Assessment of shot-peening on fatigue life of Inconel 718 turbine disk

Jean-Patrick Goulmy [a,b], V. Boyer [a,c], L. Toualbi [b], P. Kanoute [b], S. Kruch [b], D. Retraint [c], E. Rouhaud [c], A. Seror [d], Q. Puydt [a]

[a] *IRT-M2P, 4 rue Augustin Fresnel 57070 Metz, France*
[b] *Onera – The French Aerospace Lab, F-92322 Châtillon, France*
[c] *Université de Technologie de Troyes (LASMIS), 12 rue Marie Curie, 10010 Troyes, France*
[d] *Safran Aircraft Engines, 77550 Moissy-Cramayel, France*

Keywords: Shot peening, Inconel 718, Fatigue life, Residual stresses, work hardening

Introduction

Surface enhancement methods, such as shot peening, are widely used in the aerospace industry to improve the fatigue life of critical components. Such processes generate residual compressive stresses which tend to delay fatigue crack initiation and prevent small crack propagation. However, these methods are efficient only if the thermo-mechanical relaxation of residual stresses at operating temperatures is moderate. As detailed in [1], the effect of work hardening is preponderant. There is a strong dependence of the degree of work hardening induced by creation of the compressive layer on the amount of relaxation during thermal loadings. Furthermore, work hardening is strongly related to the microstructure. The microstructural state of the component part before shot peening can then significantly modify the efficiency of this surface enhancement method and the fatigue life of the component.

Objectives

The present study aims at assessing the impact of shot-peening on fatigue life of IN718 turbine disk.
To achieve this, it is necessary to understand how residual stresses relax when they are subjected to high temperatures and thermomechanical loads and determine the influence of relaxed mechanical state on fatigue life. To answer these questions experimental measurements and modeling are needed.
Experimental measurements allow understanding the influence of the process on the microstructural state, on the behavior of shot peened layer and on the fatigue lifetime.
Three main tools are developed to assess this fatigue life. The first is a constitutive model. It allows describing the cyclic behavior and the partial relaxation of the residual stresses.
The second tool developed deals with the introduction of the mechanical state induced by shot-peening in the cyclic analysis of parts. A specific methodology, based on the experimental characterization, is applied to introduce work hardening in the finite element code. Finally, the third tool concerns lifetime calculation. A multi axial fatigue criterion is then identified on as received material and applied on the stabilized mechanical state after fatigue loading shot-peened parts.

Methodology

Experimental procedure

To evaluate the impact of shot peening on fatigue lifetime, it is necessary to evaluate the evolution of residual stresses and work hardening under several conditions. That is why, analysis of residual stresses and evaluation of work hardening are carried out on shot peened samples before and after thermal and mechanical loads at 20 and 550°C.
Samples are shot-peened by conventional blasting nozzle with S110 steel shots. Two peening conditions are investigated: SP1 12/13A - 125% and F22/23A - 200%. Before shot peening, all coupons are mechanically polished to remove as much as possible residual stresses and work hardening introduced by machining. Residual stresses are evaluated by measuring the shift of X-ray diffraction (XRD) peaks by following the conventional $\sin^2\psi$ technique. Work hardening is semi-quantitatively estimated by microhardness, XRD line broadening and Electron BackScatter

Diffraction (EBSD) local misorientation methods. These three methods require however a previous calibration procedure to establish a link between the measured quantities and the level of work hardening in the material, which is performed on tensile, compressive and fatigue specimens for which the level of plastic strain is known. This calibration is used to determine semi-quantitatively the work hardening induced by shot peening as shown in Figure 1.

