EFFECT OF MOLD PREHEATING ON THE MICROSTRUCTURE OF THE INVESTMENT CAST ASTM F-75 IMPLANT ALLOY

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Abstract The ASTM F-75 (Co-28%Cr-6%Mo) is widely used as a biocompatible alloy in medicine for manufacturing implants. In this study, effect of mold preheating on the as-cast microstructure of the alloy was investigated using the solid investment casting process. Several mold preheating temperatures of 550, 700, 850 and 1000 °C were selected at the same melt superheat. The samples were characterized by optical microscopy, electron microscopy and macro-hardness test. The results showed that the size of grains and secondary carbides of the matrix was increased by increasing the mold preheating temperature. In addition, morphology of the $M_{23}C_6$ carbides was changed from the eutectic carbides precipitated in grain boundaries to the blocky shape precipitated in both carbide interface and dendritic matrix. The appropriate microstructure with nearly fine grains with homogeneous distribution of secondary phases was obtained at mold preheating temperature of about 850 °C.

Keywords Investment cast, Mold preheating, Microstructure, Co alloy

چکیده آلیاژ ASTM F-75 (Co-28%Cr-6%Mo) به عنوان یک آلیاژ زیست سازگار به طور وسیعی در پزشکی جهت ساخت کاشتنی های مورد استفاده در بدن کاربرد دارد. در این پژوهش، تأثیر درجه حرارت پیشگرم قالب در فرایند ریخته گری دقیق با قالب توپر بر روی ریزساختارهای ریختگی آلیاژ فوق مورد بررسی قرار گرفت. بدین منظور دماهای پیشگرم ۵۵۰، ۷۰۰، ۸۵۰ و ۱۰۰۰ درجه سانتیگراد در یک مقدار فوق گداز معین انتخاب گردید. نمونه ها توسط متالوگرافی نوری و الکترونی و آزمایش سختی سنجی ماکرو مشخصه یابی گردید. نتایج نشان داد که با زیاد شدن دمای پیشگرم قالب اندازه دانه های زمینه و کاربیدهای ثانویه در ساختار افزایش می یابد. به علاوه تغییر مورفولوژی کاربیدهای $M_{23}C_6$ از نوع کاربیدهای یوتکتیکی تشکیل شده در مرز دانه ها به کاربیدهای بلوکی راسب شده در فصل مشترک کاربید و زمینه دندریتی ملاحظه شد. ریزساختار مطلوب با دانه های نسبتاً ریز همراه با توزیع یکنواختی از فازهای ثانویه در دمای پیشگرم قالب ۸۵۰ درجه سانتیگراد بدست آمد.

1. INTRODUCTION

The Co and Ti alloys and stainless steels are used for the manufacture of surgical implants due to their good mechanical stability, wear behavior and biocompatibility [1]. The implants are produced by mechanical processing, powder metallurgy and investment casting process [2]. The Co alloys, which have a long history in medicine and dentistry, are usually used for the manufacture of surgical implants by investment casting [3]. The alloys in as-cast condition exhibit a microstructure consisting of a dendritic FCC matrix and grain boundary carbide phases [4]. The size, distribution, morphology and extent of these phases are important in determining their effects on mechanical properties [5, 6, 7].

The effect of pouring temperature on the microstructure of ASTM F-75 (Co-28%Cr-6%Mo) alloy was investigated by Gomez et al. [8]. They showed that mechanical properties can be optimized through controlling processing parameters.

In the present study, effects of mold preheating temperature on the size, morphology and fraction of secondary phases in the microstructure of F-75 alloy were investigated.

2. MATERIALS AND METHODS

The chemical composition of the F-75 used in this work is presented in Table 1.

TABLE 1. Chemical composition of the F-75 alloy.

Material	ASTM F-75	The alloy used
Co	Balance	65.30
Cr	27-30	28.00
Mo	5-7	5.50
Si	1	0.35
Mn	1	0.35
Ni	1	0.35
Fe	0.75	0.30
C	0.35	0.35

The samples were prepared using solid investment casting process in a rectangular shape with the dimensions of 3×12×12 (mm). The ASTM F-75 cobalt base alloy was induction melted and cast at 1450 °C with different mold preheating temperatures of 550, 700, 850 and 1000 °C. The as-cast microstructures were characterized by optical microscopy and scanning electron microscopy (SEM Philips X230). The SEM image was randomly captured from different zones of the specimens obtained in each condition. Electrolytic etching with a 5% hydrochloric acid solution in water was used to reveal the microstructure. During etching, dc voltage of 5 V was applied for 1 s. Phase identification of the samples was carried out by X-ray diffraction (Philips X'Pert-MPD) with CuKα radiation (λ=1.54 Å) in a 40 kV voltage and 30 mA current. The quantitative determination of grain and carbide sizes was performed using the Image Tool software. For each mold preheating temperature, about 15-20 images was captured and used for the calculation of the grain size and volume fraction of carbides. Hardness of specimens was measured by Rockwell C method.

