A finite element model for simulation of shot-peening

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Introduction

Shot-peening is an industrial surface treatment widely used in the aerospace industry, but still not considered during the dimensioning phase of mechanical parts. Benefits are used to increase safety margins only; today there is an industrial need for dimensioning part optimization. This work is the first part of an industrial project which aims at using numerical simulation to develop a complete model including the the simulation of the process and then the cyclic loading of a complex geometric part made of INCONEL 718 (IN718) nickel-based alloy.

Objectives

For the last decades, numerical models of shot-peening never stop developing, considering more complex aspects of the process, such as coverage, shot stream simulation or roughness. Still work-hardening is not investigated in most of the cases, but remains one influencing parameter for stress relaxation, as shown in various papers in the literature [1].

This work aims at developing a three dimensional model for shot peening, able to predict the mechanical state after the process through residual stress and work-hardening.

Methodology

The first step to build the model was the investigation of the dynamic behaviour of the material. An experimental campaign on Hopkinson split bar was set up in order to characterize the viscous stress for strain rates up to 10^4 s^{-1}. The identification was carefully lead by numerical reverse analysis. As shown in the literature, Inconel 718 does show stain sensitivity [2]. Not taking account this aspect in the constitutive model leads to a poor estimation of the residual stress state.

In order to study the behaviour more accurately, three different constitutive laws are identified with the experimental data and compared with the numerical model. The first law is elasto-plastic law proposed by Chaboche, including isotropic and kinematic hardening. The second is similar to the previous one but use a Norton law to consider viscous effect and the third one is an empirical Johnson-Cook model [3] :

$$\sigma = \left[A + B\varepsilon_p^n\right] \left[1 + C\log\left(\frac{\dot{\varepsilon}_p}{\dot{\varepsilon}_0}\right)\right] \left[1 - T^m\right]$$

Here A, B, C, n, m and $\dot{\varepsilon}_0$ are parameters to be identified, T is the homologous temperature and depends on the ambient and melting temperature of the material.

The second step is an extended X-ray diffraction campaign measurement of residual stress and work-hardening profiles on shot-peened sample with various intensities and coverage. Work-hardening was assessed with the Full Width at Half Medium (FWHM) of the diffraction pick obtained after measurement. A calibration procedure is necessary to link FHWM with work-

