Al compounds. Quantitative phase analyses by MAUD using a sum-diffraction spectrum lead to good results in the Rietveld refinement of these textured materials. The basic problem in our investigations is the grain size of the casted γ-TAB alloys, so that we have a restriction in the investigated volume fraction. But this problem is more evident for the texture work than the for the phase analyses, because for texture measurement integrations over complete Debye-Scherrer rings are not possible.

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