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Computational simulation of manufacturing processes

Simulation of shot peening: From process parameters to residual stress fields in a structure

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ABSTRACT

Manufacturing industries perform mechanical surface treatments like shot peening at the end of the manufacturing chain to protect important working parts. This treatment modifies the near surface of the treated part with the introduction of compressive residual stresses due to the repeated impacts of the shot. Then, the treated part exhibits, not only a longer life, but also a better fretting behavior, an improved resistance to corrosion… The objective of the present paper is first to study the relation between the process parameters and the material state (residual stress and plastic variables…) for a complex geometry. Next, a numerical tool is proposed, able to predict this material state in a time frame that is consistent with industrial constraints. The originality of the proposed approach thus consists in the chaining of the different steps. The first step is to choose the process parameters for the shot peening process considering conventional or ultrasonic shot peening and model the shot dynamics for a complex geometry. Once the impact velocity field is known, the objective is to compute the local incompatible plastic deformation field due to the repeated impacts using analytical methods. Then, a finite element model is used to compute the residual and deformation fields in the considered mechanical part. The complete method has been performed on the model of a gear, a mechanical part that is most often shot peened and exhibits a complex geometry.

1. Introduction

Most manufacturing industries routinely perform mechanical surface treatments at the end of the manufacturing chain to protect important working parts. Shot peening is probably the most common of these processes. The pioneering work of Almen [1] has indeed demonstrated the efficiency of shot peening processes to increase fatigue life, and this, for a very moderate cost. The treated part is in this case submitted to the impacts of many hard particles made of glass, ceramic or metal, known as the shot. The motion of the shot is produced with the help of turbines or compressed air in the

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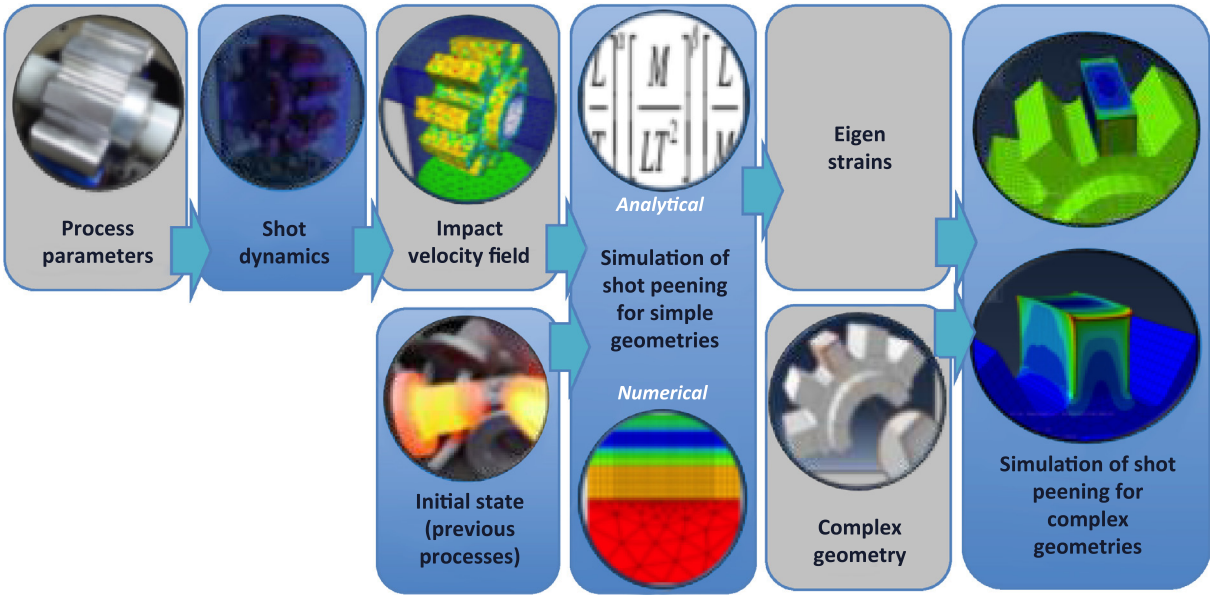

Fig. 1. Principle of the method with the chaining of different steps from the process parameters to the residual stress field in a complex geometry taking into account an initial state coming from previous manufacturing processes.

case of conventional shot peening or the vibrations of a sonotrode in the case of ultrasonic shot peening. This family of manufacturing processes modifies the near surface of the treated part with the introduction of compressive residual stresses and the modification of the structure of the material due to the repeated impacts. With an appropriate choice of process parameters, the treated part can exhibit, not only a longer life, but also a better fretting behavior, an improved resistance to corrosion…

Many parts in the aeronautical and automobile industries are shot peened. In most cases, the treatment is used to improve safety coefficients, but is not accounted for in design analyses. For the process to be taken into account at the design stage, the exact consequences of the parameters on the treated part have to be better mastered. This is further necessary for accreditation purposes in many industries. The hope is then to be able to reduce the weight of the mechanical parts, of crucial importance nowadays in transport industries. A renewed interest for pre-stressing processes has thus been observed recently. One of the objectives of the related modeling activity is to produce models that are efficient enough to enter design tools. It is thus important to understand the details of the physics at play. Then, the models should capture the essential phenomena at hand in the process and directly correlate process parameters with the consequences on the product. Furthermore, the time that is necessary to reach a solution has to be consistent with industrial constraints. Finally, in developing the models, one should keep in mind the fact that the results of the shot peening models are to be used as initial conditions for resistance or fatigue models and have to supply the appropriate data.

Proposed shot peening models are numerous in the literature and reviewed in [2–5]. Most of these models concentrate on the prediction of residual stress and plastic deformation fields and use the impact velocity as an initial condition and not the process parameters themselves. Moreover, the geometry of the treated part is most often reduced to a semi-infinite massif or to sufficiently thick plates. Nevertheless, it is clearly that the geometry of the part influences the treatment due to, for example, variations in the coverage of the impacts or the influence of boundaries on the mechanical fields.

The objective of the present paper is to propose methodologies able to produce a relation between the process parameters and the state of the treated part (stress field, hardening…) considering a complex geometry and including an initial state coming from previous manufacturing processes, this, in a time frame that is consistent with industrial constraints. Second-order phenomena will thus be neglected to simplify the model and analytical models preferred when possible. The existing methodologies proposed in the literature and suited to this specific objective are reviewed in this work. The originality of the proposed approach is thus to chain different steps, as detailed in Fig. 1, to relate the final state of the mechanical part after shot peening to the process parameters and this for a part with complex geometry. The first step is to choose the parameters considering conventional or ultrasonic shot peening and model the shot dynamics for a complex geometry. Once the velocity field of the impacts is known on the part, the objective is to compute the incompatible plastic deformation field due to the repeated impacts using numerical or analytical methods. Incompatible deformations due to other previous manufacturing processes may also be taken into account. Then, a finite element model is used to introduce the residual stress and deformation fields in a model of the mechanical part. The complete method is applied to the ultrasonic shot peening of a gear, a mechanical part that exhibits a complex geometry. Realistic (in other words industrial) conditions have been chosen for the process parameters to create a demonstrator for this methodology.