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Cooling rate and carbon content effect on the fraction of secondary phases precipitate in as-cast microstructure of ASTM F75 alloy

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ABSTRACT

Simple test castings were used to study the effect of cooling rate and carbon content in as-cast microstructure of alloy ASTM F75, Co–26 wt.% Cr–5.7 wt.% Mo. Alloys with four C content (0.45, 0.33, 0.36 and 0.25 wt.%) were poured into investment ceramic molds. In order to obtain different cooling rates, the castings were constituted of three axisymmetrical cylinders of different diameters (12, 16 and 24 mm). Cooling curves were obtained from each cylinder and the fraction of secondary phases in as-cast microstructure was measured by image analysis. Average cooling rates of 100, 60 and 20 °C/min, were obtained in the 12, 16 and 24 mm diameter cylinders respectively, at the first solidification step occurring in the temperature range from 1390 to 1350 °C. A significant effect of this cooling rate range on the fraction of secondary phase was not observed.

It was observed that the fraction of blocky carbides increased proportionally as the C content increased, whereas the amount of the eutectoid constituent showed a significant increase only in the sample containing 0.45 wt.%, as compared with the samples of other carbon contents. It was also found that the initial solidification undercooling affects the temperature of sigma phase precipitation with which the solidification of the alloy is completed.

1. Introduction

Nowadays in the surgical implant manufacture Co base alloys, Ti base alloys and stainless steels are used due to their good mechanical stability and biocompatibility. The implants are manufactured by mechanical processing, powder metallurgy and investment casting process, Mitsuo (2002).

The ASTM F75 cobalt base alloy is used for manufacturing surgical implants by investment casting. Fig. 1 shows a typical as-cast microstructure of this alloy. The alloy in as-cast condition presents a microstructure consisting of a dendritic matrix α (Co fcc) rich in Cr and Mo, and secondary phases, mainly blocky carbides of the $M_{23}C_6$ type, that appear in the interdendritic regions and grain boundary. Recent works, where X-rays diffraction measurements were made on as-cast, Ramírez et al. (2002), and heat treated samples of the alloy, Caudillo et al. (2002), revealed the presence of sigma phase in both as-cast and thermally treated pieces. Studies performed by Ramírez et al. (2002) in samples quenched during directed solidification have shown that solidification of these alloys ends with the

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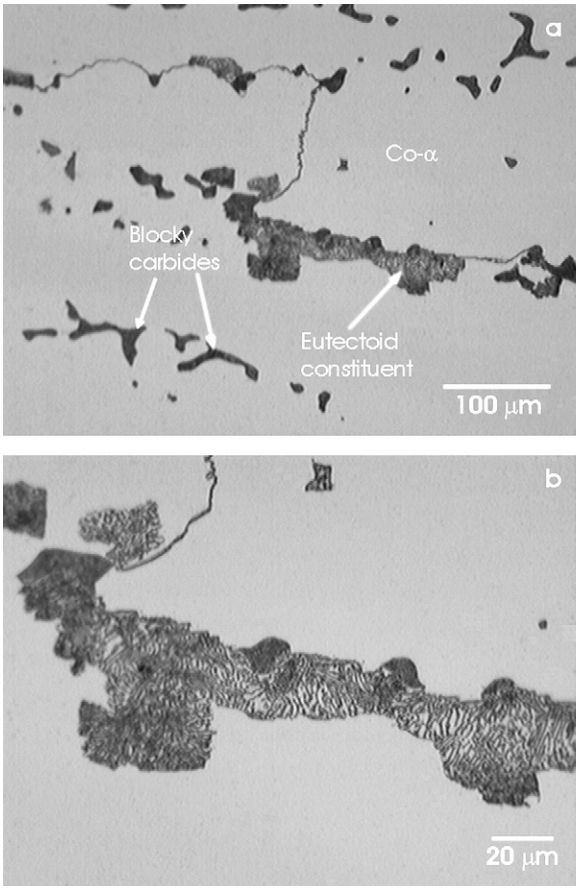

Fig. 1 – As-cast microstructure of the ASTM F75 alloy.

