Appraisal of Orthopedic Implant Co-Cr-Mo Alloy Cast by Counter-Gravity in Graphite Investment Shell Moulds

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Abstract: The microstructure of a cobalt-base alloy was cast by the investment casting process using counter-gravity pouring technique under vacuum was studied. The Co-Cr-Mo alloy is broadly employed in the manufacturing of orthopedic implants because of their high strength, good corrosion resistance and excellent biocompatibility properties. The characterization of the samples was attained by using optical microscopy, scanning electron microscopy (SEM) and energy dispersion spectroscopy techniques (EDS). The as-cast microstructure is a Co-fcc dendritic matrix with the presence of a secondary phase as carbides precipitated at grain boundaries and interdendritic zones.

Keywords: Investment casting, biocompatible Co-Cr-Mo alloy, colloidal silica binder, Zirconia, counter-gravity pouring.

1. INTRODUCTION

To increase the life of prosthetic hip joints, the claim for hip joint replacement is growing. Implant requirements such as high corrosion and wear resistance, biocompatibility and longevity are essential for successful hip joint replacement [1]. Co-Cr-Mo alloys have been used for biomedical applications such as dental and orthopedic implants because of their excellent mechanical properties and biocompatibility. Co-Cr-Mo alloys are the most commonly used metal-on-metal bearing due to their high corrosion and wear resistance. Carbides give strength and wear resistance by taking up chromium and molybdenum from the surrounding area during the solidification process [2]. Large differences exist in the mechanical properties between cast and forged alloys. The most used as-cast alloys are Co-Cr-Mo (ISO 5832-4, ASTM F7). The cast Co-Cr-Mo alloy requires rapid solidification to avoid large dendritic grains causing the yield strength reduction.

Investment casting differs from all other casting processes in the use of thin-walled shell moulds. The complexity, detail and surface finish of the casting is directly dependent upon the integrity and dimensional stability of the original pattern [3-11]. In various studies, the use of investment shell moulds was demonstrated for various applications including implants [12-16]. The Co-Cr-Mo as-cast alloy conforming to the ISO 5832-4 standard is widely used in the manufacturing of orthopedic implants with investment casting techniques [17].

The purpose of this investigation was assessment of material structure of Co-Cr-Mo alloy cast in zirconium investment shell moulds by counter-gravity poring technique. Also, the microhardness was estimated in the carbide areas of Co-Cr-Mo alloy.

2. MATERIALS METHODS

The chemical composition of Co-Cr-Mo alloy is as per ISO 5832-4 chemical composition standard [18]. In the present work, the colloidal silica binder was used to fabricate the investment shell moulds from zirconia as reinforced filler material. The silica content in the colloidal silica binder was 30%. Two grades (primary and backup sands) of stuccoing sand were employed in the present investigation. Finer grade zirconia sand having AFS grain fineness number 140 was employed for primary coats. This is synthetic sand. This sand was used for first two coats, called prime coats to get good surface finish and every detail of the wax pattern. Coarser grade fused silica sand having AFS grain fineness number 60 was employed for back up coats. The backup sand was employed to develop more thickness to the shell walls with minimum coats [19-30]. The thickness of shell moulds were 10 mm. After all coats, the shells were air dried for 24 hours. Two shells of each treatment were made as shown in figure 1. The Co-Cr-Mo alloy was melted in an induction furnace under vacuum. The investment shell moulds were preheated at 1000^o C. The preheated investment shell moulds were poured at 1360^oC by vacuum counter-gravity pouring technique as shown in figure 1. The pouring time was 2 s. After cooling, the cylindrical cast samples are cut off and cleaned.

Samples for microstructure observations were carefully polished using SiC abrasive papers, Al_2O_3 (0.2 µm and 0.05 µm) and colloidal silica on vibratory polisher to obtain as clean surface. The samples were etched in solution of 100 ml HCl, 100 ml ethanol, 5 g $CuCl_2$. Micro-hardness was measured on Vickers hardness tester. Energy dispersive spectroscopy technique (EDS NORAN System SIX/300) was also employed to provide more accurate chemical characterization of the different phases.

