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Corrosion analysis of the cold work 316L stainless steel in simulated body fluids

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ABSTRACT – The present paper deals with the characteristic of the corrosion failure of the cold work 316L stainless steel in the simulated body fluids. The steel has been cold rolled within the range of 10 to 50% reduction in thickness. The corrosion test was done for 7 days at a temperature of 37°C by immersing the steel in a 0.9% NaCl and phosphate buffered saline (PBS) solution. It was found that the steel with a higher cold reduction tend to increase the corrosion resistance of more than 50% in both simulated environment.

1. INTRODUCTION

A corrosion phenomenon is one of the major problems in any metal-based part or component. Normally, additional costs are required in order to diminish or repair the corroded metal part. If the part was considerably irreversible or too costly, then it will be replaced with a new part. Generally, almost metal alloy are chemically or electrochemically not stable. They suffered with the corrosion phenomena while expose to the environment. This scenario also occurred in the application of medical implants, particularly involving 316L stainless steel. The normal human body is considered as a neutral environment where the pH and temperature are equal to 7.0 and 37°C. However, the nature of the human body that contains of numerous metal and non-metal species contributes to the corrosion of the metal implant. Previous studies have proved that this surgical grade was also suffered to both uniform and localized corrosion [1]. Most of them more focused on the actual failed surgical implant with a less concerning on the cold work process [2-3].

In this study, the corrosion resistance of the cold work 316L stainless steel was analysed experimentally using a cyclic immersion corrosion test. The test was principally referred to ASTM G 31-72 [4] where the corrosive environment was developed to a nearly human body condition.

2. METHODOLOGY

The 316L stainless steel has been used with starting thickness of 2.0 mm with a composition of 16.61% Cr, 10.44% Ni 0.02% C as provided by the manufacturer. This commercial 316L sheet was cold rolled to 10, 30 and 50% reduction in thickness (RT) before preparing to a small test specimen. The specimens, with a three sets for each thickness reduction, have been undergone a process of CNC milling to a dimension of 20.0 x 10.0 mm. Then, the corrosion test was conducted in aerated environment using an OV-445 Gallenkomp wheel test oven. The PBS and 0.9% NaCl were used as the SBF with the initial pH of 7.31 and 6.8. The test duration was set to 7 days with a temperature of about 37°C. All specimens were rinsed with ethanol prior the pre- and post-cleaning.

The corrosion rate (mm/y) was calculated according to the mass loss using the equation [4],

$$Corrosion\ rate = (K \times W)/(A \times T \times D) \quad (1)$$

Where K = constant, W = mass loss in g, A = surface area in cm^2, T = time of exposure in hours and D = density in g/cm^3. The D and K were used 7.98 g/cm^3 and 8.76 x 10^4 mm/y, respectively.

The A for a rectangular specimen was measured by the equation,

$$A = 2(wl) + (2w)t + (2l)t \quad (2)$$

Where w = width, l = length and t = thickness. All dimensions in cm.

The morphology of the corroded steel was analyzed by using a Jeol JSM 6010 plus LV scanning electron microscope (SEM).

3. RESULTS AND DISCUSSION

Figure 1 (a-b) represents the microstructure of the steel in as-received and after 50% cold reduction. The cold-rolling process has modified the steel from polygonal to elongated grains structure. Dislocation twin structures were also appeared in some of the grains after extensive cold reduction. The modifications had strengthened and hardened the steel as it has been proved from previous study [5].

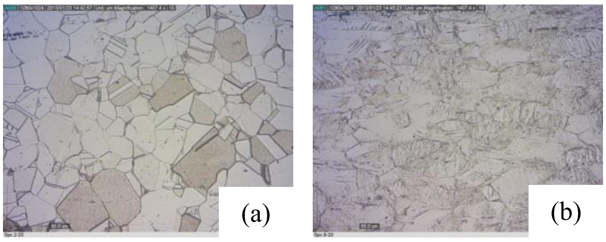

Figure 1 Optical micrograph of 316L steel with (a) 0; and (b) 50 % RT.

