Shot peening effect in F138 stainless steel surface modification

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Abstract: Stainless steel F138 is the most widely used steel as biomaterial. This metal has low toughness, so metallic implants are prone to wear [1]. Residual compressive stress and surface toughness increase can improve materials life fatigue. Shot peening is a mechanical surface treatment in which many small spheres are accelerated and blasted in materials surface, inducing residual compressive stress on materials surface. Surgical implants are submitted to this treatment to generate surface roughness increase for better adhesion too [2]. In this work, shot peening was performed using four different conditions to verify the effect on surface modification. Microscope techniques, x-ray diffraction, residual stress, toughness and roughness measurements were used to validate the tests. In conclusion, shot peening is an effective surface treatment to induce residual stress and increase roughness and toughness.
Keywords: F138, Residual Stress, Shot Peening, Stainless Steel.

Introduction

Mechanisms related to fatigue are the main failure cause in medical metallic implants [3]. Some possibilities to minimize fatigue failure are surface treatments to reduce fatigue cracks initiation and fatigue local stress concentrators. Yildz et al. report that the increase in compressive residual stress and surface hardness increases materials life fatigue, because a thin and hard layer presence prevent plastic deformation. Sliding bands movement occurs in high stress levels. So, if this movement was reduced, cracks initiation resistance increases, increasing materials fatigue resistance [1]. Conventional shot peening treatment has the main aim of induce compressive residual stress in materials surface, increasing its hardness [4]. For stainless steels F138 surgical implants the technique is used to increase surface roughness for a better implant adhesion [2]. Residual stress can be defined as any reminiscent stress (compression or tensile) after an external tension application [5]. X ray diffraction is used to measure the residual stress through interplanar distances dimensions in crystalline materials. For convention, tensile stress has a positive value (+σ) and compressive stress has a negative value (-σ). So, the aim of this work is to improve stainless steel F138 for medical application by verifying the effect on surface modification after shot peening treatment.

Experimental Procedure

The F138 austenitic stainless steel was kindly provided by Villares Metals S.A. It was received in bars with circular section of 19,05 mm diameter and was used in the as-received production state. Its nominal chemical composition is (%weight: 1,778% Mn, 0,023% P, 17.942% Cr, 14.759% Ni, 2.873% Mo, 0.019% C, 0.001% S and Fe balance). Specimens were cut in pieces with approximately 3 mm, embedding in bakelite hot process and mechanically ground using silicon carbide emery papers up to 1200 grit. The final surface finishing step was polishing by diamond paste (3 µm) followed by colloidal silica (0,04 µm), rinsed in deionized water, cleaned with alcohol and dried with a conventional heat gun. For microscopy, samples were submitted a chemical attack with (1 HCl P.A. + 1 HNO_3 65% + 1 H_2O).

Shot peening were performed by POLO-AR, Air-blasting type (pressure of 5 bar, velocity of 70 m/s). It was realized 4 treatment conditions, varying treatment time (100% - 3 seg and 200% - 6 seg) and shot size (CN10 - 0,30 - 0,21mm and CN20 - 0,40 - 0,30mm). Residual stress was analyzed by X ray diffraction (Rigaku, Rint 2000 with Cr anode). Roughness and surface morphology was examined by confocal laser scanning microscopy (CLSM - Olympus LEXT OLS4100) and hardness was obtained with Bühler equipment.

Results and Discussion

Figure 1 presents confocal laser scanning microscopy images before and after shot peening treatment. Samples presented plastic deformation in addition to the roughness variation (Table 1). Surface final morphology was presented for all treatment conditions. All of them seems similar, but and for CN10 shots plastic deformation was smaller. For 200% coverage the deformation is more pronounced. The morphology presented more deformation is CN10-200%.

