PROPERTIES OF WELDED TITANIUM ALLOYS AND THEIR APPLICATION IN THE AEROSPACE INDUSTRY

R.F. Vaughan
IMI Titanium, IMI Kynoch Ltd., Birmingham, England

Introduction

In this paper the influence of alloy composition and post weld heat treatment on the properties of welds in a number of alloys used widely in the aerospace industry are discussed. The data presented concerns the properties of electron beam welded joints in the alpha-beta alloys IMI 318 (Ti-6Al-4V) and IMI 550 (Ti-4Al-4Mo-2Sn-0.5Si) and the near-alpha alloys IMI 679 (Ti-11Sn-5Zr-2.25Al-1Mo-0.2Si) and IMI 685 (Ti-6Al-5Zr-0.5Mo-0.25Si). Applications of these alloys in the welded condition are described where appropriate.

Material

In order to make comparisons between the various alloys, ~ 10mm thick plate was used in all cases. Standard processing temperatures for each alloy were used for rolling, and all plates were subjected to heat treatment prior to welding. All mechanical properties were determined with the stress axis normal to the weld line.

Results

1. IMI 318 (Ti-6Al-4V)

Electron beam welding of this $\alpha + \beta$ alloy for critical components in airframes and aeroengines is well established in the aerospace industries of Europe and the USA. In airframes, the electron beam welded centre wing boxes for the Tornado and F14 Tomcat are notable examples, while in engines the Rolls Royce GEM, RB211 and RB199 all contain electron beam welded IMI 318.

For the present studies, the plate was annealed 1 hour at 700°C AC prior to welding, then welded material was given one of the following post-weld treatments :

1) Anneal 1 hour 700°C AC
2) Stress relieve 6 hours 500°C AC
3) None (i.e. as-welded)

Figures 1 and 2 illustrate the microstructure of the original plate and the as-welded fusion zone. The microstructure in the fusion zone was typical of this alloy in the β heat treated and rapidly cooled condition.

Tensile and fracture toughness data is shown in Table 1, while Figure 3 illustrates the room temperature low cycle fatigue properties.

Table 1 Properties of Electron Beam Welded IMI 318

Condition		0.2%PS $MN.m^{-2}$	TS $MN.m^{-2}$	EL5D %	RA %	K_Q $MN.m^{-3/2}$
1.	Welded + 1hr 700°C AC	944	1032	12	32*	63.7
2.	Welded + 6hr 500°C AC	965	1055	12	37*	58.7
3.	As welded	935	1030	12	34*	67.2
	Parent Metal	927	991	12	39	44.5

* Fracture in parent metal

It can be seen that this alloy is fully weldable in that tensile fractures occurred in the parent metal, suggesting the weld was stronger than the parent metal, and the toughness of the weld was superior to the parent metal in all post-welded conditions, as would be expected from the transformed β microstructure in this alloy. The low cycle fatigue performance of the weld was acceptable, there being no significant degradation of this property even though some fractures occurred in the weld. It can be concluded that IMI 318 is an excellent material for joining by electron beam welding techniques.

2. IMI 550 (Ti-4Al-4Mo-2Sn-0.5Si)

This alloy, which has a significant strength advantage over IMI 318, is not at present used in the welded condition for airframe or aero engine applications. The normal heat treatment is a solution treatment fairly high in the α + β phase field followed by ageing. If however the alloy is taken into the beta field, as would occur during welding and is rapidly cooled and aged, the high beta stabiliser (molybdenum) content gives rise to very high strength but reduces fracture toughness to a low level. It would be expected therefore, that welded IMI 550 would lack toughness unless heat treated.

The alloy is used widely in airframe and engine applications; flap and slat tracks, and engine mounting brackets for the A300B Airbus, Jaguar and Tornado aircraft are examples of airframe use, while the Rolls Royce Pegasus and Olympus engines include IMI 550 discs in a bolted drum assembly.

