WELDING STRAIN/SLOPE MEASUREMENTS USING A LASER-BASED TECHNIQUE

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Summary Real time strains during welding are difficult to be measured by traditional strain measurement techniques due to extreme high temperature and intensive light emittance. A laser-based optical technique, the Interferometric Strain/Slope Rosette (ISSR) technique, was employed for the first time to measure the real time strains and slopes during arc welding process. Advantages of this technique over traditional techniques include short gage length, non-contacting, thermal resistant, robust and ability of measuring both in-plain strains and out-of-plane slopes simultaneously. The ISSR was successfully applied in arc welding processes and the measurement results of the dynamic in-plane strains and out-of-plane slopes were obtained and are presented in this paper.

INTRODUCTION

Due to high transient thermal effect, dust disturbance and intensive light, it is difficult to measure the real time strains occurred during welding process. Resistance strain rosettes (RSRs) when applied are usually with low thermal resistance and temperature compensation is often required. Until recently, an optical method, the Digital Image Correlation (DIC) technique, was introduced to measure the real time strains during welding on pipes. However, since the speckles required by the DIC technique can be burnt at high temperature, strain measurement area must be located far away from the weld. In addition, the DIC technique has low accuracy for small strain measurement which limits the usage of this technique in the application.
The laser-based ISSR technique has been successfully developed for measuring strains/slopes, and measuring residual stresses associated with hole-drilling and ring-core cutting methods [1, 2]. The ISSR is thermal resistant and non-contacting in nature. The gage length of the ISSR is on the order of 100 μm, which is much shorter than the conventional RSR technique (on the order of millimetres). A RSR measures the averaged strain over the relative larger gage length. Therefore, the ISSR is more suitable for measuring high strain gradients such as in welding process. Furthermore, the ISSR measures both in-plane strains and out-of-plane slopes of the deflections simultaneously, while a RSR only measures in-plane strains. This study investigates the feasibility of applying the ISSR to the challenging problem of measuring welding strains/slopes. Obstacles during the experiment were overcome such as the intensive welding light and extreme environmental disturbances. The strain/slope history of welding process was successfully obtained. The residual strains were evaluated via the released strains and residual stresses measured using the RSR/hole-drilling method.

EXPERIMENTS

An ISSR consists of three shallow indentations depressed on a specimen surface [1, 2]. A six-facet delta rosette shown in Fig. 1(a) is used in this test to measure strains and slopes over the three gages defined between each pair of the indentations as shown.

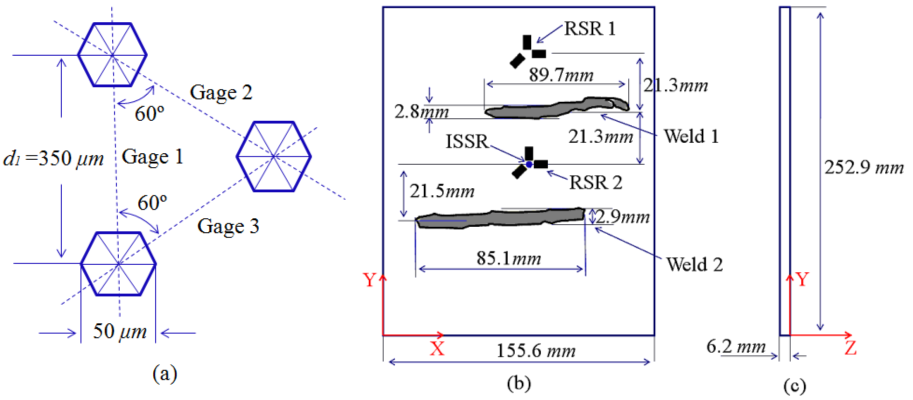

Fig. 1-Schematic of (a) the ISSR, (b) top view of the test specimen, weld and ISSR, (c) side view of the test specimen

When the ISSR is illuminated under a normally incident laser beam, all the facets of the indentations reflect and diffract the laser beam and interference occurs for laser beams reflected in same direction. Therefore, there are six interference patterns with 60° apart from each other. Three gages correspond to the three pairs of interference patterns along the three gage directions. When specimen deforms, the interference patterns will move. By measuring fringe shifts of the interference patterns the strains/slopes can be obtained using the ISSR governing equations [1, 2]. The three in-plane strains are $\delta d_1/d_1, \delta d_2/d_2$ and $\delta d_3/d_3$, where d_1, d_2, d_3 are gage lengths, δd_1, δd_2 and δd_3 are relative change of the gage lengths of gages 1, 2 and 3, respectively. The slopes are $\delta w_1/d_1$, $\delta w_2/d_2$ and $\delta w_3/d_3$, where δw_1, δw_2 and δw_3 are relative out-of-plane displacements of gages 1, 2 and 3, respectively. Using strain transformation equations,

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strain components in XY coordinate can be obtained. Since three slopes along gages 1, 2 and 3 are measured, a least square solution is used to gain slopes in the XY coordinate.

