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Assessment of a controlled solidification aluminium investment casting technique for use in helicopter gearboxes

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ABSTRACT

By using a combination of cast plates and a helicopter gearbox casting, the superiority of a controlled solidification investment casting process in terms of strength, ductility and fatigue resistance was observed, when compared to three sand casting processes (conventional, low pressure and low pressure with chills) and a conventional investment casting process was observed. The most important factors responsible for the high levels of tensile strength and ductility and fatigue life were a refined grain size, a fine distribution of particles, a low level of porosity and a reduction in the level of bifilm formation. When porosity levels were low, i.e. less than 0.6%, a refined grain size and microstructure have been shown to be the most important factors influencing strength and ductility. Further improvements in the fatigue life within the 'as-cast' controlled solidification investment process can be achieved by the use of hot isostatic pressing (HIPping). No statistically significant difference in the fatigue life between the 'as-cast' and machined surfaces was observed.

A higher degree of mechanical property scatter, as measured by Weibull Modulus and the Coefficient of Variance (CV), was observed between the TGB casting and the cast plates inferring the design of the filling system used by the foundry had not been optimised resulting in higher metal flow and surface turbulence and a greater likelihood of bifilms occurring within the casting.

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1. Introduction

Helicopter gearbox casings are primarily designed to withstand the bearing loads imposed by various gears and shafts, together with structural loads delivered from air-ground cycles and flight manoeuvres. Consequently, casings require sufficient strength, stiffness and fatigue properties over the operational temperature envelope combined with minimum weight. AgustaWestland Limited (AWL) has traditionally used sand cast magnesium alloys [1] as the material of choice for its gearbox housings. However, while all aerospace castings are weight sensitive, in the case of tail (TGB) and intermediate (IGB) gearbox casings weight is of critical importance due the effect a larger mass can have on the pitching moment of a helicopter. However, advances in aluminium alloy casting techniques, especially with regard to investment, has meant the 30% weight benefit attributable to magnesium due to its lower density can be eliminated by using investment castings ability to manufacture parts with lower nominal wall thicknesses (i.e. 3 mm rather than 5 mm) and produce complex castings which are closer to the optimum design. Consequently, aluminium alloy investment casting technology has been introduced into later AW helicopter designs. While aluminium alloy investment casting used by AWL have proven successful, there was a desire to further enhance the mechanical property balance and reduce the mechanical property variability through the use of either a controlled solidification or low pressure casting techniques on newer designs/redesigns.

As helicopter gearbox castings are classified as vital/critical components any change would require not only in-house testing and evaluation of the most promising techniques currently commercially available, but also a thorough evaluation of the selected technique through a component cut up and validation of the part through structural testing.

As AWL was redesigning the TGB centre housing on the one of its medium lift helicopters a review was carried out into the most promising techniques commercially available, which based on the review of the literature appeared to be controlled solidification investment casting processes. Consequently, AWL Materials Technology Laboratory undertook a comprehensive evaluation of a controlled solidification investment casting process and compared the results against both sand and investment casting processes currently used. Also evaluated and assessed was the significance of HIPping as a means of further reducing mechanical property variability in class 'A' castings, the results of which form the basis

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of this paper. In addition tensile and fatigue data will also be presented from data obtained from the first off TGB casting cut up, in which the resultant data will be compared against a similar TGB centre casting manufactured using a conventional investment casting process.

2. Experimental procedure

2.1. Manufacturing history

Details concerning the plates supplied by the controlled solidification investment foundry together with similar cast plates supplied to AWL from previous assessments is summarised in Table 1. The various foundries that supplied the cast plates have been identified by a specific numerical identity for ease of reference. Although variations in composition were observed between the plates, they all complied with the chemical compositional requirements specified for BS L169 T6 and A357 T6, as shown in Table 2, the exception being foundry 3 which had a titanium content of 0.26%. In addition although plate thicknesses varied between foundries, any mechanical property differences were unlikely to be statistically significant between 5 and 20 mm, based on the property limits defined in BS L169.

In the case of the controlled solidification investment casting batch from foundry 5, half the samples were subjected to HIPping prior to solution treatment and ageing as detailed in Section 3.2, in order to assess whether HIPping would enhance mechanical properties. HIPping was carried out in accordance with DENSAL 2 (Bodycote's proprietary HIPping process).

