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Excessive coverage effect (over peening) in the blasting operation of aluminum alloy “AA 7475-T7351” with steel shot

Efeito de cobertura excessiva (excesso de peening) na operação de jateamento da liga de alumínio “AA 7475-T7351” com granalha de aço

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ABSTRACT

Aluminum and its alloys are widely used in the aeronautics industry due to its high lightness and ductility, and it can add other elements, thus changing its characteristics. Fatigue is the major cause of failure of metal materials due to the dynamic and oscillating stresses of the finished materials. The objective of this work is to evaluate the effect of Shot Peening with coverage percentages 1blasting, 3 blasting and 10 blasting in fatigue life of aluminum alloy AA 7475-T351. Shot Peening is a cold surface treatment used to increase fatigue life of the alloy by inducing residual stresses of compression on the surface of the part. In the Shot Peening process, spherical steel grids of type S230 were used, in which the specimens were subjected to 1blasting, 3 blasting and 10 blasting coverage in two stress levels (42 Ksi and 50 Ksi). The results presented in the fatigue tests and electron scanning (SEM) showed the increase in the mechanical properties of all the samples, and those exposed to 1 blasting and 3 blasting presented better results.

Palavras-chave: Shot Peening; Stress Strain Curve, Saturation Curve, Coverage, Fatigue.

RESUMO

O alumínio e suas ligas são amplamente utilizados na indústria aeronáutica devido à sua alta leveza e ductilidade, podendo adicionar outros elementos, alterando suas características. A fadiga é a principal causa de falha de materiais metálicos devido às tensões dinâmicas e oscilantes dos materiais acabados. O objetivo deste trabalho é avaliar o efeito do *Shot Peening* com porcentagens de cobertura 1 jateamento, 3 jateamentos e 10 jateamento na vida à fadiga da liga de alumínio AA 7475-T351. *Shot Peening* é um tratamento de superfície fria usado para aumentar a vida em fadiga da liga, induzindo tensões residuais de compressão na superfície da peça. No processo de *Shot Peening*, foram utilizadas grades esféricas de aço do tipo S230, nas quais as amostras foram submetidas à cobertura de 1 jateamento, 3 jateamentos e 10 jateamentos em dois níveis de estresse (42 Ksi e 50 Ksi). Os resultados apresentados nos testes de fadiga e na varredura eletrônica (MEV) mostraram o aumento nas propriedades mecânicas de todas as amostras, e as expostas a 1 jateamento e 3 jateamentos apresentaram melhores resultados.

Keywords: Shot Peening; Curva Tensão Deformação, Curva de Saturação, Recobrimento, Fadiga.

1. INTRODUCTION

The most commonly used alloys for manufacturing structural components in the aeronautics industry are thermally treatable or Hardened by Precipitation, more specifically those of the 2XXX and 7XXX series [1]. Aluminum alloys containing magnesium in its composition are thermally treatable because magnesium combines with other elements such as copper, silicon or zinc accelerating or accentuating precipitation hardening [2]. Among the alloys of the 7XXX (Al-Zn) series, the Al-Zn-Mg and Al-Zn-Mg-Cu are more common [3]. Since Al-Cu and Al-Mg-Si alloys are hardened alloys by precipitation under controlled heat

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treatment under specific, generally solubilizing and aged conditions, they exhibit significant hardness gains. They find their main application in aircraft manufacturing, since these 7XXX series alloys are those that achieve the highest levels of mechanical strength among aluminum alloys [4].

The temperatures of solubilization of the 7XXX series alloys are relatively low when compared to other types of aluminum alloy. A typical solubilization temperature of an Al-Zn-Mg alloy would be about 480 °C, whereas for an Al-Mg-Si alloy would be about 560 °C [5,6].

Due to the applications this alloys are exposed a fatigue stress. Fatigue is a form of failure that occurs in structures that are subject to dynamic and oscillating stresses (e.g., bridges, aircraft, and machine components) [7]. Under these circumstances, a failure at a pressure level considerably lower than the tensile strength limit or flow limit for a static charge is possible. The term "Fatigue" is used because this type of failure normally occurs after a long period of repetitive strain or strain cycle [8]. Fatigue studies are important in that it is the largest single cause of metal failure, and it estimated that it comprises approximately 90% of all metal failures [9].

