AN OPTICAL STRAIN ROSETTE/RING-CORE METHOD APPLIED ON LASER WELD

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Summary As a newly developed residual stress measurement method, the optical strain rosette/ring-core cutting method is introduced. Optical rosette has short gage length and noncontacting nature. Ring-core cutting involves almost complete relaxation of residual stresses. The principles of the method are presented and the test on the laser weld demonstrates its advantages over conventional measurement methods.

INTRODUCTION

Residual stresses exist in many industrial parts due to the inelastic strains induced in manufacturing processes. These stresses can largely affect the mechanical performances of the parts. The measured residual stress data can aid fatigue analysis, safety design and strength evaluation. Resistance strain rosette/hole-drilling method is a widely used method for residual stress measurement. During the drilling process, the resistance strain rosette detects the relieved strains. Numerical method is used to relate the relieved strains and the in-plane residual stresses. Therefore, the unknown residual stresses can be calculated. There are limitations for this method. The measuring grid with carrier of a resistance rosette has large size. The measured strains are the averaged values over the gage length. It is not suitable for the measurement on the small areas with high stress gradients.

An optical rosette called Interferometric Strain/Slope Rosette (ISSR) is developed with short gage length and noncontacting nature [1]. It can be used to measure displacements, strains and slopes. It was used in conjunction with the hole-drilling method to measure the residual stresses on the shot-peened titanium block [2]. One problem of hole-drilling method is that the sensitivity of the strain measurement is low due to the incomplete strain relief. To more fully relieve the residual stresses, the ring-core method is considered. The newly developed ISSR/ring-core method shows many advantages over the conventional methods. Since the ISSR is tiny (gage length is on the order of 100 micrometers), the central core can be cut small and it is suitable to be used on the small areas with high stress gradients.

BASIC PRINCIPLES

ISSR method and its measurement system

An ISSR consists of three micro-indentations and these indentations can form delta or rectangular shape. Indentations can have several types, such as four-faced, six-faced and eight-faced. Normally, the size of indentation is on the order of 10 micrometers (μm). Commonly used gage length is between 100μm and 250μm. An ISSR with delta configuration is shown in Fig. 1. If a normally incident laser illuminates the delta rosette, the six faces of each indentation reflect and diffract the light in six directions (60° apart). The diffraction patterns in the same direction interfere each other. So in every 60° direction, there exists an interferometric pattern. These fringe patterns would shift due to deformation or movement of the specimen. Considering that every two indentations constitute an optical gage, the in-plane strain and out-of-plane deflection of this gage can be determined using the following Eq. (1) [1].

$$\frac{\delta d}{d} = \frac{\lambda}{2d\sin\beta}(\delta m_1 + \delta m_2) \qquad \frac{\delta w}{d} = \frac{\lambda}{2d(1+\cos\beta)}(\delta m_1 - \delta m_2) \tag{1}$$

where λ is laser wavelength (0.6328μm for He-Ne laser in the test), d is gage length (250 μm in the test), β is the angle between the reflection beam and the normal of specimen surface, and δm_1 and δm_2 are the fringe shifts in the same gage direction. Three strains measured for the 60° ISSR are in 0°, 60° and 120° directions, respectively.

