Effects of conventional shot peening and surface mechanical attrition treatment on the mechanical properties of a Titanium alloy

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Abstract
Shot peening (SP) is one of the most popular surface plastic deformation process used in industry to improve mechanical properties of metallic parts. It consists in impacting the surface of pieces with shot. The multiple impacts induce superficial compressive residual stress in the material and enhance the surface characteristics and fracture resistance of the mechanical components. The surface mechanical attrition treatment (SMAT) technology has the quite same principle than SP but the main differences lie in the size, sphericity and velocity of the shot as well as the mean of projecting the shot onto the surface. In this paper the effects on the mechanical properties of conventional SP and SMAT are compared considering a titanium alloy. On the one hand, the intensities of these two mechanical treatments are compared. On the other hand, the roughness, micro hardness, microstructure and residual stress state induced by SP and SMAT are analysed and discussed taking into account titanium alloy plates.

Keywords: Titanium Alloy, Shot peening, SMAT, Residual stress, Hardness, Roughness

Introduction
Surface plastic deformations produce metallic components with superior mechanical properties and shot peening (SP) is the most popular plastic deformation process used by industries. In SP the work piece is struck with a stream of shot (Fig.1a). The multiple impacts induce superficial compressive residual stress on the surface, which improves mechanical properties and fracture resistance of the treated part.

Surface mechanical attrition treatment (SMAT), in Figure 1b, is based on the same principle than SP.Tthe main differences are the size of shot, (between 0,25 mm to 1 mm for SP, and 1 mm to 8 mm for SMAT) and the velocity (between 20 m/s to 150 m/s for SP, and 3 m/s to 20 m/s for SMAT). Also, the shape of the elements composing the shot is not the same; for SMAT the shot is composed of very regular hard spheres. Another difference resides in the device that is used to project the shot. In SMAT the shot is placed in a closed chamber and set in motion with the vibration of a sonotrode (the chosen frequency is here 20 kHz) [1].

These differences have a significant impact on surface characteristics and mechanical properties. We thus propose to compare both processes by analyzing and quantifying the consequences of these processes. An experimental and analytical study is thus proposed to evaluate and compare the induced surface characteristics and residual stress profiles.

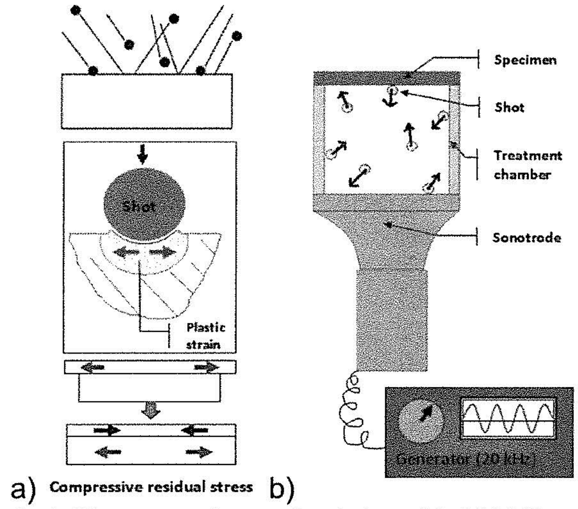


Figure 1 a) Shot peening principle. b) SMAT principle.

Specimen

The comparison of the treatments has been conducted on specimens made of Ti-6Al-4V. Titanium alloys have very good mechanical properties (tab. 1), low weight ratio and corrosion resistance. They are widely used in a very large range of applications like aerospace industry, biomedical applications, marine applications, chemical industry and gas turbine. The Ti-6Al-4V is based on 90% on Titanium, 6% on Aluminum and 4 % on Vanadium (weight %). The studied alloy is an $\alpha + \beta$ alloy; the α phase is hexagonal close packed and the β phase is body centered cubic with grains size around 10 µm.

Ti-6Al-4V	
Yield Strength (MPa)	950
Ultimate Tensile Strength (MPa)	1020
Vickers Hardness (HV)	311
Modulus of Elasticity (GPa)	110
Density (kg/m^3)	4400
Poisson's ratio	0,34

Table1 Properties of Ti-6Al-4V.

