SHOTVISUAL: A software to visualize shot dynamics

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Introduction

Cold working processes such as mechanical pre-stressing treatments are widely used in automobile, aeronautic and biomedical industries, and lead to a substantial improvement of mechanical parts and structures. A rather conventional method is shot peening, air blast or ultrasonic [1]-[4], which uses projected spherical media in order to create surface compressive residual stresses. The impact produces surface hardening which protects the structure from fracture as fatigue cracks propagates mostly from surfaces during operation. The gain in strength and fatigue life observed after such a treatment can be spectacular while offering the advantage of being relatively easy to perform technically.

However, the relationship between the operating conditions (chamber and part geometry, shot weight,…) and the impact properties (velocity, coverage, impact angle,…) is partially if not entirely unknown. The situation becomes even worse for the case of ultrasonic shot peening in which the spheres are propelled by an ultrasonic vibrating wall (a sonotrode), and bounce around in a blind peening chamber [5]-[6]. While the determination of the velocity of a single steel sphere bouncing on a plate is relatively straightforward, the description of a collection of spheres needs, indeed, an adapted framework typical of many body problems.

The absence of such operating parameter/impact property relationships is clearly a major drawback of the technology since such impacts must obviously affect the targeted mechanical properties, and might influence the design of adapted peening chambers. Therefore, in order to make additional progress and bring the technology to the next level, there is need to understand how shot behaves collectively inside the peening chamber, and how it is influenced by the operating parameters.

In addition, a direct visualization of the shot could provide an interesting added value to the problem posed because one might be able to detect the dynamics of the shot with time. This might lead to an increased rationale for the choice of process parameters given that most of them remain largely empirical at this stage, making it costly, time consuming and only partially optimized, the situation being also more problematic when complex industrial parts are to be considered.

Objectives

In order to respond to the lack of models and visualization possibilities for shot peening, we describe in this contribution how our software SHOTVISUAL is capable to provide clues and simple answers to the optimization of shot treated mechanical parts. SHOTVISUAL is able to simulate a tremendous number of operating possibilities for complex parts in industrial conditions, while keeping the computation time to a minimum. This may well lead in future to reasoned surface treatments, having in hand all possible impact data.

Methodology

An event-driven molecular algorithm [7] is used to model the behavior of a finite number of spheres representing the shot, inspired by the statistical physics treatment of vibrated granular gases [7]-[8]. Previous applications for simple geometries have led to a precise knowledge of the physics that is at play when such spheres collide inelastically between themselves [9]-[11]. Such event-driven simulations allow studying different operating conditions among which air blasted or ultrasonic peening. The treated parts can be complex and their geometries defined by e.g. a finite element mesh (FEM), made of triangular elements. This allows conducting efficient 3D simulations in short computing times, achieving in certain situations a 1:1 ratio between effective peening time and the simulation time [12]. The realistic operating process parameters such as shot diameter and density, velocity stream of the blaser, amplitude and frequency of the ultrasonic sonotrode, as well as the process duration are read and act as input data for the event driven simulation. The use of an OpenGL C++ library permits a direct 3D visualization that renders the individual trajectories of the spheres and meshes during the simulation. Once the operating conditions are roughly optimized, impact related data are saved for each FEM meshed triangle: coordinates, impact time and velocity, impact angle. Such data can afterwards be used for a second refinement of the operating conditions, and provide now quantitative relationships between the process control parameters and the various impact properties, including surface.

