Efficient eigenstrain model for laser peen forming of panels with stiffening rib

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Introduction

Laser peen forming (LPF), a derivative of laser peening, is a locally effective forming process to form complex curvatures without dies. It is now emerging as a viable means for the shaping of large scale panels with stiffening ribs. Shape prediction of large scale panel after laser peen forming is challenge due to high computation cost to simulate a large amount of laser shocks[1]. Therefore, developing an efficient way is expected to simulate laser peen forming process and predict the geometry shape. Eigenstrain-based modelling has been proposed as an effective method to predict the geometry shape of a large scale specimen with small curvatures. Korsunsky predicted the deformed plate shape, residual stresses and strains after shot peening treatment with the prescribed distribution of eigenstrain[2]. DeWald and Hill used contour method to measure residual stress and established a model with laser peening induced eigenstrain for a range of material thickness[3]. Hu and Grandhi proposed an eigenstrain-based numerical model to predict the LPF processes efficiently [4].

Objectives

The objective of this work is to provide an efficient model to predict the geometry shape of panel with stiffening ribs in LPF by adopting eigenstrain methodology. It allows to predict the shape only with a static elastic model after embedding the inversely determined eigenstrain strain field into thickness section of shell element.

Methodology

The eigenstrain, noted by ε^*, is proposed to indicate any permanent strain arising in material due to inelastic processes. With the eigenstrain prescribed in a static model, the deformation and residual stress field can be induced through the generated incompatibility of displacement. The eigenstrain in LPF is only represented by the plastic strain. Its value is geometry insensitive, while mainly related to the process parameters, material properties and specimen thickness. Our earlier work proposed the eigenstrain-based modelling method for laser peen forming, and this method is verified to provide a consistent prediction with that from an equivalent wholly explicit simulation [4]. Therefore, the geometry prediction of a large-scale panel after LPF can be conducted efficiently with the determined eigenstrain.

A spatial-distributed eigenstrain along the thickness section is necessary for the prediction. To determine the eigenstrain including these factors above, the eigenstrain with a specified process condition is determined by developing a dynamic explicit model. And the calculated results in two directions are further validate and calibrated by the deformation profiles of a small square metal plate. The procedure to determine the eigenstrain is shown in Fig. 1. First, the time history and spatial profile of shock pressure is calibrated with serval indentation profiles through a 2D single shock model. Then, an explicit-infinite plate model to determine the eigenstrain in a representative cell along two directions and varying by thickness. The calculated eigenstrain profiles are further calibrated to provide consistent predictions of geometry profiles along two centreline of square specimens to avoid model incompleteness to accurately describe the material properties. A static elastic shell model of panel with stiffening ribs is constructed for the shape prediction with the determined eigenstrain field. In the shell model of integral panel, both the skin and stiffening ribs are constructed with shell and beam element. The determined eigenstrain is embedded into the skin of the shell model by assigning the anisotropic thermal expansion ratios. After applying a unit temperature variation, the final deformation can be computed with the elastic model. .

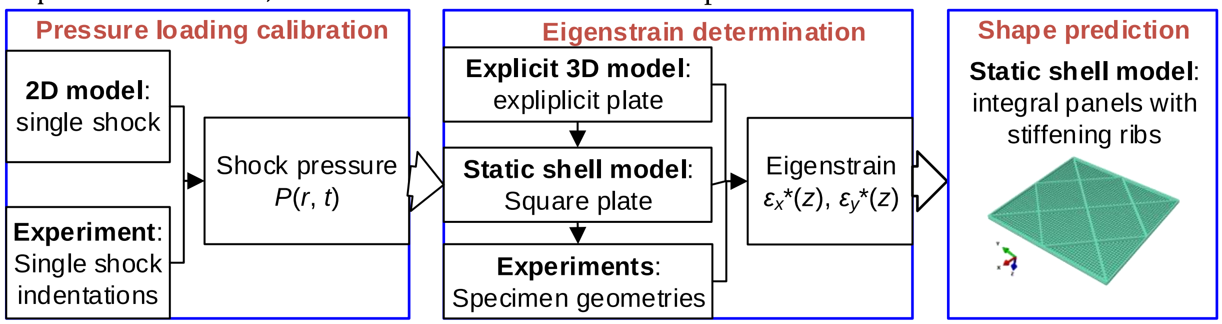

Fig.1 Flow chart to determine eigenstrain field to predict the geometry shape of integral panel