Method for improve the fatigue resistance are use of steel shot blasting process, also known as "shot peening" [10-12]. This process can defined as a cold surface treatment performed by the controlled impacts of spherical shots projected in high velocities on the part surface. It discovered in the late twenties by accident. A small batch of automobile valve spring behaved much better than expected after finished by shot blasting. After that, studies about the mechanisms of the benefit started and shot peening knowledge stayed confined on some companies up to the Second World War that caused a rapid development of the process [3].

Nowaday, shot peening applications can be found at automobile (gears and springs) and aeronautical industries (turbo fan blades, structural parts). Shot peening utilized for increasing the fatigue life is different of abrasive blast cleaning process applying for cleaning metal surfaces [11]. Particles for shot peening are spherical while particles for abrasive blast cleaning do not have a specific shape [13].

The shot peening processes can be defined as a cold surface treatment applied on finished parts obtained by the uniformly distributed impact of spherical grids, projected onto the surface of the material under conditions strictly controlled. The purpose of this process is to induce residual compression stresses on the metal surface and therefore, failures resulting from nucleation processes and growth of surface cracks such as fatigue and stress corrosion can be delayed [14]. When applied in restricted regions of a part causes changes in the equilibrium condition of stresses that result in geometric changes very useful in processes of forming or performing parts [15]. Other advantages of the process are related to an increase in the useful life of the parts and the possibility of reducing the weight of structures dimensioned by fatigue or tolerance to the damage, through the re-design of the components [16]. Coverage is defined as the proportion of area of a blasted part that is effectively covered by the impressions left by the impact of the shot. For purposes of improving the properties already mentioned, coverage of 100% is normally unnecessary, provided that another important process variable, saturation, is reached [17].

The saturation condition is reached by doubling the time of exposure to the jet with certain characteristics (intensity), a benefit less than 10% is obtained in terms of the magnitude of the resulting residual stresses. Under these conditions the process is commonly called "shot peening" saturation [18]. When blasting is applied for conformation or performance purposes, it is called "shot peening" of performance or conformation or even "peen forming" and in these cases, as the objective is simply to reach the geometric shape, there is no strict control over the coverage. Consequently, in this process, the coverage may result in both lower values and values well above the 100% common in the saturation shot peening process. Shots are the main tool of the process. Their size, shape and hardness shall be controlled in order to assure the process parameters and avoid damages to the part surface [19].

There are several different shot types and sizes: (Steel shot, Iron Shot, Glass bead, Conditioned Cut Wire (CCW), Ceramic shot, Plastic shot, Non-Ferrous shot (Al, Zn, Cu). In the process, the particles shall be free of corrosion, oils, grease and other contaminants. It will avoid system-clogging problems and assure the process parameters.

Almen Test strips are standard specimens used to check the intensity to be applied on a part surface. J.O. Almen from Research Department of General Motors has introduced them [20]. The Almen Test strip made by spring steel according SAE J442 (R) [21] and AMS-S-13165 [22]. There are three different kinds, where the relation are attributed as function of thickness of almen test strips, type "C" with 2.382 mm of thickness, and the "A" sheet we have a thickness of 1.295 mm, and the "N" sheet with a thickness of 0.787 mm, as showed in figure 1.

