Application of Low Transformation Temperature (LTT) Material to Weld Joint for Improvement of Residual Stress and its Measurement Using Contour Method

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1. Introduction

Safety of welded high strength steel structures calls for precise knowledge of the welding residual stresses which profoundly influence the crack resistance and the service load. The fact that the filler material, apart from constructional design and purposeful heat control, may contribute significantly to residual stress reduction is reflected in many studies [1]. Steels with different strength levels have been developed and applied to the welded structures. However, there are major problems exist in the application of these high strength steels to structures. One of these problems is that the fatigue strength of the welded joint is much lower than that of the base metal [2]. Therefore, one feasible and efficient mitigation technique, that alters the residual stresses developed during welding, includes the use of low martensitic transformation start (Ms) temperature welding wire. On the other hand, the contour method (CM) is a newly invented relaxation method that enables a 2D residual stress map to be evaluated on a plane of interest. It provides a higher spatial resolution. CM is performed by a straight cutting along the plane of interest and measuring the resulting deformations on the new free surface. The methodology of the contour method consists of four major steps: cutting, surface topography measurement, data processing and elastic calculations for obtaining stresses from displacements [3].

2. Background and objective

While general weld material causes a tensile residual stress to be generated at a welded part, the low transformation temperature (LTT) weld material uses the transformation expansion of the weld metal to generate a compressive residual stress at the weld metal part and weld toe part. In a previous study, the effect of Ms temperature of weld metal on residual stress distribution in an elongated bead boxing fillet welded joints has been studied and the change of Ms temperatures showed differences in the resulting residual stress [4]. So that, in order to evaluate the resulting residual stresses of welded plates with different Ms temperatures; the contour method using the computational analysis is a powerful tool that can help in predicting the resulting residual stress of different Ms temperatures at the plane of interest.

3. Computational procedure

In this study, two test models have been studied as shown in Fig. 1 using different martensitic transformation start temperatures. A bead-on-plate welding along the model length is carried out with the same welding conditions (6500 W as a heat input and 3 mm/s as welding speed) for the two models.

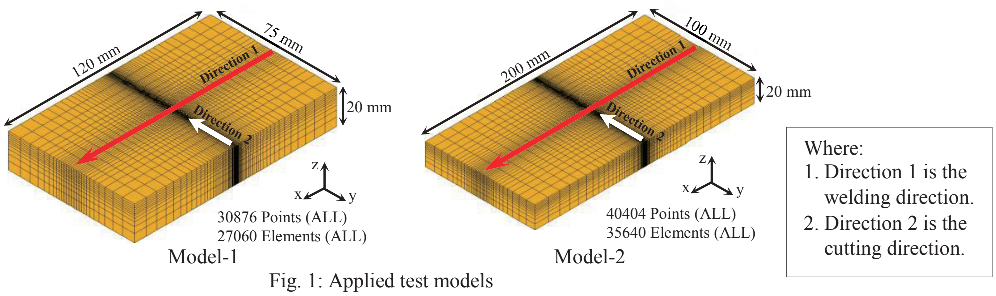

Fig. 1: Applied test models

4. Computational analysis approach

The first stage in this study focuses on validating the contour method using 2-models with different dimensions. In order to achieve this, 3-steps are performed as following: 1) welding step, 2) cutting step, and 3) reproducing the residual stress. In the welding step, the resulting residual stresses due to welding can be computed as σ_1. After that, cutting step is carried out where the created cut surfaces locally deform owing to the relaxation of residual stresses present before the cutting. In this step, the residual stresses (σ_2) normal to the cut surface should be almost zero. On the other hand, the resulting deformations in the cutting step are applied as a forced-displacement to a stress-free model to reproduce the distribution of the residual stress (σ_3). Therefore to validate the contour method numerically, Eqns. (1) to (3) should be achieved. In the second stage, the effect of Ms temperature of the weld metal on the resulting residual stresses is studied by applying five different Ms temperatures as 150, 250, 350, 450 and 500 °C.

$\sigma_1 = \sigma_2 + \sigma_3$ (1) $\sigma_2 \simeq 0$ (2) $\sigma_3 = \sigma_1$ (3)

5. Results and Discussion

In order to select the suitable Ms temperature when using LTT welding wire, contour method was numerically conducted for 2-models with different Ms temperatures; for example as shown in Fig. 2. The original residual stress (σ_1) and the reproduced one (σ_3) show a good agreement for models 1 and 2. On the other hand, Fig. 3 shows that by decreasing the Ms temperature (*e.g.* from Ms 500 °C to Ms 150 °C); the displacement difference between the two cut halves increases and as a result the resulting compressive residual stress at the welding zone increases and becomes almost -600 MPa at Ms 150 °C for the 2-models as shown in Fig. 4. However, the resulting residual stress at Ms 500 °C is compressive in case of model-1 and tensile in case of model-2 as shown in Fig.4. This may be due to the model edge effect. In other words, the edge effect appears when the length of the model becomes short.

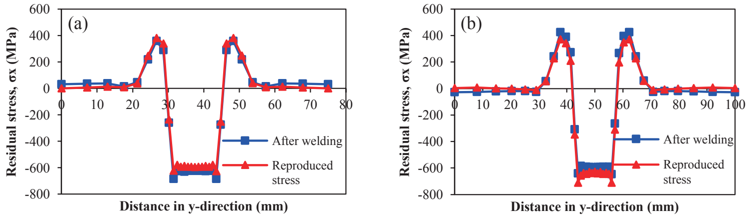

Fig. 2: Contour method validation with Ms temperature 150 °C (a) Model-1 and (b) Model-2.

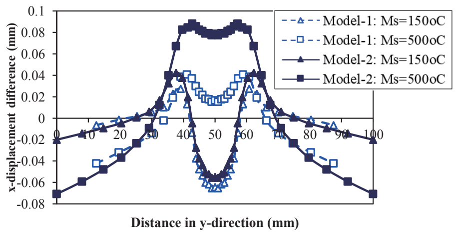

Fig. 3: Displacement difference of models 1 and 2 with different Ms temperatures

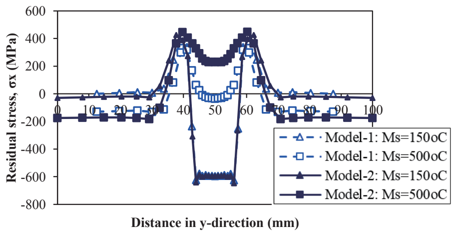

Fig. 4: Resulting residual stresses of models 1 and 2 with different Ms temperatures

6. References

[1] T. Kannengiesser and A. Kromm: Formation of welding residual stresses in low transformation temperature (LTT) materials, Soldagem Insp. São Paulo, 2009, vol.14, pp. 74–81.

[2] S. Zenitani, N. Hayakawa, J. Yamamoto, K. Hiraoka, Y. Morikage, T. Kubo, K. Yasuda and K. Amano: Development of new low transformation temperature welding consumable to prevent cold cracking in high strength steel welds, Science and Technology of Welding and Joining, 2007, 12, pp. 516-522.

[3] D. Braga, H. Coules, T. Pirling, V. Trummer, P. Colegrove and P. de Castro: Assessment of residual stress of welded structural steel plates with or without post weld rolling using the contour method and neutron diffraction, J. of Materials Processing Tech., 2013, 213, pp. 2323-2328.

[4] C. Shiga, H. Murakawa, Y. Matsuo, U. Ohsuga, K. Hiraoka, Y. Morikage and K. Yasuda: Fatigue improvement in high strength steel welded joints with compressive residual stress, IIW Document, 2012, IX-2417-12, IX-L-1100-12.