Wear Evaluation of the ASTM F138 Austenitic Stainless Steel for Biomedical Applications Treated by Optical Fiber Laser

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1. Introduction

The implants, due to corrosion and even friction against implantable components, bones or other body parts can detach particles, which coming into contact with bodily fluids, are able to be placed in locations far from the removed source causing complications to the patients [1]. Metallic particles released from the corrosion process may move passively, through tissue and/or circulatory system or can be actively transported [2], compromising the biomaterial’s biocompatibility.

According to Anderson [3], it is not possible to assure a biocompatible biomaterial for a given application will also be biocompatible to another area of application. Besides, following Black [2], three areas of evaluation are important when studying implants in patients: the implant function, change in pain status and change in quality of life.

The ASTM F138 stainless steel is one of the metallic materials used for implants manufacture, because of its mechanical and electrochemical properties and low cost [4,5]. Additionally, the laser technique is commonly used for identification of the metallic implantable medical device manufactured with those material [4-7].

In other line of research, the micro-scale abrasion test (or ball-cratering wear test) is a practical method to analyze the wear resistance of diverse materials [8-10].

The ball-cratering wear test has gained large acceptance at universities and research centers and is widely used in studies focusing on the abrasive wear behavior of different materials [11-15]. Figure 1 presents a schematic diagram of the principle of this wear test; “h” is the depth of the wear crater.

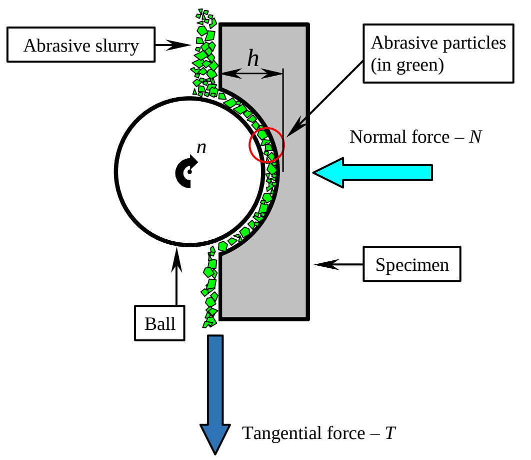

Figure 1. Ball-cratering wear test: a representative figure showing the operating principle.

In this type of test, a rotating ball is forced against the specimen being tested and an abrasive slurry or a liquid solution is supplied between the ball and the specimen during the experiments; the aim of the ball-cratering wear test is to generate “wear craters” on the specimen. The wear volume (V) may be determined using Equation 1 [11], where “d” is the diameter of the wear crater and “R” is the radius of the ball.

$$V \approx \frac{\pi d^4}{64R} \tag{1}$$

Wear tests conducted under the ball-cratering technique present advantages in relation to other types of tests, because it can be performed with normal forces (N) and rotations of the sphere (n) relatively low ($N < 0.5$ N and $n < 80$ rpm) [16-20].

The aim of this work was to evaluate the tribological behavior of ASTM F138 austenitic stainless steel (SS) treated by laser process, using the ball-cratering wear method.

2. Experimental procedure

2.1. Ball-cratering equipment

An equipment with free-ball configuration (Figure 2) was used for the wear tests.

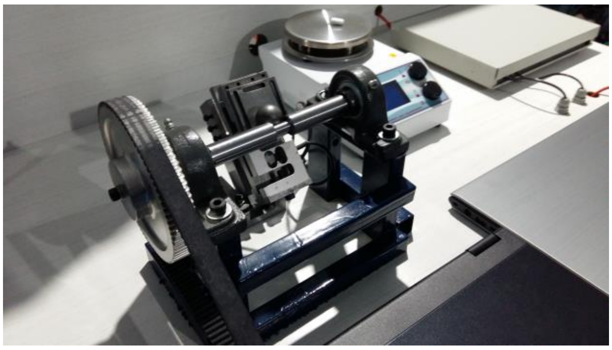

Figure 2. Ball-cratering equipment with free-ball configuration designed and constructed for the tests.

Two load cells were used in the ball-cratering equipment: one load cell to control the normal force (N) and one load cell to measure the tangential force (T) developed during the experiments. “Normal” and “tangential” forces load cells have a maximum capacity of 50 N and an accuracy of 0.001 N. The values of “N” and “T” are read by a readout system.

2.2. Materials

The tested specimen was an ASTM F138 austenitic stainless steel biomaterial (chemical composition (wt%): 0.023 C, 0.78 Si, 2.09 Mn, 0.026 P, 0.0003 S, 18.32 Cr, 2.59 Mo, 14.33 Ni and Fe balance) treated with a nanosecond optical fiber ytterbium laser at four different pulse frequencies, as Table 1 shows.

Table 1. Frequencies used for laser treatment.

Sample	1	2	3	4
Laser frequency [kHz]	80	188	296	350

One ball made of AISI 316L stainless steel, with diameter of D = 25.4 mm, was adopted as counter-body.

Table 2 shows the hardness (H) of the materials used in this work (specimen and ball).

Table 2. Hardness of the materials used in this work – specimen and ball.