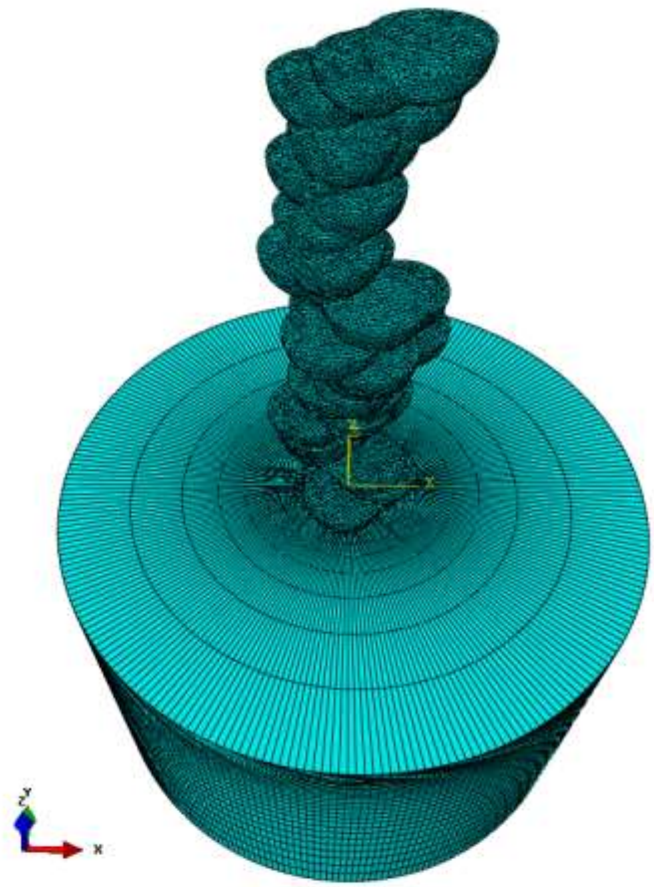

Fig. 1 Numerical shot peening model

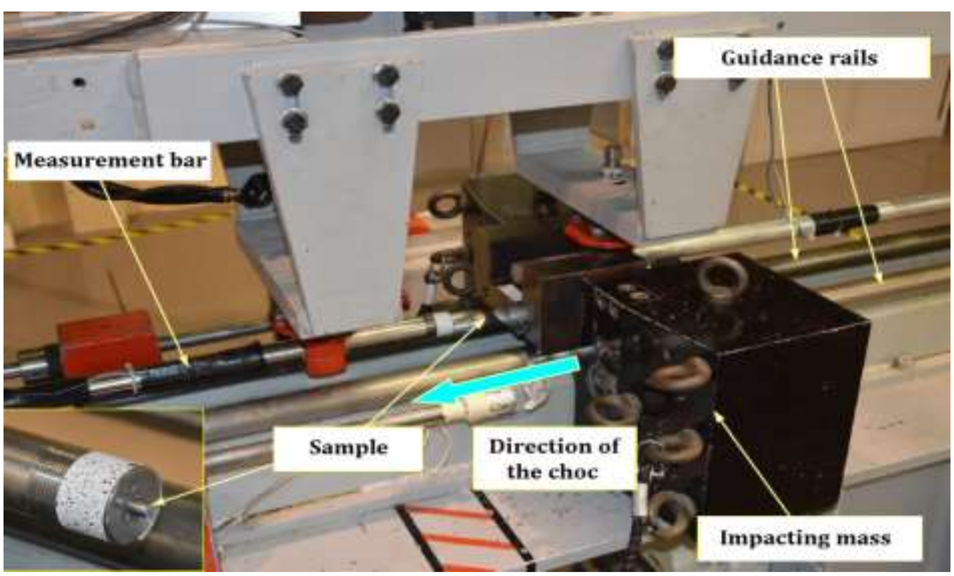

Fig.2 Experimental apparatus for the investigation of dynamic behaviour of IN718

Intensity	coverage (%)				
8-9A	-	-	200	-	-
12-13A	65	125	200	320	400
17-18A	-	-	200	-	-
22-23A	65	125	200	320	400

Fig.3 Peening conditions investigated in X-ray experimental campaign

hardening. This method consists in measuring FWHM for sample deformed at known plastic deformation.

Concerning numerical results, variability of some process parameters is investigated. The shot mean velocity and dispersion was measured on the stream and implemented in the model as well as shot diameter. The dispersion of numerical residual stress state is also assessed among each element layers of the model. These two points aims at questioning the general assumption of deterministic aspect of numerical results.

Results and analysis

It appears that it is of the utmost importance to take into consideration the viscous and kinetic aspects. Shot-peening simulation lead with purely cyclic constitutive law underestimates de residual stress state whereas purely isotropic model strongly overestimates it. With elasto-visco-plastic model, numerical results are in good agreement with experiment.

Conclusions

A three dimensional model of shot-peening is proposed. Investigations upon constitutive law lead to the conclusion that it is of the utmost importance take into account both dynamic and kinematic aspects for the simulation of shot-peening of IN718. Once considered these aspects, the model could correlate precisely the experimental data.

It also appears that parameter variability (velocity and diameter of the shot) has no significant importance on the residual and work-hardening profiles. But, on the other hand, important deviation is observed among the stress and work hardening of the elements at the same depth. Experimental X-ray investigations proved this observation have physical meaning. Such information could be a useful tool to predict the crack initiation, as it can evaluate the worst mechanical state that can appear on a shot-peened surface.

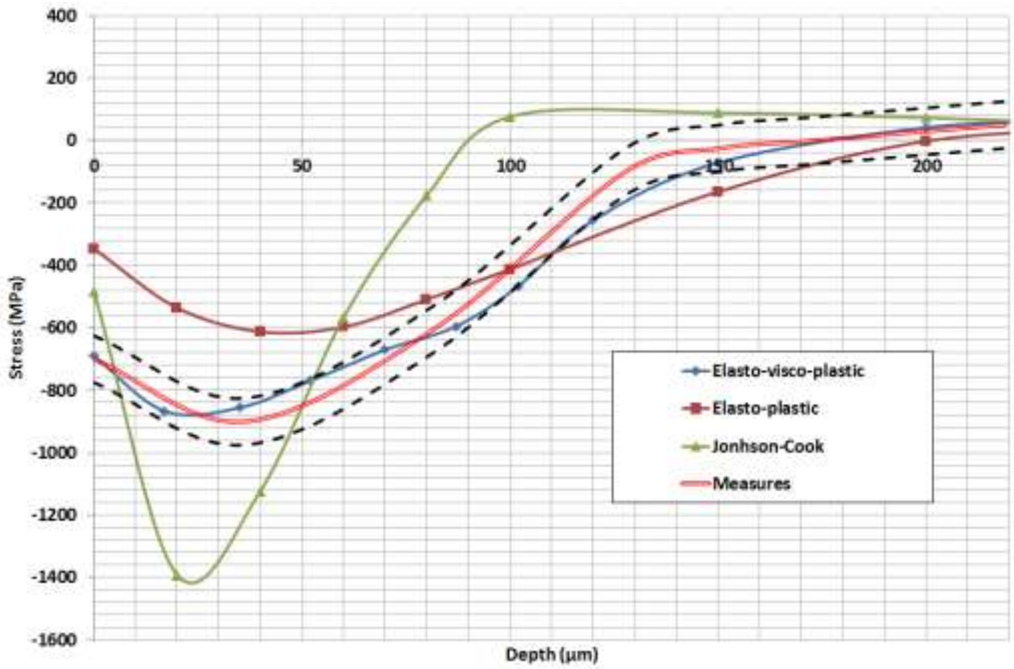

Fig.4 Comparison between experimental and numerical models for three different constitutive laws.

An important distortion is observed numerically among the elements of the model after simulation of the process. These distortions are about 350 MPa at the surface of the model, and keep superior to 100 MPa down to 200 µm depth. This order of magnitude at the surface was experimentally observed by Vöhringer [4] on a peened steal alloy.

References

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