3. RESULTS AND DISCUSSIONS

Fig. 1 shows SEM images of the as-cast microstructure of the F-75 alloy in two magnifications. The microstructure is consisted of a strongly cored dendritic matrix with a distribution of dispersed carbides. The X-ray diffraction pattern of the as-cast microstructure is shown in Fig. 2. It can be seen that solidification of the alloy was ended with the formation of FCC matrix, HCP phases and $M_{23}C_6$ carbides as the major secondary phases.

Three different morphologies of the carbides in the as-cast microstructure can be detected [9]. The "eutectic" carbide with lamellar morphology was formed at grain boundaries by interlayer plates of $M_{23}C_6$ carbide and a phase that has not been clearly identified yet (maybe σ or both α and σ phases). The other carbide morphology was "blocky" appearance found within the dendritic matrix. The last carbide morphology was also "blocky" but precipitated at the interface between the matrix and the "eutectic" carbides. The chemical composition of these carbides was similar to the $M_{23}C_6$ (M = Co, Cr and Mo) carbide.

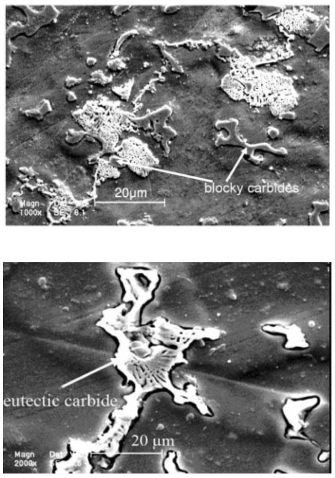

Figure 1. Microstructure of as-cast ASTM F-75 alloys.

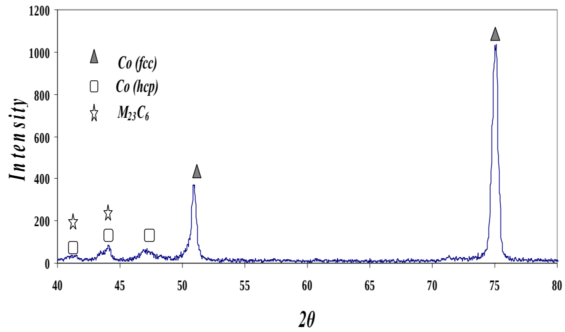

Figure 2. X-ray diffraction pattern of the as-cast F-75 alloy.

Fig. 3 shows the microstructural changes induced by different mold temperatures. As illustrated in Fig. 3a, the blocky and lamellar carbides were formed in grain boundaries at mold preheating of 550 °C. As the mold temperature was increased, morphology of carbides was changed to blocky and precipitated in both matrix/carbide interface and dendritic matrix. This change of precipitation morphology was probably as a result of a sharp reduction in the stacking fault density regions, as discussed by Taylor and Waterhouse [7]. They found that at or above this temperature, there was a change in the active nucleation and growth mechanisms responsible for the carbide precipitation reactions. Nevertheless, the size of carbides was decreased as the preheating temperature was increased.

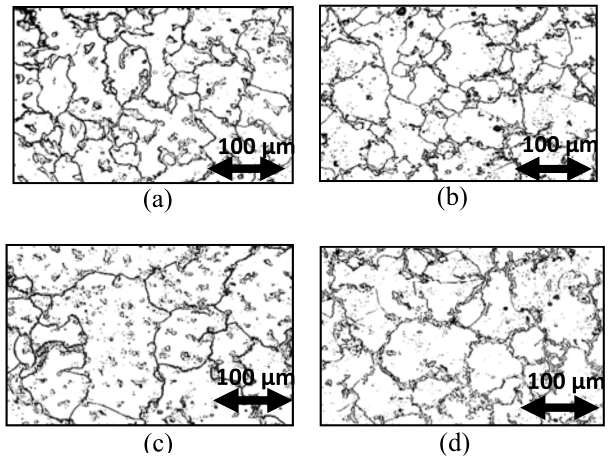

Figure 3 Microstructures of the as-cast F-75 alloys with the mold preheating at: (a) 550 °C, (b) 700 °C, (c) 850 °C and (d) 1000 °C.

The effect of the mold preheating temperature on the matrix grain size was shown in Fig. 4. It can be seen that the grain size is increased with mold preheating temperature from about 50 μm at 550 °C to 150 μm at 1000 °C. Based on the fact that a fine distribution of precipitates can effectively pin grain boundaries, the intrinsic differences in the carbide morphology and distribution were responsible for the different matrix grain size.

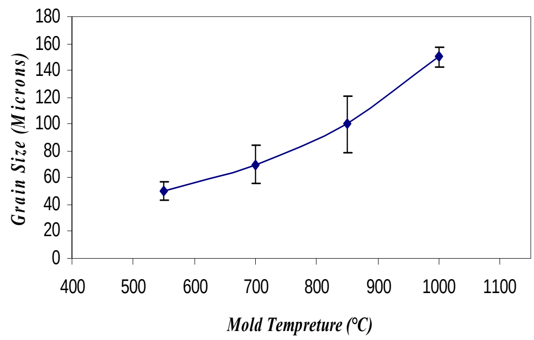

Figure 4. Effect of mold preheating temperature on the matrix grain size.