Results and analysis

I. Shock pressure calibration

Shock pressure loading is determined by matching the calculated indentation profiles to the experimental results. The experiments of the seperated laser shocks were performed with a laser head of 11.2 J pulse energy and 15 ns pulse energy. And the round laser spot was set with 4.0 mm in diameter. Fig.2a presents the indentations of experiments. And Fig. 2b shows the 2D exlicit model to provide a contour of displacement field under single laser shock. The time and spatial distributions of shock pressure are calibrated by adjusting their several coefficients in the model. Fig.3c presents the indentations profiles both from experiments and model predition. It can be found that the model can provide a consistent results with the experiments with the calibrated time history and spatial distribution of shock pressure as shown in Fig. 2d and e.

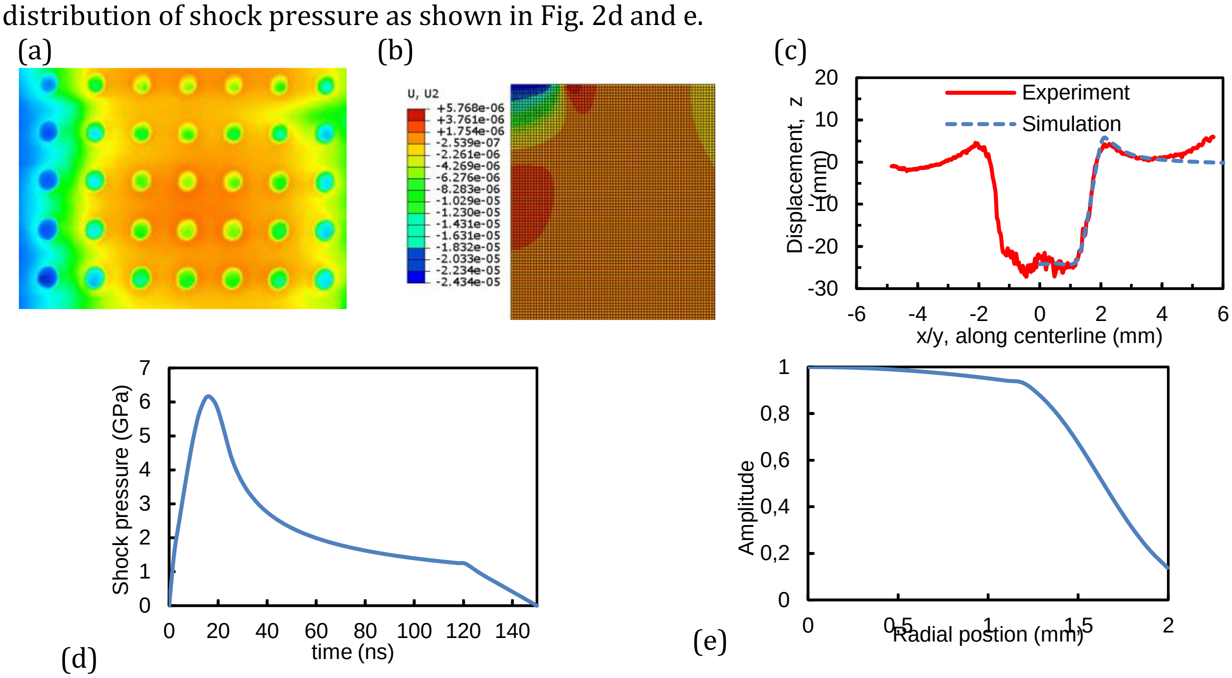

Fig. 2 Shock pressure calibration with the indentation profiles from both experiments and numerical model: indentations from (a) experiments and (b) mdoel prediction; (c) indentation profiles.; (d) time history of shock pressure; (e) sptial distrition of shock pressure

