FINITE ELEMENTS MODEL OF SHOT PEENING, EFFECTS OF CONSTITUTIVE LAWS OF THE MATERIAL

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Abstract

While very useful to understand the phenomena at hand, experiments can be very costly and time consuming if done for the purpose of setting a new set of shot peening parameters for the treatment of a new part. In the last 15 years, many finite element models have been proposed. Existing simulations show their efficiency to better understand the mechanism of residual stress introduction and better evaluate the influence of the shot peening parameters on the residual stress profile although some discrepancies still remain.

It is not necessary to say that the constitutive law chosen to model the shot peened material strongly influences the residual stress field obtained after finite element computation. In this paper, we wish to address the following question:

Should the model take kinematic hardening into account?

Indeed, with a kinematic hardening model, plastic effects can appear during unloading as well as during loading. It seems very likely that such effects do appear during shot peening. Further, kinematic hardening effects are particularly influential when the loading is cyclic. As the numbers of impacts at one location on a shot peened surface with a high coverage can be important, cyclic effects do occur during the process. We thus discuss the different options offered for constitutive laws with a presentation of numerical strategies for cyclic plasticity modeling and the residual stress field obtained.

Introduction

Experimental studies can represent a considerable cost when a new set of parameters is optimized for the shot peening process. Many shot peening models have been proposed and are reviewed in [1]. Existing simulations show their efficiency to better understand the mechanism of residual stress introduction and better evaluate the influence of the shot peening parameters on the residual stress profile although some discrepancies still remain.

The constitutive laws chosen necessarily influence the residual stress field obtained with the models. Indeed with a kinematic hardening model, plastic effects can appear during unloading as well as during loading. It seems very likely that such effects do appear during shot peening. Further, kinematic hardening effects are particularly influential when the loading is cyclic. As the numbers of impacts at one location on a shot peened surface with a high coverage can be important, cyclic effects do occur during the process. Cyclic effects in shot peening have been studied with cyclic hardening laws and this improved the profile of the residual stress [2]. We thus discuss different options offered for constitutive laws including kinematic hardening plasticity modeling and show the residual stress field obtained.

Geometry and mesh

To model shot peening, a spherical shot that impacts a semi-infinite body; the impact is normal to the body. Preliminary studies have shown the interest of this simplified model of shot peening [3]. With this configuration, the system is axi-symmetric and the 2D mesh presented in Figure 1 is used. A shot of radius 0,4 mm with a velocity of 75 m/s has been chosen for the computation; this corresponds to 6,03 mJ for the kinematic energy of the shot. We present results for one impact and for several (up to seven) impacts at the same position.

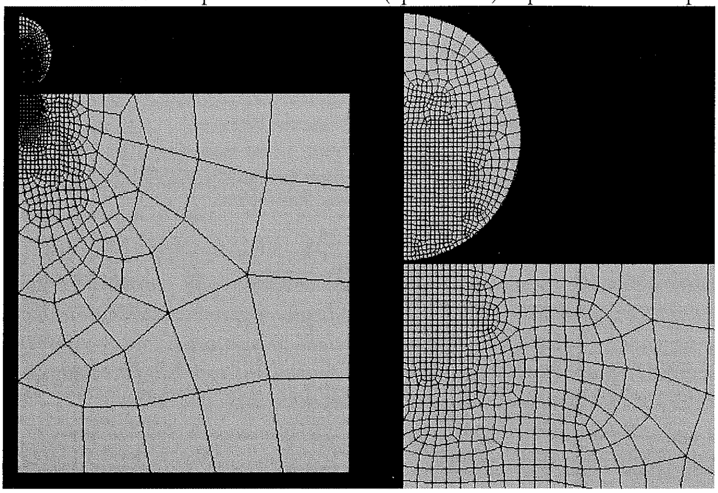

Figure 1: 2D mesh chosen for the computation with a close up of the contact area

Constitutive laws for the materials

The shot is chosen with an elastic behavior. Several former results have shown that during an impact, the shot is often deformed elastically and that the elastic energy in the shot is not negligible [4]. The shot in the models presented is thus chosen elastic and made of steel. The semi-infinite body is made of a typical steel encountered in the surface treatment industry. We have chosen several types of constitutive laws to evaluate the influence of the laws themselves and their parameters. Four laws have been chosen with a yield stress of 1680 MPa :

- One with isotropic hardening. The hardening slope follows the stress/strain curve of a tensile test.
- Three laws with kinematic hardening. The hardening slopes are chosen to best model i) the first part of the tensile test (from 0 to 3% of plastic deformation), that corresponds to a high hardening slope, ii) an averaged slope between 0 and 6 % of plastic strain which correspond to soft slope and iii) an intermediary slope.

The corresponding stress/strain curves are presented Figure 2. The strain rate sensitivity of the material is neglected in the following computations.