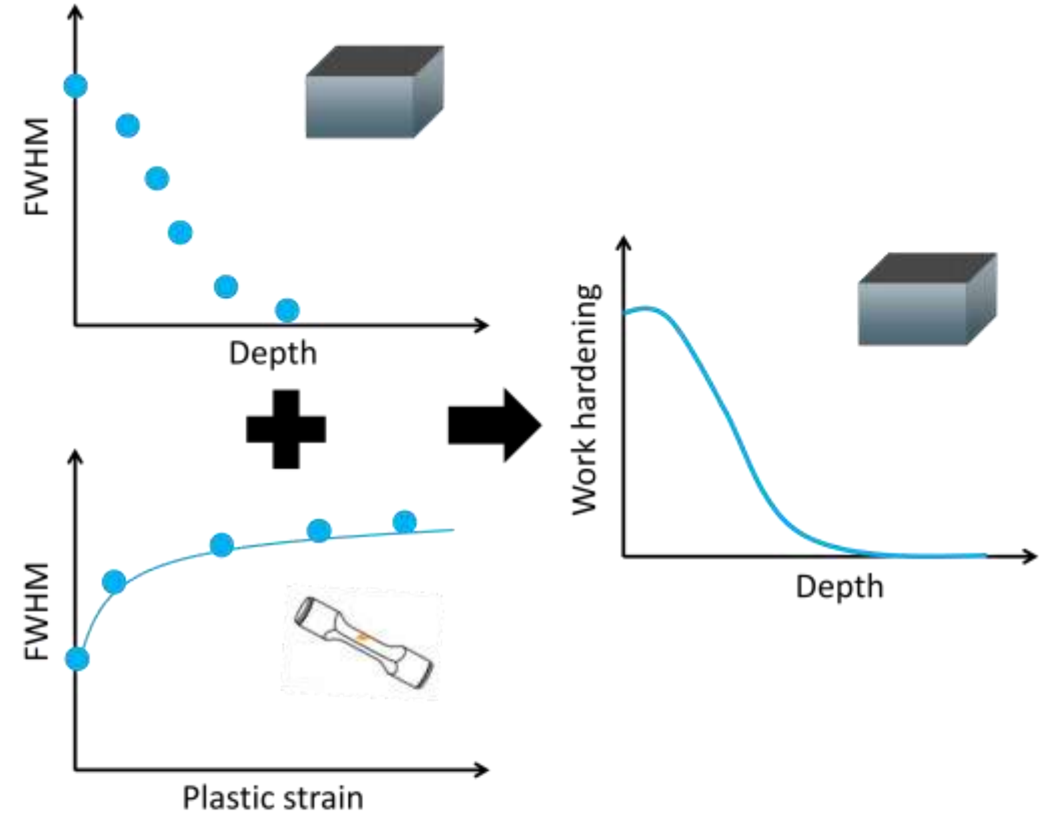

Figure 1. Semi-quantitative evaluation of work hardening in a shot penning component.

Modeling approach

Figure 2 shows the modeling approach used to predict fatigue lifetime on shot peened component. The principle of this approach is as follows. Work hardening and residual stress profiles experimentally measured are introduced as an input for the numerical analysis in the finite element code Zset/Zebulon. A cyclic mechanical loading is then applied using the elasto-visco-plastic law to determine the stabilized cycle. Then, fatigue lifetime analysis is performed using a SWT base fatigue damage criterion.

