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Experimental and Simulation Method of Introducing Compressive Residual Stress in ASTM A516 Grade 70 Steel

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Abstract. Compressive residual stress below the surface of material could increase fatigue life as it encounters the tensile loading applied on the material during operation. Shot peening process is a common surface treatment to introduce this stress. This study will investigate on how to introduce the same amount of residual stress by simulation using FEM as introduced in experimental shot peening process. Actual shot peening process was done using a particular sets of parameters and FEM with single shot is used to simplify the simulation procedure. Result shows that using a single shot simulation could also introduce the equivalent amount of residual stress as in the experimental multi-shots shot peening process. This value could be used in further study to study the relaxation of the stress after load is being applied.

Introduction

There are two type of residual stress. One is in tension and another one is compressive. Many processes could introduce tensile residual stress in a body such as welding, bending, cold-drawing and many others. The most common process to introduce compressive residual stress is shot peening. During the process, a large amount of small sphere-like particles, called shots, are bombarded onto a metallic surface, at high velocities (20– 150 m/s) [1]. Other processes include grinding, lapping, super-finishing, and burnishing [1].

Many studies have been done on the shot peening simulation. Finite Element Method (FEM) is the common study approach in the past whereby the change in standard parameters of shot peening like shot size, speed, shot angle and material has been investigated. Random shot positions were selected in previous study to determine the effect [2-7].

Compressive residual stress (CRS) is introduced by this process. Single shot is used in this simulation to simplify a method of introducing the same amount of CRS as introduced experimentally by particular shot peening parameters. CRS is important to encounter the external tensile loading applied during operation.

Material selected for this study is ASTM A516 Grade 70 Carbon Steel. This material is widely used in many application in automotive and oil and gas industry because of its high demand due to high availability and low cost [8].

Experimental Setup

Sample preparation. The material ASTM A516 Grade 70 using plasma cutting method into dogbone shape according to standard ASME 1989 based on the tensile and fatigue test sample dimension with the ratio of the plate thickness of 6.4mm as shown in Fig.1.

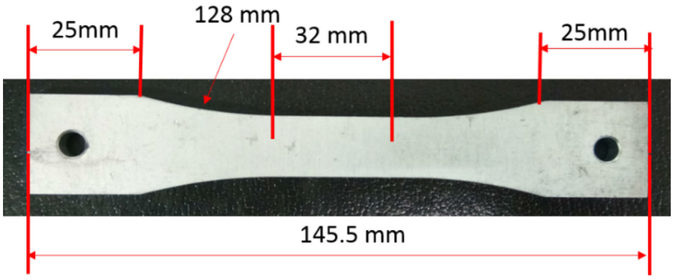

Figure1. ASTM A516 Grade 70 Testing Sample Dimension

Shot peening. Shot peening process was used in this study to introduce the compressive residual stress. Two shot peening intensities are used to evaluate the value of compressive residual stress. The parameters of the process are tabulated in Table 1.

Table 1. Shot peening parameters

Steel shot grade	SAE S-110	SAE S-230
Steel shot size (mm)	0.4	0.7
Arc height (x10-3 inch)	6.6	12.9
Applied pressure (Mpa)	0.21	
Nozzle angle (degree)	45	
Nozzle speed (m/s)	0.1	
Part to nozzle distance (mm)	152.4	
Media flow (kg/s)	0.023	

Residual stress measurement. X-Ray diffraction measurement was done on the samples after shot pening to measure the introduced compressive residual stress. The measurement were made at the surface only in the longitudinal direction in the centre of the gage region on the side opposite the specimen identification markings. X-Ray diffraction were performed using two-angle sine-squared-psi technique, in accordance with SAE HS-784, employing the diffraction of chromium K-alpha radiation from the (211) planes of the BSS structure of the material.

Simulation Setup

Theoretical background. When shot particles are passing through these regions, they are accelerated by the drag force from the nozzle and the equation of particles may be described as

$$m\frac{d^2y}{dt^2} = -\frac{\pi D^2}{8}C_D\rho_a(y)\{u(x,y) - v(x,y)\}^2$$

m is the particle mass and C_D is the coefficient of drag. For the spherical shape in turbulent flow, C_D is 0.47. $\rho_a(y)$ is the air density. D is the particle diameter. U(x,y) is the air velocity and v(x,y) is the particle velocity. The term related to velocities means the relative velocity between air and shot particle. Air density, $\rho_a(y)$, and air velocity, u(x,y) depend on the region of the shot particles [9-11].

