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Estimation of peening effects of random and regular peening patterns

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ABSTRACT

Shot peening and peen forming are respectively used to strengthen and form a component by blasting numerous shots on the component. A large number of analytical and numerical researches have focused on revealing the effects of various peening parameters. The shot impacting positions are usually supposed as a regular or random distribution, but there is a lack of intermediate measurand to connect the regular and random peening effects. This paper is aimed to estimate the peening effects of different peening patterns with different measurands, such as peening coverage and impacting density. Two types of 3D finite element (FE) models with regularly and randomly distributed shots are developed with dynamic-implicit solver of Abaqus. A theoretical equation for calculating random peening coverage is developed to calculate the coverage within an area with symmetry boundaries. The simulation results reveal the evolutions of indentation size, peening coverage and stress field. The equivalent forces on the cross section of plate corresponding to the induced stresses of regular and random peening are compared under the same coverage and impacting density respectively. Peen forming experiments with strict boundary constraints are performed to verify the simulation methods and agreement is observed.

1. Introduction

Shot peening and peen forming are surface treatments usually used in the aerospace and automotive industries. Shot peening is mainly used to improve the fatigue properties of metallic components by introducing compressive residual stress and producing strain-hardening in surface layer. Peen forming is mainly used to create desired shapes of large and thin metallic component by upsetting the initial mechanical equilibrium of component with induced stresses. Baughman (1986) described the mechanism and application techniques of peen forming.

In the peening process, numerous shots impact target randomly. To precisely control peening parameters and simplify analyses, regular peening patterns are usually adopted in many researches. Majzoobi et al. (2005) investigated the effect of impact multiplicity and velocity on residual stress by simulating the processes of multiple shots impacting target at regular positions. Taro et al. (2015) developed a model with regularly located three impacts to predict peening roughness. However, the verification of the results of regular peening research is usually depend on the random peening experiments. In addition, owing to the randomicity of impacting position of random peening, there may be small deviations among repeated experiments. In view of this, the aim of this paper is to discuss how to reliably estimate peening effects of different peening patterns.

Peening coverage is a commonly adopted visible measurand for monitoring peening process, which is defined as the ratio of indented area at least once to target area in SAE J2277 (SAE, 2013). Chardin et al. (1995) proposed a statistical method based on random set theory to determine the peening coverage with impacting density and dimple size. Bagherifard et al. (2012) introduced several coverage requirements from literature, and practical measuring methods of peening coverage: visual inspection, blue-ink/fluorescent tracer method, replicas and so on. A difficulty involved in above measuring methods is determining suitable threshold values to distinguish the covered and blank areas on digital images. In view of the difficulty, Vieira et al. (2010) proposed a combined method to estimate low coverage within relative error of 5% with an inductive algorithm using a multiagent system. In the finite element simulation, the peening coverage can be estimated with strain or displacement field. Miao et al. (2009) suggested an estimating method based on distribution of von Mises plastic equivalent strain (PEEQ). In Miao's definition, the coverage is the ratio of the area with PEEQ larger than a threshold of the PEEQ at the boundary of single dimple to the total representative area. When the value of coverage is relatively large, the material pile between adjacent dimples results in the overestimation of covered area where PEEQ is larger than the threshold. Gangaraj et al. (2014) used Miao's method to estimate peening coverage in simulation and obtained relatively greater values than the calculated results of Avrami equation. In this paper, the coverage in simulation is programmatically calculated on the plane of

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initial peening surface from impacting positions and indenting depths.

Impacting density can also be a visible measurand for monitoring peening process, which is defined as the impacting times within unit area. The impacting density can be determined by counting the dimple within representative area in experiments or simulations when the peening coverage is relatively low. However, few researches are focused on the relationships between peening effects and impacting density. In this paper, the capabilities to represent peening effects by the peening coverage and impacting density are discussed.

To study the peening effects under different peening patterns, finite element (FE) method is widely used. Limited to available computational resources, the FE model generally represents a piece of typical peening process, involving a small symmetry cell of target. The distributions of impacting positions are approximately divided into regular and random patterns. The aims of adopting regular pattern in place of practical random pattern are to obtain stable results, a high coverage with comparatively fewer impacting times, interrelationships among adjacent impacts and to control input parameters accurately. Kim et al. (2010) investigated the peening residual stress with a 3D multi-impact symmetry-cell finite element (FE) model. Xiao et al. (2016) investigated the stress field of stress peen forming with regular model. Random pattern is mostly used in the simulations. Bagherifard et al. (2012) reviewed different multiple impact patterns and proposed a method to obtain high coverage percentages in random peening simulation. In this paper, regular and random peening patterns are adopted and the results are compared.