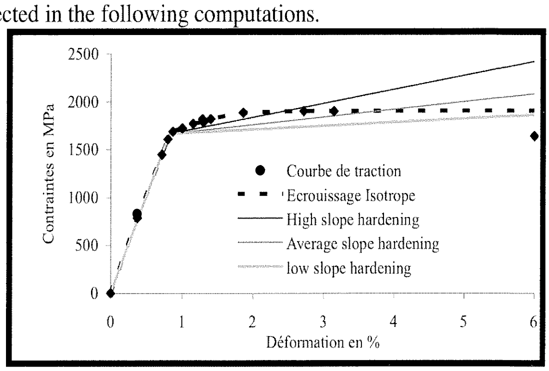

Figure 2 : stress strain curves used in the numerical analysis to model the steel

Computation

Shot peening computations have been completed with a static analysis. Dynamic analysis generates elastic vibrations in the material and the computations that are necessary to reach equilibrium can be time consuming. Further it can be shown that these types of impacts are quasi-static indeed [1,3] and we have proposed a method allowing a static computation based on an energetic criterion; the method is detailed in [3]. The contact model used is a normal contact with no friction. Computations have been done under large deformation conditions using the Finite-Element package Abaqus. The size of the body, the number of elements and the number of time-steps have been optimized to guaranty computational efficiency.

Analysis

To analyze the results we present the cumulated plastic strain and the residual radial stress obtained on the axis of symmetry of the system and as a function of the depth into the semi-infinite body. Figure 3 presents the residual stress obtained after one impact and for several constitutive laws. It is interesting to note that the use of kinematic hardening generates a change in the shape of the residual stress profile compared with the isotropic hardening case; an analysis of the cumulated plastic strain presented in Figure 4 shows that in this case, the cumulated plastic strain changes after the maximal penetration of the shot, meaning that there is plastification while the shot is going up; this is of course not observed in the isotropic case. It is interesting to note that the maximal residual stress becomes smaller and is located deeper in the semi-infinite body while the hardening slope increases. When a single impact is modeled, the maximal residual stress obtained is always larger than the yield stress. This is observed in Figure 3 and is commonly reported in the literature [1].

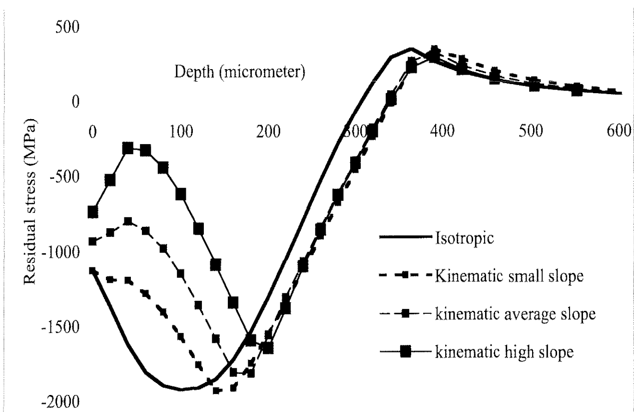

Figure 3: Radial residual stress versus the depth in the semi-infinite body after the impact of an elastic shot and for four constitutive laws.

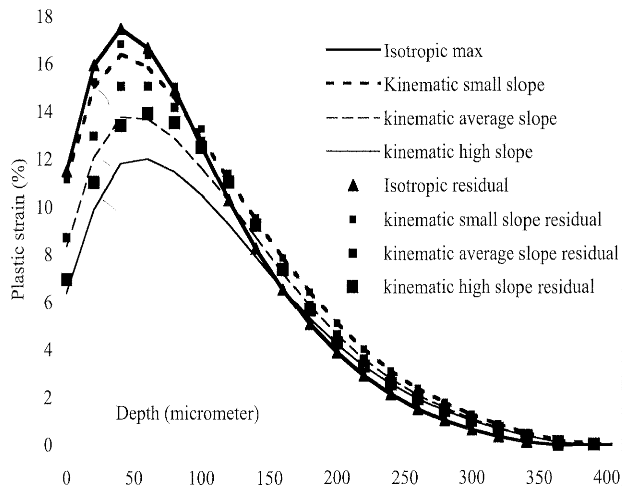

Figure 4: Maximal and residual cumulated plastic strain versus the depth into the semi-infinite body after the impact of an elastic shot for four constitutive laws. The lines represent the cumulated plastic strain when the shot is at its maximum penetration depth and symbols represent the final cumulated plastic strain.

The shape of the residual stress profile obtained for kinematic hardening is not the one commonly observed for measured residual stresses profiles. However if several impacts hit the semi-infinite body at different places, the integration of the different stresses could lead to the observed experimental stress, reducing the maximal values observed for one impact. Also, kinematic hardening is seldom pure in common steels : it is often in conjunction with isotropic hardening.