Shot peening model. Model developed using Hyperworks Altair software as per dimension of the actual part. Meterial properties is defined as isotropic elasto-plastic using tabulated piecewise liner. This methods defines the material behaviour based on the stress-strain curve values resulted from experimental tensile test done on the sample. The curve values include elastic and plastic region of the material. To cover the middle part of the sample using single shot, a ball model is developed using 10 mm of diameter. Using explicit solver in the software, an impact analysis is run between the two bodies as shown in Fig.2 to simulate the shot peening process. The ball hits the sample at 90° angle from the centre.

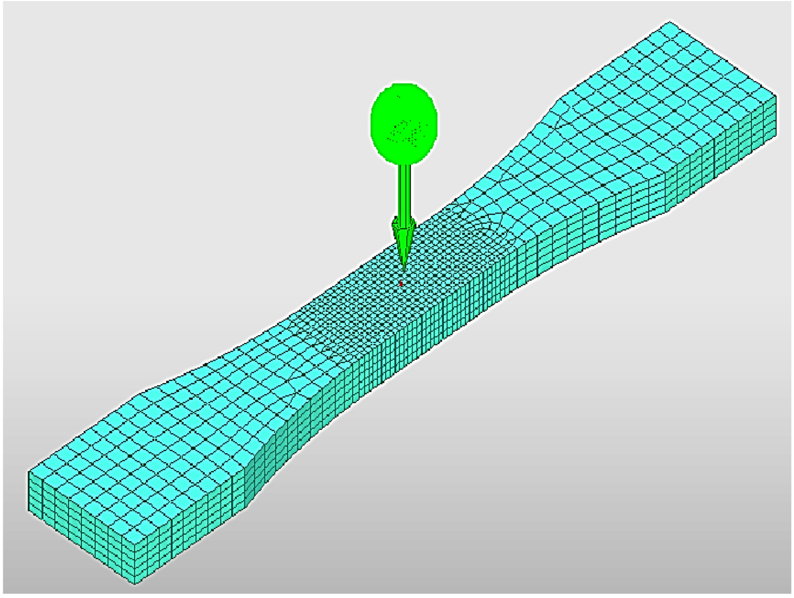

Figure 2. Simulation setup of shot peening

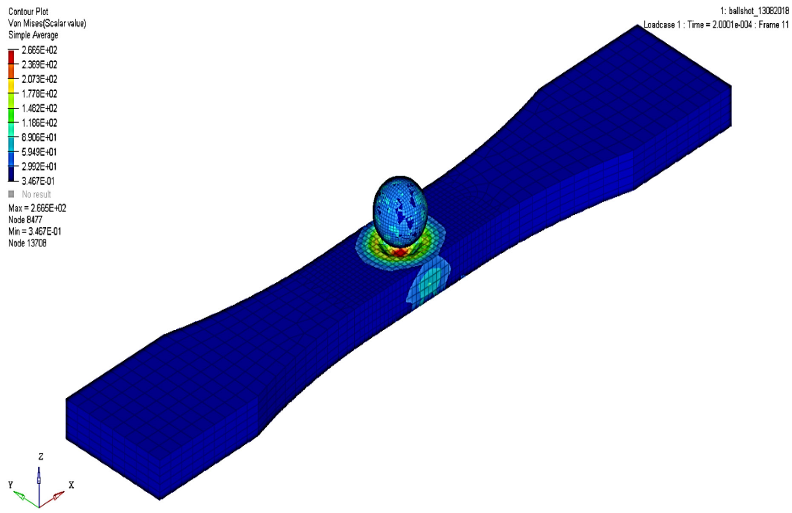

Figure 3. After collision result

Loading and boundary condition. Bottom surface of the sample is fixed in all direction by applying "ENCASTRE" as boundary condition. Single sphere ball is set to hit the sample by applying initial velocity perpendicular to the impacted surface.

Result and Discussion

Experimental. By applying shot peening using parameters described in Table 1, the maximum residual stress introduced in the middle part of the sample is 259 MPa and 272 MPa using SAE S-110 and SAE S-230 respectively. This shows that using bigger size of steel shot will introduce higher stress due to bigger impact between the bodies.