	Material	**Hardness**
Specimen	ASTM F138 SS	88 HRB
Ball	AISI 316L SS	25-39 HRC

Table 3 shows the micro-hardness measured for each type of sample studied.

Table 3. Micro-hardness values for each type of surface finish.

Sample	**Blank**	**1**	**2**	**3**	**4**
Micro-hardness [HV]	199.3	204.3	215.4	226.1	239.9

2.3. Wear tests

Table 4 presents the test conditions selected for the experiments conducted in this work.

Table 4. Test conditions selected for the ball-cratering wear experiments.

Normal force – (N)	0.25 N
Sliding distance – (S)	8 m
Ball rotational speed – (n)	50 rpm
Tangential sliding velocity – (v)	0.066 m/s
Test time – (t)	2 min

As a function of the density (ρ) of the material of the ball (AISI 316L SS: ρ = 8 g/cm³) was defined the value of the normal (N) for the wear experiments: N = 0.25 N.

The ball rotational speed was n = 50 rpm and with the diameter D = 25.4 mm, the tangential sliding velocity of the ball was equal to v = 0.066 m/s.

The wear tests were conducted under t = 2 min and with the value of v = 0.066 m/s was calculated a value of sliding distance (S) between the specimen and the ball of S = 8 m.

All experiments were conducted without interruption and a chemical solution was continuously agitated and fed between the ball and the specimen during the experiments, under a frequency of 1 drop / 2 s.

Both the normal force (N) and the tangential force (T) were monitored and registered constantly. Then, the coefficient of friction was determined using the Equation 2:

$$\mu = \frac{T}{N} \tag{2}$$

Surface analyses of the wear craters were conducted using an Optical Microscope.

3. Results and discussion

3.1. Analysis of the volume of wear – V

For comparison reasons, surfaces of this biomaterial without laser were also evaluated. These are relevant results to the biomaterial's field, because when manufacturing an implant, one has to choose a suitable area to identification number engravings to avoid wear.

Figure 4 presents an image of the specimen submitted to wear tests.

Figure 4. Example of wear crater obtained.

Figure 5 presents the behavior of the wear volume (V) for the conditions which the specimen is without laser and textured with laser.

It is possible to observe that the wear volume decreased when the specimen was treated with laser. This decreasing is associated to a possible increasing of the hardness of the specimen.

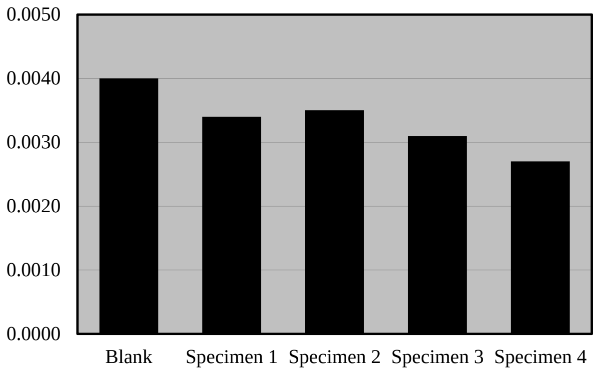

Figure 5. Wear volume (V) as a function of the surfaces treated by laser.

3.2. Analysis of the coefficient of friction – μ

Figure 6 shows the behavior of the coefficient of friction (μ) for the blank and for the conditions which the specimen was treated by laser.

Coefficient of friction – μ

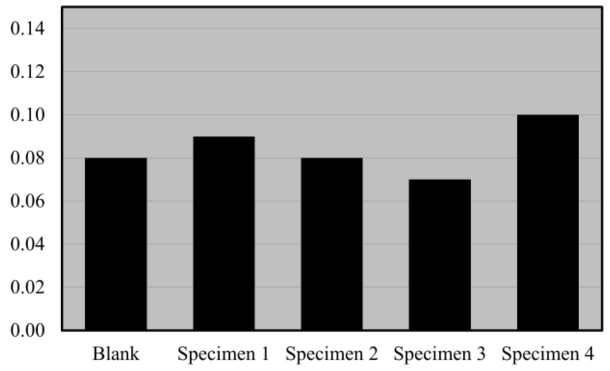

Figure 6. Coefficient of friction as a function of the surfaces treated by laser.

Magnitudes of these values were reported by Cozza *et al.* [12] with the same type of assay under different tribological systems.

Besides, it is possible to note that the coefficient of friction was independent of the laser frequency.

No direct relationship between volume of wear and coefficient of friction was observed, *i.e.*, the highest value of volume of wear was not related to the higher value of coefficient of friction [21,22].

4. Conclusions

The results obtained in this work indicated the following:

(1) The surface characterization showed modifications due to the high temperatures involved in the laser melting process;

(2) The tribological behavior was influenced by frequency laser used for this biomaterial;

(3) The surfaces treated by laser increased the wear resistance of the samples;

(4) The highest values of volume of wear were reported for samples without marks;

(5) The coefficient of friction was independent of the laser frequency;

(6) It was not reported direct relationship between volume of wear and coefficient of friction for the ASTM F138 austenitic stainless steel biomaterial.

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