A weld (weld 1) was directly applied on one stainless steel (grade 304) surface using a gasless wire feed welder. A 0.89 mm diameter gasless flux-cored wire was used. The dimensions of the steel, weld and distance to the ISSR are shown in Fig. 1(b) and (c). During the welding, the steel was fixed to a flat table surface using clay at four corners.

Six linear photodiodes were used to intercept the six interference patterns. Installing optical filters on the photodiodes improved the ISSR system from only dark room usage to both dark room and bright room usage. To further prevent the dust and strong welding light from disturbing the laser beam and ISSR, a special shield structure was designed and used. As a result, the ISSR was successfully applied as close as 9 mm distance to the weld in a trial test. Experiments with closer distance between ISSR and weld can be possible. For the test of weld 1, a newly developed real time data acquisition software started recording about 30 seconds before the welding starts, and continued recording during the welding and cooling till specimen was fully cooled down to room temperature. To study repeatability of the test, another welding (weld 2) on the opposite side of the same ISSR was conducted.

RESULTS AND ANALYSIS

Repeatable strain/slope trends are measured for the two welding tests conducted on the stainless steel shown in Fig. 1(b), thus only test results for weld 1 are presented in Fig. 2(a) and (b). Because strains/slopes become stable after 200 seconds, only results between 0 to 200 seconds are shown. As shown, both the strains and the slopes change dynamically with high gradient during welding, and become stable during the cooling process to result in residual strains/slopes. Residual strain/slope in vertical direction are opposite in sign and are higher in magnitude than those in the horizontal direction.

To evaluate the test results of the residual strains, a hole drilling technique is used to cut two holes at the center of the two RSRs installed at the location of the ISSR and opposite to the ISSR as shown in Fig. 1(b). The cumulative strains released by the two 0.8 mm diameter, 0.38 mm deep holes and the corresponding residual stresses are listed in Table 1. Since hole drilling only release strains partially, the released strains are smaller in magnitudes than the residual strains. The released strains have opposite signs compared with the residual strains, which is reasonable because strain gage around the hole is compressed as tensile residual strain is released or vice versa. The released strain magnitude in the vertical direction is about 2.5 times greater than that in the horizontal direction for RSR1, which compares with the ratio of the two residual strains. Furthermore, residual strain results agree with the residual stresses since tensile (compressive) residual strains are expected to correspond with tensile (compressive) residual stresses. Comparisons of the released strains and residual stresses between RSR1 and RSR2 are also reasonable, because RSR2 measures the superposition effects of weld 1 and weld 2.

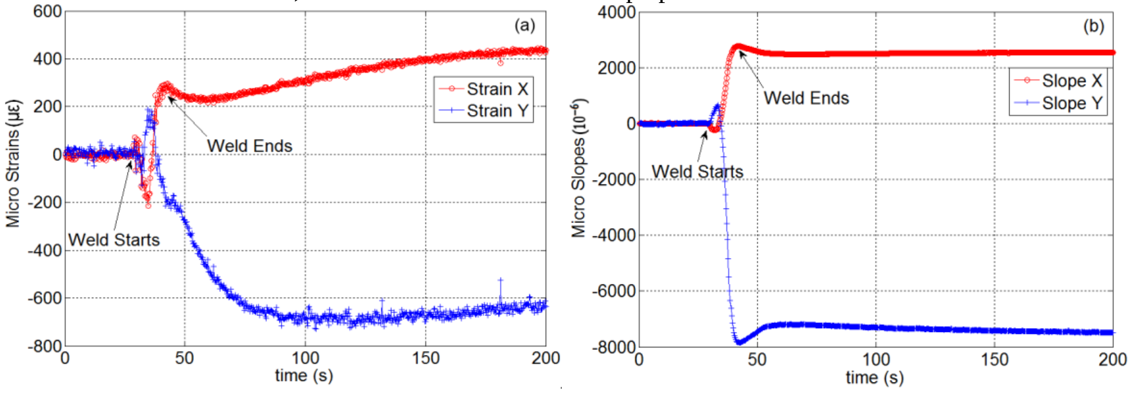

Fig. 2-(a) Strain X and strain Y history (b) Slope X and slope Y history

Table 1-Released strains and corresponding residual stresses by hole drilling technique

	RSR 1 Released Strain	RSR 2 Released Strain	RSR 1 Residual Stress	RSR 2 Residual Stress
Horizontal	-63 $\mu\varepsilon$	-139 $\mu\varepsilon$	35 MPa	117 MPa
Vertical	161 $\mu\varepsilon$	226 $\mu\varepsilon$	-196 MPa	-259 MPa

CONCLUSIONS

The laser-based ISSR technique is, for the first time, successfully applied to measure real time strains and slopes during welding process. This study demonstrates the unique advantages of ISSR such as short gage length, thermal resistant, non-contacting nature, robust and ability of measuring strain/slopes simultaneously under an extreme environment of arc welding with high temperature, dust disturbance and intensive light. In-plane strains and out-of-plane slopes versus time history during welding is successfully measured. The test result is evaluated as reliable since it compares reasonably with the released strains/residual stresses by using hole drilling technique.

References

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[2] Li, K.: Interferometric Strain/Slope Rosette for Static and Dynamic Measurements. *Exp Mech* **37**:111-118, 1997.