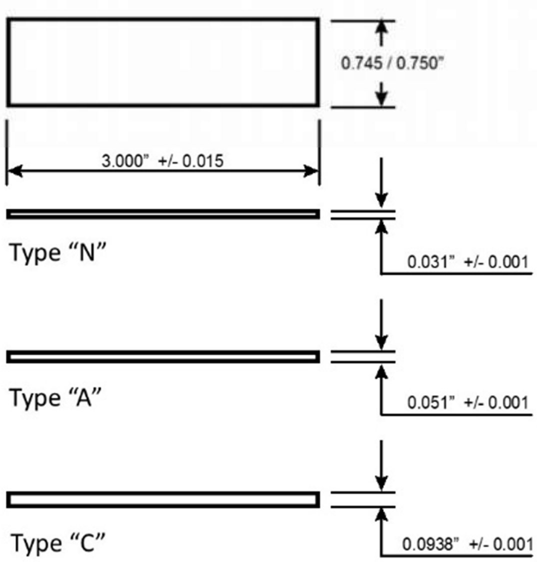


Figure 1: Representative chart of the thickness of the almen strips

Type C used for high intensities, A used for intermediate intensities and N used for low intensities. The figure 2 show of Shot Peening Blasting evidencing the parameters indications, such as jet angle, shot, print and part. These parameters, which must be controlled.

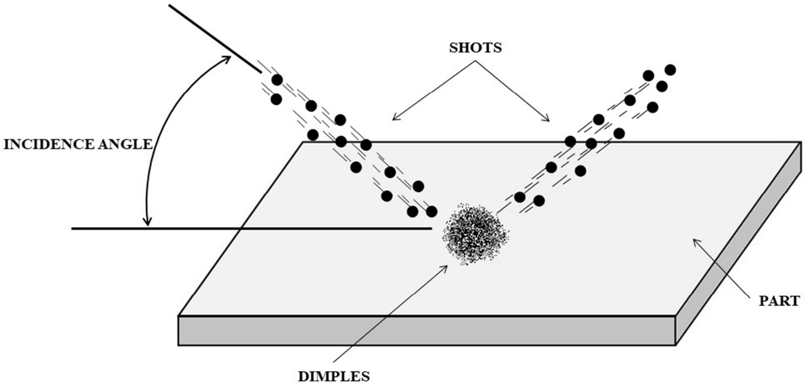


Figure 2: Scheme of parameters applied in the shot peening process

The main purpose of shot peening process is to induce compressive residual stresses on the part surface. The process generates a compressive stressed thin layer that is responsible for improving the fatigue life of the component, figure 3. The residual stressed layer thickness depends on the material to be worked and the intensity level applied by the shot. The compressive stress induced can prevents some failures on the part like crack formation/propagation due fatigue strength, failures due SCC – Stress Corrosion Cracking.

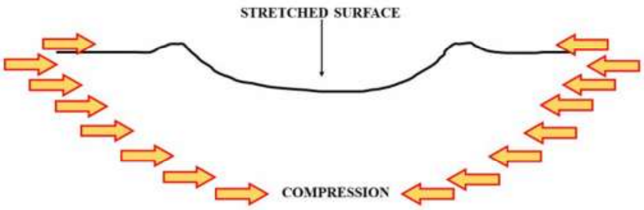


Figure 3: Scheme of stress generated on the surface of the piece by the application of the shot peening

There are other different methods for inducing residual compressive stresses, such as Rolling, Heat treatments, Laser peening, and others [23].

As it is difficult for the operator to check if whether the process on the part is right correctly carried out, the shot peening is considered a special process, e.g., the operator shall control the process parameters to assure the operation on the part. Parameters to control the process shot size, mass, hardness and shape, exposure time, firing velocities (pressure or rotational speed), distance and direction of firing flow, roughness of the workpiece surface after the process [24].

The intensity control starts with measures of mass, hardness, velocity, shape and size of shot. The shot mass, its hardness and its velocity influence directly the kinetic energy of the impact. The mass and its hardness shall be checked before charging in the machine and adjusting the parameters. Shot size and shape inspections are important to avoid any damages to the surface part. Those inspections shall occur periodically for evaluate the occurrence of shots with defects [25].

The most usual check for kinetics energy is the Intensity control. It can indicate in an indirect way how big is the compressive stress induced and/or the energy applied on the part surface. The impacts of the shot deform plastically a thin layer of the material. That thin layer would expand in the plane (two directions), but the rest of the material try to keep the original dimension [26].

