Characterisation of texture in Ti-6246 alloy fibre laser welds using Electron Backscattered Diffraction (EBSD)

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Abstract. In this study, fibre laser welds of alloy Ti-6%Al-2%Sn-4%Zr-6%Mo have been characterised. It has been found that although the microstructure of the welds is important in predicting properties, it is not enough to simply characterise the welds based on the microstructure, as crystallographic texturing is also important in determining mechanical properties. The texturing of the fibre laser welds is being characterized using EBSD mapping, with light microscopy to characterize the microstructure. This has been carried out for a weld that has been heat treated for 3 hours at 550 °C. At this temperature, relaxation of residual stress will occur, but changes to the microstructure will be minimal. It is planned that EBSD will now be carried out on the as received sample, and the results will be presented, along with a comparison with the heat treated weld.

1. Introduction
Titanium alloys are finding ever more applications in a wide range of fields; hence it is becoming increasingly important to develop ways of joining them. Welding of titanium alloys is notoriously difficult, due to their high affinity for oxygen and low thermal conductivity, which makes many traditional welding methods difficult to use. New methods of welding are continuously being developed to combat these problems, but thorough characterization of the welds is necessary to ensure that welds with the correct properties are produced.

Some preliminary work that has been carried out on Ti-6Al-4V (Ti 64), which is the most widely used titanium alloy, is discussed. However, for this project Ti-6%Al-2%Sn-4%Zr-6%Mo (Ti 6246) is being investigated instead. This is an α + β alloy that is finding increasing application in the aerospace industry. Although its usage is increasing, at present no work on the laser welding of this alloy is available.

The use of lasers in welding of titanium is well documented, and characterization of the microstructure of laser welds of various titanium alloys have been carried out in the past [1,2]. Traditionally, CO₂ lasers have been used for welding, but use of fiber lasers is now being explored. Advantages of fibre lasers are that a high energy laser beam is produced, and more complex geometries can be welded with this method than with conventional lasers [3].

It is not adequate when characterizing welds to simply examine the microstructure. The presence of texture (preferred crystallographic orientation) is also important, as it has been shown that this can affect the mechanical properties, in particular the fatigue properties [4]. Electron backscattered diffraction (EBSD) is a technique that allows the mapping of texture over a small area of the microstructure, so that variations in texture may be observed.
In any welding technique that relies on a highly localized heat input, the residual stresses that are left in the weld and the alloy surrounding it will be high. It has been shown in previous studies that residual stress patterns will have an effect on EBSD results. Residual stress may also affect the textures that are present, but the extent of this effect is not yet known. It is hoped that in this study, by comparing a sample that has been heat treated to remove some of the stresses with one in the as welded condition, some conclusions can be drawn as to what textural features are present, and whether they are a result of the residual stresses, or the formation of the microstructure following welding.

Preparation of samples for EBSD is difficult, because it is necessary to minimize topography and surface deformation as much as possible, as it has a serious effect on the quality of the results. This means that deformation of the surface should be minimal, so polishing regimes must be far gentler than in preparation for light microscopy. Ideally, mechanical polishing would not be used at all, and electropolishing and chemical polishing techniques would be employed instead. However, the voltages that are required to electropolish certain titanium alloys, including Ti-6246 are prohibitively high, and chemical polishing techniques have been used with little success due to the problems of hydrogen penetration. For this reason, the decision has been made to use mechanical polishing methods for this study.

2. Experimental Method

2.1. Sample Preparation
A fibre laser welded section provided by TWI was sectioned using a cutting wheel, to create two slices across the weld, each of approximately 10mm thickness. The base metal, with the exception of approximately 12mm on either side of the weld was also removed. One sample was then heat treated in a pre-heated furnace at 550 °C for 3 hours. The sample was then removed from the furnace and allowed to cool in air. Both samples were then hot mounted in bakelite such that a cross section of the weld was visible, and ground using silicon carbide papers of increasingly fine grade. They were then polished using a diamond polishing wheel down to a 1 µm finish for approximately 4 minutes.