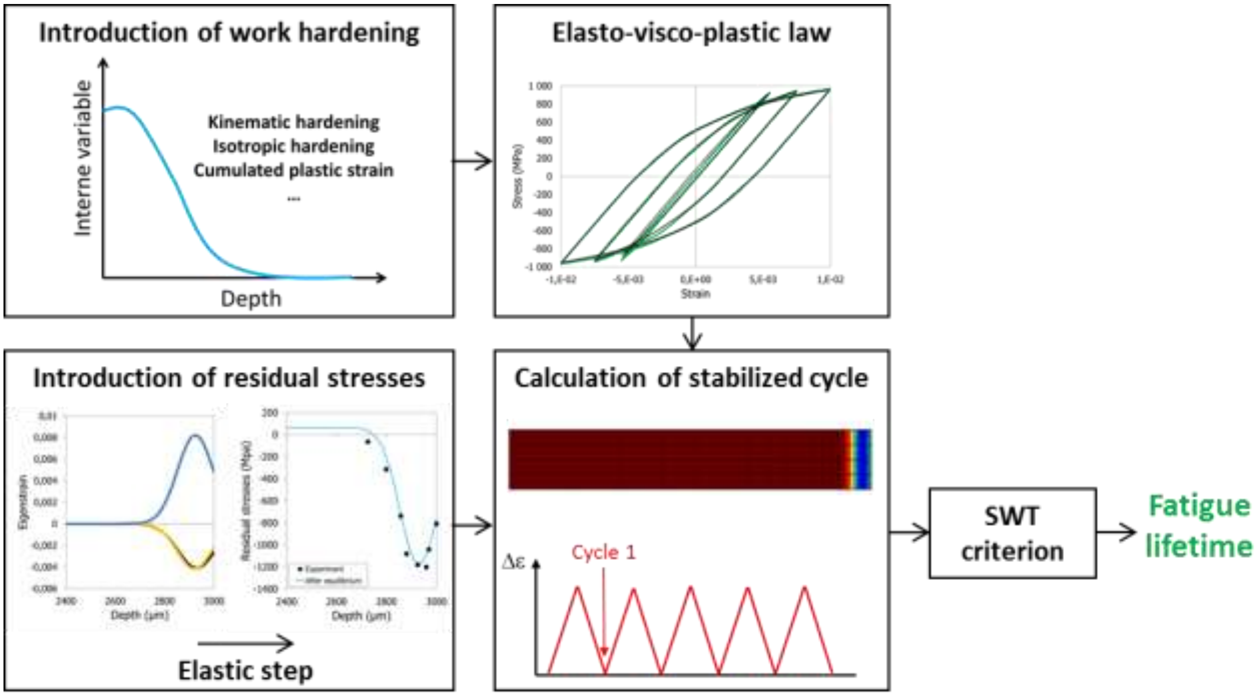

Figure 2. Modeling approach to predict fatigue life time on shot peened component.

Three main tools are developed to implement this approach: an elasto-visco-plastic law, a methodology to introduce the residual mechanical state (residual stresses and work-hardening) of shot peened specimens and a fatigue model.

A new constitutive model has been proposed and validated on complex multi-level and multi-rate cyclic tests. This model, based on phenomenological viscoplastic constitutive equations, allows considering the influence of the microstructure on the cyclic behavior as well as to determinate the partially relaxed mechanical state needed for the fatigue life calculation. Mechanical tests are carried out on as received material to determine the behavior at 20 and 550 °C. Figure 3 compares experimental and simulated hysteresis loops obtained for a complex multi-level and multi-rate cyclic test.

The initial residual stresses are introduced in the F.E. analysis using the classical eigen-strain approach. A specific numerical method has been developed to introduce work hardening induced by shot peening. All the corresponding internal variables in the constitutive law are calculated, and then introduced as initial values in the inelastic cyclic analysis of the specimen. These new developments are more fully presented in [2].

Multiple flexion and traction-compression fatigue tests are finally performed to identify SWT criterion. Fatigue lifetime of shot-peened samples is compared to the simulation in order to evaluate the impact of shot peening.

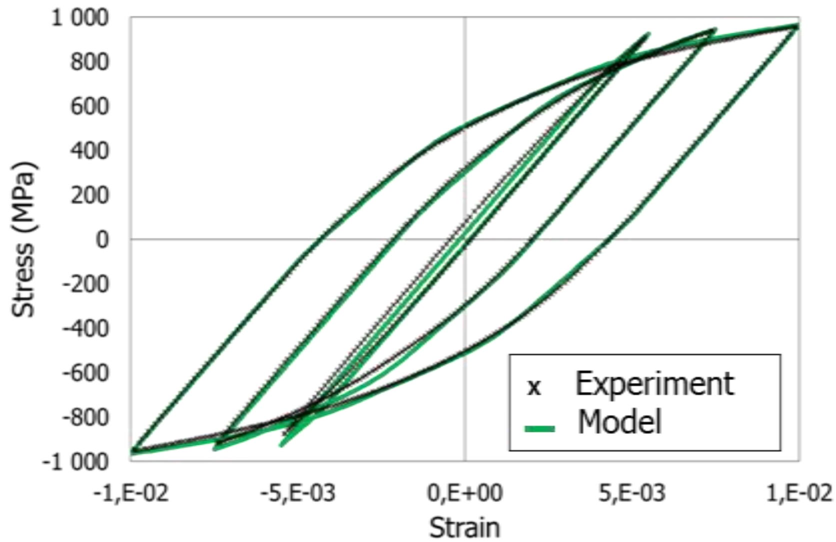

Figure 3. Hysteresis loops for Inconel 718 DA.

Results and analysis

Measurements done by EBSD on different samples don't show a specific influence of shot peening on grain size. Figure 4 shows an example of measurements for three treatment conditions. The shot peening condition has a straight influence on the value of the KAM parameter. The affected depth is higher when intensity and coverage are increased.