The Almen Test slides are small SAE 1070 cold rolled steel day plates with hardness from 44 to 50 HR and with a planning of +/- 0.0015 of the inch according to SAE J442 (R) [21] standard with parameters or controlled characteristics.

The Figure describes the blades which are small platelets of a SAE 1070 cold rolled spring steel, with a hardness of 44 to 50 HRC and with a flatness of +/- 0.0015 of the inch according to SAE Standard J442 (R) (2017) [21] and ASM S-13165 [22], with parameters or controlled characteristics.

Those dimension differences generate a Momentum, which in the equilibrium ($\Sigma M = 0$) generates a deflection figure 4.

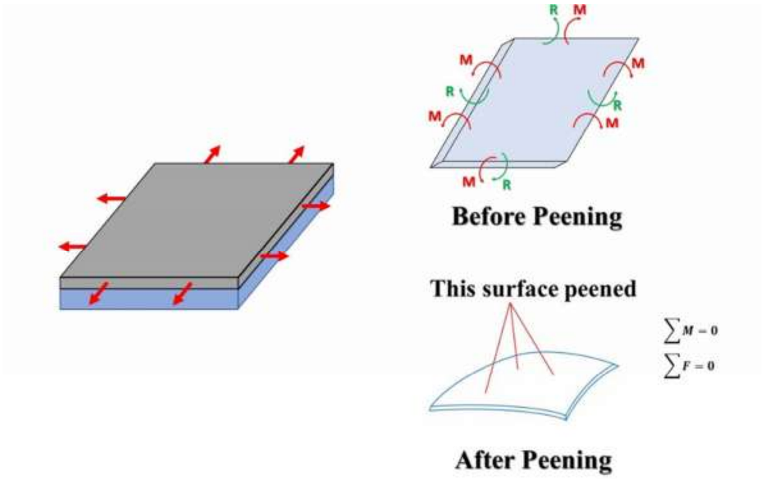


Figure 4: The Almen's Before and after Shot Peening

After a given exposure time, the arc height measured on an Almen specimen increases very slowly. It means that the shot peening effect on the peened surface has decreased due the cold work generated by the shot impacts. Saturation point is then obtained when the exposure time is doubled and the arc height increases no more than 10% of its value. The measured arc on Saturation Point is the Almen Intensity.

The group of saturated points generates a Saturation Curve. This curve defines the Almen Intensity for a defined set of parameters process figure 5.

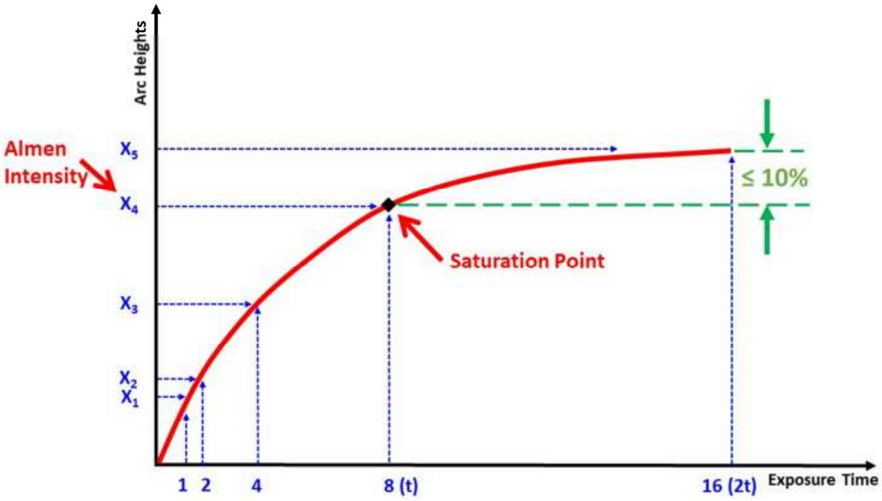


Figure 5: Representation of Saturation Curve for determined Almen Intensity.

The coverage is the percentage of the surface that has been dimpled by the shot impacts. In addition to the saturation of the almen, the surface must be satisfactorily coated, which in automated machines is recommended 100%. For operations using manual machines, at least 200% coverage is required.