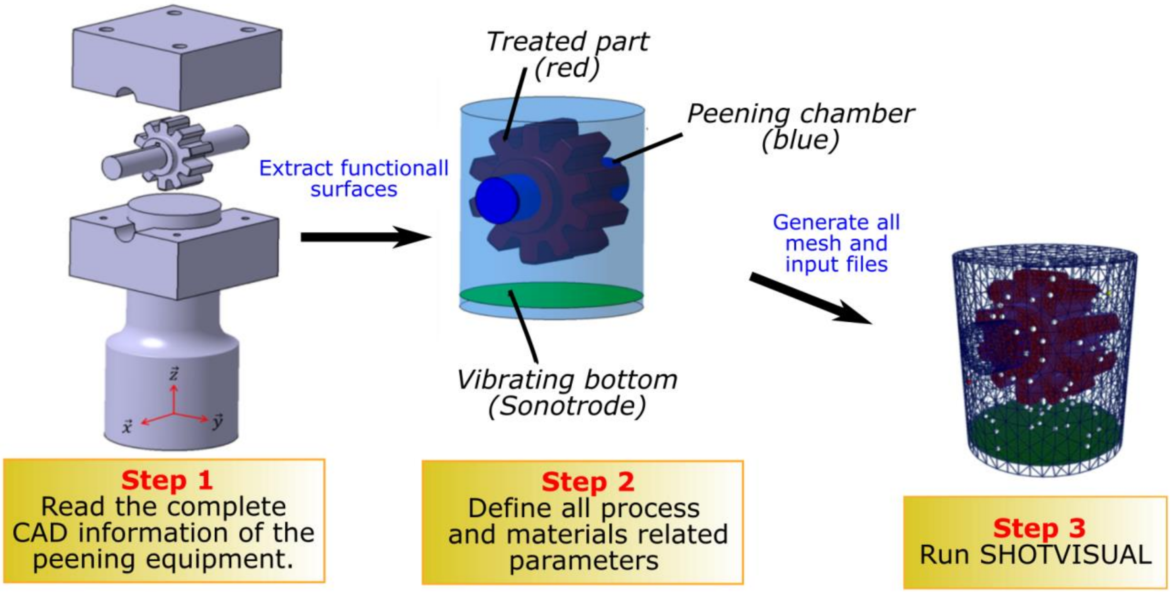

Figure 1: Schematics of the SHOTVISUAL simulation (see section Methodology for details)

A first step consists in reading the CAD triangular mesh representing the part which is for instance an aluminum spur gear (Figure 1). All relevant surfaces in direct contact with the spheres are selected and grouped according to their nature (part, chamber, sonotrode) and their material characteristics. A library of velocity dependent restitution coefficients for various materials (Ti, Ni, Al,…) is used to define precise collision rules. An Aligned Axis Bounding Box (AABB) based collision tree is then constructed for each of the colliding possibilities (shot, walls, sample, eventually sonotrode) using the *OPCODE* library [12]. This permits conducting fast sphere-mesh collision detection queries in order to rebuild the trajectories with time of each of the shot spheres. Ultimately, the trajectory of all spheres can be visualized in order to probe the effect of a given set of operating conditions.

Results and analysis

Results show that standard peening conditions (20kHz, 20g shot quantity) lead to normal impact velocities that are found between 1.5 and 6 m/s, depending on the radial distance between the boundaries and the center of the parts (Fig. 2).

The obtained heterogeneity may influence the mechanical properties and a visualization of the sphere trajectories permits one to determine the origin of the lack of homogeneous surface treatment. It is due to inelastic collisions with the side-walls of the peening chamber (e.g. step 2 in Fig. 1) that leads to a partial adsorption of weakly moving steel spheres close to the sample [9]. An appropriate change in the operating conditions (e.g. an increase of the amplitude) reveals that this flaw can be cured, whereas alternative solutions that might be seen as reasonable (e.g. an increase of the shot density) should not be chosen. Indeed, a larger number of colliding spheres increases the local shot density and produces an opposite effect, i.e. the inelastic collapse of the colliding spheres is promoted and this ultimately results in an enhanced

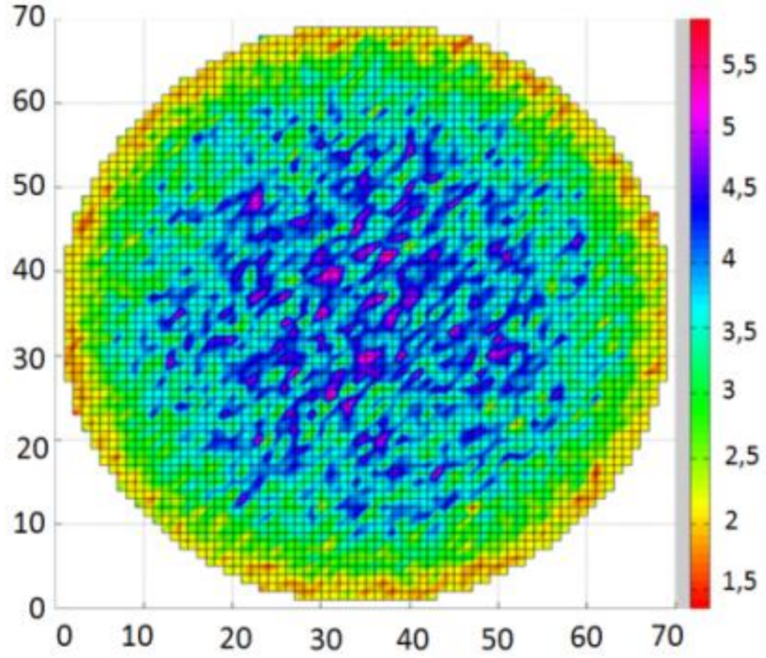

Figure 2: Impact velocity field (in m/s) for an ultrasonic shot (20 kHz) peened aluminium sample. Cylindrical chamber diameter 70 mm, height 45 mm, Shot diameter 3 mm. Shot quantity 20 g.

heterogeneity of the treatment. This situation is also encountered when the local density of the shot is substantially increased [10,11].

