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The Effect of F-75 Alloy Mixed with HAP on Microstructure in Corrosion Test for Biomaterial Applications

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Abstract— Co-Cr-Mo (ASTM: F-75) alloy is generally used because of their mechanical properties, good wear and corrosion resistance as well as biocompatibility. In order to obtain chemical similarity and interfacial bond form between implanted biomaterials and living tissue, addition of Hydroxyapatite (HAP) is required. This study has focused on a research in F-75 alloy mixed with HAP fabricated by powder metallurgy (P/M) technique. The effect of HAP addition ranging 2 to 10 wt. % of HAP on biocompatibility (corrosion resistance) was examined. To analyse the result, the reference sample (F-75 alloy without HAP) and composites are compared. All samples are immersed into 0.9% NaCl solution at 37 ˚C in 6-week duration. Every interval of 48 hours, the weight loss per area is recorded. By increasing amount of HAP, it is noticed that corrosion rate is increasing except for composite with 2 wt.% of HAP which has the lowest corrosion rate among others. The possibilities of increasing corrosion rate are the formation of general attack and pitting. Besides, the formation of apatite layer can be seen as predicted.

***Keywords*:** Co-Cr-Mo alloy, hyroxyapatite, powder metallurgy, biocompatibility, corrosion resistance

I. Introduction

A biomaterial can be defined as any material used to make devices to replace a part or a function of the body in a safe, reliable, economic and physiological acceptable manner [1].

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The major metals used in medical applications today include stainless steel, cobalt-based alloy and commercially pure titanium and its alloys [2].

F-75 alloy is considered to be biocompatible materials and widely used for orthopedic applications such as hip and knee joint replacements. It also demonstrates the most useful balance in strength, fatigue and wear along with resistance to corrosion.

In order to form biocompatible materials, a biocompatible addition has to add into fabrication F-75 alloy which is HAP. HAP has been clinically applied in many areas of dentistry and orthopedics because of its excellent osteoconductive and bioactive properties [3],[4].

At least three methods to manufacture F-75 implant: casting, hot forging and powder metallurgy (P/M). Among these, P/M offers interesting technological solutions in the range of obtaining new exploitative materials.

II. Methodology

The raw materials used were ready-mixed F-75 powder and HAP. The F-75 powder was supplied by Sandvick Osprey Ltd with the size of 10.62μm meanwhile HAP was supplied by Berkeley Advanced Materials, Inc USA with the size of 11μm. F-75 powder contains base chemical composition of 28 wt.% Cr, 6 wt.% Mo and balance Co which has similar composition stated in ASTM F75-98 [5].

The fabrication of composites was carried out by using P/M technique that consist process of mixing, compacting and sintering. In mixing process, F-75 powder is mixed up with 2 to 10 wt.% of HAP respectively. The 8g composite was compacted in room temperature inside a stainless steel die using uniaxial press machine at 500MPa. The composites were sintered in argon atmosphere using tube furnace at 1100˚C with the heating rate of 20˚C/min.

Corrosion test using immersion technique was carried out using simulated body fluid (SBF) 0.9% NaCl solution at 37˚C (internal body temperature) [6]. Before immersed

into SBF, the composites' dimensions, appearance and initial weight were recorded. After completed 6-week duration of corrosion test, the samples have been viewed under scanning electron microscopic (SEM) and calculated the corrosion rate using as in (1). The k is a constant for mpy corrosion rate, W weight loss of sample (g), D is density (g/cm^3) of the sample, A sample's area and T time of immersion (hour) [7].

$$\text{Corrosion rate} = \frac{k \times W}{D \times A \times T} \quad (1)$$

III. RESULTS AND DISCUSSION

Figures 1(a) to (f) show the micrographs of samples after completed corrosion under SEM. Based on overall microstructure analysis within 6 weeks of immersion test, no cracks or defects were found on the surface area of the immersed composites. Nevertheless, at the third week of immersion test, the powdery layer was clearly traced scattered on the surface area of composites. This powdery layer remains on the surface until the last day of immersion test. According to energy dispersive spectroscopy (EDS) analysis, it was proven as HAP. From the previous investigation, it was termed as formation of apatite layer.

The apatite layer formed due to the reaction between electrolyte (SBF) and HAP. During the immersion test, apatite layer starts to nucleate and growth. Within the presents of electrolytes which contained Ca^{2+}, PO^{2-} and OH^-; they contribute to the spontaneously growth of apatite layer. Besides, the dissolution of these ions increases the degree of the supersaturation of the electrolyte. This explanation can be correlated to the (2). Due to increasing amount of HAP and increasing immersion time, the formation of apatite layer also increased.

$$10Ca^{2+} + 6PO_4^{3-} + 2OH^- \longleftrightarrow Ca_{10}(PO_4)_6(OH)_2 \quad (2)$$

Figure 1(a): The micrograph of reference sample after completed 6 weeks corrosion test

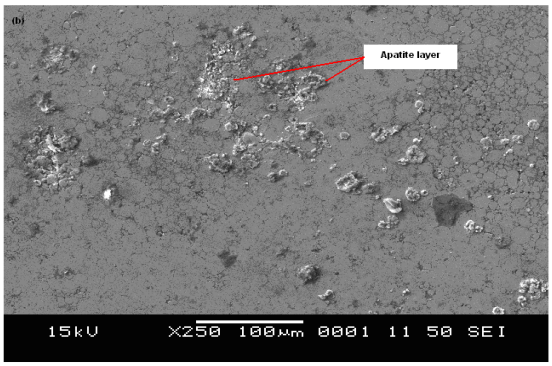

Figure 1(b): The micrograph of composite with 2 wt.% of HAP after completed 6 weeks corrosion test