A percentage higher than 100% can checked measuring the exposure time to obtain 100% and the total exposure time applied on the surface analyzed [26].

This work aims to evaluate the effect of shot peening with coverage percentages of 1 blasting, 3 blasting and 10 blasting in the fatigue life of aluminum alloy AA7475-T7351.

2. MATERIALS AND METHODS

Initially, it was necessary to adjust the experimental parameters of the equipment to define the conditions of 50% coverage, because the Shot Peening machines used have established the coverage parameters for a percentage well above 100%, according to norms MIL-S-13165 [27].

Before starting the shot peening treatment, the parameters of the equipment must be adjusted to achieved 50% coverage [28]. To validate the settings of the parameters of the equipment a almen test is made, using the fixing device showed in figure 6, and compared the curvature with determined for the material.

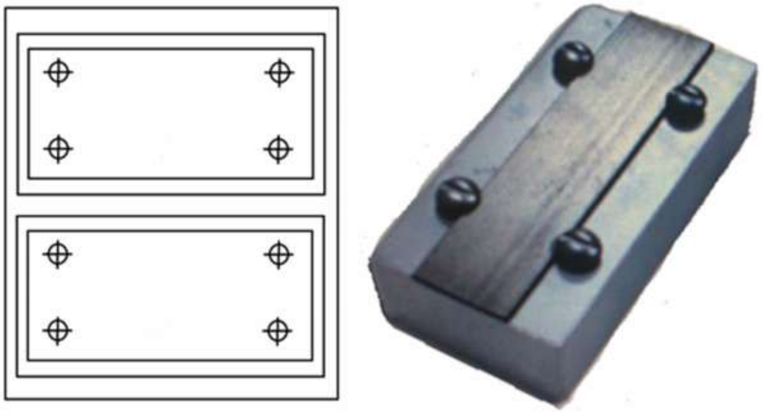


Figure 6: Fixing Device for Almen Test.

The specimens were made from aluminum DOWEL 7475-T7351, 1.5 inches thick according to ASTM-E-466 (2015) [29] and were type KT1 according to figure 7. The specimens must be machined and have a good surface finish so as not to impair the results of the test in accordance with ASTM-E 466 [29]. It was performed 24 fatigue tests with factor KT = 1 and R = 0.1

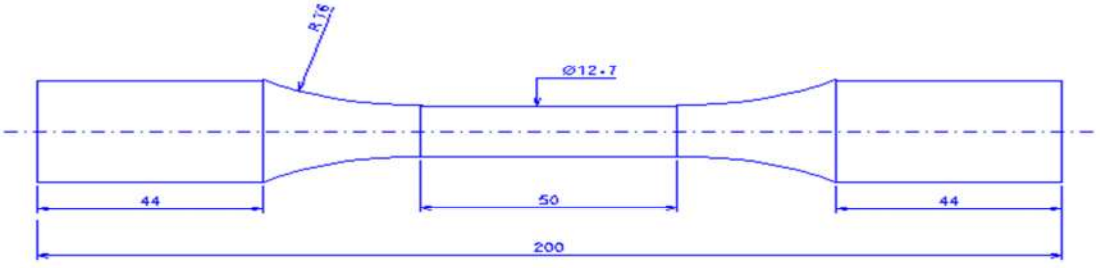


Figure 7: Parameters of Fatigue Test Specimens thick according to ASTM-E-466 (2015).

The specimens were positioned on the machine and killings were made in different times and intensities, Table 1 shown nomenclatures and test data. Was used a pressure of 42 and 50 Ksi for the exposure of 1blasting, 3 blasting and 10 blasting.

