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Effect of electron-beam irradiation on water wettability of hydroxy apatites for artificial bone

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The influence of electron-beam irradiation on the wettability of hydroxy apatites (HAP) has been investigated. The wettability was evaluated from the interfacial energy between HAP and water. It was measured by the contact angle of distilled water on HAP. Electron-beam irradiation increases the wettability. Based on the rate process, the influence of electron-beam irradiation on wettability is discussed. Using electron-beam irradiation, we can precisely control the surface condition of HAP.

1. Introduction

From the biological point of view, it is important to know the wettability of hydroxy apatite of artificial bone. However, argon-ion irradiation can modify surface properties [1, 2], but the irradiation retains the argon atoms in the sample. Because electron-beam irradiation does not retain the impurity atoms, reproducible values can be obtained. Therefore, the influence of electron-beam irradiation on wettability of HAP was investigated.

2. Experimental procedure

Electron-beam irradiation [3, 4] was homogeneously performed using an electrocurtain processor (Iwasaki Electric Group Company, type: CB 175/15/180L). Fig. 1 shows a schematic drawing of the apparatus. The acceleration potential and the irradiating current were 175 kV and 4 mA, respectively. The electron-beam treatment was not continuously performed. In order to control the temperature of the sample surface, the conveyer speed was kept constant at $0.17\ \mathrm{m\,s^{-1}}$ and the sample temperature was below 323 K just after the irradiation. The irradiation dose was increased by repeating the treatment. Although electron-beam irradiation is generally performed in vacuum, the irradiated specimen was kept under nitrogen at atmospheric pressure in the apparatus. The oxygen concentration was less than 400 p.p.m. in the atmosphere. The irradiation dose was proportional to the electron-beam irradiation time, t_i, as follows

$$\text{Dose} = 36t_i \quad (1)$$

3. Results and discussion

Wettability was evaluated by measuring the contact angle, θ, of a drop of water. θ was measured by taking a photograph of the water drop (see Fig. 2): the higher the wettability the lower is the value of θ. The mass of the drop is approximately 0.001 g.

Wettability is often evaluated by interfacial energy, W_a, at constant temperature

$$W_a = \sigma_0(1 + \cos\theta) \quad (2)$$

where σ_0 is the interfacial energy of water between liquid and gas. The reduced interfacial energy, $R(x)$, depends on the term $(1 + \cos\theta)$ of the contact angle

$$R(x) = W_a/\sigma_0 = (1 + \cos\theta) \quad (3)$$

Fig. 3 shows the relationship between the reduced interfacial energy, $R(x)$, versus the electron-beam irradiation time, t_i. $R(0)$ is about 1.391 for the HAP sample before irradiation. Electron-beam irradiation enhances the wettability, as shown in Fig. 3: the longer the irradiation time, t_i, the larger is the reduced interfacial energy $R(x)$. As shown in Fig. 4, electron-beam irradiation increases the lattice constant. If the polarization generates an increase in volume of the HAP sample by electron-beam irradiation, the influence of the irradiation on $R(x)$ can be explained.

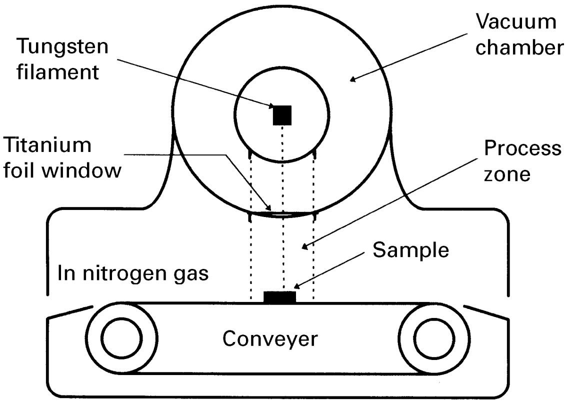

Figure 1 Schematic diagram of the electrocurtain processor.

