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Comparison between conventional shot peening (SP) and surface mechanical attrition treatment (SMAT) on a Titanium alloy.

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Abstract

In this paper the residual stress states induced by conventional shot peening (SP) and surface mechanical attrition treatment (SMAT) are compared. The treated parts correspond to plates made of a titanium alloy. Different intensities of these two mechanical treatments are first considered: their influence on the surface characteristics (roughness, hardness…) is studied.
These experimental data are then used to develop a model for the residual stress profiles with dimensional analysis. Experimental and analytical approaches are then discussed.

Introduction

Surface plastic deformation processes have become extensively used by industries to produce metallic components with superior mechanical properties. Shot peening (SP) is absolutely the most popular plastic deformation process. In SP a stream of shot is blasted against the workpiece (Fig.1a), and the multiple impacts induce superficial compressive residual stress on the surface. This residual stress 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, the 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, these are very regular and hard spheres for SMAT. Another difference resides in the device that is used for projecting the shot. In the SMAT the shot is 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 analyze and quantify the consequences of both processes in the present work. An experimental and analytical study is thus proposed to evaluate and compare the induced surface characteristics and residual stress profiles.

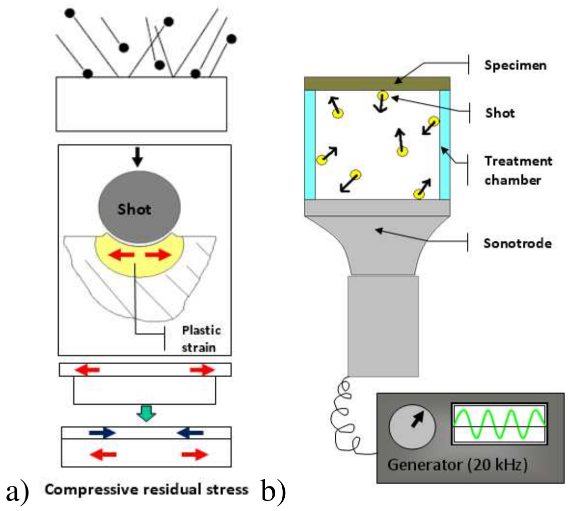


Figure 1 a) Shot peening principle; b) SMAT principle.

Titanium Alloy Ti-6Al-4V

Titanium alloys are known for their 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 α + β alloy; the α phase is hexagonal close packed and the β phase is body centred cubic with grains size around 10 µm.

Table1 Properties of Ti-6Al-4V.

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

Treatments

We have essentially tested two different conditions for both treatments:

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

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 (15A) and 10 mm for the high intensity conditions (23A).

Surface Quality: Roughness

Regarding surface treatments, roughness is an important parameter because it has a significant influence on the lifespan of mechanical parts. Experimental results show an important difference between SP and SMAT concerning the roughness (Fig.2a). 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.