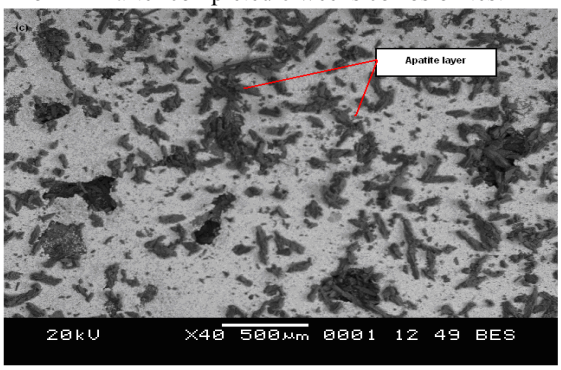

Figure 1(c): The micrograph of composite with 4 wt.% of HAP after completed 6 weeks corrosion test

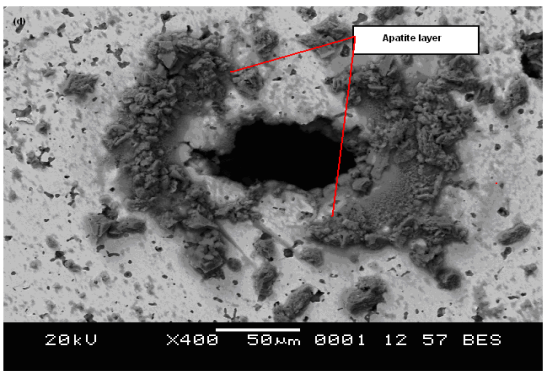

Figure 1(d): The micrograph of composite with 6 wt.% of HAP after completed 6 weeks corrosion test

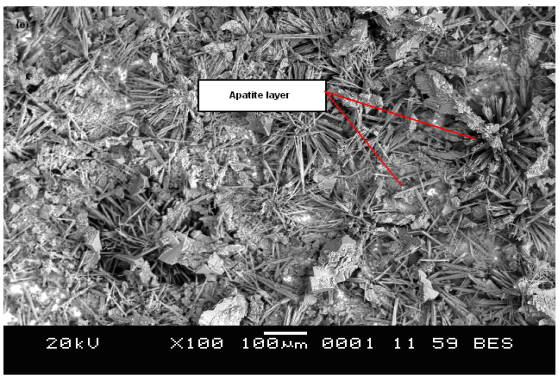

Figure 1(e): The micrograph of composite with 8 wt.% of HAP after completed 6 weeks corrosion test

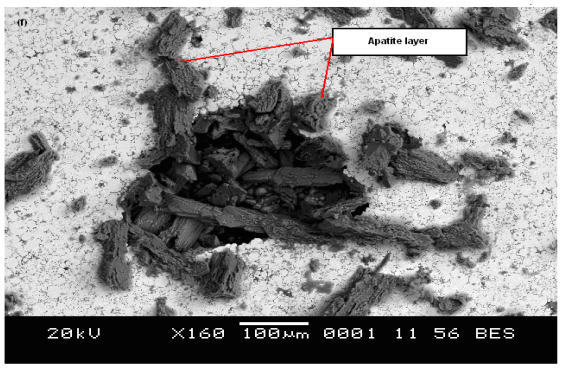

Figure 1(f): The micrograph of composite with 10 wt.% of HAP after completed 6 weeks corrosion test

Reference [8] have conducted a research on apatite formation mechanism of $CaO\text{-}SiO_2\text{-}P_2O_5$ glasses in simulated body fluid. In their research, they have stated that body fluid is supersaturated with respect to apatite under normal condition. Under such environment; once the apatite nuclei are formed, they can grow spontaneously by consuming the ions from surrounding body fluid.

Reference [9] depicted the mechanism of apatite layer in their research of formation of hydroxyapatite on $CaSiO_3$ powders in simulated body fluid. Besides, reference [10] was also found the apatite formation layer on porous and nonporous Ti composites in corrosion test. In Figures 1(a) to (f), they represented micrographs of the composites observed under SEM. It is clearly seen that between the range of 2 to 10 wt.% addition of HAP, the surface area of immersed composites were indicated the formation of apatite layer.

Table 1 shows the value of corrosion rate as a function of of HAP addition at after completed 6-week of immersion test. The results revealed that the composite contains 10 wt.% of HAP has greater value of corrosion rate meanwhile 2 wt.% of HAP has the lowest value of corrosion rate compared to other composites. The reference sample revealed the corrosion rate of 15.94 mpy, followed by composites with 4 wt.% of HAP, 6 wt.% HAP, 10 wt.% of HAP and 8 wt.% of HAP. As shown in Table 1, the addition of HAP above 4 wt.% will result the increasing of corrosion rate.

Table 1: The value of corrosion rate as a function of HAP addition after completed 6-week duration of immersion test

Material of specimens	Corrosion rate (mpy)
Reference sample (F-75 alloy without HAP)	15.94
Composite with HAP addition	
2 wt.%	2.53
4 wt.%	24.56
6 wt.%	27.61
8 wt.%	37.01
10 wt.%	36.86

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