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IMPROVEMENT OF MECHANICAL PROPERTIES AND FATIGUE LIFE OF STAINLESS STEEL 316L IN 0,9 % NaCl ENVIRONMENT BY APPLYING SHOT PEENING AND PLASMA NITRIDING TREATMENTS

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Among metallic biomaterials, AISI 316L has the cheapest price yet but the lowest mechanical properties and it is prone to corrosion. Bone plate failure is often triggered by dynamics load, crevice or pitting corrosion, or a combination of fatigue and crevice or pitting corrosion attack at the same time. Shot peening and plasma nitriding are surface treatments that enhance material properties. This work examined the shot peening duration effects and plasma nitriding on surface to the depth hardness, roughness, droplet contact angle, and fatigue life in environment containing rich chloride ions. The results revealed that shot peening and plasma nitriding improved both surface layer roughness and hardness. Furthermore, shot peening and plasma nitriding reduced droplet contact angle and enhanced the fatigue life of the material.

Keywords: steel 316L, shot peening duration, plasma nitriding, fatigue life, droplet contact angle

INTRODUCTION

Victims of natural disasters, work and traffic accidents usually experience broken bones. The domestic demand for medical bone plates is still largely imported [1]. Orthopedic implant materials have very strict requirements [2].

Among metallic biomaterials, AISI 316L has the cheapest price but the lowest specific strength and corrosion properties [2]. Mechanical properties of AISI 316L can be improved by surface treatment [2]. AISI 316L is the material most often used for orthopedic implants [3]. Bone plate failure is usually caused by dynamics load or corrosion attack, or a combination of corrosion and fatigue attack [4-5]. Holes in bone plates receive the highest stress [6].

Process of shot peening increases surface layer roughness and hardness, and induces residual stress profile [7]. Rough surface and hydrophilic properties play a pivotal role in medical bone plate materials due to their significance in promoting bio-adhesion properties, triggering protein adsorption to initiate human bone development [8]. Residual compressive stress can inhibit the development of micro cracks and reduces the rate of fatigue crack propagation [9-11]. Shot peening also decreases corrosion rate of AISI 316L [11].

Plasma nitriding enhances hardness and fatigue strength of both AISI 316L and AISI 304 through the Cr-N precipitation and formation of highly durable Fe-N layers [12-14]. In medical application, plasma nitriding forms anti-bacterial layer and it improves the hardness and corrosion resistance of beta-titanium alloys [15], lean duplex stainless steel 2101 [16], and AISI 316L [17]. This work was performed to examine the effect of shot-peening and plasma nitriding on the hardness and roughness, wettability and fatigue life of stainless steel 316L in Cl^- ions environment.

EXPERIMENTAL PROCEDURE

AISI 316L was the main material used in. Two surface treatments that included shot-peening followed by plasma nitriding. Shot-peening was carried out within eight varieties of durations from 0 to 60 minutes with increments of 10 minutes each, at a pressure of 8 bar, utilizing 0,6 mm diameter ball of steel, and a shooting distance of 80 mm. Plasma nitriding was carried out for 60 minutes at a temperature of 400° C and pressure of 1,6 bar using 100 % nitrogen gas, to identify the treatment processes, specimen symbols were employed. For instance, "SP10+PN" denotes samples subjected to shot-peening for 10 minutes followed by nitriding. Meanwhile, raw symbol refers to untreated sample. The fatigue test sample underwent those two treatments on both sides.

The samples were cut in the lateral direction, polished using sandpaper and metal polisher until forming mirror-like finishing. After that, these prepared specimens underwent etching with a mixture composed of 65 % HCl and 35 % HNO_3. The specimens were then ob-

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served using a computerized digital microscope. Roughness test was carried out using "Mitutoyo SJ-210" a roughness tester. Furthermore, ASTM E-384 standard was the basis of the hardness test. Wettability value was measured based on the average droplet contact angle with the surface.

Fatigue crack propagation was observed while specimens were submerged in 0,9 % NaCl solution until fractures appeared. Data regarding fatigue crack propagation were analysed based on ASTM E647 to examine relationship between da/dN and ΔK. The trendline of the da/dN-ΔK relationship is reflected in Paris constants (C and n) which can be used in determining the fatigue life of stainless steel 316L submerged in environment containing rich Cl^- ions.

Fatigue tests were performed using a servo pulser machine under constant amplitude with at a stress ratio of 0,1, and 10 Hz a frequency with specimens prepared based on ASTM E647.