The advantage of using SHOTVISUAL is that it permits to characterize the impact properties on rather complex geometries. Fig. 3a represents another test case of application showing the dynamics of the shot in turbine projected shot peening treatment applied on a spring used in the automotive industry. Simulations (Figure 3b) indicate that the impacts depend on the position of the spring with respect to the turbine output (an expected result) but also reveal that the average impact velocity (63.2 m/s) remains close to the turbine output velocity (81.8 m/s) with essentially transverse impacts given that average impact angle is of about 35.5 degree. Similarly, a moving gear contained in an ultrasonic peening chamber can be simulated and its impact properties characterized (Fig. 3c).

Given the rotational motion of the gear, the distribution of impacts is more or less homogeneously distributed, with a maximum impact velocity of 11 m/s. It should be also noted that because of lateral bounces between gear teeth that lead to partial dissipation and inelastic collisions, the velocities close to the centre are somewhat reduced as compared to the top of the teeth. Ultimately, one is in a position to design adapted corrections in order to improve such characteristics.

Conclusions

SHOTVISUAL is a recent developed software [13] able to simulate various peening conditions and situations for complex geometries. By linking quantitatively process parameters and the very local impact properties, one is now in a position to fully control the shot peening technology, blasted or ultrasonic. These new and exciting developments also open the possibility to easily obtain targeted surface treatments without numerous labor hours. The software also provides chamber design, impact analysis on dedicated work parts, optimization routes. This should reduce the need to spend time and money in routine experiencing and analysis. Researchers and engineers having questions, queries or service requests about shot visualization and surface treatment optimization should contact the authors.

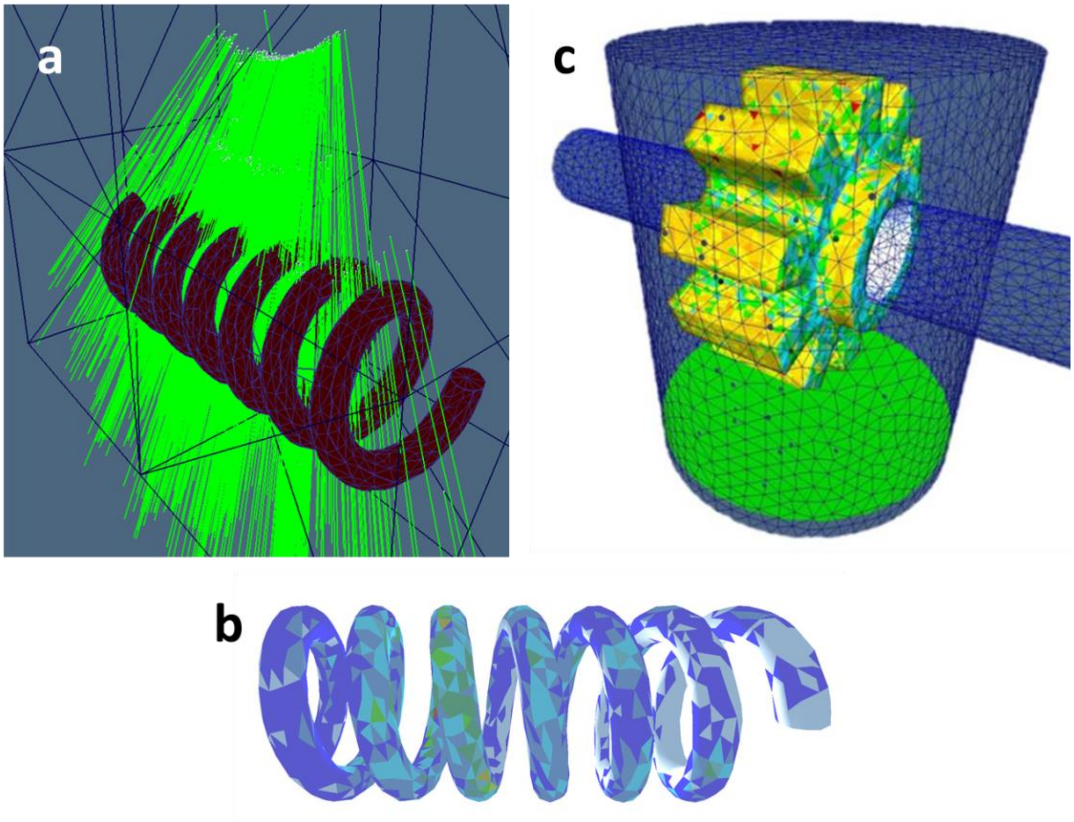

Figure 3: a) Direct visualization of the shot stream projected from a turbine. Shot peening simulation of a spring with given operating conditions (shot diameter 1.6 mm, output turbine velocity 82.1 m/s with angular velocity of 5000 rpm). b) Resulting impact properties after 1 second of treatment. c) Ultrasonic shot peening on a moving gear. Distribution of impact velocities ranging up to 11.2 m/s (average 6.2 m/s).

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