Dependency of the volume fraction of eutectic and blocky carbides on the mold preheating temperature is illustrated in Fig. 5. It can be seen that the fraction of eutectic or blocky carbides are decreased with increasing mold preheating temperature. However, at the mold temperature of

1000 °C, the volume fraction of both carbides was sharply changed.

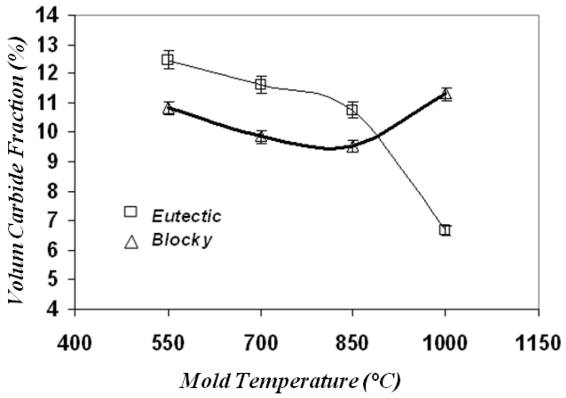

Figure 5. Effect of mold preheating temperature on the volume fractions of eutectic and blocky carbides.

Fig. 6 shows the effect of mold preheating temperature on the ratio of the volume fraction of "blocky" carbides to that of "eutectic" carbides, R(B/E). It is observed that at low temperature, the R(B/E) ratio is approximately close to unity, but it is increased at 1000 °C. This may be associated with the undercooling caused by differences between the pouring temperature and the mold preheating temperature. Alloy preheating at or above 850 °C induced a transition in the carbide morphology from the eutectic to blocky, probably as a result of a sharp reduction in the stacking fault density [7]. As the higher mold preheating temperature resulted in a lower undercooling, the time for the morphology transition was increased and consequently this led to a higher R(B/E) ratio. This transition could not happen at the lower mold preheating temperature due to the higher undercooling.

The effect of mold preheating on the sample hardness is shown in Fig. 7. It can be seen that increasing the mold preheating temperature from 550 to 1000 °C only has lead to an increase of about 1.5 RC in hardness. Although it is not significant, but it could be due to the homogeneous distribution of secondary phases in matrix at the higher mold temperature, as shown in Fig. 7.

The present results showed that increasing the mold preheating temperature resulted in a lower

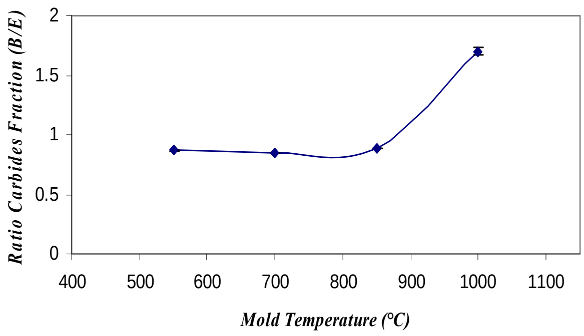

Figure 6. Effect of mold preheating temperature on the ratio of the volume fraction of "blocky" carbides to that of "eutectic" carbides, R(B/E).

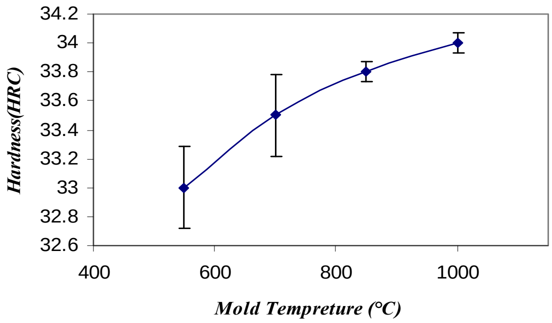

Figure 7. Effect of mold preheating temperature on the hardness of as-cast alloy.

level of the interdendritic carbide precipitation and lead to breakup of the dendritic structure. A relatively homogeneous and fine equiaxed grain structure and secondary phases was obtained at the mold preheating temperature of 850 °C. Investigating effects of other casting parameters on the as-cast and as-heat treated microstructures and mechanical properties are also in progress.

5. CONCLUSION

This work clearly showed that the as-cast microstructure of the investment cast ASTM F-75 Cobalt-based alloy was depended upon the mold preheating temperature. The main effect of mold preheating temperatures was manifested as to decrease the amount of extensive interdendritic carbide precipitation and appreciable breakup of the dendritic grain structure. This led to the development of a homogeneous equiaxed grain structure and the consequent improvement in hardness. The size of carbides was also increased as the mold preheating temperature increased. The best microstructure with nearly fine grains and homogeneous distribution of secondary phases was obtained at the mold preheating temperature of 850 °C.

6. REFERENCES

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