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The influence of polymer content and sintering temperature on yttria face-coat moulds for TiAl casting

Chen Yuan *, Dave Compton, Xu Cheng, Nick Green, Paul Withey

School of Metallurgy and Materials, The University of Birmingham, Birmingham B15 2TT, England, United Kingdom

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Abstract

Yttria is an important primary coat material in investment shells for casting extremely reactive TiAl alloys and polymer is usually added to slurry to improve strength of the shell. In this investigation, systems that vary the polymer content through 0%, 6% and 30% were produced and the samples were sintered at 1000 °C, 1200 °C and 1400 °C. The results suggest that polymer content and sintering temperature appear to have little effect on the hardened alpha layer of the cast alloy, which is elevated by near-surface oxygen content. Silica from the backing coat is seen to travel through the primary coat and diffuse into the alloy regardless of the shell system. Firing temperatures above 1200 °C increase the shell strength undesirably but the friability of the primary coat decreases as firing temperature increases. Higher mould permeability was found in the mould containing higher polymer level and this would be advantageous for complete mould filling.

Keywords: Investment casting; Yttria; Polymer; TiAl

1. Introduction

Titanium aluminide alloys are widely used in engineering applications such as car engine valves and turbochargers, and are now being used in aero-engines to replace nickel superalloys in low pressure turbine blades. This is possible due to their superior properties and performance under centrifugal loading, especially density corrected strength and creep resistance up to temperatures around 650 °C.[1] Compared to other modern techniques for "precision" casting liquid metals, investment casting is considered to be a suitable processing method for the manufacture of TiAl turbine blades, as it will give a near net-shape product with high dimensional accuracy. The manufacture of an investment casting requires an expendable pattern, which is coated with multi-component slurries, or 'investments', to form a ceramic mould.[2,3] The pattern is dipped into a ceramic facecoat slurry, sprinkled with a coarse grained refractory 'stucco' and dried. The dipping and stucco coating process is repeated many times to produce a graded mould. Flexibility exists in changing the composition of each layer. The particle size of the stucco is increased as more coats are added to maintain maximum mould permeability and to provide bulk to the mould. The pattern is then removed, leaving a hollow mould with an extremely smooth internal surface. Moulds are fired and cast with molten metal. After cooling, the ceramic is removed by mechanical or chemical methods to obtain the metal parts. In recent years, this process has increasingly been used to produce components for the aerospace industry and it has been intensively studied for the production of TiAl turbine blades.[2,4–6]

Due to the very high reactivity of molten TiAl alloys, the main problem encountered with investment casting has been interaction between molten alloys and moulds. Reaction is usually manifested as elevated near-surface oxygen content (alpha case) with high hardness, decreasing with distance from the interface.[7] As shown by Jia et al.[8] common casting ceramics such as zirconia will result a reacted brittle layer up to 325 μm deep. This decreases the ductility and strength of the casting, a problem recognised by Lassow et al, which their early yttria mould patents started to solve.[9] According to Barbosa et al, there is no thermodynamic basis for a reaction between yttria and TiAl,[7] and the overall situation was summarised by Koboyashi.[10]

Polymer is usually added to the yttria slurry to improve pre-fired strength (important during wax removal), and to burn out during sintering to leave a porous network and so improve

* Corresponding author. Tel.: +44 121 4147839; fax: +44 121 4147890.
E-mail address: c.yuan@bham.ac.uk (C. Yuan).

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Table 1
Slurry compositions for ceramic mould samples.

Slurry	Materials	Composition
Primary 1 (0% polymer)	Nyacol yttria sol	14 wt% yttria colloidal sol
	Victawet 12 wetting agent	0.3 wt% of total liquids
	Burst RSD-10 antifoam	0.5 wt% of total liquids
	Treibacher Auercoat −200 mesh yttria filler	5 kg/l refractory loading
Primary 2 (6% polymer)	Nyacol yttria sol	14 wt% yttria colloidal sol
	EVO STIK PVA polymer	6 wt% of total liquids
	Victawet 12 wetting agent	0.3 wt% of total liquids
	Burst RSD-10 antifoam	0.5 wt% of total liquids
	Treibacher Auercoat −200 mesh yttria filler	5 kg/l refractory loading
Primary 3 (30% polymer)	Nyacol yttria sol^{+}	14 wt% silica of colloidal sol
	EVO STIK PVA polymer	30 wt% of total liquids
	Victawet 12 wetting agent	0.3 wt% of total liquids
	Burst RSD-10 antifoam	0.5 wt% of total liquids
	Treibacher Auercoat −200 mesh yttria filler	5 kg/l refractory loading
Secondary slurry for produced steel mould	LP-BV silica sol	25 wt% silica of colloidal sol
	Polymer BV-LP	6 wt% of total liquids
	Molochite −200 mesh fused silica	57 wt% refractory loading