Medium residual stress values obtained by 〖sen〗^2 ψ method were presented in Table 1. The material as received already presented some tension probably provided during its process. After polishing and surface treatment was observed compressive residual stress induction and, consequently, crystal structure deformation. After polishing and mechanical surface treatment, negative stress was induced (compressive). For CN10, independent of coverage type, the residual stress induction was higher than for CN20 treatment. So, it`s possible to conclude that the smaller shot size in the same parameters of test produce higher induction of residual stress in stainless steel F138. The coverage of 200% induced higher residual stress than 100% coverage, showing that higher treatment times produce higher induction of residual too.

CN10 shot showed low roughness and toughness with 100% coverage, but induced residual stress was elevated, the second higher. For 200% coverage, roughness, toughness and residual stress increased, being obtained the higher residual stress. Analyzing CN20 shot treatment, 100% coverage showed roughness and toughness very similar to CN10 shot with 200% coverage, but residual stress was the smaller, about 200 MPa lower. For 200% coverage, CN20 shot obtained reduced roughness and residual stress, but elevated toughness. In this way, till this step the more effective surface treatment in stainless still F138 is blasting with CN10 shot and 200% coverage.

Table 1 – Roughness.

	Roughness Ra (µm)		*Hardness HV*		*Residual Stress (MPa)*
	Average	*St. Dev.*	*Average*	*St. Dev.*	
Polish	0,008	0,001	173,94	1,28	-385,41
CN10 100	0,513	0,030	258,10	10,06	-870,95
CN10 200	0,611	0,011	366,14	6,87	-902,98
CN20 100	0,600	0,022	360,68	10,72	-671,09
CN20 200	0,414	0,012	411,70	16,54	-758,61

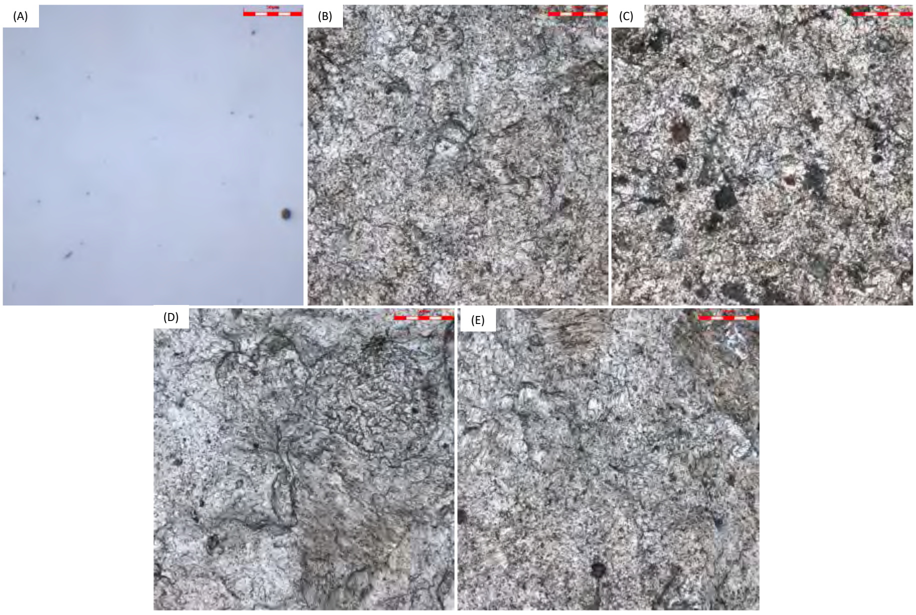

Figure 1: Confocal laser scanning microscopy images before (a) and after shot peening treatment (b) CN10-100%, (c) CN10-200%, (d) CN20-100% e (e) CN20-200%.

Conclusions

Mechanical polishing process can induce lower compressive residual stress, so shot peening is performed from a low compressive residual stress. Shot peening surface treatment is capable to induce residual stress in stainless steel F138, being obtained higher residual stress and roughness with shots in lower sizes. For the presented coditions, the best surface tretament was performed with CN10 shot and 200% coverage.

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