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Determination of corrosion rate of artificial bone made of metal at different pH conditions using x-ray radiography

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Abstract. The purpose of this research is to observe the mechanism and the rate of corrosion of artificial bone made of metal by using x-ray radiography technique. Artificial bones can be made of metallic materials and composites which are biomaterials. The most commonly used metal for bone graft is stainless steel. The interaction between artificial bone and human tissue will have important medical impacts that need to be observed and examined. This interaction can be a mechanical or chemical interaction. X-ray radiography technique is selected because it uses non-destructive method. This method is done by x-ray radiation exposure on the observed body part. The bone density and bone fracture can be seen on the resulted radiographic film or image on the monitor screen.

1. Introduction

Bone damage due to fractures often occurs in humans. Research and Development Agency, Ministry of Health, Republic of Indonesia has reported during period 2008-2010 amount of 80.943 accident cases occurred. About 21,% (3.781 peoples) got fractures and even too much accident victims have suffered permanent bone defects. This is a challenging problem for researchers in playing active roles in preventing permanent bone defects.

Bone plate technique is applicable in substituting defect bones. This technique uses metal as an implant substrate and developable as the artificial bone for humans. Bone plate availables in repairing fracture bone [1]. The use of metal as substitute of bone find some weaknesses: biocompatibility problem (local corrosion), unable to regenerate new bone, limited organ function, and affecting bioactivity in human body. The mechanical properties of artificial bones are important parameter in designing bone substitute materials which will get outside loads [2].

The largest part of human body consists of water. If the body contains abnormal liquid, digestive enzymes are inactive, food can't be digested properly, and allergic reactions may occur. All regulation mechanisms (breathing, circulation, digestion, and hormone production) toward pH equilibrium, by reducing acid residue causes which is metabolized from body tissue without damaging live cells. If pH is imbalanced, over acid or over base, the cells will be poisoned. Imbalanced pH will corrode all body tissues, it slowly will sacrifice 60.000 mil blood vessels and arteries, and finally it will destroy all activities and cellular function of body. The corrosion leads to damage, appearance decrease, maintenance cost improve, product contamination, and safety decrease. Some types of corrosions that can occur among others: galvanic, uniform, crevice, pitting, inter-granular, selective leaching, erosion corrosion, and stress corrosion cracking. The important corrosion aspects include: anode, cathode, conductor and electrolyte. All reactions in water environment are assumed not different with simple



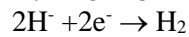
wet corrosion cell [3,4,5]. Even although the cell is a part of the same metal surface, anode and cathode are usually distinguishable. We can assume that iron will become anode when compared with Hydrogen ions.

The chemical reactions occur as the followings:

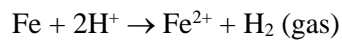
Iron dissolution:



Hydrogen gas formation:



Total reaction:



2. Methods

Bone plate was used in this research and cut into four parts. Each sample dipped into pH 3 (acid), pH 7.3 normal, and pH 10 (base). Bone plate sample was not dipped and fixed as control variable. The method used to analyze corrosion in the metal surface using radiography digital technique and CCD (Charge Coupled Device) microscope. The corrosion rate of bone plate was calculated based on the mass loss method. Each sample was dipped in solutions at variated pH for 72 hours. Next, rust is removed from material using solution (100 ml nitric acid + 900 ml water) and then specimen was heated up 600°C during 20 minutes. Each bone plate was tested using digital radiography and optic microscope to analyze surface image of bone plate before and after corrosion. To determine corrosion rate of bone plate, the specimen first was weighed to know mass loss using the following formula:

$$mpy = \frac{3,45 \times 10^6 \times W}{A \cdot T \cdot D}$$

where,

mpy = Corrosion rate (mils/year); W = Weight loss (g); A = Area (cm²); T = Time (jam) and D = Density (g/cm³).

3. Result and Discussion

Digital radiography was operated at Voltage 40 kV for 0,125 s with generated current 16 mA (Figure 1, Figure 2, and Figure 3).

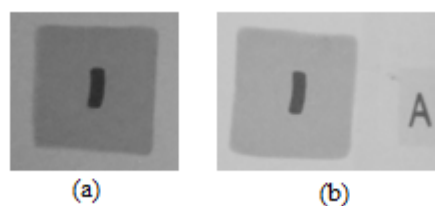


Figure 1. Digital radiography images for sample A dipped in solution pH 3: (a) before and (b) after corrosion.

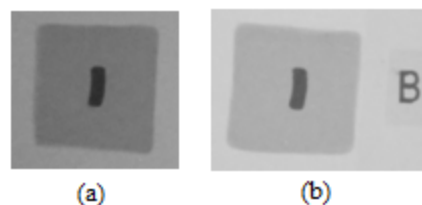


Figure 2. Digital radiography images for sample B dipped in solution pH 7,2: (a) before and (b) after corrosion.

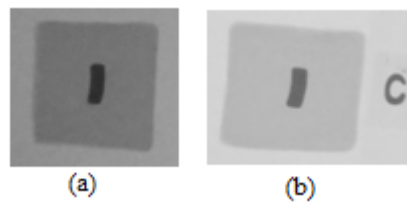


Figure 3. Digital radiography images for sample C dipped in solution pH 10: (a) before and (b) after corrosion.