These surface modification were greatly affected the corrosion resistance of the mechanically treated steel. Figure 2 shows the average corrosion rate of all specimens obtained from the equation (1) and (2). For specimen with 0% RT, the rate was about 0.22 mm/y and 0.23 mm/y in 0.9% NaCl and PBS solution. However, it has been reduced to 0.11 mm/y and 0.09 mm/y for each SBF solution, after extensive cold reduction.

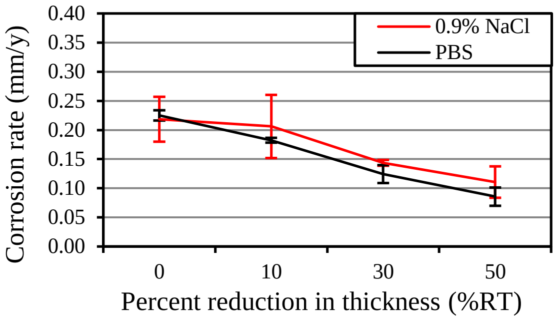

Figure 2 The average corrosion rates of 316L steel in PBS and 0.9% NaCl.

The steel tends to be more corrosive in NaCl rather than PBS for each particular cold reduction. This was possibly due to the presence of a higher concentration of chloride, Cl^- ion, such that an aggressive species in the corrosive environment. In addition, the initial pH of the solution, which more acidic tends to increase the corrosion rates.

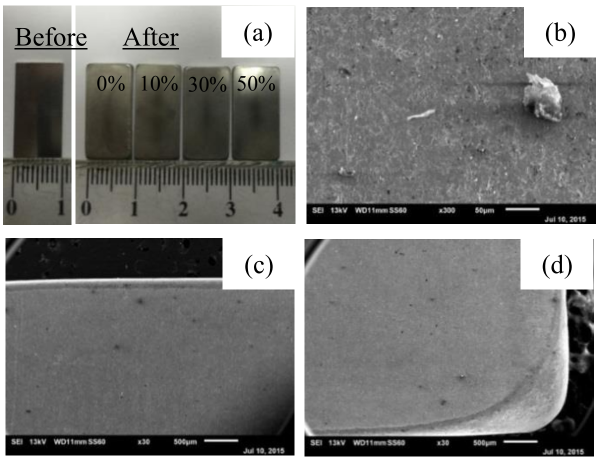

Figure 3 The morphology of the 316L steel (a) before and after the test; and after 10% RT at (b) normal; (c) edge; and (d) corner surface after immersing in PBS.

The corrosion rates obtained from this study was considered higher compare with previous study. The acceptable rate of metal implant in the human body was about 2.5 x 10^{-4} mm/yr [6]. It can be explained according to the morphology of the corroded steel as shown in Figure 3 (a-d). Generally, the corrosion process was uniformly occurred at the entire surface as shown in Figure 3 (b), without any evidence of the localized corrosion.

However, the corrosive phenomenon was different at the sharp surface as shown in Figure 3 (c-d). It's clearly shows that the surfaces were not only affected with the corrosion but also with a wear process. The wear might occur due to the friction during the cyclic test between the specimens and glass container. Thus, the combinations of both processes were greatly influenced their corrosion resistance. Also, the wear failure tends to be lowered for the steel with extensive cold reduction. This was due to the microstructure changes caused by the cold work process.

4. SUMMARY

The corrosion characteristic of the cold work 316L stainless steel in SBF environment has been analyzed experimentally using the immersion corrosion test. As a result, it can be concluded that:

a. The corrosion resistance was gradually increased for the steel with higher cold reduction. In addition, the resistance slightly low for the steel in 0.9% NaCl compare to PBS solution.
b. The morphology of all corroded steel shows the existence of the uniform corrosion. While, the wear plays a dominant process at the sharp surfaces.

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