The final polish was carried out using colloidal silica mixed with hydrogen peroxide, to prevent etching. This was done initially using a polishing cloth on a wheel, on which the sample was placed for 6 minutes. Immediately before EBSD, another colloidal silica and hydrogen peroxide polish was carried out by hand.

Some results are also included for a Ti-64 fiber laser weld sample (identical to the Ti 6246 sample) that was prepared for optical microscopy in exactly the same way as that detailed above, with one sample being heat treated under the same conditions as described above, and one being left in the as received state.

2.2. EBSD
A step size of 5 µm was selected, because of the small grain size that is seen in the Heat Affected Zone (HAZ) of the weld. Initially, a profile was carried out over a long, thin strip. Following EBSD, the sample was etched in 2 % hydrofluoric acid. The area of the sample that has been mapped using EBSD did not etch, while the rest of the sample did. The reasons for this are still being discussed. This allowed the area of the EBSD map to be clearly marked out.

3. Results
In order to achieve the aims of this work, it is necessary first to ensure that the applied heat treatment has reduced residual stresses while not affecting the microstructure. This has not yet been done for the Ti 6246 samples, as optical microscopy is best done after EBSD, so as
not to damage the surface by excessive grinding before all EBSD work is complete. However, work has been done on Ti 64. Figure 1a shows the microstructure of the base metal of a Ti 64 fiber laser weld in the as received state, and figure 1b shows the fusion zone of the same weld. Early examination of the Ti-6246 welds showed them to have a very similar microstructure and response to heat treatment.

Figure 1a – Ti 64 weld base metal   Figure 1b – edge of fusion zone in Ti64 weld

Figure 1a shows that the microstructure of the base metal of the weld (i.e. the part of the metal that is not altered by the heat input of welding) consists of alpha grains of approximately 1 µm average size, in a transformed beta matrix (which has a lamellar alpha and retained beta structure). As the weld is approached, the volume fraction of transformed beta, and the amount of retained beta within it increases. The fusion zone (as shown in figure 1b) shows large prior beta grains, which have largely transformed to give martensite and retained beta. It was shown for this alloy that the microstructure was not changed in any way by the heat treatment at 550 °C. It was shown for the Ti 64 sample that the heat treatment did cause a relaxation of residual stresses. This was shown by carrying out microhardness profiles of the welds before and after heat treatment. The as received sample showed peaks in hardness at the edges of the heat affected zone, while the heat treated sample didn’t. As there was no difference in microstructure between the two samples, it can only be concluded that the effect is due to the relaxation of residual stresses, caused by the heat treatment.

The pole figures for the α and β phases in the as received Ti6246 sample are shown in figures 1 and 2 respectively. These pole figures are taken over the heat affected zone of the weld. In the future the EBSD study will be continued both well into the base metal (to determine better the full extent of the heat affected zone) and into the fusion zone. The results are at this stage not complete, but it is hoped that pole figures for the corresponding area of the as received weld will be presented at the conference. It is also planned to include maps of texture across both areas. The texture map is not included at this time, as some slippage of the sample during measurement makes the map somewhat ambiguous.

Figure 2 – pole figures for the hexagonal alpha phase

Figure 3 – Pole figures for body centred cubic beta phase
4. Discussion
From the results obtained so far, it is difficult to draw any meaningful conclusions as to texturing within welds, and why it occurs. However, some useful points can be made from the work carried out so far.

The method of sample preparation used here has been shown to be successful. However, the number of points that produced patterns that were recognized was approximately 20%. It is hoped that further work to refine the method of sample preparation will improve this.

From the pole figures shown in figures 1 and 2, it can be seen that some preferential texturing exists in the welds for both the alpha and the beta phases. If there were no overall texturing, the points would appear at random over the pole figure. The fact that there is clear contouring shows the presence of texturing. Further work is needed to show which preferential textures appear in which areas of the heat affected zone.

5. Conclusions
It is clear at this stage that some texturing exists in Ti-6246 fibre laser welds. It is unclear at this stage what the patterns in texturing are – further work is required to investigate this. The mechanical method of polishing that is described here has been shown to be adequate, although there is room for improvement.

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