The rate process is a useful equation to describe the phenomena [5–7]. If it is applied here to the electron-beam irradiation process, the change, X, in the reduced interfacial energy, $R(x)$, is assumed to be expressed by the following equations in relation to the irradiation time, t_i

$$X = 1 - \exp(-kt_i^n) \quad (4)$$

where k and n are constants. X is assumed to be expressed by

$$X = [R(x) - R(0)]/[R(m) - R(0)] \quad (5)$$

where $R(m)$ and $R(0)$ are the $R(x)$ values after infinite irradiation time and before irradiation, respectively. The values are calculated in a self-consistent way. $R(x)$ of the irradiation sample approaches $R(m)$; it is the saturated value. When the correlation coefficient, F, of Equation 4 is maximum, as shown in Fig. 5, the saturated reduced wettability value, $R(m)$, is 1.968. From these results, X can be expressed by the following equation

$$\log_{10}[-\ln(1 - X)] = n\log_{10} t_i + \log_{10} k \quad (6)$$

The linear plot (see Fig. 6) of Equation 6 confirms the assumption of the rate process (see Equation 4). The values of n and $\log_{10} k$ are 0.62 and -0.042, respectively.

Thus, it is precisely possible to control the surface condition of HAP by using electron-beam irradiation.

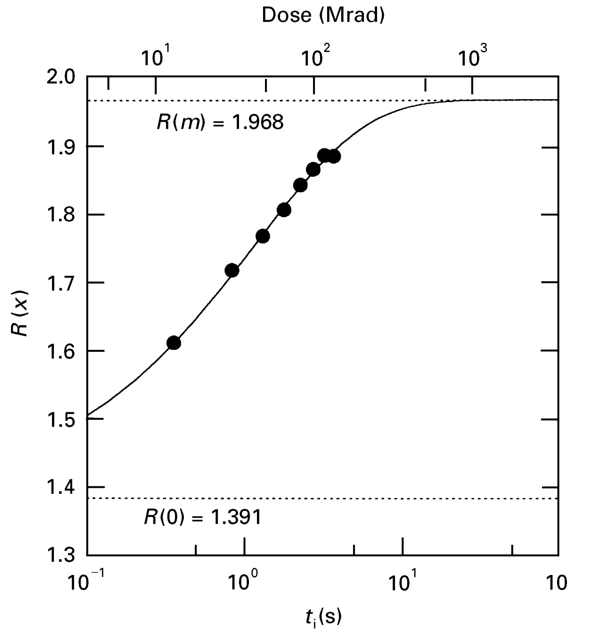

Figure 3 Change in reduced interfacial energy, $R(x)$, with electron-beam irradiation time, t_i.

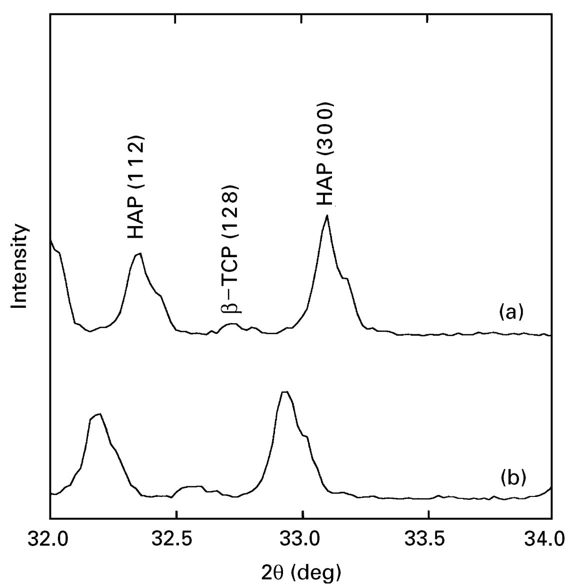

Figure 4 X-ray diffraction patterns of apatite ceramics (a) before and (b) after electron beam irradiation.

