Chapter 4
The Effect of Residual Stress on Aluminum Strength Using Thermoelastic Stress Analysis

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Abstract Residual stress existing in a material can possibly yield the undesired deflection or fracture occurred in an engineering structure. Hence, it would be very helpful for the industry to monitor residual stress and further analyze the influence of residual stress on the strength of a material. Thermoelastic stress analysis is an experimental technique which is able to determine the full-field residual stress by recording temperature changes due to loading. This work analyzes the residual stress distributed over the perforated aluminum plate based on using thermoelastically measured results and further investigate the effect of residual stresses on the material strength.

Keywords Thermoelastic stress analysis · Residual stress · Non-destructive experiment · Stress measurement

Introduction

Thermoelastic stress analysis (TSA) is a non-destructively experimental technique which records the temperature disturbance of a stressed material to provide the stress information throughout the surface. Under adiabatic and reversible conditions, thermoelastic theory indicates the temperature change induced by the dynamic loading will be associated with the sum of principal stresses. Traditional thermoelasticity gives the relation between TSA measured results and the sum of normal stresses remains linearly. Since TSA provides the combination of stresses and individual components of stresses are always necessitated for determining structural failures, many works related to TSA emphasized on separating TSA measurements. Rauch and Rowlands [1] separated TSA results, using finite element method. Lin et al. [2–4] combined Airy stress expression and TSA recorded data to provide individual stresses for symmetrically and un-symmetrically perforated aluminum plates. However, it has to be noticed that while traditional thermoelasticity has been substantiated to provide accurate stress information, the effect on mean stress on TSA measurements is not involved in the traditional TSA theory. When Machin et al. [5] conducted TSA experiment, they found that TSA measured results can be changed as mean stress varies. Later, Wong et al. [6] reviewed thermoelastic theory and gave that as the elastic properties are assumed to be temperature dependence, the thermoelastic response is not only associated with the sum of principal stresses but the mean stress. Since the mean stress is a static stress component and residual stress is mechanically regarded to as static stress, thermoelastic stress analysis is then getting applied to monitor the residual stress existing in a material.

This work employs thermoelastic stress analysis to help determine the residual stress existing in the perforated aluminum plate and analyze the strength variation due to residual stress based on comparing unresidual stressed members.

Thermoelastic Experiment and Results

The specimens utilized in this work are 2024 aluminum pates having dimensions of 300 mm long, 51 mm wide and 5 mm thick. Each aluminum plate has a hole with the diameter of 25 mm located at the center. Prior to conducting TSA test, all of specimens were coated by a thin and flat paint to enhance the emissivity of the aluminum material. Figure 4.1 shows the TSA experimental setup.

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A. Baldi et al. (eds.), *Residual Stress, Thermomechanics & Infrared Imaging and Inverse Problems, Volume 6*,
Conference Proceedings of the Society for Experimental Mechanics Series, https://doi.org/10.1007/978-3-030-30098-2_4

Fig. 4.1 Thermoelastically experimental setup

In order to analyze the residual stress, the present work applied cyclic loading conditions with the mean load of 6 kN and range load of 10 kN as well as the mean load of 7 kN and range load of 10 kN on the specimen. The loading frequency for all of TSA tests is 3 Hz. Once the thermoelastic responses resulting different mean stresses are acquired, the residual stress can be evaluated based on employing revised TSA theoretical expression. Figures 4.2, 4.3, and 4.4 show the TSA-determined residual stress located approximately 1.1R, 1.25R and 1.5R away from the center of the hole. R is the radius of the circular cutout.

Discussions

Figures 4.2, 4.3, and 4.4 indicate that the residual stress determined by the mean load equal to 6 kN is very close to that provided by the thermoelastic measurement as the mean load selected 7 kN. It supports the accuracy and reliability of the TSA-determined residual stress. Moreover, as can be observed in Figs. 4.2, 4.3, and 4.4, the maximum compressive residual stress appear at θ equal to 0° and as θ equals 90°, the tensile residual stress will attain maximum.