RESULTS AND DISCUSSSIONS

The composition of AISI 316L is still within the standard composition range of AISI316L as shown in Table 1. Figure 1 shows that the double treatment process leads to an initial increase in surface roughness followed by a subsequent decrease, conforming the results of prior research [11]. Shot-peening played a more significant role in altering surface roughness compared to plasma nitriding as shot-peening is a collision process while plasma nitriding is diffusion of nitrogen atoms process. Plasma nitriding does not trigger changes in surface roughness since nitrogen atoms tend to diffuse on the surface of the substrate [18]

Figure 2 depicts the relationship between hardness and depth, where surface hardness surpasses the depth. As seen in the figure, shot peening duration leads to a corresponding increase in surface hardness. High density of dislocations on surface layer increases the surface hardness [10]. Greater surface hardness is also influenced by compressive residual stress induced on surface layer [19]. In addition, the reduction in grain size due to collisions with steel balls further contributes to the enhancement.

Figures 3 and 4 show relationship between wettability and shot-peening duration. Wettability increases along with increases in shot-peening duration. Wettability exhibits an upward trend as shot-peening duration increase. This phenomenon can be linked to the alterations in surface layer roughness induced by shot peening [8,20]. The characteristics of wettability are strongly affected by some factors that include surface characteristics, surface chemistry, and surface topography. Droplet dispersion and wetting behavior are affected by the basic nature of substrate such as roughness, porous, coating, absorbed layer etc. [8]. These changes transform the surface from hydrophobic to hydrophilic, as evidenced by the expanded shape of liquid droplets and

Table 1 **Chemical composition / mas. %**

	Cr	Ni	C	Mn	Mo	Fe
AISI 316L	16,78	10,87	0,03	1,08	1,89	Bal.

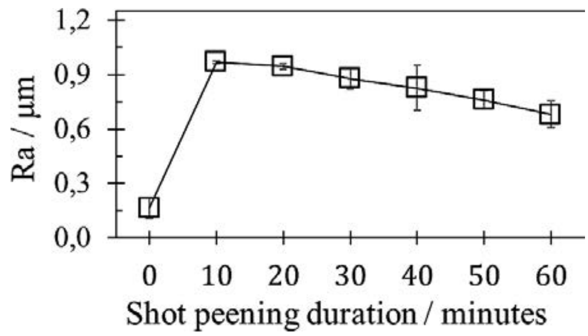

Figure 1 Roughness of the treated samples

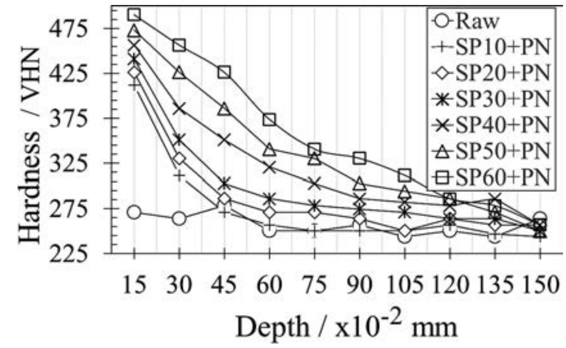

Figure 2 Surface to the depth hardness

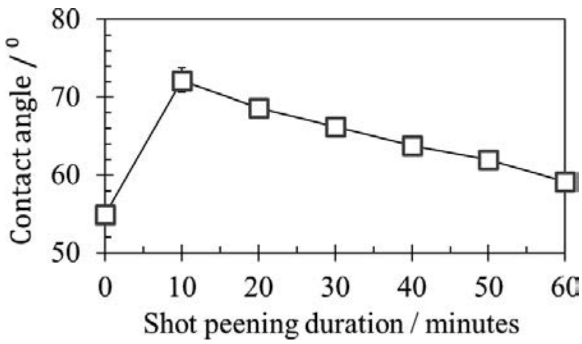

Figure 3 Shot peening and plasma Nitriding effect on wettability

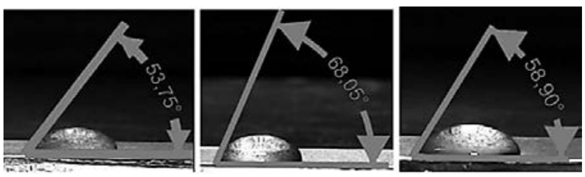

Figure 4 Droplet contact angle of Raw, SP20+PN and SP60+PN

the reduction in surface contact angle, ultimately rendering the surface more receptive to liquid interactions.

