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Effect of the chemical milling process on the surface of titanium aluminide castings

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Abstract

Most of titanium aluminide (TiAl) castings used in the automotive and aeronautical industries, such as turbines, are high added-value parts with complex geometries. Due to high reactivity of TiAl cast into ceramic moulds, most of the castings require post-processing in order to remove a brittle surface layer named alpha case. Furthermore, the complex geometry and thin walls of this type of components makes difficult to cast net shape parts; so, near-net shape components with machining allowance are often produced to improve mould filling (better fluidity). To solve this technological limitation, the chemical milling process is used to eliminate this layer and the machining allowance. In bibliography there are only a few systematic studies about the influence of chemical milling in TiAl surface castings. So, this experimental work seeks to contribute to understand the influence of this finishing process on the TiAl castings surface quality (dimensional accuracy, roughness and microhardness) and intends to establish which of the two chemical solutions tested is better for chemical milling of TiAl castings.

Keywords: Chemical milling; titanium; titanium aluminide; investment casting.

1. Introduction

Chemical milling (CM) is a surface finishing process that has been used since the 50s and is characterized by the use of a strong acidic or basic solution for the surface dissolution of metals such as titanium, aluminum or steel. Due to the capability of removing metal, this process is used to remove a brittle and hard surface layer named alpha case, formed on the surface of titanium and its alloys by dissolution in the liquid alloy of carbon, nitrogen and especially oxygen from the ceramic material of the shell, during the investment casting process. Some of the problems associated with the existence of alpha case are: initiation of cracks and their propagation, embrittlement of the alloy due to the change of microstructure on the surface of the melt [1-3], reduction of fatigue resistance, lower ductility and difficulty to be machined [4]. So, it is mandatory to remove it. In Fig. 1 is presented a microstructure of a Ti alloy with alpha case layer on the left.

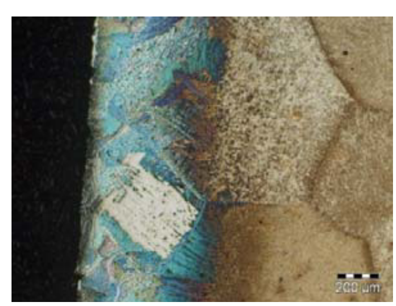

Fig. 1. Ti10V2Fe3Al alloy microstructure, alpha case on sample's surface (left layer), etched with Kroll's reagent [5].

During the project the parts were dimensioned with a machining allowance corresponding to the alpha case

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layer which will be removed by chemical milling [6,7]. The metal removal, based on chemical reactions, is achieved by submerging the castings into a solution that reacts with their surface and removes the allowance. In order to promote a homogeneous metal removal, the bath should be permanently stirred [8]. In comparison with conventional machining, the process of chemical milling is capable of removing metal from castings with complex geometry, with thin thickness without causing deformations and maintaining tight tolerances [6,9]. However, this process is relatively inefficient, expensive, dangerous, due to the type of chemical solutions, and also harmful to the environment [8].
To reach this type of finishing it is necessary that the chemical solution promotes a good and homogeneous metal removal rate and eliminates or avoids the formation of the hydrogen embrittlement on the surface of the parts. At the end of chemical milling the castings should detain a bright and smooth finishing. Some additional aspects, such as process efficiency, air quality in the surroundings, capability to recycle the solution or neutralize it and not being harmful to the environment, must also be considered in process implementation [8,9].
In chemical milling of titanium alloys the most used solution, according with ASM [4], is a combination between hydrofluoric acid (HF) and nitric acid (HNO_3), as shown in Table 1, because of the high acidity which improves the metal removal rate [8]. The HF is used due to its high acidity. However, there is the possibility of a hydrogen layer formation on the casting surface, due to the high affinity of the titanium for hydrogen, which can promote the embrittlement of the components surface. Thus, HNO_3 is employed because it helps to reduce the danger of contamination by hydrogen. The proportion of HF in the chemical milling bath varies in a range between 1 and 10% and the proportion of HNO_3 between 1 and 40%. These solutions are used at a temperature of 40 to 60ºC [8,10,11].

Table 1. Solution commonly used on chemical milling of titanium alloys [9].

Alloy	Type of product	Chemical solution	Surface finishing Ra (µm)
Titanium alloys	Sheet, plate, forging	HF, HNO_3	0.25-1.0
	Casting	HF, HNO_3	0.75-1.5

However, for TiAl castings, a different mixture is proposed by Chen [12], which replaces HNO_3 by sulfuric acid (H_2SO_4) and adds some sodium chloride (NaCl). H_2SO_4 is used to promote a good surface finishing and NaCl prevents hydrogen embrittlement. This solution should be used at a temperature between 38ºC and 52ºC [12].

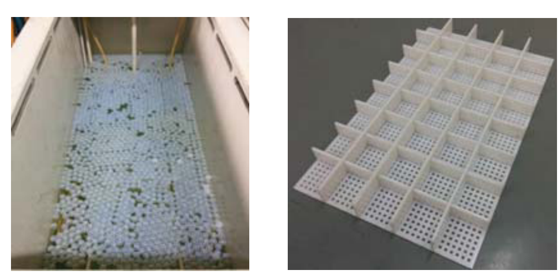
2. Experimental Procedure

In order to perform the experimental tests, turbine investment castings in Ti-33.7Al-4.77Nb-1.05Cr were used. The ceramic shells used to obtain these castings have an yttria face-coat and details of its preparation are presented in previous works [13,14].
These specimens were immersed in two different acid solutions. The composition of these solutions is presented in Table 2 [15].

Table 2. Composition of the chemical solutions [13,15].

Solution (vol.%)	HF	HNO_3	H_2SO_4	Erkantol	NaCl	H_2O
1	4.5	7.5	-	5	-	83
2	2	-	4	-	3.5	90.5

The use of a wetting agent "Erkantol" on solution 1 is due to the fact that it allows a greater wettability of the specimens to be chemically milled.
Both solutions were placed on a 550 L volume tub. However, only 250 L of the two solutions were used for the chemical millings tests. The temperature of both solutions was 35ºC, measured with a thermometer ± 0.1ºC, in order to make an accurate comparison and it was also the maximum temperature possible to reach by the bath heating system available. Fig. 2 a) shows the apparatus. This tub contains an agitation system and small plastic floating balls on the surface to prevent the solution vaporization during the heating cycle. A thermoplastic tray (Fig. 2 b)) was also made to support the TiAl standard test castings and to promote bath circulation in the bottom area of the parts.



a) b)

Fig. 2. a) Tub used on experimental tests and b) tray to support the TiAl test castings.