Table 1: Specimens and parameters tests

Specimen	Impact Intensity	Time (minutes)	Shot Size	Cycles blasting
BLASTED 1X_42	42 Ksi	30	S 230 (0,84 mm)	1
BLASTED 3X_42	42 Ksi	30	S 230 (0,84 mm)	3
BLASTED 10X_42	42 Ksi	30	S 230 (0,84 mm)	10
BLASTED 1X_50	50 Ksi	30	S 230 (0,84 mm)	1
BLASTED 3X_50	50 Ksi	30	S 230 (0,84 mm)	3
BLASTED 10X_50	50 Ksi	30	S 230 (0,84 mm)	10
BASE LINE	-	-	-	0

The baseline of the samples sprayed and subjected to parameter variations to determine the percentage coverage, 0°, 45° and 90° tilt angles were used to determine the best impact condition [30]. The fatigue tests carried out until the rupture of the samples for analysis of improve of resistance of samples. The surface analyzed by scanning electron microscopy to evaluate the deformations generated by the impacts in the shot peening process.

3. RESULTS AND DISCUSSIONS

The angle of inclination of the test is determined with respect to the neutral axis of fixation of the part in the equipment, the angle of 0° that acts perpendicular to the surface of the sample while the angle of 90° acts parallel to the surface of the sample. Thus the tests performed to determine the angle of incidence of the shots for the shot peening test showed that the incidence at 45° resulted in a coverage of 80%, figure 9 (a). With a 90° inclination (flush to the part) resulted in a coverage of 70%, figure 9 (b) and the best result was that presented with the incidence of shots perpendicular to the sample, 0 °, with coverage of 90% of the surface, figure 8 (c).

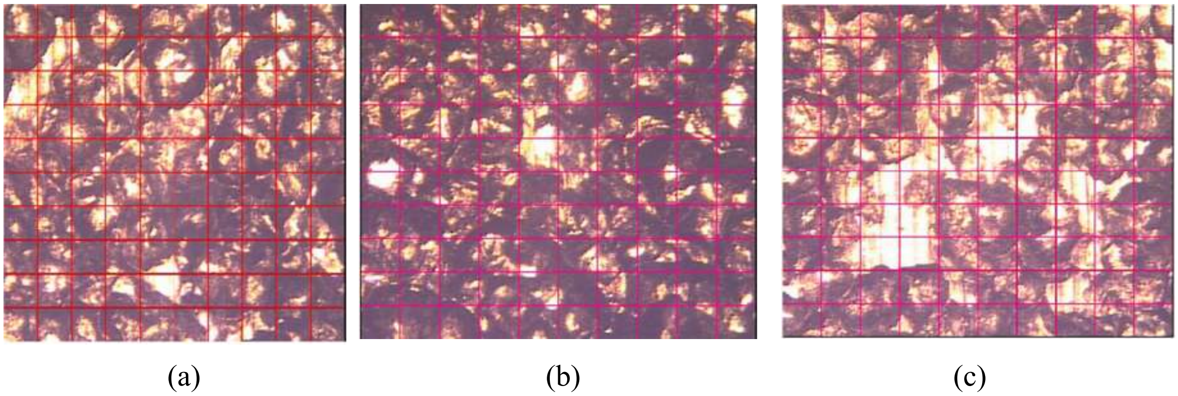

(a) (b) (c)

Figure 8: Macrography of the surface tested by shot peening at different angles of incidence. (a) 45°; (b) 0° and (c) 90°.

Then with the determination of the best angle of incidence, the tests with the shot peening cycles were performed with a 0 ° incidence to guarantee the best coverage. The cycles obeyed as described in table 1.

The results of average the fatigue tests are shown in figure 9, it is observed that in general the samples treated with 42 Ksi impact intensity obtained better fatigue results when compared to samples treated with 50 Ksi intensity.

