Contributed paper

The future use of gamma titanium aluminides by Rolls-Royce

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Abstract

Gamma titanium aluminide is a material essential for meeting military and civil engine performance targets in the future and potentially it could be used throughout the engine from compressor to combustor to turbine. The current alloy being used within Rolls-Royce is the established Ti-45-2-2-XD. This is competing for lower temperature applications such as stators and structural components which take advantage of the lower costs arising from the casting route. Rigorous design criteria are required to compensate for the risks in using these relatively new materials in components and this requires investigation into the effects of manufactured surface conditions, of microstructures local to load bearing regions and of compositional variations. For the future, Rolls-Royce has patented a next generation gamma titanium resulting from alloy development programmes undertaken by the University of Birmingham. The aim is to optimise castability with strength and creep resistance and their potential for commercial use within the aero-engine is discussed.

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Introduction

Ti-45-2-2-XD (XD = Trade Mark) is an established gamma alloy with the highest strength of those commercially available. Competitively high specific tensile and fatigue strengths, fire resistance as well as inherent castability and consistent properties due to its XD grain refinement make it very attractive. However, cost remains a negative factor coupled with a perceived inherent “brittleness” at temperatures less than 600°C.

For commercial use these negative factors need to be addressed. Casting is considered to be the most cost effective processing route but licensing and a single source supply make components more expensive than they could be.

Low temperature ductility and lack of toughness is a design consideration which can be overcome by understanding the nature of the material and adapting design criteria accordingly (Perrin, 1997). The material has to be utilised from an intermetallic perspective which places emphasis on its unique properties rather than the more conventional metallic perspective which highlights titanium aluminide’s deficiencies.

If cost and property deficiencies can be overcome, there will be a future for Ti-45-2-2-XD in relatively low temperature aero-engine applications. However, for temperatures above 650°C, creep and oxidation resistance become important, which has led to the promotion of a new, more highly alloyed gamma titanium aluminide Ti-45-4-4-1 which is even stronger than the Ti-45-2-2-XD. Rapid progress with this new alloy may even displace the introduction of its Ti-45-2-2-XD predecessor to become the ubiquitous cast gamma titanium aluminide alloy for Rolls-Royce use. It is also being considered for wrought applications.

Ti-45-2-2-XD

Ti-45-2-2-XD applications

Ti-45-2-2-XD has been used to make a number of different aero-engine components by Rolls-Royce; compressor stator vanes and blades, LP turbine blades and large complex cast components. All manufacturing issues have been resolved for the production of compressor vanes and blades from investment cast blanks by electro-chemically machining the aerofoils followed by standard machining of the ends (see Figure 1). Such components have been tested and engine run and they are likely to be the first components to be introduced into service.

Although LP turbine blades have been successfully cast and machined, the temperature capability of Ti-45-2-2-XD has prevented its introduction because, even though it is currently suitable for the ultimate blade, future trends are towards higher temperatures and towards its additional requirement for the penultimate blade. Since it is not feasible to introduce different materials for two similar components, the new high temperature alloy is more likely to be used.

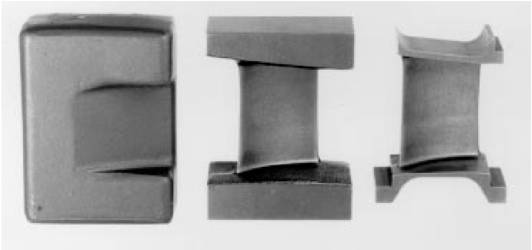
Large complex static components have been successfully cast and machined in Ti-45-2-2-XD and these may have a future in the engine under the right conditions.

Ti-45-2-2-XD prospects

It is unfortunate that the cost of Ti-45-2-2-XD is currently at an uncompetitive level which is inhibiting its introduction into service. Future costs can be expected to fall if the material becomes more widely used but the single source supply and the inherently expensive machining costs suggest that Ti-45-2-2-XD will always be at a cost disadvantage. Note that the machining of XD titanium aluminide causes relatively heavy tool wear and poor surface finish, thus pushing up the cost of the final component.

There are also a number of microstructural considerations in the application of Ti-45-2-2-XD. The standard ageing treatment is a relatively long 50 hours at 1,050°C, which is an additional cost burden. This stabilises the microstructure by converting an estimated one third of the remaining α_2 to γ. This is thought to benefit higher temperature operation where the transformation of α_2 to fine equi-axed γ grains particularly at grain boundaries is known to aid creep (Crofts, 1997). No evidence was found to suggest that strength and ductility are affected by heat treatment.

Figure 1 HP4 Stator: cast pre-form, post ECM and post end machining

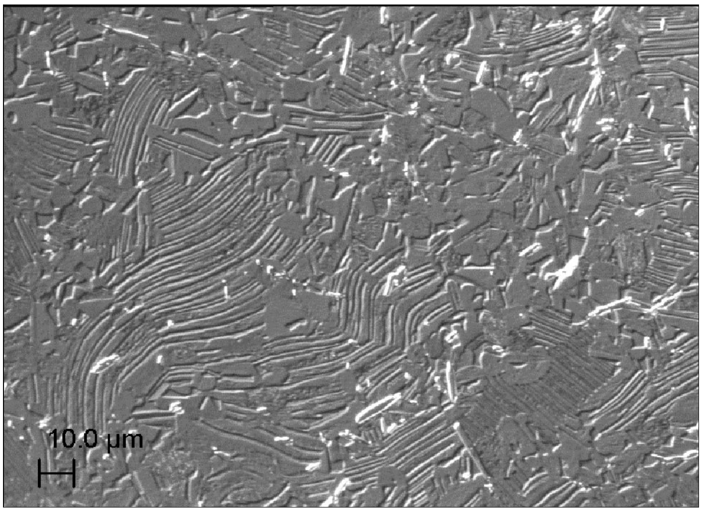


There are also microstructural features arising from the casting process which may be of concern. Notably castings have regions of porosity which close during HIPing and become rich in equi-axed γ grains as a result of dynamic recrystallisation (see Figure 2). Such a duplex lamellar with equi-axed γ grain microstructure appears to give different mechanical properties.

