The Corrosion Studies of Powder Metallurgy Co-Cr-Mo (F-75) Alloy

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ABSTRACT

Co-Cr-Mo (F-75) alloy was investigated for biomedical application due to its mechanical properties and good corrosion resistance. This study has been focusing on the corrosion behavior of PM Co-Cr-Mo alloy. The Co-Cr-Mo powder were first blended with binder using rotation mill and compacted using uniaxial cold press to a pellet shape and then sintered at two sintering temperatures (1300°C and 1350°C) with 90 minutes of sintering time. Immersion test was carried out in a water bath with maintaining the temperature at 37°C for 90 days. The results show that sample sintered at 1350°C has the lowest mpy result after 90 days immersed in 0.9% sodium chloride.

INTRODUCTION

Implants are fabricated from a wide variety of materials, including metals, polymers, ceramics and their composites. Among these materials, metals are an important group. Stainless steel, Co-Cr alloys and Ti alloys are the common metals used in orthopaedics applications. Alloys selection for a specific application has depended upon a variety of design criteria, including biocompatibility, corrosion resistance, tensile strength, fatigue strength, modulus wear resistance, processing and also cost [1-2]. In metallic biomaterials, corrosion is the unwanted chemical reaction of a metal with its environment. Tissue fluid in the human body contains water, dissolved oxygen, proteins, and various ions such as chloride and hydroxide. As a result, the human body presents a very aggressive environment for metals used for implantation. Therefore, corrosion resistance of a metallic implant material is consequently an important aspect of its biocompatibility.

Cobalt based alloys are highly resistant to corrosion even in chloride environment due to spontaneous formation of thin passive oxide layer within human body environment [3-4]. Until recently, its unique properties have attracted attention. Many previous studies tested *in vitro* corrosion characteristics. Hodgson et al. [5] investigated the behaviour of a Co-Cr-Mo alloy under simulated body conditions. They focused on the electrochemical properties of the alloy and the relevant mechanism in the passive and transpassive states. They have reported that the passive film on Co-Cr-Mo changed in composition and thickness with both potential and time. They also stated that the passive behaviour of the Co-Cr-Mo alloy is due to a formation an oxide film highly enriched with Cr (≈ 90% Cr oxides) on the alloy surface. Krasicka-Cydzik et al. [6] have done corrosion testing on the sintered samples made of Co-Cr-Mo alloy for surgical applications. They have found that the re-pressing and subsequent heat treatment applied to the sintered samples made of the Co-Cr-Mo alloy powder influenced significantly and beneficially their microstructure, porosity and corrosion resistance. Thus, the aim of this work is to study the corrosion behavior of sintered PM Co-Cr-Mo (F-75) alloy.

Methodology:

Co-Cr-Mo powder with average size 8.8 µm was used as starting materials. This powder was supplied by Sandvik Osprey Ltd, UK. The samples were fabricated using a powder metallurgy route in which Co-Cr-Mo

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powders and 2 wt. % of stearic acid (as a binder) were blended for 30 min. The mixed powders were poured into a die with 13 mm diameter and compacted using uniaxially cold press at a pressure of 500 MPa. The green compacts were sintered using WEBB 84 furnace at two different temperatures; 1300 ºC and 1350 ºC and known as sample A_1 and sample A_2 respectively. The samples were sintered for 90 minutes in argon atmosphere. The bulk density and apparent porosities of each of the samples were determined using the Archimedes principle. The sintered samples were polished according to the standard preparation of metallographic specimen. Samples were then immersed in 0.9 % NaCl solution at 37°C for 90 days. The corrosion rate by mils per year expression was calculated according to the ASTM G31, Eq. [1],

$$mpy = \frac{KW}{DAT} \tag{1}$$

where K is the constant, W is mass loss (g), D is density (g/cm^3), A is area of sample (cm^2) and T is time of exposure (hr).

The microstructures of the sample before and after immersion test were observed under optical microscope (Olympus BX41M).

RESULT AND DISCUSSION

Table 1 shows the properties of PM Co-Cr-Mo alloy sintered at 1300°C and 1350°C respectively with 90 minutes of sintering time. It is seen that the bulk density increased with increasing the sintering temperatures. Meanwhile an opposite trend was obtained in properties of apparent porosity.