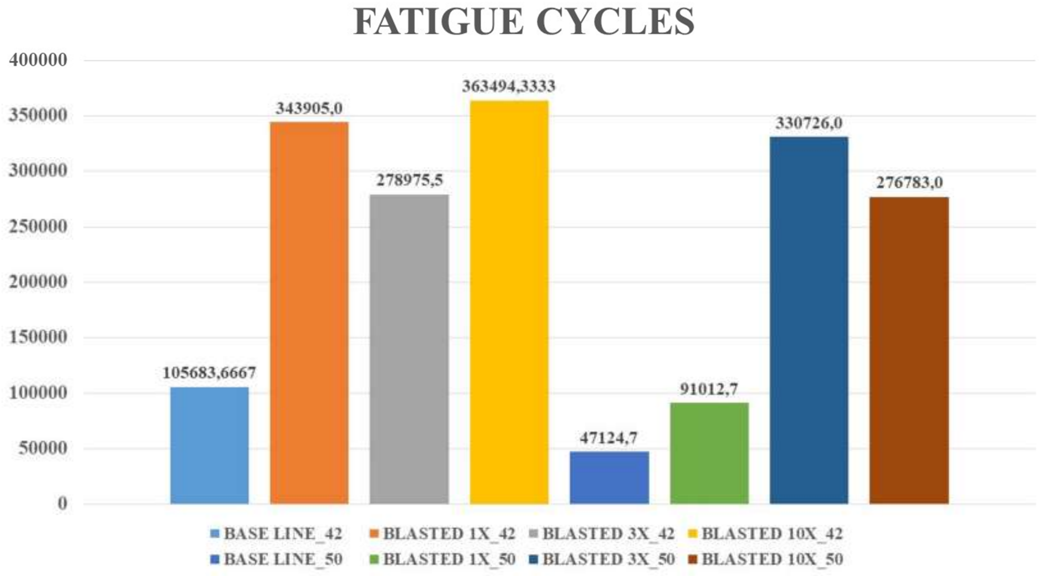


Figure 9: Mean values of the fatigue cycles supported by the studied samples.

It also observed that for samples treated with 42 Ksi integrity there is a tendency in the increase in fatigue strength with the increase of shot peening blasting cycles. While for samples treated with 50 Ksi, a peak of improvement with the accomplishment of 3 cycles of blasting what cannot observed with the increase of blasting cycles, where with 10 times a decrease in the fatigue resistance of the studied pieces occurred.

To compare the obtained results, a fatigue curve of MMPDS-HANDBOOK used as reference. This comparison shown in figure 10. It can observe that the basic specimens without blasting, relatively low-level, and a fatigue life slightly below the reference curve, at two stress levels tested.

In relation to the three blasted specimens, it is noticed that the pressure level of 50 Ksi, for 1blasting, 3 blasting, showed similar behavior. And all presented the fatigue behavior superior to the reference data [21].

The 1-blasting specimens presented an average of 91000 cycles, the 3-blasting, presented an average of 87000 cycles, and the base-line presented 47000 cycles, indicating a fatigue improvement of 94% for 1blasting and 3-blasting. For 10-blasting, we had an average of 73000, at the pressure of 50 Ksi, for 42 Ksi had 360000. After fatigue tests SEM analysis of the fracture surfaces where it was can see as characteristics of the material 11blasting, 3-blasting and 10-blasting that obtained acceptable relation between the coverage and distortions observed at each concentration of tension.