Simulation. Initially the speed used for the ball to hit the sample is 2 m/s. As the selected speed introduced a very small residual stress in comparison with expected value from experimental result, higher speed was used for the ball to hit the sample. The simulation result is as shown in Fig. 4 and the values of residual stress introduced by each shot speed is tabulated in Table 2.

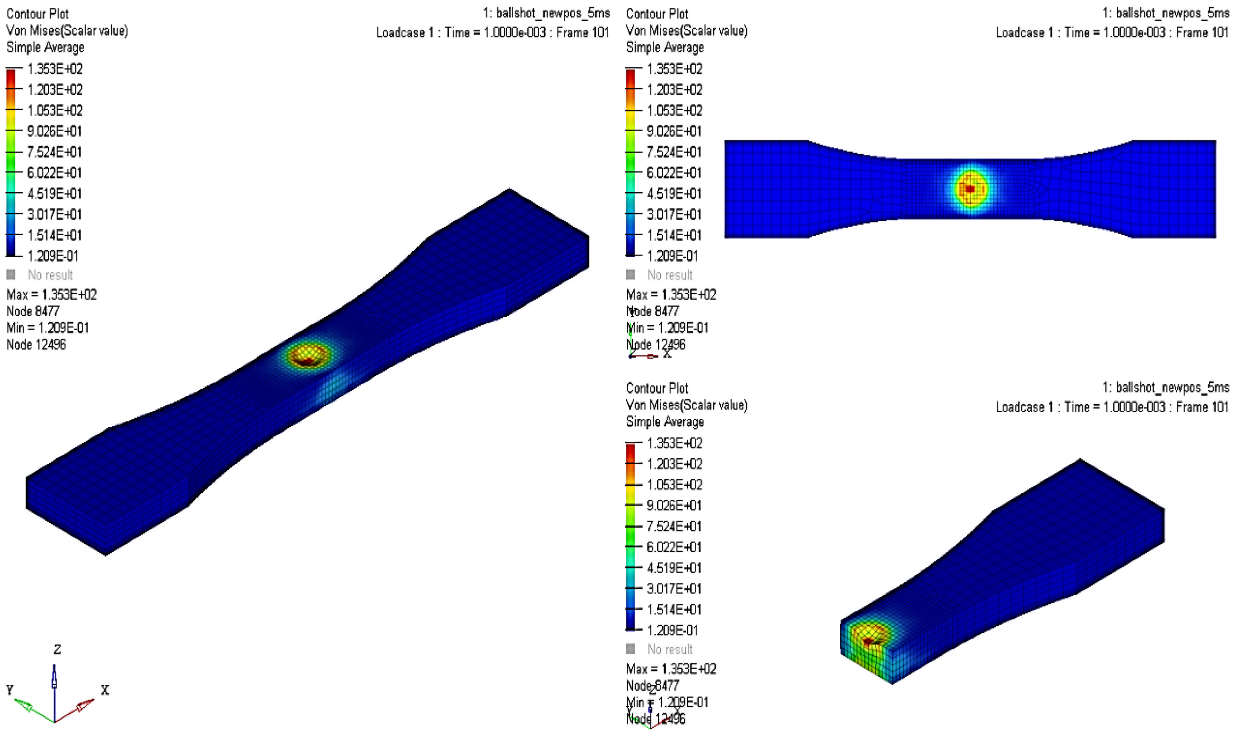

Figure 4. Final simulation result

Table 2. Residual stress values for different shot speed

Shot Speed (m/s)	Residual Stress (MPa)
2	19.91
5	36.94
25	75.35
50	135.30
100	266

Based on the result, it is found that the most suitable shot speed to introduce the equivalent amount of residual stress from experimental shot peening process using SAE S-230 in Table 1 is 100 m/s.

Conclusion

Compressive residual stress is very important to encounter the external tensile load during operation. Shot peening is the most common method used in practical to introduce this stress. As the multiple shots is not easy to be simulated, single shot simulation could also be used to simulate the introduction of the compressive residual stress which could be verified with actual shot peening process. Further study can be done on the relaxation of residual stress due to cyclic loading.

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