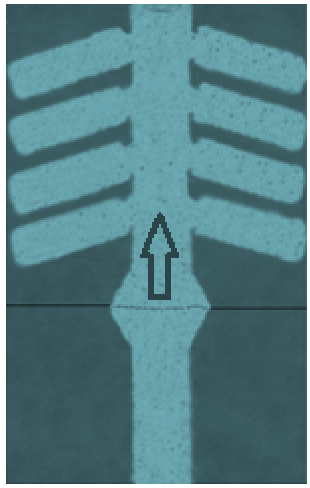

Figure 1: Investment shell moulds counter-gravity poured.

3. RESULTS AND DISCUSSION

The optical micrograph of as-cast Co-Cr-Mo alloy is shown in figure 2. The microstructure observed by optical microscopy consisted of a dendritic matrix and a continuous carbides network.

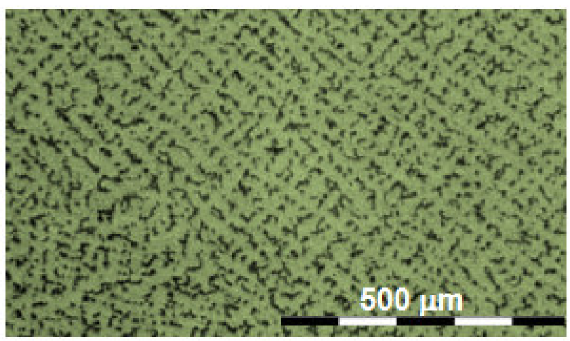

Figure 2: Optical micrograph of the as-cast microstructure of Co-Cr-Mo alloy.

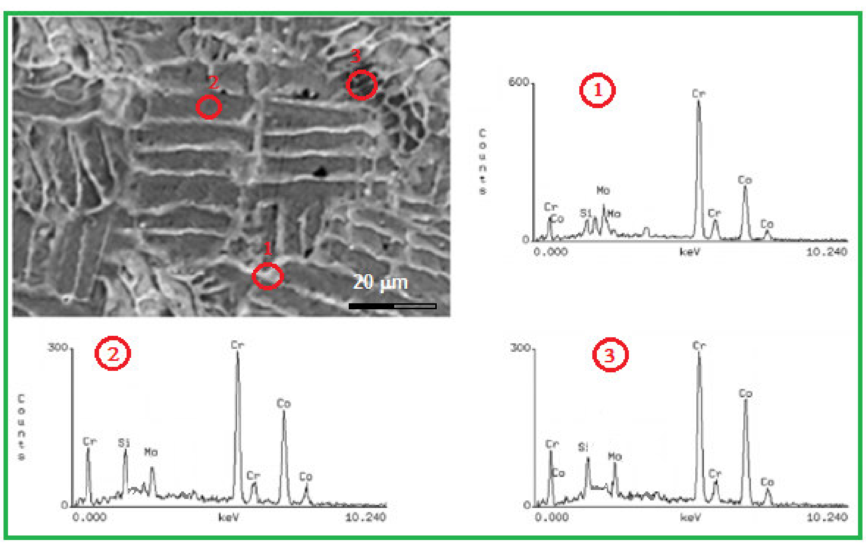

Figure 3: SEM micrograph of main phases present in Co-Cr-Mo alloy.

The chemical composition of areas 1, 2 and 3 are given in Table 1. Furthermore, scanning electron microscopy (SEM) micrograph shows the presence of precipitates at grain boundaries and interdendritic zones, which are Cr-rich, Co-rich and Mo-rich. In general, the microstructure reveals a continuous carbide network. The microhardness values of matrix and precipitates are, respectively, 425 HV and 864 HV.

Table-1: Chemical composition, % weight.

Area	Co	Cr	Mo	Si
1	37.26	48.78	11.65	2.31
2	45.96	32.82	15.86	4.36
3	43.76	36.82	12.48	6.94

4. CONCLUSIONS

The different phases present were revealed by using optical and electron microscopy and EDS technique. The carbides were recognized and detected at grain boundaries and interdendritic zones. EDS show that these precipitates are Cr-rich, Co-rich and Mo rich in the cast samples. The carbides have a continuous network.

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