The plates were nominally 300 mm by 250 mm and the tensile and fatigue samples were manufactured parallel to the 250 mm dimension.

All the plates were radiographically inspected and achieved the acceptance criteria detailed in AMS 2175 for a class 'A' casting. In addition the castings were also dye penetrant inspected in accordance with AWPS006X and ASTM E1417, for the presence of undesirable features such as cold shuts, cracks, shrinkage cavities etc. In all cases no undesirable features were observed.

Manufacturing details regarding the TGB that was used to assess the controlled solidification investment casting process are shown in Table 3. Tensile and fatigue specimens were removed from the TGB at the locations indentified on the drawing as shown in Plate 1. The casting was inspected using the same NDI techniques as the cast plates.

Table 2
Chemical composition of cast material supplied by each foundry.

Foundry	Element (wt%)										
	Cu	Mg	Si	Fe	Mn	Ni	Zn	Pb	Sn	Ti	Al
1	0.03	0.56	7.1	0.11	0.05	0.01	0.02	0.01	0.01	0.11	Rem
2	0.01	0.52	7.0	0.08	0.02	0.01	0.02	0.01	0.01	0.08	Rem
3	0.01	0.57	7.3	0.07	0.02	0.01	0.01	0.01	0.01	0.26	Rem
4	0.01	0.56	6.8	0.05	0.01	0.01	0.01	0.01	0.01	0.12	Rem
5	0.01	0.57	7.0	0.07	0.01	0.01	0.01	0.01	0.01	0.15	Rem
5 (TGB)	–	0.58	6.9	0.05	0.01	0.01	0.01	0.01	0.01	0.13	Rem

Table 3
Manufacturing details of the TGB casting submitted for evaluation.

Foundry	Melt/ batch	Certificate of conformity	Heat treatment	Method of manufacture
5	2197	4803	Solution treat: 14 h at 540 °C age: 7 h at 160 °C	911 15225 Issue 5

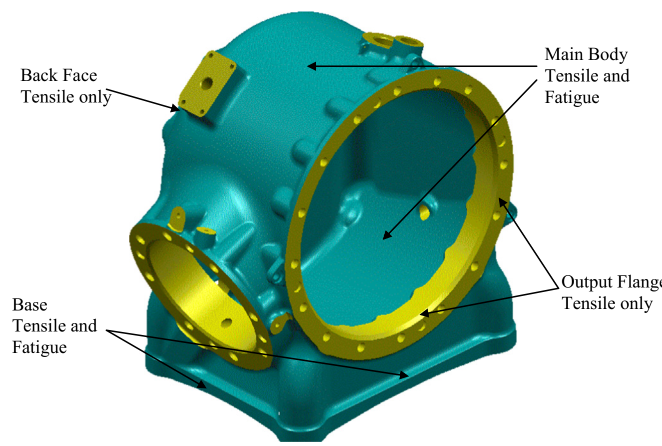

Plate 1. Schematic of the TGB (showing location of the Tensile and Fatigue specimens).

2.2. Mechanical and microstructural property assessment

2.2.1. Re-heat treatment trials

Within BS L169 there exists a range of heat treatment conditions especially with regard to artificial ageing times, which can be used. This variation regarding heat treatments can be seen with

Table 1
Manufacturing history of 'as-cast' plates.

Foundry identity [casting type]	Plate thickness (mm)	Heat treatment			Finish	Alloy composition
		Solution treatment	Quenchant	Ageing		
1 [Sand (conventional)]	10	11 h at 540 °C	WQ at 35 °C	24 h At RT and 5 h at 160 °C and Air cooled	Abrasive blasted	BS L169 (A357)
2 [Sand (low pressure)]	10	24 h at 545 °C	PQ (ucon A) at 35 °C	8 h At 165 °C and air cooled		
3 [Sand low pressure/chill)]	10	12 h at 535 °C	Not specified	6 h At 160 °C and air cooled		
4 [Investment] + HIP	16	11 h at 540 °C	WQ at 30 °C	8 h At 165 °C and air cooled		
5 [Investment (controlled solidification)]	12.5	14 h at 540 °C	PQ at 30 °C	7 h At 160 °C and air cooled		

Notes – WQ = water quenched, PQ = polymer quenched and RT = room temperature.

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