Fig. 1 shows the trend of weight loss per area as a function of time for 2 samples with different sintering temperatures (1300°C and 1350°C). It can be seen that, sample A_1 give the highest weight loss per area, meanwhile sample A_2 shows the lowest weight loss per area. To clarify the trend of each sample, the graph is divided into four parts.

Part (I) represents the value of weight loss per area in the range of 0 to 36 days of immersion. The graph plotted shows the weight loss per area were gradually increased started from 6 to 30 days. Part (II) illustrates the weight loss per area in the range of 30 to 48 days. Based on this part, the weight loss per area was drastically increased for samples A_1. Part (III) in the range of 48 to 60 days of immersion; showing a drastically decrease in weight loss per area for samples A_1. Meanwhile, the weight loss per area for sample A_2 remains consistent started from 24 up to 66 days of immersion. Part (IV) shows the weight loss per area in the range of 60 days to 90 days. Overall, the weight loss is found to be constant for all samples.

The results in Table 2 showed that the sample A_1 has the highest value (0.122 mpy) of corrosion rate and sample A_2 has the lowest value (0.006 mpy) of corrosion rate. Thus, sample A_2 has the highest corrosion resistance after completed 90 days of immersion test. In this study, the porosity was influenced the corrosion behavior of PM Co-Cr-Mo alloy.

Table 1: The properties of PM Co-Cr-Mo alloy sintered at different sintering temperatures

Properties	Sintering temperatures	
	1300°C	1350°C
Bulk density (g/cm^3)	7.23	7.49
Apparent porosity (%)	1.90	0.02

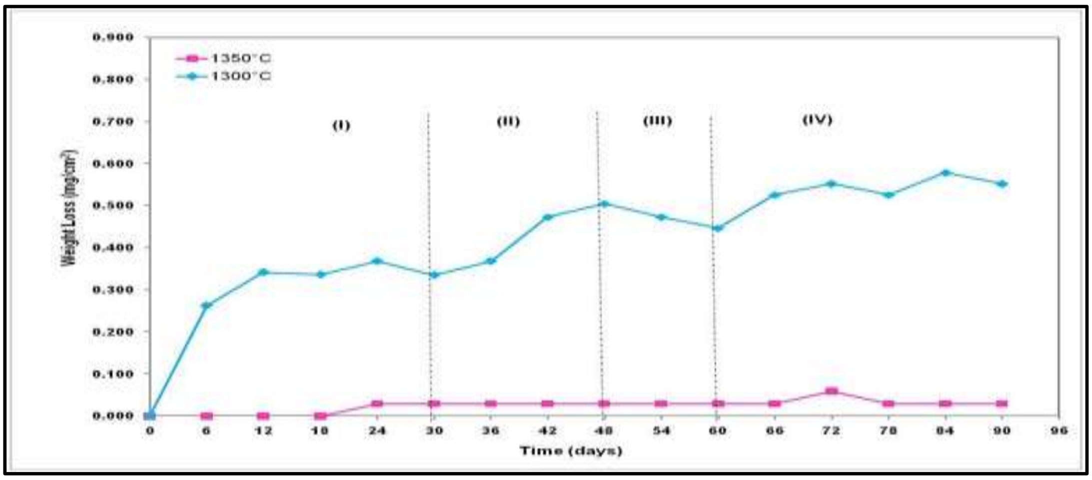

Fig. 1: The weight loss in mg/cm^2 for samples A_1 and A_2 after 90 days

Table 2: The value of corrosion rate (mpy) after completed 90 days duration of immersion test.

Samples with different temperatures	Corrosion rate (mpy)
Sample A_1	0.122
Sample A_2	0.006

From the observation, it was shown that the holes or pores are observed at all sintered samples before immersed in 0.9% NaCl solution (Fig. 2). After completed 90 days of immersion test, the pores become bigger compared to the samples before immersion. Fig. 3 exhibits optical micrographs of the samples after completed 90 days of immersion test. It can be seen that the corrosion attacked in the pores area due to reaction of aggressive ions between samples and solution. Because of that, the smaller pores become bigger with an irregular shape and spherical shapes were observed in the samples after completed immersion test. Virtanen et al. [7] stated that the corrosion behaviour is influenced by a wide variety of factors, including the material itself (the chemical composition, microstructure, surface condition) and the surroundings (temperature, O_2 content). Changes in these variables can influence the mode and rate of metal ion release. The corrosion attacks in all samples can be categorised under pitting corrosion. Generally, it occurs when discrete areas of material undergo rapid attack while most of the adjacent surface remains virtually unaffected. It is generally associated with specific ion in solution, which the most common is chloride [8-9].