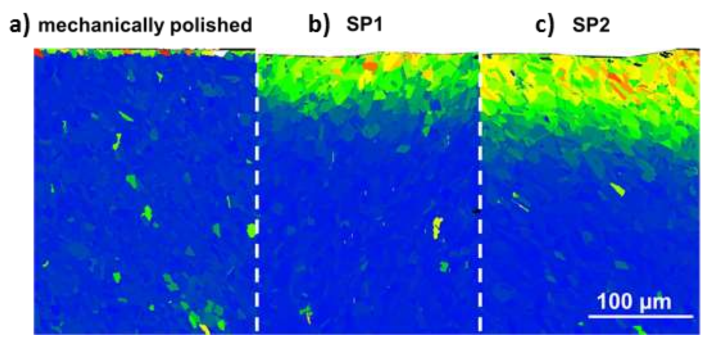

Figure 4. Comparison of EBSD (GOS) mappings for IN718 a) mechanically polished, b) shot peened with I = 12-13A and 125% coverage and, c) shot peened with I = 22-23A and 200% coverage.

Experimental study carried out to evaluate the evolution of residual stresses and work hardening under mechanical or thermal loading has the same results as previous papers [3]–[6]. A thermal loading at 550°C during 500 hours induces partial relaxation of residual stresses and work hardening. Relaxation of residual stresses under thermal loading is bigger on the surface, where work hardening is more significant.

Fatigue loading at 20 and 550°C induces partial relaxation of residual stresses. Higher the temperature and strain amplitude are, the more relaxation of residual stresses occurs. Fractographic analyses (Figure 5) are consistent with these measurements. When strain amplitude is low, they indicate that the subsurface residual stresses from the shot peened process are substantially retained, even after fatigue cycling at 550°C because the subsurface initiation sites corresponded roughly to the depth of compression.

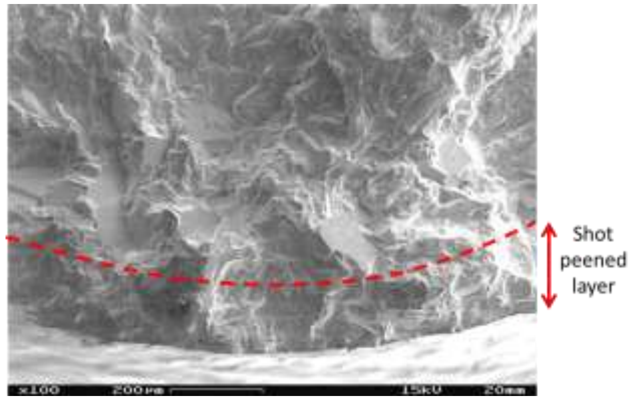

Figure 5. SEM observation of shot peened component after fracture à 550°C.

The modeling approach has been applied for notch and flexion specimens to evaluate shot peening influence. First results prove that it allows taking into account the effect of shot-peening on fatigue life of IN718 turbine disk. These results show the interest of developing such phenomenological approach in the context of lifetime analysis for industrial components and will be analyzed and discussed during the presentation.

References

[1] P. S. Prevey, "The Effect of Cold Work on the Thermal Stability of Residual Compression in Surface Enhanced IN718," in *20th ASM Materials Solutions Conference & Exposition*, St. Louis, Missouri, 2000.

[2] J.-P. Goulmy *et al.*, "Modeling of the work hardening influence on the relaxation of residual stresses for shot peened Inconel 718 turbine disk," presented at the ICSP17, Montréal, 2017.

[3] P. S. Prevey, D. J. Hornbach, and P. W. Mason, "Thermal Residual Stress Relaxation and Distortion in Surface Enhanced GasTurbine Engine Components," *ASM Int.*, 1998.

[4] N. Masmoudi Khebou, "Etude de l'évolution des contraintes de grenaillage en fatigue à haute température pour le superalliage base nickel IN100," Thèse Doctorat, Arts et Métiers ParisTech, France, 1990.

[5] J. Hoffmeister, V. Schulze, A. Wanner, R. Hessert, and G. Koenig, "Thermal relaxation of residual stresses induced by shot peening in IN718," in *10th International Conference of Shot Peening*, Tokyo, 2008.

[6] I. Lillamand, "Evolution d'une couche grenaillée sous sollicitations thermiques et mécaniques, cas de la fatigue oligocyclique," Thèse de doctorat, ENSAM, 1999.