M. ALVAREZ-VERA, A. HERNÁNDEZ-RODRÍGUEZ, M. A. L. HERNÁNDEZ-RODRÍGUEZ, A. JUÁREZ HERNÁNDEZ, J. R. BENAVIDES-TREVIÑO, J. H. GARCÍA-DUARTE

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EFFECT OF COOLING RATE DURING SOLIDIFICATION ON THE HARD PHASES OF $M_{23}C_6$-TYPE OF CAST CoCrMo ALLOY

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Microstructural morphology of CoCrMo alloy by control of the cooling rate during the solidification was investigated. Samples were obtained using both an induction furnace for slow cooling rate and electric arc furnace for fast cooling rate. Microstructural characterizations were performed with metallographic techniques. It was found that the difference between the formation temperature of hard secondary phases of $M_{23}C_6$-type carbides determine the reduction of carbide size by increasing the cooling rate.

Key words: CoCrMo alloy, cast, solidification, cooling rate, microstructure

INTRODUCTION

The CoCrMo alloys are widely used in medical application as implant materials such as prosthetic hips and knees bearings. Cast implants of CoCrMo alloy have a long history of successful use since Vitallium alloy was developed at the beginning of the last century due to their wear resistance, strength, impact resistance and low friction in the human body [1].

Many efforts to improve the mechanical and tribological properties of cast CoCrMo alloys have been made. There are CoCrMo alloys available in several different conditions defined primarily by their starting composition (e.g. low or high carbon content) [2], the conditions of manufacture (e.g. casting or forging) [3], subsequent thermal treatments (solution heat treatment, hot isostatic pressing or sintering) [4,5] and engineering surfaces by physical vapor deposition and chemical vapor deposition [6]. Henriques et al. [7] performed studies on mechanical properties of CoCrMo alloy compacts produced by hot pressing powders in a graphite die at different temperatures. However, there are few studies assessing the effect of cooling rate during the solidification on the microstructure. Zhuang et al. [8] has studied the dendritic and equiaxial grain structures and the mechanical property of fatigue improvement by cooling rate. Studies performed by Ramirez et al. [9] have shown the effect of different carbon content and cooling rate on microstructure of secondary phase. Lia et al. [10] examined the microstructural and mechanical properties of the hard phases of $M_{23}C_6$-type in CoCrMo alloys in both cast and wrought conditions. They found the origin of the nanostructured hard phase mixture to be related to slow cooling during casting.

The aim of the present work was to provide more information about the effect on microstructure of CoCrMo alloy by control of the cooling rate during the solidification process.

MATERIAL AND METHODS

Samples of CoCrMo alloy were prepared using both induction and electric arc furnaces. Type R thermocouples were used to obtain the temperature curves. The cooling curves and their derivatives were analyzed in order to obtain the temperature of start and end of solidification process. The chemical composition analyses of the CoCrMo alloys according to ASTM F-75 07 [11] are given in Table 1.

RESULTS AND DISCUSSION

The temperature and cooling rate curves are shown in Figure 1. A typical cooling curve obtained from the experimental technique is shown in Figure 1a). In this case, two reactions are observed, the first peak is associated to onset of solidification process at 1 383 ºC corresponding to the primary phase Co-α matrix exothermic reaction (A), and the second is associated to the end of solidification at 1 258 ºC, having 6,7 ºC/s average cooling rate (B). These results are agreed with Ramirez et al. [9] research showing the first thermal signal at 1 390 °C, and the second peak around 1 200 °C.

In Figure 1b) is shown a higher cooling rate curve having 23,2 ºC/s. The liquid temperature and the end of solidification decreased to 1 264 ºC (C) and 1 190 ºC (D), respectively as solidification velocity increased. After the solidification is completed, the transformation

M. Alvarez-Vera, A. Hernández-Rodríguez, COMIMSA- Corporación Mexicana de Investigación en Materiales SA de CV, M. A. L. Hernández-Rodríguez, A. Juárez Hernández, J. R. Benavides-Treviño, J. H. García-Duarte, Universidad Autónoma de Nuevo León, México.