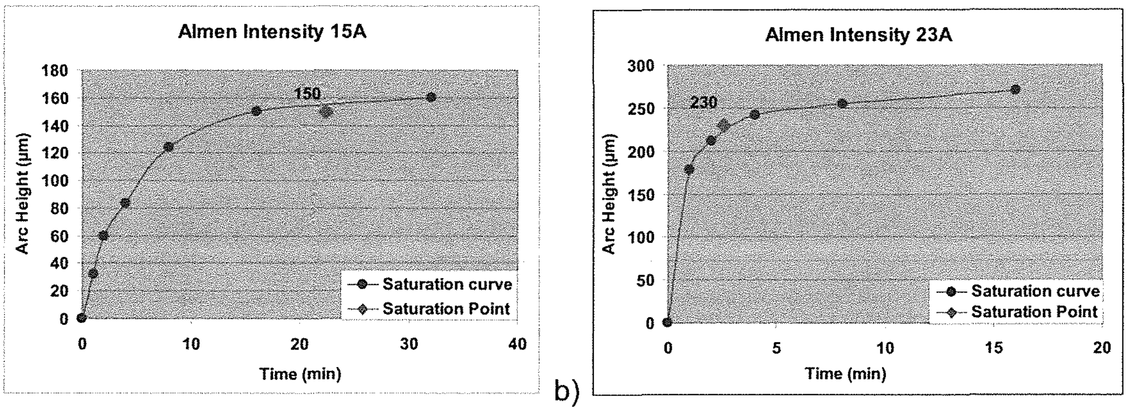
The treated specimens are circular plates with a diameter of 80 mm. Two thicknesses have been considered according to the treatment intensity to avoid a potential bending of the plates: 6 mm for the LOW intensity conditions and 10 mm for the HIGH intensity conditions.

Treatments

SP and SMAT have different process parameters. It is then necessary to define equivalent conditions to compare these two processes. The comparison is made for treatments with the same intensity and same coverage. Two different conditions are tested for both treatments:

- A LOW condition with an Almen intensity of 15A and a coverage of 125%.
- A HIGH condition with an Almen intensity of 23A and a coverage over 3000%.

The Almen intensity is a measure of the warp on a standard thin strip (Almen strip) treated with the same conditions as the specimens. The variable parameters on SMAT are the amount and size of the shot, the amplitude of vibration and the distance from the part to the sonotrode, The residual stress introduced by the peening deforms the strip into an arc. This arc height is measured at different time and plotted as a function of time (figure 2a et 2b). The Almen intensity is obtained the arc height does not increase more then 10% when doubling the time of peening.



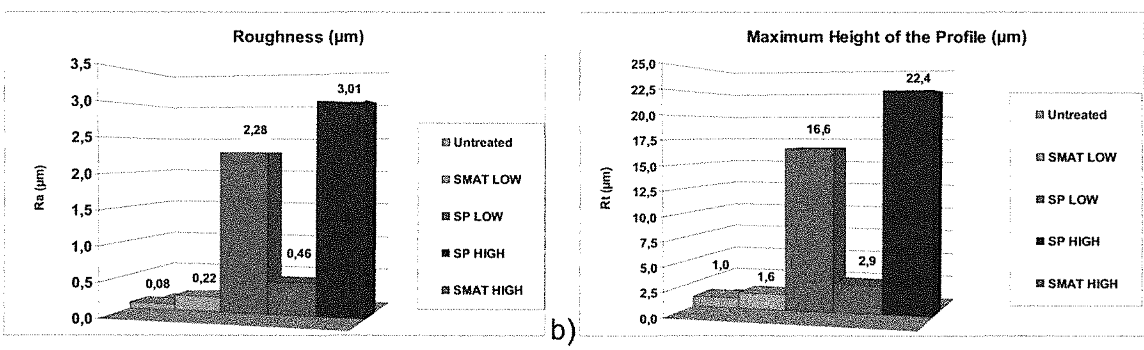
a) b)

Figure 2 Saturation curve : a) Almen Intensity 15A; b) Almen Intensity 23A;

Coverage consists in measuring the time to obtain coverage of 100% of the treated surface. Conventional shot peening parameters have been adjusted to have the same Almen intensity and coverage as SMAT, setting the pressure of shot, the distance between nozzle and piece, the displacement velocity of the nozzle, the flow of the shot and the treatment time.

Surface Quality: Roughness

Roughness is an important parameter because it has a significant influence on the lifespan of mechanical parts. We carried out an analysis on surface roughness after both treatments, and experimental results show an important difference between SP and SMAT (Fig.3a). Conventional shot peening increases roughness more then SMAT due to the irregular shape of the shot that impact the specimen at very high velocity. Actually, a factor around ten between SMAT low and SP low and a factor of about seven between SMAT high and SP high was observed.



a) b)

Figure 3 Roughness on the surface treated with SP and SMAT (a) and height of surface profile (b)

Another important parameter that has to be taken into account when a good quality of surface is required is the height of the surface profile (Fig.3b). This is actually a measure of the thickness of the material that has to be removed to achieve a smooth surface. The figures 4a and 4b show a cross section of treated parts, it is evident that conventional shot peening generates an irregular surface that seems damaged. To achieve a smooth surface after conventional shot peening an intensive polishing is required.