To determine the properties of welds in IMI 550 the plate was heat treated 1 hour 900°C AC + 24 hours 500°C AC before welding. This is the standard heat treatment for the alloy. Post weld heat treatments were :

1) 1 hour 900°C AC + 24 hours 500°C AC (re-heat treated)
2) Stress relieve 6 hours 500°C AC
3) None (i.e. as welded)

Figures 4 and 5 illustrate the microstructures of the parent plate and the fusion zone in the as-welded condition. The weld microstructure consisted of prior β grains, the boundaries of which were clearly visible. The transformation product was not resolvable under the optical microscope, giving rise to a "mottling" within the β grains. The centre line of the weld was virtually free of mottling, suggesting a very fine transformation product in this region.

Tensile and fracture toughness properties are shown in Table 2.

Table 2 Properties of Electron Beam Welded IMI 550

	Condition	0.2%PS $MN.m^{-2}$	TS $MN.m^{-2}$	EL5D %	RA %	K_Q $MN.m^{-3/2}$
1.	Welded + 1hr 900°C AC + 24hr 500°C AC	1127	1281	8	27	61.3
2.	Welded + 6hr 500°C AC	1160	1315	10	37*	+
3.	As welded	1130	1295	8	13	26.2
	Parent Metal	1125	1275	13	44	52.4

* Fracture in parent metal. + Failed during precracking

In contrast to the IMI 318, IMI 550 welds exhibit a low fracture toughness except when fully re-heat treated. Toughness was measurable in the as-welded condition but it is doubtful if this level would be acceptable for critical air-frame and engine applications unless the design was such that a crack would not propagate along the direction of the weld.

3. IMI 679 (Ti-11Sn-5Zr-2.25Al-1Mo-0.2Si)

The near α alloy IMI 679 was developed to be high temperature creep resistant, and was specifically intended for engine, rather than airframe, applications. Most of the IMI 679 manufactured by IMI Titanium has been used in the Rolls Royce Spey engine as a blade and disc material in a bolted drum assembly. This alloy is not so heavily β stabilised as IMI 550, but does display high strength in a quenched and aged condition. It would be expected therefore, that the fracture toughness could be borderline in a welded and stress relieved condition.

For welding trials, the plate was heat treated 1 hour 900°C AC + 24 hours 500°C AC prior to welding. Post weld heat treatments were :

1) 1 hour 900°C AC + 24 hours 500°C (re-heat treated)
2) Stress relieved 6 hours 500°C AC
3) None (as welded)

Figures 6 and 7 illustrate the microstructures of weld and parent metal.

Table 3 contains tensile and fracture toughness data. Low cycle fatigue testing has not been carried out to date.

Table 3 Properties of Electron Beam Welded IMI 679

	Condition	0.2%PS $MN.m^{-2}$	TS $MN.m^{-2}$	EL5D %	RA %	K_Q $MN.m^{-3/2}$
1.	Welded + 1hr 900°C + 24hr 500°C AC	1006	1128	13	23	36.0
2.	Welded + 6hr 500°C AC	982	1113	10	39*	+
3.	As welded	++	1162	9½	29½*	45.0
	Parent Metal	997	1115	10½	39	43.7

* Fracture in parent metal. + Failed during precracking. ++ Not determined

Rather surprisingly, one tensile test piece from the as welded material fractured before a proof stress value had been obtained. Because of this the extensomer was not used for the remainder of the testing in this condition, thus no proof stress level is available. It is possible that the poor tensile result may have been due to the use of material very near to the end of the weld and may not be representative of "sound" weld. The fracture toughness tests, which should provide a better indication of weld "brittleness", gave a value almost identical to the parent metal.

Welded and stress relieved (6 hours 500°C) tensile specimens gave acceptable properties, with fractures occuring in the parent metal. However fracture toughness in this condition was not measurable with failure occuring during pre-cracking.

Fully re-heat treated IMI 679 gave acceptable toughness and tensile properties, although the toughness was lower than in the parent metal. It is concluded that this alloy can be used in a welded construction provided that the direction of operational stresses makes it unlikely that a crack would propagate along the weld and/or the alloy is fully heat treated after welding.