Table 1 **Chemical composition of the alloys studied / wt. %**

Alloy	Co	Cr	Mo	Ni	Fe	C	Si	Mn	B
ASTM F-75 07	Bal.	27-30	5-7	<0,5	<0,75	<0,35	<1	<1	<0,01
Slow cooling	Bal.	28,3	5,9	0,19	0,13	0,21	0,32	0,41	0,003
Fast cooling	Bal.	29,2	6,1	0,18	0,17	0,23	0,28	0,43	0,002

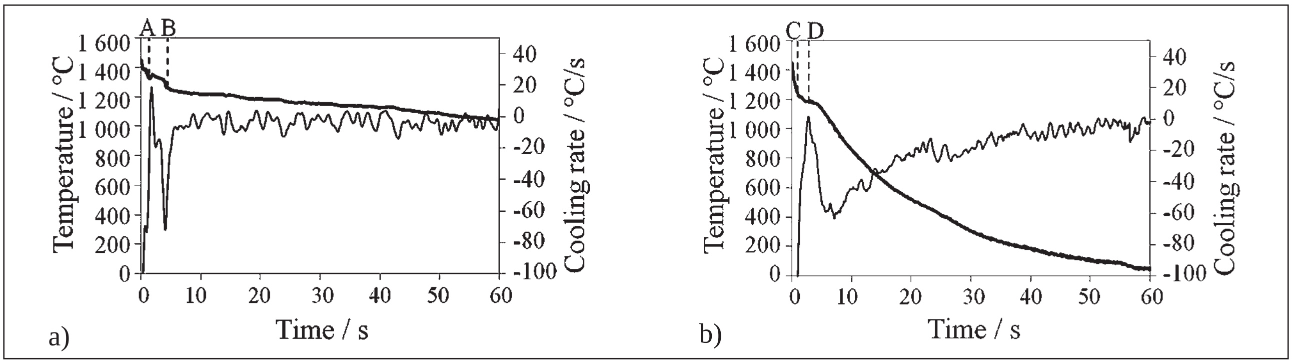

Figure 1 Cooling curves and their derivatives obtained by thermal analysis of CoCrMo alloy. a) Slow cooling and b) fast cooling

Table 2 **Main features by controlling cooling rates of the CoCrMo test samples**

Alloy	Hardness / HV	Error*	Nominal secondary particle size / μm	Error*	Fraction area of secondary phase / %	Error*
Slow cooling	355,8	7,2	10,1	1,2	7,6	0,8
Fast cooling	347,6	5,3	4,4	0,9	9,7	0,9

*Error: Standard error of the mean.