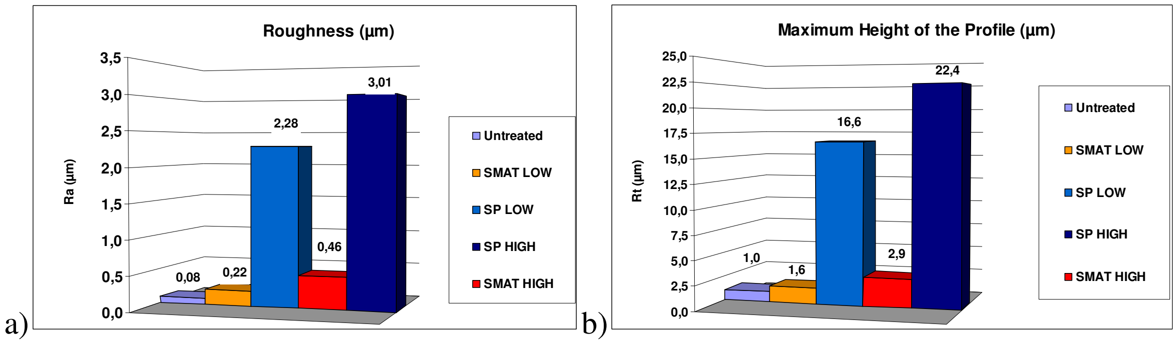


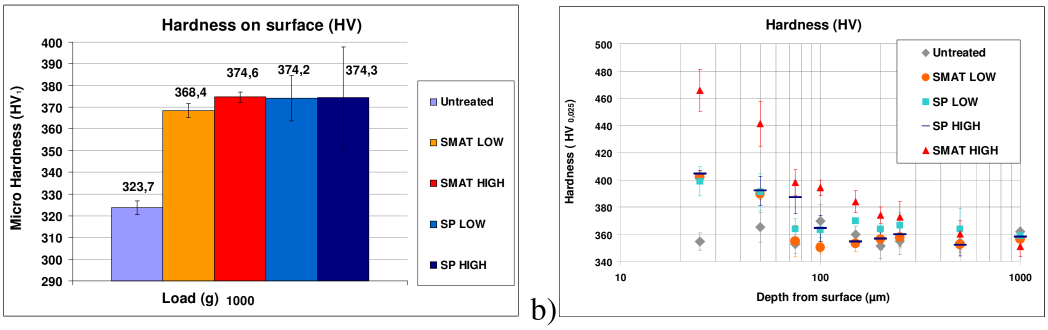
Figure 2 Comparison between SP and SMAT on Roughness (a) and height of surface profile (b)

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.2b). This is actually a measure of the thickness of the material that has to be removed to achieve a smooth surface. Looking at Figures 3a and 3b, 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 3 Cross section and microstructure for both treatments; a) LOW; b) HIGH.

Hardness

Figure 4a presents the surface Vickers micro-hardness for all specimens compared to the untreated material using 1 kg load. The surface hardness has increased by about 15 % in every treated specimen. More interesting and accurate results are obtained on the cross-sections: Figure 4b presents the micro-hardness evolution as a function of the depth beneath the surface for all the samples.



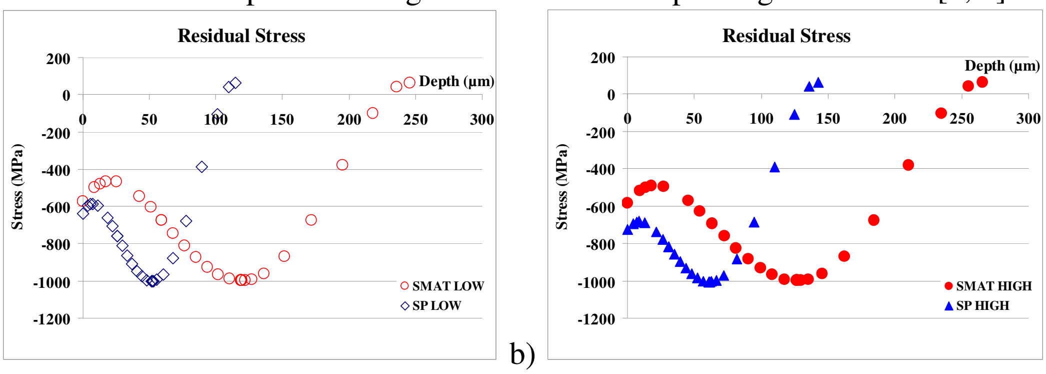
a) b)

Figure 4 a) Micro-hardness on top treated surface; b) Micro-hardness as a function of depth measured on cross-section.

While no significant difference can be noticed between the different treated specimens in Fig. 4a, a remarkable increase of hardness is obtained for the part treated with SMAT with the HIGH condition as shown in Fig.4b. The micro-hardness measurements performed on the surface (Fig. 4a) affect a quite thick layer below the surface (about 80 micrometers) and present a quite huge discrepancy induced by the rough surfaces. The high micro-hardeness values reached below the surface after SMAT HIGH (Fig. 4b) could be explained by the presence of nanostructures created with the treatment. The multiple directional impacts of SMAT treatment change the size of the grains, hence generating a superficial nanostructure layer [2]. The effect of grain size on hardness is formulated in Hall-Petch relation wich reveals an inverse relationship between the hardness and grain size. It’s observed that grain boundaries act as a barrier to dislocation motion: reducing the grain size will increase the volume fraction of grain boundaries and reduce the possibility of dislocation movement.

Residual Stress state

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. 5a, 5b) 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].



a) b)

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

With this model, it is possible to do qualitative considerations on residual stress profiles after SP or SMAT treatments. One important 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. The radius of shot influences the depth of the compressive residual stress layer. Indeed the thickness of compressive residual stress is deeper for SMAT treatment as expected [5].

Conclusion

This paper presents experimental data, whose objective is to point out at the differences between conventional shot peening and surface mechanical attrition treatment. A residual stress model is also presented to quantify the difference in the residual stress state for both treatments. Experimental evaluation of the stress field is planned.
The main advantages of SMAT are better surface quality, higher hardness, 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.

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