On the side surfaces of the target in simulation, symmetry constraints are applied to reduce model size. For the lack of material out of the symmetry surfaces, a shot model located near the target boundary should be given a lumped mass less than the real mass of single shot, such as a shot located at the corner of a rectangular peening surface given a quarter of the real mass. It is hard to directly determine the lumped mass of each shot in random peening simulation. In view of this, Miao et al. (2009) and Bagherifard et al. (2012) modeled the representative target surrounded by additional material with coarse meshes. The symmetry constraints are applied on the surface of additional material. The model of additional material increases the cost of computational resources exponentially. To reduce the cost, the additional material is avoided in the simulation model proposed in this paper by calculating the lumped mass from the impacting positions of each shot.

The simulation results need be verified with practical experiments. Since strict boundary constraints are applied in the simulation model, the same constraints should also be applied in experiments that the deformations of specimen should be minimized in the peening process. A strategy is adopted in experiments to mostly reduce the deformations.

This paper is divided into five sections. Section 2 describes developed finite element models, determination of lumped mass for shot model, material properties of target, determination of peening coverage in simulation and related theories. Section 3 presents the performance of peen forming experiments. Section 4 gives and discusses the simulated and experimental results in the aspects of indentation, coverage, stresses and estimation of peening effects. Section 5 concludes this work and suggests topics for future researches.

2. Finite element simulation models

2.1. Finite element model

Two kinds of peening patterns that random peening and regular peening are adopted in FE simulations executed with commercial software ABAQUS 6.14. As Fig. 1 shows, 65 shots successively impact a square block target at regular positions. The peening region is denoted as AB. The shots are divided into seven groups. Each group of impacts generates a uniform distribution of impacting locations. The impacting sequence is also denoted in Fig. 1. The dimensions of the target are selected as 8 mm width (L_x) and length (L_y), and 5 mm thickness (L_z) by

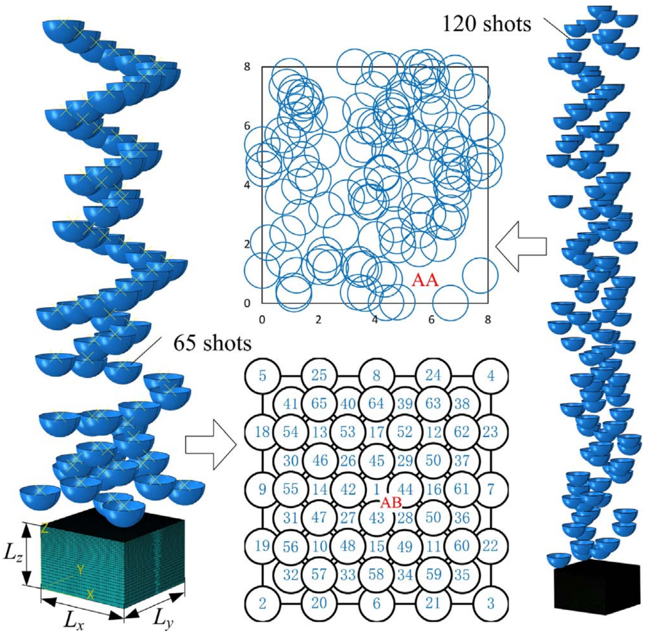

Fig. 1. FE model for impacting at the same position, at regular positions and at random positions. The diameter of circles approximately represents the dimple diameter.

considering stress field sizes of single shot impacting. The target is meshed with biased seeding in z direction. The size of the finest element on the peening surface is selected as 0.08 mm. The size of the coarsest element on the bottom surface is selected as 0.3 mm. In x and y direction, the size of each element is 0.08 mm. The shots are modeled as analytical rigid bodies with diameter of 3.175 mm considering the hardness being much great than the hardness of target. The initial impacting velocities of shots under study are 40 m/s. The shots impacting the target corners are given a quarter shot mass, and those impacting the edges half shot mass. The mass of a shot m_{shot} is 0.12975 g. The impacting process are solved with dynamic/implicit procedure. In the impacting process, the four side surfaces of target are fixed with symmetry boundary conditions, and the bottom surface is fixed in z direction. Hard contact and frictionless behaviors between shots and target are adopted.

With the same conditions, another simulation is performed with 120 shots successively impacting the target. The peening region is denoted as AA. The impacting location on the peening surface of each shot is generated with the uniform random program in Matlab2010a. The separation distance in the z direction of adjacent shot is selected as 0.6 mm to ensure each shot have rebounded before the following shot contacting target.

The random distribution of each sample is different. To study the influence of the distribution variation on peening results, the AA region is further divided into four subregions as shown in Fig. 2, denoted as region A00, A01, A10 and A11 respectively. In the A00, A01, A10 and A11 region, the numbers of located shots are 26, 28, 22 and 44 respectively, determined from the locations of indentation centers. The distributions of the shot sets in the subregions have different features. The shots in region A00 are dispersed overall. The shots in region A01 are gathered around a point. The shots in region A10 are mainly located in the upper left region. The shots in region A11 fill up the whole region. The five samples of shot distribution (AA, A00, A01, A10 and A11) can partly represent the random distribution of random peening.

2.2. Lumped mass applied on analytical model of shot

Owing to the symmetrical boundary conditions of target, the lumped mass applied on the shot model varies according the impacting position. To determine the lumped mass of each shot model in the