The fatigue-corrosion tests were conducted on both treated and untreated samples immersed in a 0,9 % NaCl solution to determine the characteristics of fatigue-corrosion crack propagation rate of samples before and after treatments. Figure 5 presents relationship between length of crack and number of cycles of fatigue-corrosion test.

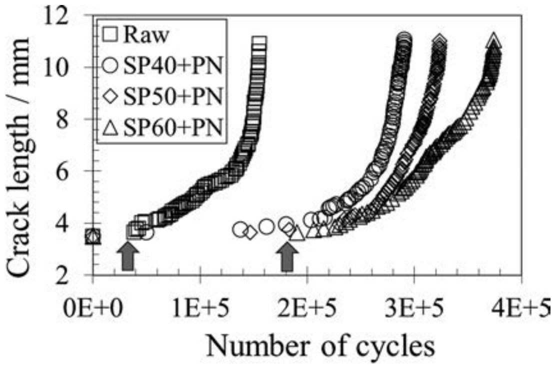

Figure 5 Fatigue crack growth vs cycles

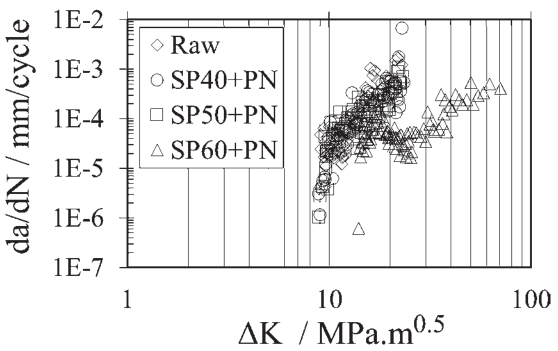

Figure 6 da/dN vs DK relationship

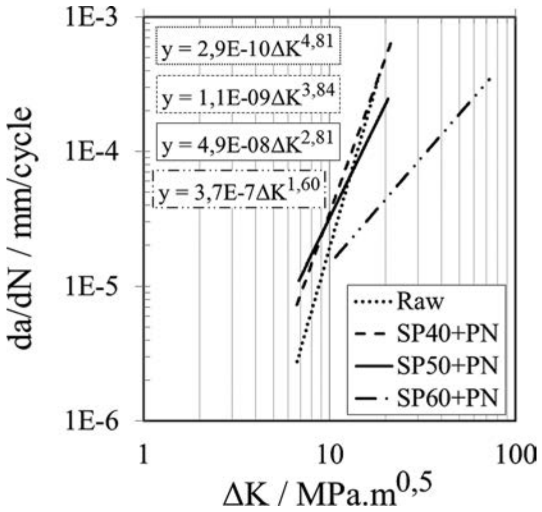

Figure 7 Trend-line of da/dN vs DK

Figure 5 shows that the SP60+PN specimens exhibited fracture at 374,091 cycles, whereas the untreated specimen failed at 155,477 cycles. The longer corrosion-fatigue life is partly affected by shot-peening and plasma nitriding that decelerate the crack initiation process as indicated by the red arrow in Figure 5, and Table 2.

Figure 6 shows the fatigue-corrosion crack growth rate, while the ones of fatigue-corrosion crack growth rate obtained by linearly connecting the data in zone two are shown in Figure 7. The linear line in Figure 7 was then used to analyze the fatigue life of the specimens, where line gradient of treated samples was found decreasing which means there was a decrease in the crack growth rate. The primary mechanism responsible for the increased fatigue-corrosion life lies in the ability

Table 2 **Paris constants**

Specimens	Max. cycles	C	n
Raw	155,477	$2{,}9 \times 10^{-10}$	4,81
SP40+PN	290,799	$1{,}1 \times 10^{-09}$	3,84
SP50+PN	323,591	$4{,}9 \times 10^{-08}$	2,81
SP60+PN	374,091	$3{,}7 \times 10^{-07}$	1,60

of shot peening and plasma nitriding to impede the crack initiation process and reduce the rate of fatigue-corrosion crack propagation.

CONCLUSIONS

Plasma nitriding and shot peening significantly increase the surface layer hardness and roughness. Plasma nitriding and shot peening also decrease the droplet contact angle as hydrophilic and improve fatigue life in rich chloride ions environment at the same time. In addition, plasma nitriding and shot peening enhance the fatigue resistance and corrosion resistance of a material by reducing the crack growth rate, and delaying the crack formation. This research revealed that the treated samples exhibited a fatigue corrosion life that is more than two times longer than that of the untreated samples.

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