> **'... Another innocuous feature of casting XD material is a copious thin ribbon type of titanium di-boride which forms at the edge of castings... '**

Unfortunately mechanical tests are often carried out on cast cylindrical test bars with a high aspect ratio, for example 15mm diameter by 150mm long, which inevitably have a central equi-axed γ region. Machining the test-piece reduces the section to the mainly equi-axed γ grain centre with the consequence that tests show a worse ductility and diminished creep strength compared with the normal near lamellar microstructure. In addition, crack initiation sites appear to be influenced by the interface between areas rich in equi-axed γ grains and almost fully lamellar areas although there is no evidence that fatigue lives are affected (Jeon *et al.*, 1998).

Figure 2 Ti-45-2-2-XD HIP closed porous region: recrystallised equi-axed γ grains amongst deformed lamellar grains



Another possibly innocuous feature of casting XD material is a copious thin ribbon type of titanium di-boride which forms at the edge of castings (see Figure 3). Components presently have the main load-bearing surfaces machined to shape but it is perceived that net shape castings will lower processing costs. The effect of this edge of casting feature must therefore be assessed prior to manufacturing trials.

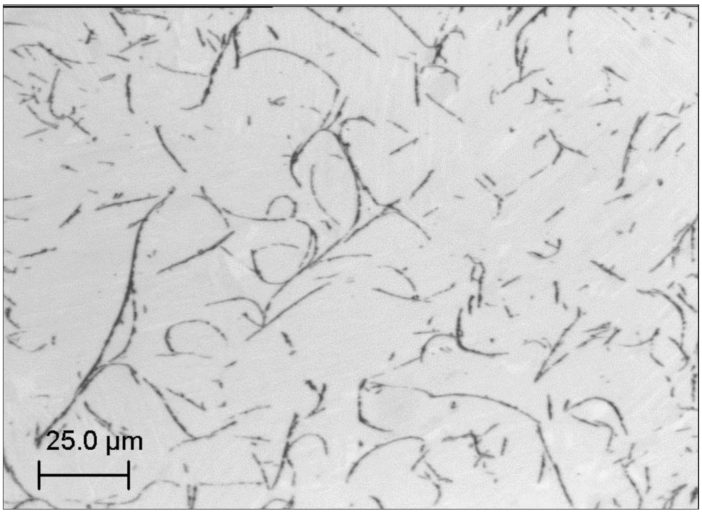
New alloy Ti-45-4-4-1

The new gamma titanium aluminide was developed at the Interdisciplinary Research Centre at the University of Birmingham by Dr T.T. Cheng and Prof. Ian Jones (Cheng and Jones, undated). The patent is based around the composition Ti-45Ti-4Nb-4Zr-B-Si and is optimised for high tensile and creep strength coupled with high oxidation resistance.

The alloy differs from conventional γ-TiAl structures in that the colony boundaries of the lamellar grains consist of mixed γ, ω and α_2 phases resulting from transformed β.

The alloy has good castability and is equally amenable to wrought processing routes. An important aspect is the need for just 0.3 per cent boron for grain refinement which confers better castability and consistency of properties whilst being outside the XD patent. The low boride content has the additional benefit of improving machinability and possibly improving crack resistance over XD material through the omission of large titanium diboride particles.

Figure 3 Ti-45-2-2-XD. Thin ribbon shaped TiB_2 formed at edge of casting



A total of 0.2 per cent proof stress research shows TiAl-4-4-1 to be over 50 per cent stronger than most commercial "first generation" gamma alloys and about 30 per cent stronger than Ti-45-2-2-XD whilst its ductility is at similar levels. Probably more important is that this strength is maintained over long term exposure at service temperatures, for example at room temperature after 5,000 hours at 700°C (Cheng, in press).

Creep resistance appears to be almost comparable with the best commercially available gamma (ABB) alloy based on time to 0.5 per cent strain. Again this resistance is maintained after exposure at service temperatures as shown in the more detailed creep data in Table I (Cheng and Willis, 1998).

Considerable work still has to be undertaken before this alloy can be considered for aero-engine applications but clearly its prospects are good. Its castability and stable high temperature strength make it an obvious choice for LP turbine blades and combustor components.

Summary

There is a high probability that gamma titanium aluminide will be used in Rolls-Royce aero-engines in the near future (Cheng *et al.*, 1999). In the near term, the Ti-45-2-2-XD alloy will be considered for applications requiring temperatures of up to 650°C where established casting and machining processes can be relied upon.

In the longer term, there is a need for a stronger alloy with a much higher temperature capability for which the new Ti-45-4-4-1 alloy is a promising candidate. Combustor and turbine components reaching

Table I Creep properties of Ti-45-4-4-1 after 700°C exposure crept at 200MPa/700°C

Condition	Strain % after 500h	Primary % after h	Secondary s^{-1}
As Cast	0.70	0.66/400	$9.4 * 10^{-10}$
+ HIP + Age	0.36	0.35/440	$6.0 * 10^{-10}$
+ 1,000h/700°C	0.30	0.33/650	$3.9 * 10^{-10}$
+ 2,000h/700°C	0.36	0.39/625	$5.3 * 10^{-10}$
+ 5,000h/700°C	0.28	0.31/630	$4.9 * 10^{-10}$

temperatures as high as 800°C would then be under consideration.

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