permeability. Work by Chao and Chou[11] has gone some way to justifying the addition of polymer, but with reference only to an alternative ceramic system formed of kaoline and alumina. Their work suggests that the addition of PVA polymer does not significantly affect the final sintered density, or porosity fraction, of the ceramic, but rather increases the average pore size; and by this method increases the permeability of the system. However, they found that increasing polymer content reduces the final sintered strength by a small amount, and so there is a compromise to be reached on the optimum amount.

Regarding TiAl casting, yttria will normally only be used as the primary coat, which is directly in contact with the molten alloy. All other layers are silica based and mainly for structural purposes, to improve the strength of the mould. Silica has a melting temperature of around 1700 °C, so will sinter better than the yttria, which has a melting point around 2457°. This means that any bonding is likely to be due to silica diffusing around and onto the yttria particles. The effect of silica penetration into the primary coat could affect the inertness of the yttria face coat.

In this paper, the reported experimentation was designed to compare the effect of polymer content on the properties of the ceramic shell system and the reactivity with TiAl after various sintering temperature. The polymer used here was PVA and the amount added into the slurry was 0 wt%, 6 wt% and 30 wt% of the total liquid. The penetration of the silica from the backup layers was also investigated in this work.

2. Experimental procedure

2.1. Ceramic shell specifications

Details of slurry composition and mould build are given in Tables 1 and 2. The primary slurry, which would ultimately be in contact with molten alloy, consisted of a colloidal yttria binder (Nyacol, yttria sol), yttria filler (Treibacher Auercoat, −200 mesh yttria), liquid polymer (EVO STIK, PVA), wetting agent (Remet, Victawet 12) and anti-foam (Remet, Burst RSD-10). The polymer modified primary slurry contained different weight percentage (0 wt%, 6 wt% and 30 wt%) of the total liquid, whilst the same secondary slurry was used for all shell systems.

The shells were made by first investing the wax pattern into the primary slurry. An yttria stucco (Treibacher Auercoat, yttria 50/80 mesh) was applied using a rainfall sander. The assembly was rotated to achieve an even coating of stucco material, which adheres to the surface of the wet slurry. This coat was dried at a temperature of 21 °C, 50% relative humidity and 0.4 ms^{-1} air speed for 24 h. Two backup coats were then applied. A coarse alumino-silicate stucco (ECC International, Molochite 30/80 mesh) was used as first backup stucco. Each secondary coat was dried at a temperature of 21 °C, 50% relative humidity and 3 ms^{-1} air speed for 90 min. The following four backup coats used with a coarser alumino-silicate stucco (ECC International, Molochite 10/30 mesh) as a backup stucco. Finally a seal coat of secondary slurry without stucco was applied and dried at a temperature of 21 °C, 50% relative humidity and 3 ms^{-1} air speed for 24 h. The wax inside the ceramic mould was then removed by steam autoclave at 8 bar maximum pressure for 4 min, followed by a controlled de-pressurisation cycle at 1 bar/min using a Quicklock Boilerclave™ (Leeds and Bradford Boiler Company Ltd., UK).

For flat bar mechanical testing and reaction testing, the samples were prepared on a wax pattern with dimensions of

Table 2
Shell build for polymer modified yttria face-coat samples.

Coat	Slurry type	Stucco	Dip time (s)	Drain time (s)	Dry time (h)
1	Primary	50/80 Y	30	60	24
2–3	Secondary	30/80 M	30	60	1.5
4–7	Secondary	10/30 M	30	60	1.5
8	Secondary	–	30	60	24

Key: Y, yttria; M, Molochite™ (alumino-silicate); 50/80, 50/80 mesh stucco; 30/80, 30/80 mesh stucco; 10/30, 10/30 mesh stucco.