Fig. 4.2 Residual stress located 1.1R away from the center of the hole

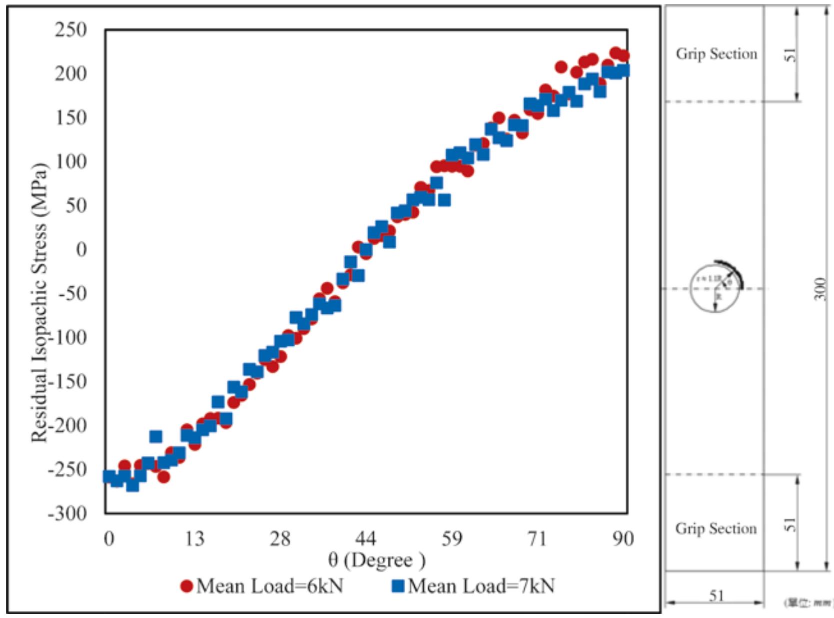
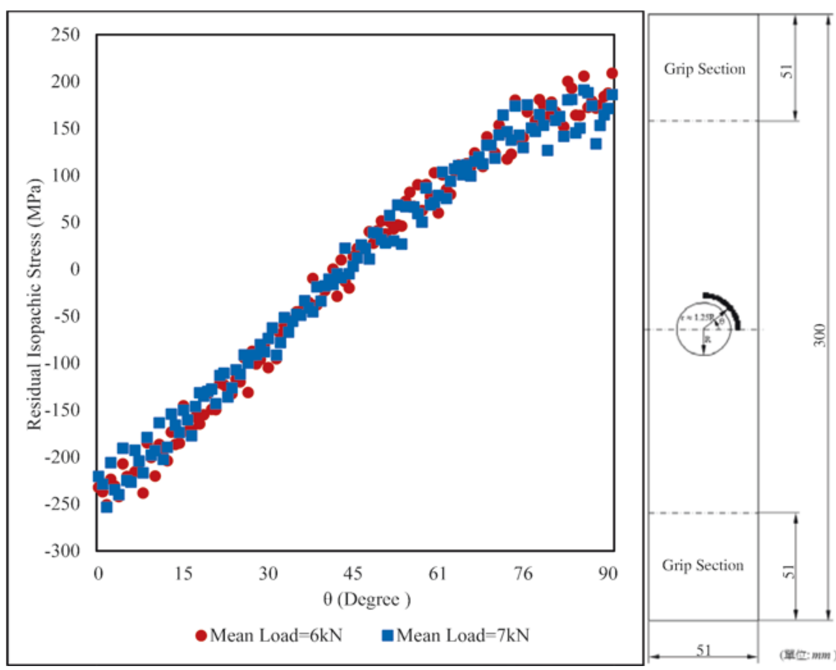


Fig. 4.3 Residual stress located 1.25R away from the center of the hole



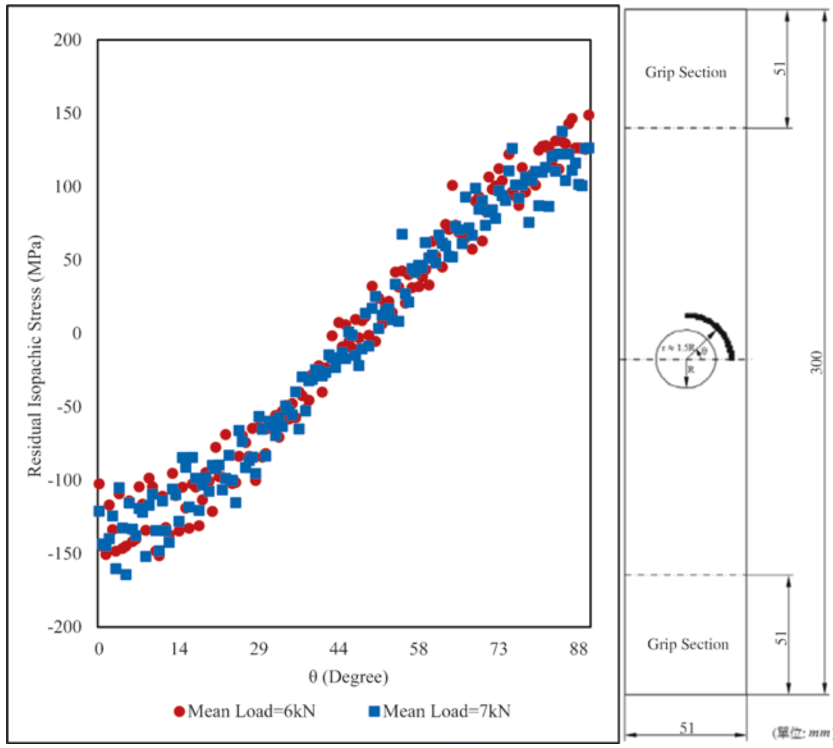


Fig. 4.4 Residual stress located 1.5R away from the center of the hole

Conclusion

The present work utilizes thermoelastic stress analysis to investigate the residual stress for the perforated aluminum plate. Based on results acquired in this work, the TSA technique is indeed able to help provide accurate residual stress existing in the material. As specimen is respectively subjected to the mean loads equal to 6 kN and 7 kN and the rage load as well as the loading frequency are fixed, their corresponding thermoelastic responses yield the approximately same residual stresses over the perforated material. It further validates the accuracy of residual stress analyzed by thermoelasticity.

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