The surface image testing of bone plate before and after it corroded using digital radiography is a Non Destructive Test (NDT). This testing is aimed to investigate defects, microstructures and mechanical properties of materials without destroy it. This equipment is completed X-ray generator or radioactive isotope which transmits material and captured by film or digital equipment. After X-ray exposure, a variety of density of bone plate seems at the image or film. Figures 4, Figure 5 and Figure 6, images of bone plate captured using optic microscope in magnification of 100X.

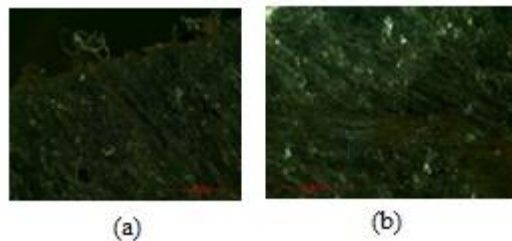


Figure 4. Microscope images for sample A dipped in solution pH 3: (a) before and (b) after corrosion.

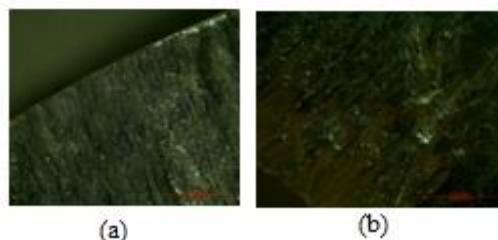


Figure 5. Microscope images for sample B dipped in solution pH 7,2: (a) before and (b) after corrosion.

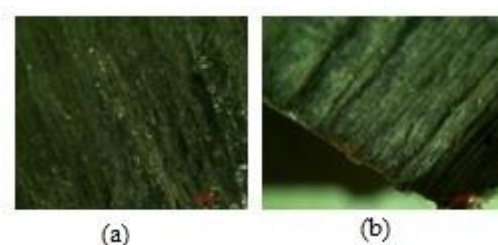


Figure 6. Microscope images for sample C dipped in solution pH 10: (a) before and (b) after corrosion.

In Figures 4, Figure 5 and Figure 6, corrosion seems on cavity and metal surface has changed to yellowish, a pitting corrosion is founded. This corrosion is caused by chemical environment of solution pH (HCl and NaOH). This corrosion expanded to an arch area due to voltage difference on

arch area and straight area. On the arch, the residual stress produced by deformation process leads to the elements in the arch are instable so that the atoms will discharge electrons. The corrosion is initiated by the formed passive layer destroy, so electron in Fe transforms to Fe^{2+} ion. Except it, in the arch area higher energy exist than the surrounding area due to bonding force between archs. This energy causes Fe is easier to discharge electron and it will change it into ion. The corrosion in sample B is greater than that of samples A and C. The method used in this analysis is the mass loss method. The corrosion testing result is tabulated in Table 1 and shown graphically in Figure 7.

Table 1. Corrosion rate of bone plate at different pH.

pH	Mass before corrosion (g)	Mass after corrosion (g)	Mass Loss (g)	Area (cm^2)	Density (g/cm^3)	Corrosion rate (mpy)
3	0,97	0,95	0,02	0,36	$4,85 \times 10^{-2}$	54887,361
7,2	1,14	1,12	0,02	0,48	$5,70 \times 10^{-2}$	35025,803
10	1,33	1,32	0,01	0,60	$6,65 \times 10^{-2}$	12100,168

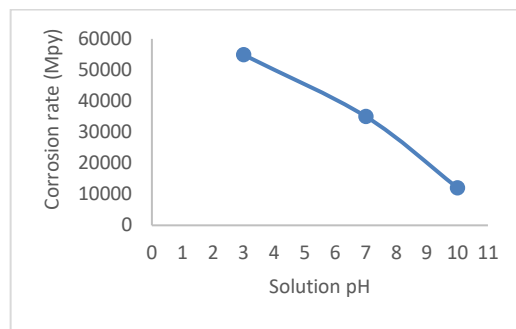


Figure 7. Corrosion rate versus solution pH.

Based on Table 1, as acidity increases, the corrosion rate increases as well. The largest corrosion is founded in the pH 3 (acid condition). In Figure 7, the highest corrosion rate is achieved at solution pH 3, while the lowest corrosion rate is achieved at solution pH 10. In this process, bone plate metal experiencing reduction reaction, while oxygen experiencing oxidation. The higher acidity level the higher ion concentration in HCl. Ion H^+ plays role as reductor and ion Cl^- as passive layer (Cr_2O_3) and metal bonding destroyer, so that the amount of ions increase will spur corrosion reaction. The aeration effects will accelerate the corrosion rate, where oxygen around the material surface will be removed when dipped in solution. The dissolved oxygen in HCl increase will improve cathodic reaction. A correlation between data in Table 1 and Graph in Figure 7 is confirmed.

4. Conclusion

The bone plate metal dipping into acid solution will cause corrosion. Image digital radiography for samples do not infom the significant change. As a proof that corosion occur is observed cavity and the material surface change to yellowish at images which were captured using optic microscope. Here is pitting corrosion type. The highest corrosion occur at solution pH of 3 and the lowest one is at pH 10.

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