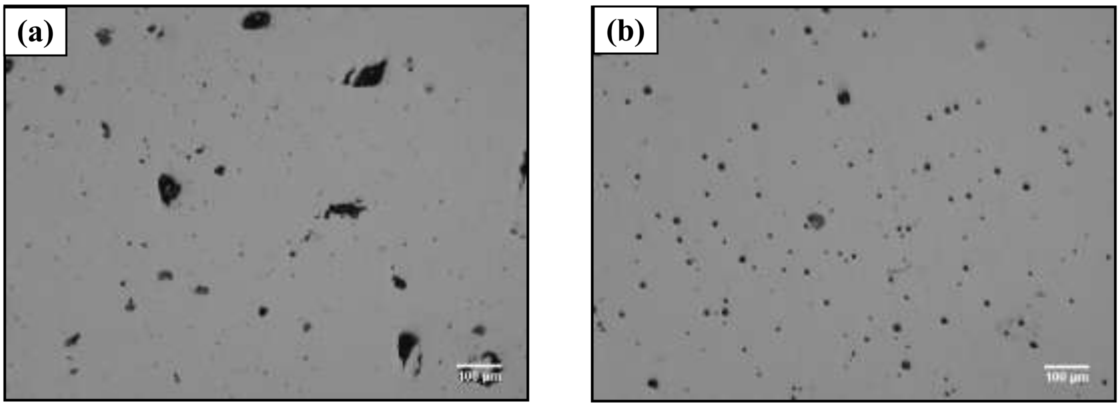

Fig. 2: Optical micrograph of 2 different samples before an immersion test (a) Sample A_1, and (b) Sample A_2

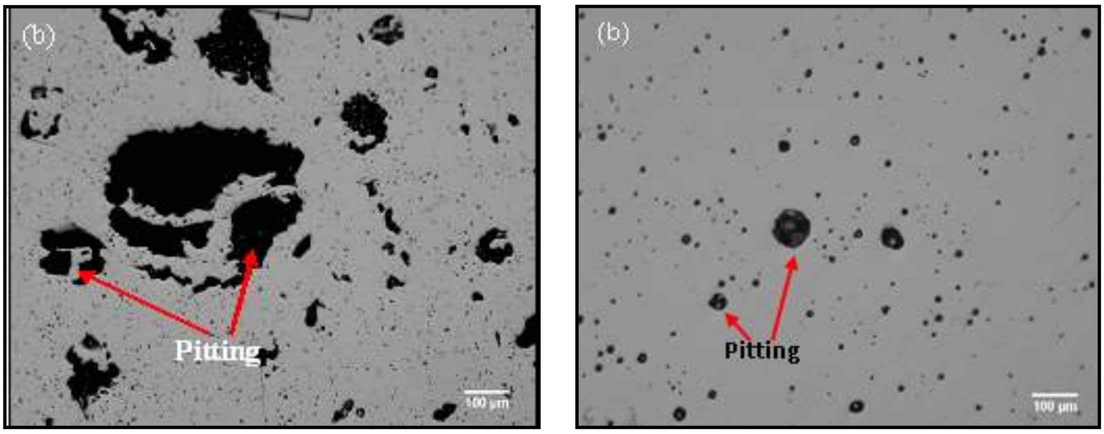

Fig. 3: Optical micrograph of 2 different samples after an immersion test (a) Sample A_1, and (b) Sample A_2

Conclusion:

Corrosion behavior indicated that the sample sintered at temperature 1350 ºC (sample A_2) has the lowest mpy value after 90 days immersed in 0.9% sodium chloride solution. Thus, this sample has good corrosion resistance compared to sample sintered at 1300°C (sample A_1).

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