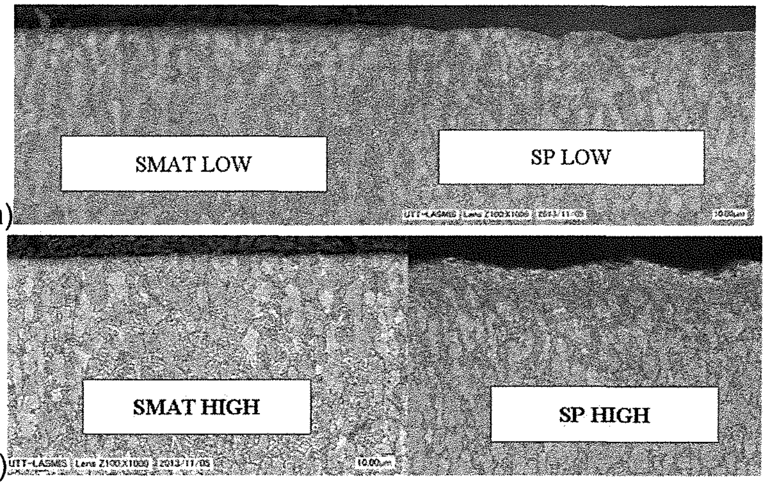


Figure 4 Cross section and microstructure for both treatments; a) LOW; b) HIGH.

Residual Stress state

In this section the residual stress state has been analyzed using a simple analytical model, based on dimensional analysis [3]. With the model, it is possible to plot a residual stress profile (Fig. 6a, 6b) knowing the shot peening parameters and mechanical properties of the shot and specimen. A model to calculate the velocities of the spheres during the ultrasonic shot peening is also used [4, 5].

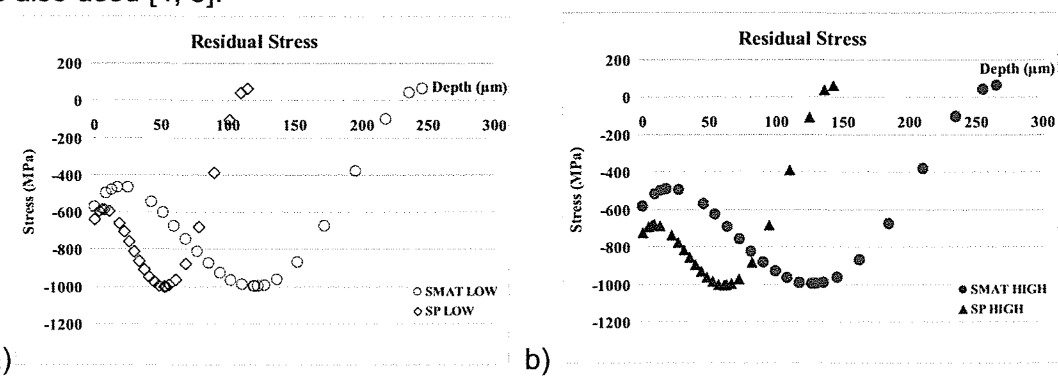


Figure 5 Residual stress profiles calculated with an analytical model; a) Low conditions; b) High conditions;

The aim of this part of work was to do qualitative considerations on residual stress profiles after SP or SMAT treatments. The biggest difference between SP and SMAT is the size of the spheres composing the shot. SMAT uses bigger shot then SP, a factor about ten has been used in the treatments presented in this work. A direct influence of the radius of shot was observed in the depth of the compressive residual stress layer. Indeed the thickness of compressive residual stress is deeper for SMAT treatment as expected [5].

Conclusions

The main objective of this work is to compare conventional shot peening and surface mechanical attrition treatment focusing on the surface quality and the residual stress of the treated part.

First, a method has been proposed to define equivalent treatments and enable the comparison. A residual stress state analysis, using an analytical model is also carried out to quantify the difference in the residual stress state for both treatments due to the difference in size and shape of shot.

The results show that SMAT offers better surface quality, and presence of surface nanocrystalline layer. SP has the advantage of being more versatile in treating complex geometries, with shorter treatment time. SMAT is more effective than SP and is expected to further improve fatigue resistance. Experimental evaluations of the stress field and fatigue resistance are planned.

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