II. Eigenstrain determination

A method based on the bending geometry of a small square metal plate is proposed to determine the eigenstrain in depth. As shown in Fig. 3a, the experiments of LPF was conducted with a metal plate of 80 mm×80 mm. And laser shocks were applied on the top surface of 60 mm×60 mm. Similar to our previous work [4], an explicit-infinite model was developed to simulate several laser shocks to obtain the eigenstrain filed in the representative cell. Two components of eigenstrain in plane is extracted and averaged in the cell to obtain the eigenstrain varying by depth as shown in Fig. 3b and then they are used to calculate the bending geometry of the square plate. Due to the incomplete material properties, there is a little difference between the prediction and experiments as shown in Fig. 3. The eigenstrain as shown in Fig. 3b are further calibrated by adjusting a specified ratio of 85% to provide a consistent prediction of geometry profiles in two direction as shown in Fig. 3d, thus determining the in-plane eigenstrain varying by depth.

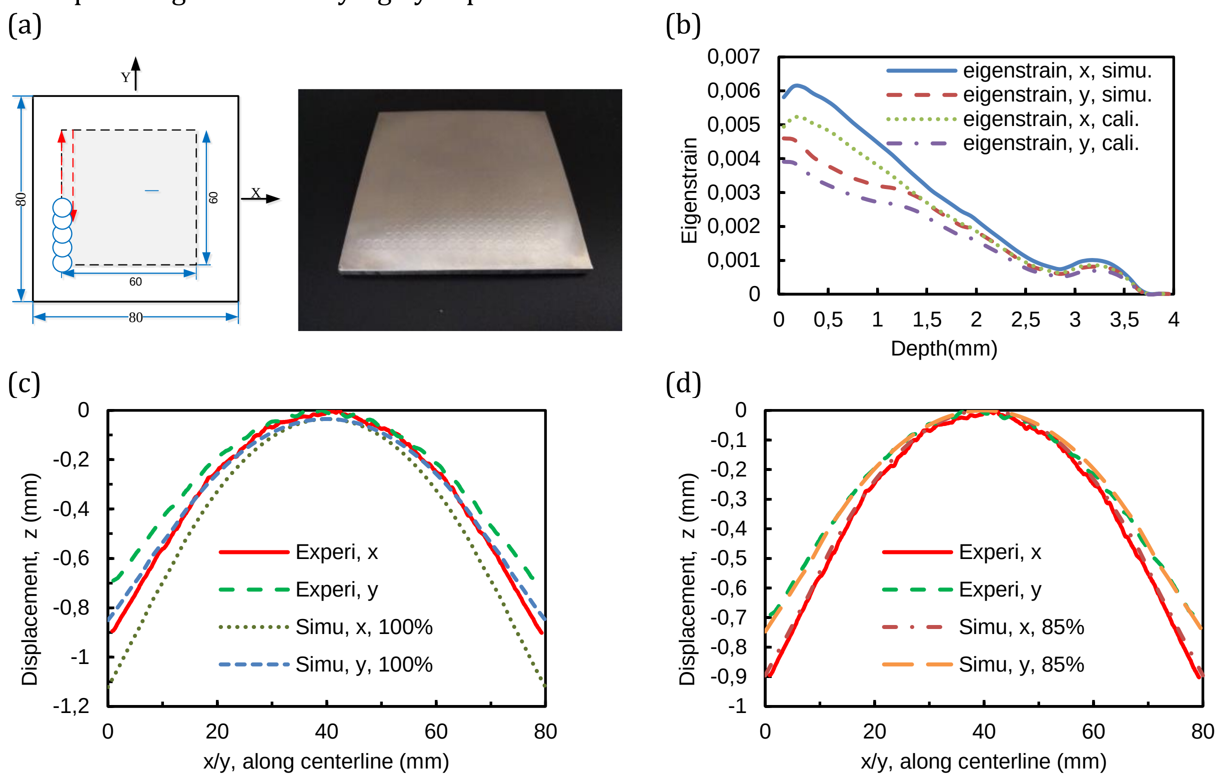

Fig. 3 Eigenstrain determination with a square metal plate under laser peen forming: (a) specimen geometry and scanning of laser shocks; (b) eigenstrain field along two directions; (c) direction predicted geometry profiles; (d) calibrated geometry profiles with 85% calculated eigenstrain.