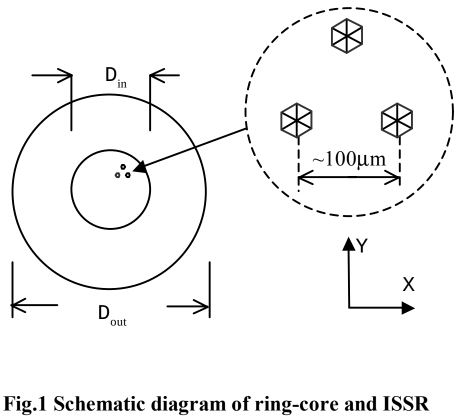

Fig.1 Schematic diagram of ring-core and ISSR

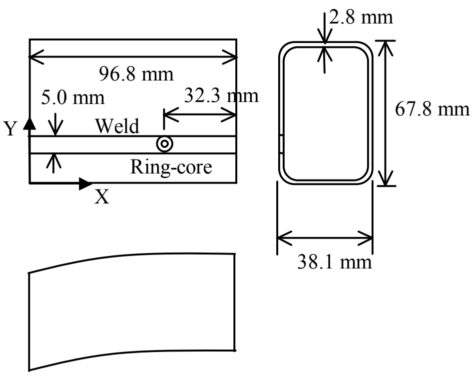

Fig. 2 Plan, elevation and side views of the hydroformed frame part

Ring-core cutting method

Ring-core cutting method is to mill an annular groove on the material surface. Ring-core cutting involves almost complete relaxation of residual stresses [3]. The ring-core method has higher sensitivity for strain measurement than the hole-drilling method. Small indentations of the ISSR are indented before ring-core cutting is performed. As shown in Fig. 1, the ISSR is located at the central core surface. The ring-core with smaller inner diameter could improve the measurement accuracy. To obtain the stress distribution with respect to the depth, layer-by-layer incremental ring-core cutting is carried out. Data acquisition is conducted before and after each step of cutting.

MEASUREMENT ON THE LASER WELD AND STRESS CALCULATION

A tubular member was cut from the truck frame as shown in Fig. 2. The seam was laser-welded and then the tube was hydroformed. Welding process induces highly concentrated residual stresses in the weld and the surrounding heat-affected zone (HAZ). So the fractures would most likely occur at weld and HAZ during the operation. Since the weld width is only 5mm, resistance strain rosette is too large to be applied on the weld.

The ISSR/ring-core method was conducted and five steps of incremental ring-core cutting were performed on the laser weld. A finite element model was built to simulate the cutting process. By applying the given loads to the inner and outer walls of the ring-core model, the stress-strain response relationship was established. The obtained coefficients were used to back-calculate the residual stresses and the integral method was adopted to correlate the residual stresses in different cutting layers. The core diameter D_{in} is 2.03mm and the outer diameter D_{out} is 4.76mm. As shown in Fig. 1, if $\vec{r}$ is defined as the vector from the core center to the ISSR center and θ is the angle from the x-axis to the vector $\vec{r}$ in CCW direction, norm of $\vec{r}$ is 0.25mm and θ is -84.07°.

RESULTS AND ANALYSIS

The measured strains for each incremental ring-core cutting and the calculated residual stresses are shown as marks in Fig. 3. The strains are fitted by the 3rd order polynomial and the fitted curves are used to calculate the residual stresses. The stress distributions are obtained by fitting the calculated residual stresses with the 4th order polynomial. The measured tensile stress in the hoop direction is caused by the stretching of the weld due to the spring-back tendency of the bent C-shape tube. This tensile stress in the hoop direction is the most concerned stress since it could be superposed upon the operation stress. The superposed resultant stress might cause the structure to fracture under the cyclic loadings. So the existence of this tensile stress could mainly reduce the frame fatigue life.

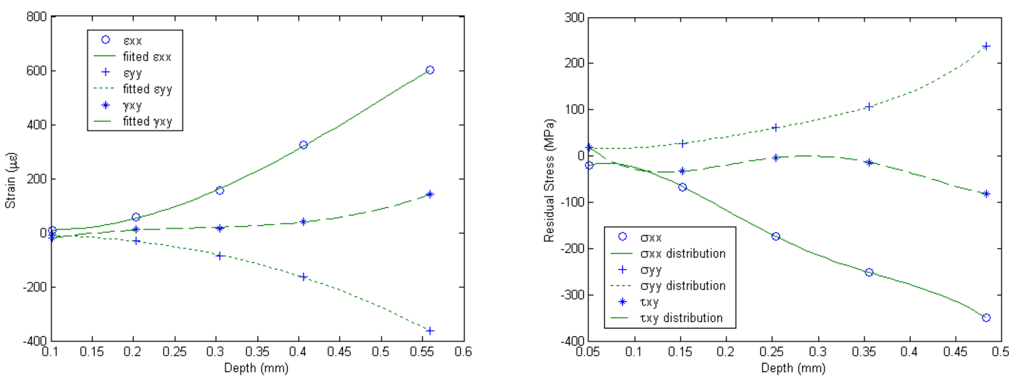

Fig. 3 Relieved strains and residual stresses on the laser weld

CONCLUSIONS

As a newly developed measurement method, the ISSR/ring-core method can be successfully applied to the residual stress measurement. Since the ISSR is tiny, the method is very suitable to the measurement on the small areas with high stress gradients. The experiment on the laser weld demonstrates its advantages over the conventional methods. The test results provide the valuable references for industrial applications. Micro ring-core cutting will be investigated to study the stress distribution across the laser weld.

References

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