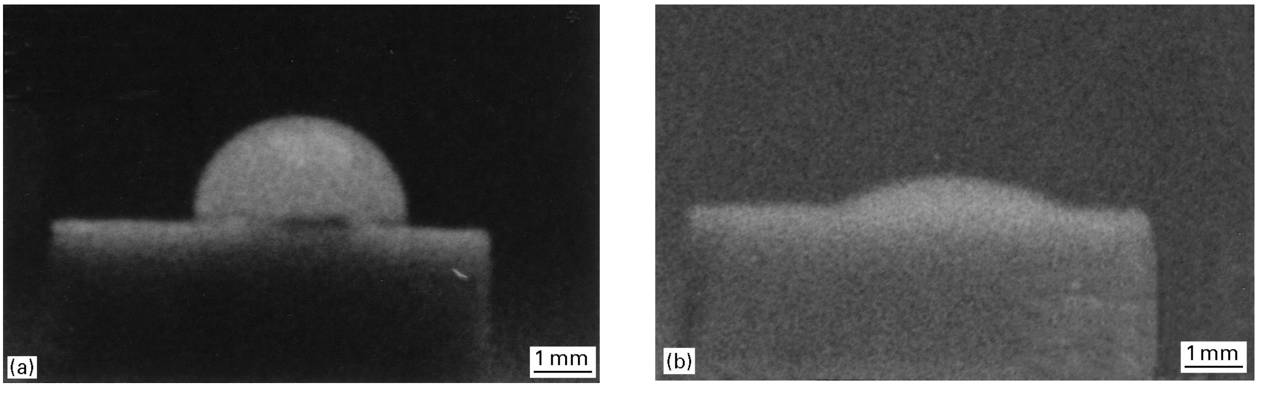

Figure 2 Photographs of a sessile drop of water on apatite ceramics, (a) before, and (b) after electron-beam irradiation.

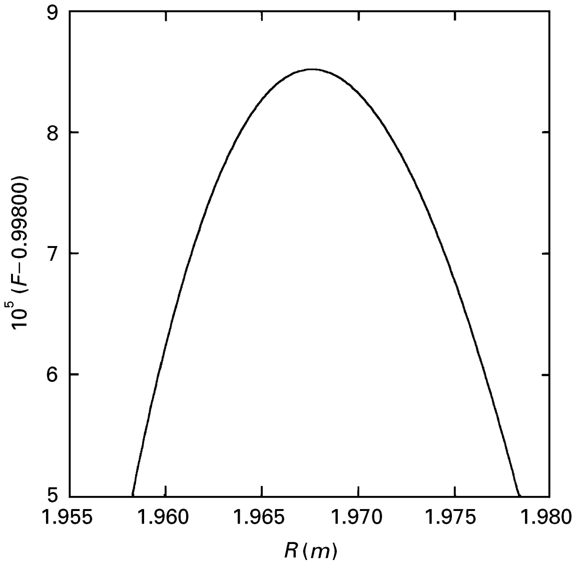

Figure 5 Change in correlation coefficient, F, with $R(m)$.

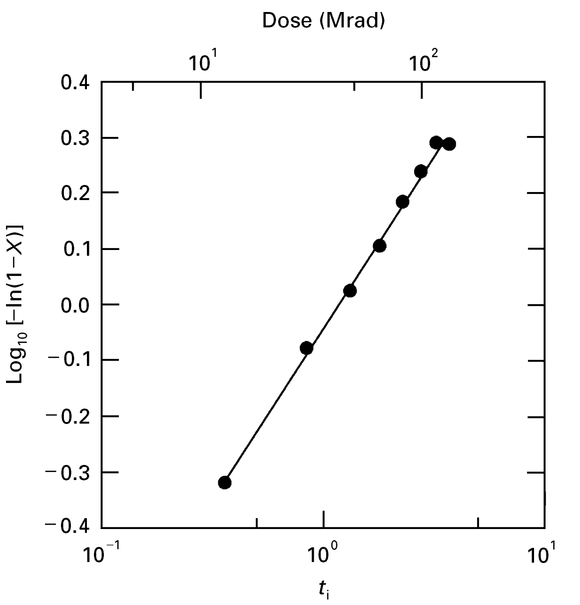

Figure 6 Change in $\log_{10}[-\ln(1-X)]$ with electron-beam irradiation time, t_i.

4. Conclusion

Electron-beam irradiation enhances the water wettability of hydroxy apatite. The wettability is evaluated by the reduced interfacial energy, $R(x)$, between HAP and water. If the change in $R(x)$ is applied by the rate process, the rate index n is 0.62. The saturated reduced wettability is about 1.968. Thus, we can precisely control the surface condition of HAP.

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