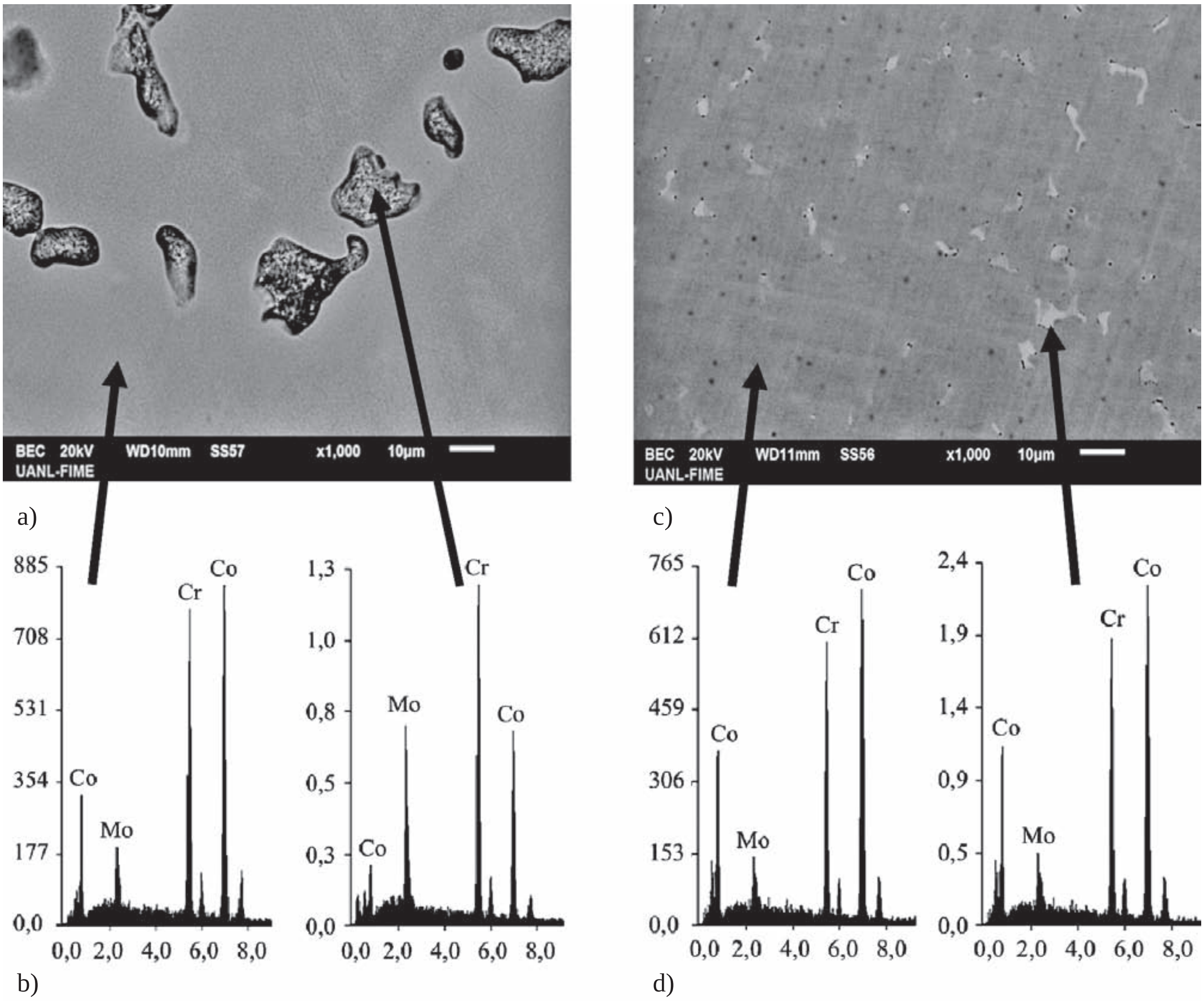

Figure 2 SEM micrographs for both conditions a) slow and c) fast cooling rates, EDS analysis in the Co-α matrix and secondary phases b) slow and d) fast cooling rates

of the sigma phase to ($M_{23}C_6$) blocky carbides between 1 150 and 1 050 ºC, has been reported [9]. This effect was not detected in both at 1 050 °C, slow and fast cooling rate. Micrographs for both cooling rate conditions were obtained using a scanning electron microscope (SEM) (Jeol model JSM-6490). The microstructures for both conditions are shown in Figure 2. It can be observed the effect of fast cooling which results in a finer microstructure leaving smaller secondary precipitates.

All the samples were identified, the secondary phases ($M_{23}C_6$ blocky carbide and sigma phase) embedded in the cobalt-base alpha matrix (fcc). The EDS analysis, Figure 2b), shows cobalt-base alpha matrix and the intermetallic compound sigma phase (CoCr).

The microstructure of fast cooling samples, consisted of a dendritic cobalt-base alpha matrix (fcc) and interdendritic precipitates of ($M_{23}C_6$) "blocky type" carbide resulted in a chromium-rich as shown in Figure 2d). Gianchi et al. [3] have reported that the "blocky type" and lamellar carbide formation consisted of interlayer plates of ($M_{23}C_6$) and cobalt-rich alpha matrix (fcc). This is in agreement with the results in this work. The fraction area of blocky carbides and eutectoid constituent were affected by cooling rates. The effect of the main features of the test samples are shown in Table 2.

CONCLUSIONS

Microstructural precipitation of secondary phases and grain size of CoCrMo alloys were modified by the control of the cooling rate during the solidification process. The precipitation of secondary phases of fast cooling rate showed a reduction of nominal particle and grain size. An slight difference between microhardness of slow and fast cooling rate from 347,6 to 355,8 HV was observed.

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Note: The responsible for English language is the lecturer from COMIMSA Saltillo, México