4. IMI 685 (Ti-6Al-5Zr-0.5Mo-0.25Si)

IMI 685 was designed from the outset as a creep resistant near-α alloy which could be welded. These attributes, combined with good elevated temperature strength, have resulted in the alloy being used for five major European gas turbine aero-engine projects. The alloy is used in the welded condition in the high pressure compressor of the Rolls Royce RB211, RB199, Snecma M53 and the multinational Adour and Larzac engines. In the M53, Adour and Larzac engines, the complete HP compressor drum is made up from welded discs and spacers. These drums are built up in stages, with a stress relief of 4 to 6 hours at 550°C after each stage. Consequently, some discs can receive several stress relief anneals on top of the initial age of 24 hours at 550°C. Tests at IMI Titanium have shown that the mechanical properties of the alloy are not adversely affected by this.

To obtain the maximum creep strength, IMI 685 is heat treated in the β field, cooled in air or oil depending upon the section thickness, and finally aged at 550°C for 24 hours. The parent metal structure is similar to that developed in a weld zone, and because of this similarity there should be little difference in properties between weld and parent metal.

10mm thick plate was heat treated 1 hour 1050°C AC + 24 hours 550°C AC for welding trials. Air cooling is recommended for sections up to ~ 25mm. Post weld treatments were :

1) 1 hour 1050°C AC + 24 hours 550°C (re-heat treated)
2) Stress relieved 6 hours 550°C AC
3) None (as welded)

Figures 8 and 9 are photomicrographs of weld and parent metal. Table 4 shows tensile and fracture toughness test results. Low cycle fatigue data is presented in Figure 10.

Table 4 Properties of Electron Beam Welded IMI 685

	Condition	0.2%PS $MN.m^{-2}$	TS $MN.m^{-2}$	EL5D %	RA %	K_Q $MN.m^{-3/2}$
1.	Welded + 1hr 1050°C AC + 24hr 550°C AC	880	999	9	22*	86
2.	Welded + 6hr 550°C AC	894	1023	9½	24*	65.2
3.	As welded	892	1021	12	24*	67.5
	Parent Metal	879	994	9	19	65

* Fracture in parent metal

Tensile and fracture toughness values were acceptable in all welded conditions, being very comparable to the parent metal properties. Similar comments apply to the low cycle fatigue properties. These results confirm the expectations from the observations on microstructural similarity between weld and parent metal that this alloy is fully weldable.

Conclusions

Sound electron beam welds could be made in all four alloys.

Whilst the mechanical properties of welded IMI 318 and IMI 685 were satisfactory after a simple ageing/annealing treatment, the fracture toughness of IMI 550 and IMI 679 was acceptable only after a full re-solution treatment and age.

However, welding of the alloys IMI 550 and IMI 679 may be justified for applications where the stress system is such that crack propagation along the weld line is unlikely.

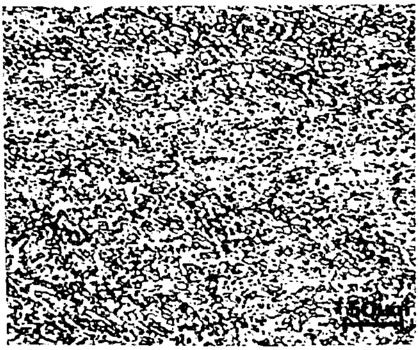


Figure 1
IMI 318 Original Plate

Figure 2
IMI 318 Weld

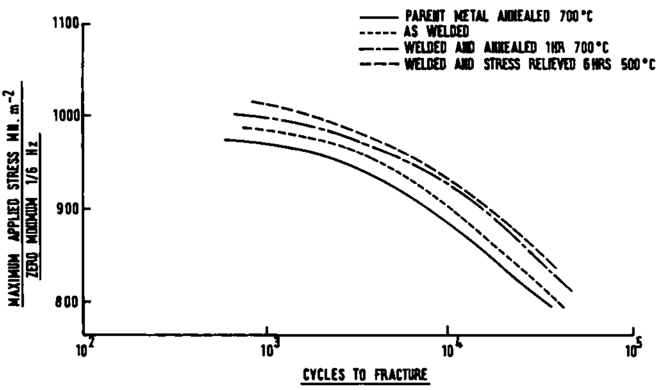
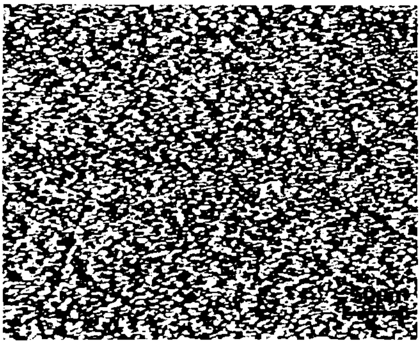