III. Geometry shape prediction

With the determined eigenstrain, the deforming shape of a integral panel with stiffening rib can be predicted efficiently. Fig. 4a presents a panel with the cossing ribs for the shape predition. The dimension of the panel is 270 mm×270 mm. The stiffening ribs is 3.5 mm in width and 6 mm in height. The experiments were conducted with the same process conditions to determine the eigenstrain. As shown in Fig. 4b, the panel was operated by an industrial robot wo apply scanning of laser shock on the skin. And black tape was used as the absorbent layer. Fig. 4(c) presents the predicted geometry shape by the developed panel model. Fig. 4(d) compared the predicted profiles along two across directions with the experimental measured shape. It can be found that the mode can provide a good prediction of bending profiles with the inversely determined eigenstrain. However, a little difference can also be found in Fig. 4d, which still requires further work to improve the prediction accuracy,

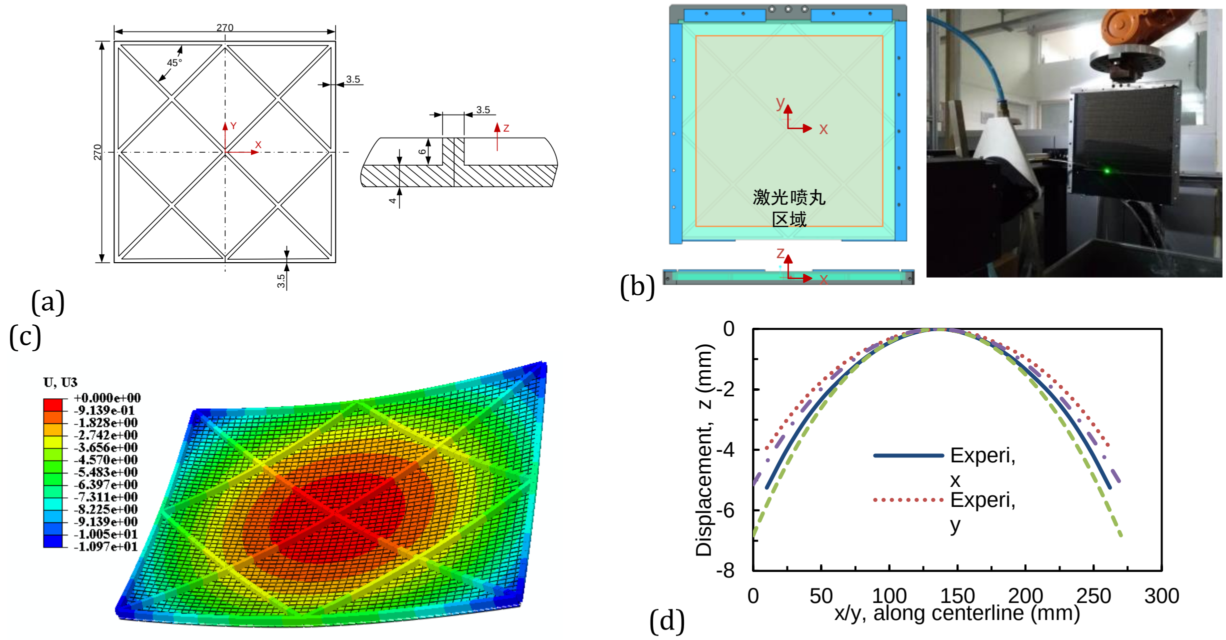

Fig. 4. Prediction of geomery shape for integral panel with stiffening rib : (a) specimen of planel for experiments; (b) laser peen forming experiments; (c) predicted shape; (d) predicted profiles compared with experiments.

Conclusions

In this work, an eigenstrain model is proposed predict the geometry shape of a integral panel with stiffening ribs generated by laser peening forming. Pressure loading generated by laser shocks is calibrated by the indentations of experiments. And then the presussure loading is used as the input to a explicit model to compute the eigenstrain field in an representatie cell of scanning laser shocks. After calibration of in-plane eigenstrain to provide a consistent prediction deforming shape of a small square metal plate, the deterimined eigenstrain can provide a good prediction of geometry shape of a integral panel with stiffening ribs.

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