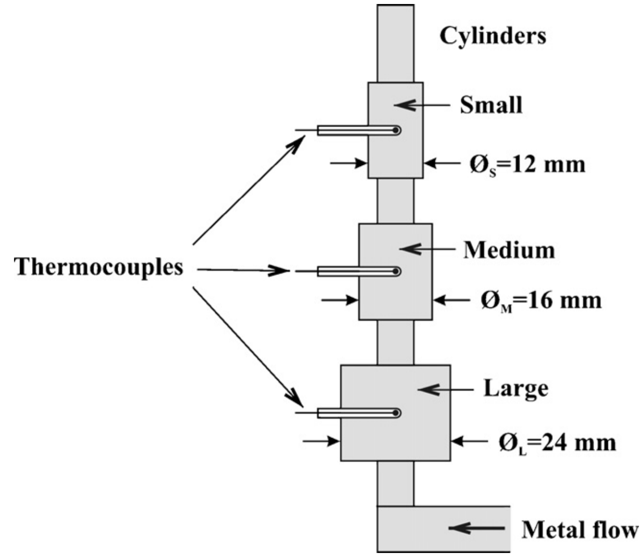

Fig. 2 – Schematic illustration of the casting arrangement.

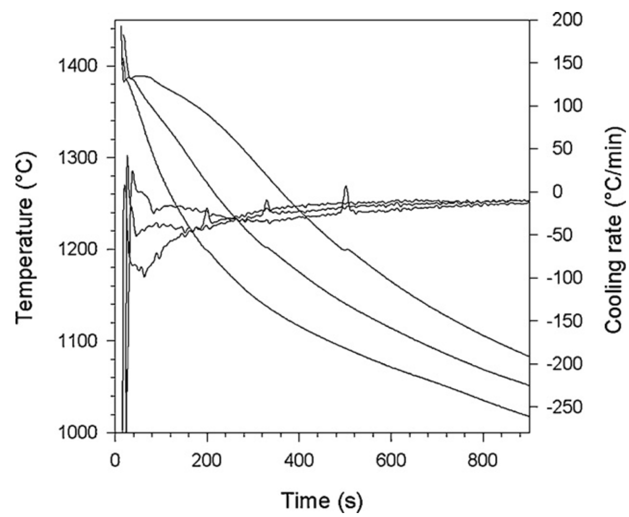

Fig. 3 – Typical cooling curves and their derivatives obtained by thermal analysis of the ASTM F75 alloy. Cooling curves from casting A1–2, 0.26 wt.% carbon.

sigma phase precipitation around 1220 °C, which in turn transforms to the $M_{23}C_6$ carbide at temperatures below 1150 °C.

In these alloys a lamellar component has been also observed in the grain boundaries. This lamellar component is formed by interlayed plates of $M_{23}C_6$ carbide and a phase that has not been clearly identified yet, some possibilities are the σ phase, Weeton and Signorelli (1954), both α and σ phases, Silverman et al. (1957), and either α or M_6C carbide phases, Sims (1969). Quenching during directional solidification studies conducted on this alloy by Ramírez et al. (2002), show that this lamellar structure corresponds to a eutectoid constituent that in an alloy with a C content of 0.26% precipitates below 989 °C, when the cooling rate is below 35 °C/min.

Carbides have important effects on the corrosion performance and wear resistance of ASTM F75 alloy. Cawley et al. (2003) showed that the volume fraction, size and distribution of carbides are critical to the development of a low wear rate system. They observed that as-cast materials have greater abrasive wear resistance when compared to single or multiple heat treated materials. Also Wang et al. (1999) concluded that wear resistance of the couple as-cast Co–Cr on as-cast Co–Cr alloy was superior to the high carbon wrought on the high carbon wrought couple tested.

Table 1 – Chemical composition of alloys

Alloy	C	S	Mn	Si	Ni	Cr	Mo	Fe	Liquidus temperature (°C)	Piece
A1	0.26	0.02	0.32	0.68	0.76	26.23	5.80	0.31	1408	A1–1, A1–2 and A1–3
A2	0.33	<0.01	0.36	0.77	0.68	26.48	5.96	0.74	1399	A2–4 and A2–5
A3	0.36	0.01	0.42	0.74	0.69	26.63	5.84	0.51	1398	A3–6
A4	0.45	0.02	0.48	0.77	0.63	26.30	5.51	0.97	1394	A4–7