Figure 3 : Low cycle fatigue properties of Electron Beam welded IMI 318



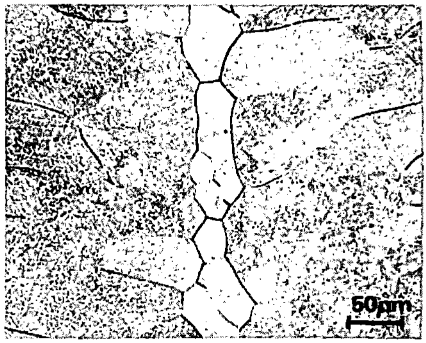
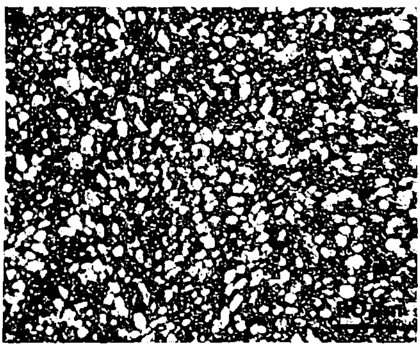


Figure 4
IMI 550 Original Plate

Figure 5
IMI 550 Weld



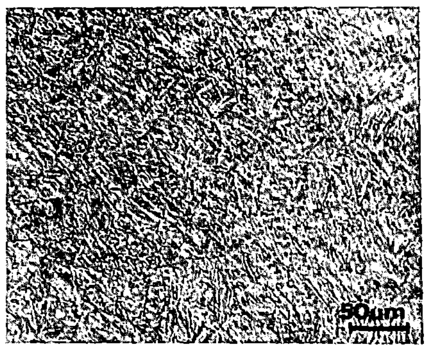


Figure 6
IMI 679 Original Plate

Figure 7
IMI 679 Weld

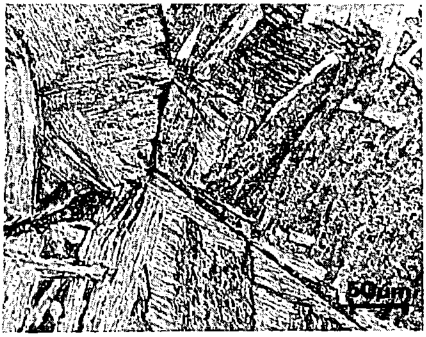


Figure 8
IMI 685 Original Plate

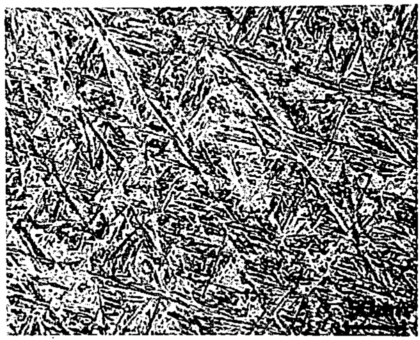


Figure 9
IMI 685 Weld

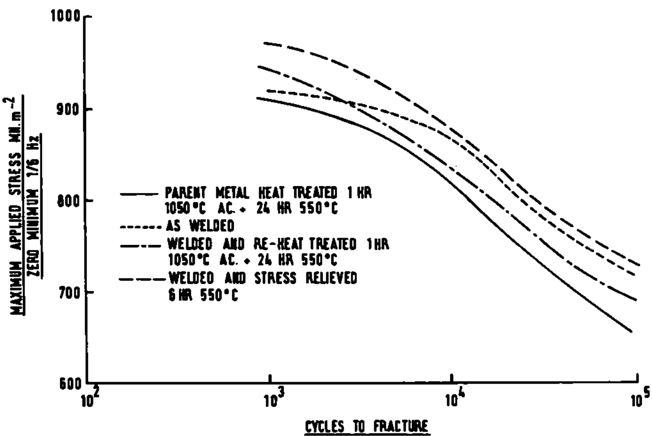


Figure 10 : Low cycle fatigue properties of Electron Beam welded IMI 685