To further investigate the influence of kinematic hardening, several impacts at the same position have been modeled. This has been done for an isotropic hardening model and a kinematic hardening model with a high slope. Impacts are modeled until the residual stress profile saturates. Figure 5 and Figure 6 show the evolution of the residual stress profile after the different impacts in the case of isotropic and kinematic hardening respectively. A steady state is reached after seven impacts for isotropic hardening and six impacts for kinematic hardening. Figure 7 and Figure 8 show the cumulated plastic strain associated to these residual stresses. In the case of isotropic hardening the maximal value of the residual stress increases with the impacts to reach the non-realistic value of 2500 MPa. After the sixth impact the cumulated plastic strain is quasi stable; the seventh impact generates mainly elastic effects and the residual stress reaches a steady state. For the kinematic hardening case, the residual stress reaches a steady state with a maximal value of 1700 MPa; this is close to the yield stress value. The maximal value of the residual stress does not change with the number of impacts but is located deeper and deeper after each impact. The cumulated plastic strain does not reach a steady state.

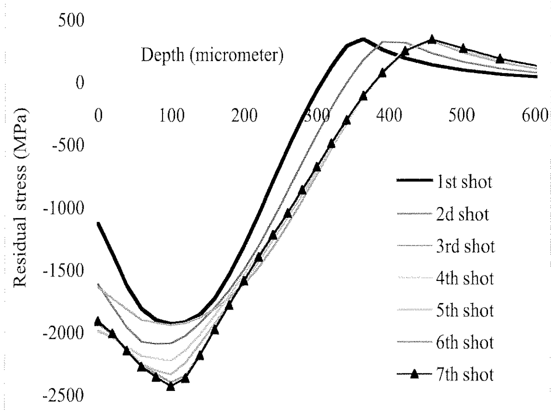

Figure 5: Evolution of the radial residual stress after the impacts of an elastic shot for a semi-infinite body with isotropic hardening.

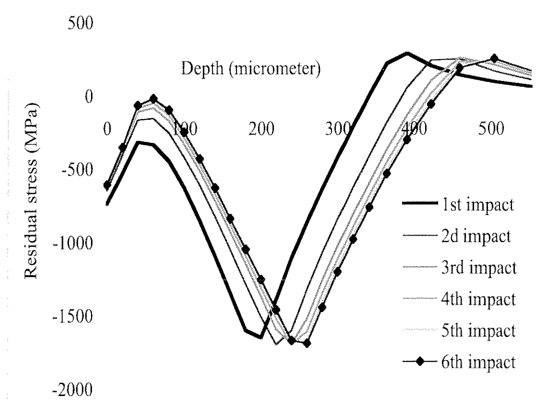

Figure 6: Evolution of the radial residual stress after the impacts of an elastic shot for a semi-infinite body with kinematic hardening plasticity with a high hardening slope..

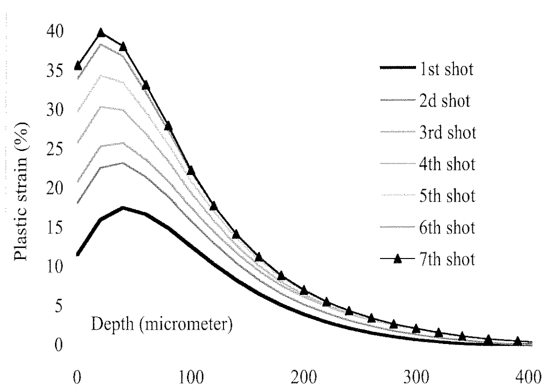

Figure 7 : Evolution cumulated plastic strain after the impacts of an elastic shot for a semi-infinite body with isotropic hardening; a total of seven impacts have been modeled.

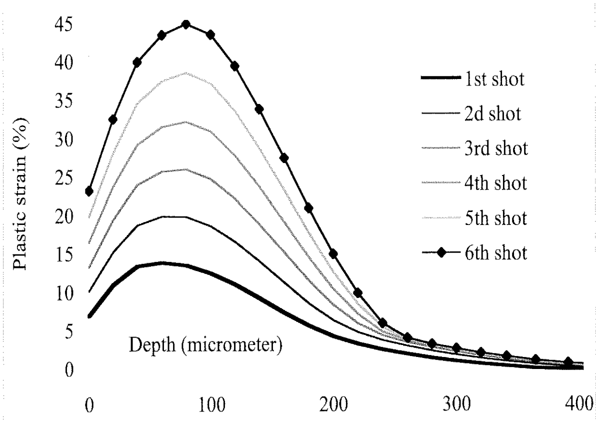

Figure 8: Evolution of the cumulated plastic strain after the impacts of an elastic shot for a semi-infinite body with kinematic hardening plasticity with a high hardening slope; a total of six impacts have been modeled.

Conclusion

A study of the residual stress profiles obtained after one and several impacts at the same position of an elastic shot on an elasto-plastic semi-infinite body has been presented; the case of isotropic and kinematic hardening is presented. The results clearly show that the model and the associated parameters chosen for plasticity can clearly influence the residual stress profiles, and in particular the maximal value of the residual stress and its location. Because kinematic hardening models are well suited for cyclic solicitations, it can greatly enhance shot peening models. It is now necessary to investigate similar shot peening models but with several impacts at different positions.

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