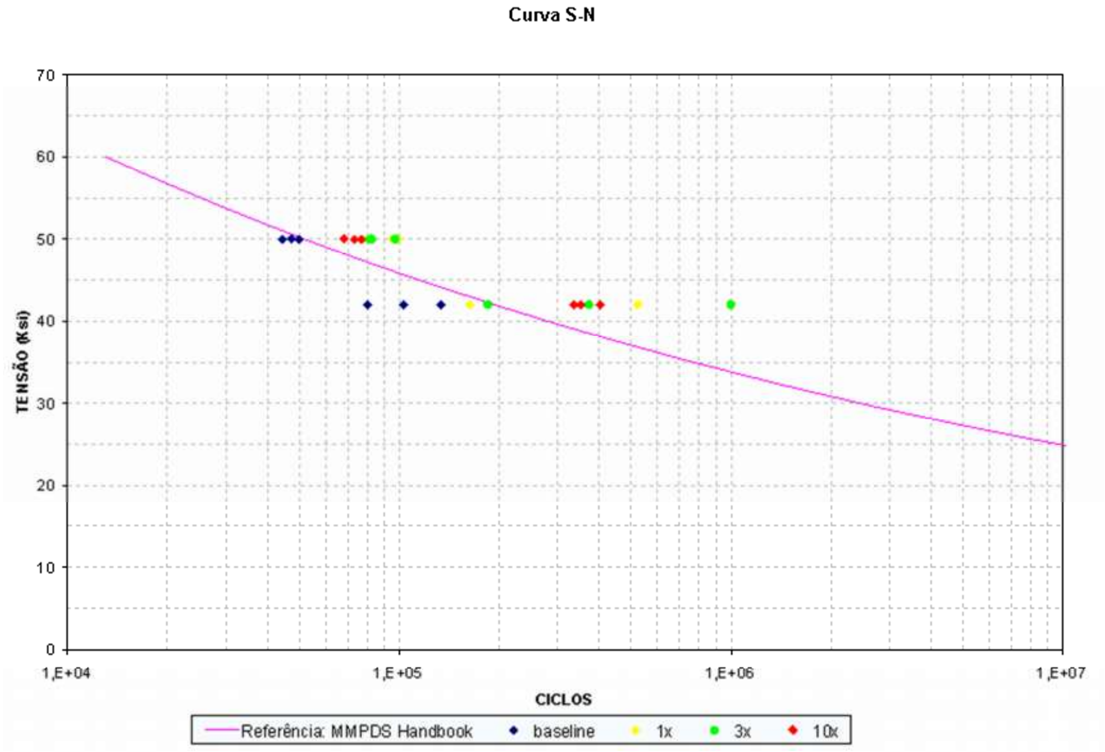
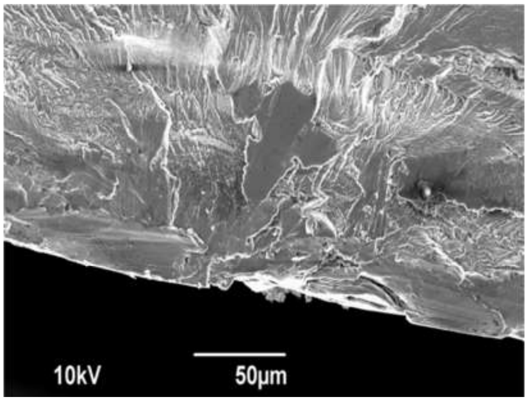


Figure 10: Comparative curve of theoretical data for fatigue and data obtained in the empirical tests for different intensities of impact and cycles of peening.

In the sample with 3-blasting exposure, it an area not covered by blasting can be observed, denoting a less rough surface. In the same sample, observing the beginning of the crack in the surface of the region of the elastic caused by the shot peening, as a region of kneading caused by the fatigue cycle.



(b)

Figure 11: SEM of the surface of the sample indicating the beginning of the crack in the surface, the elastic region caused by Shot Peening and a region of kneading due to the fatigue cycle.

The figure 11 shows the rough fracture surface characteristic of a ductile fracture caused by fatigue. In the base-line sample, we observed the direction of cracks, which start at the surface and go towards the enter, figure 11, in the same sample; observe a presence of particles that did not leave the cleaning before SEM testing.

4. CONCLUSIONS

The base-line specimens, without blasting, presented a relatively low dispersion in relation to the fatigue life, slightly lower than the S-N reference curve, at the two pressure levels (42 Ksi and 50 Ksi). For the 50 ksi pressure level, the corpo de prova, with 1-blasting and 3-blasting exposure exhibited similar fatigue behavior and higher than the S-N reference curve. For the 10-blasting exposure at the pressure level 42 Ksi and 50 Ksi, they showed dispersion to the right of the reference curve S-N and left of the 1-blasting and 3-blasting dispersion, thus indicating a less favorable situation in relation to the 1-blasting and 3-blasting exposure. We can conclude with this work, according to results observed through the SEM and graph of the reference curve S-N, that the best condition for obtaining results in relation to life in fatigue and mechanical resistance was 1-blasting and 3-blasting exposure, observing that the Over Peening, this is the exposure from 3-blasting.

5. ACKNOWLEDGEMENTS

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