Experimental report

21/08/2015

Proposal: 1-02-145 **Council:** 4/2014

Title: The effect of weld bead shape on residual stress in novel low heat input welding of steel

Research area: Materials

This proposal is a new proposal

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Local contacts: Thilo PIRLING

Samples: Low carbon steel

Instrument	Requested days	Allocated days	From	To
SALSA	4	4	17/09/2014	21/09/2014

Abstract:

The aim of this experiment is to investigate the effect of weld bead profile on residual stress in steel welded joints. Generally welding of thick steel plate requires high heat input and this leads to poor mechanical properties in the welded joint. The recently developed low heat input submerged arc welding (hereinafter called "SAW") process may offer a solution. The weld bead profile is different from that of conventional welding. It is well known that lower weld heat input can reduce residual stress but the effect of weld bead profile on residual stress is not clarified. This experiment will clarify the difference of residual stress distribution in welded joint manufactured by conventional process and the new method. This work is a part of a collaboration between University of Manchester and JFE Steel Corporation (Japan). The welding process used for the samples is applied to manufacturing pipelines and shipbuilding.

Experimental report for proposal : 1-02-145

Date of experiment : 17th - 20th September 2014

Beamline : SALSA

Title : The effect of weld bead shape on residual stress in novel low heat input welding of steel

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Introduction

Many industrial applications rely on thick section steel welds where the structural member requires high tensile strength, good low temperature toughness, high deformability and corrosion resistance. Welding is widely used to fabricate such steel structures and various welding processes are used. It is well understood that residual stress develops in the welded region of steel materials due to the expansion and contraction associated with the weld thermal cycle and the restraint imposed by the surrounding parent material. Since tensile weld residual stress can negatively affect mechanical properties such as fatigue strength, buckling strength, fracture toughness, stress corrosion cracking, creep damage, weld deformation and weld metal cracking, it is desirable to reduce tensile residual stresses or to introduce compressive residual stress. Though high heat input welding is typically applied to join heavy gauge steel plate for high productivity reasons, this can leads to high residual stresses. Consequently, low heat input welding is widely studied as a mean of reducing residual stress.

On the other hand, the effect of weld bead shape on residual stress distribution in welded joints of heavy gauge steel plates is not clarified. Recently multiple electrode submerged arc welding (SAW) using a smaller diameter welding wire has been newly developed. In this SAW process the smaller diameter welding wire enables arc concentration and an increase in resistant heating, resulting in deep penetration and a high deposition rate. Consequently, a sharp penetration tip with large bead width at the surface is characteristic of this developed SAW process (Figure 1). When applying this Sharp Penetration SAW (hereinafter called SP-SAW) to double side welded joint, it is desirable to know the effect of weld bead shape on residual stress distribution since the penetration tip lies deep within the surface where stress triaxiality is high and is considered to affect the fracture toughness of welded joints. Thus a means of measuring the stresses deep within the bulk is required. With regard to the plate surface region, the residual stress around the bead toe would be expected to affect the fatigue property of the welded joint significantly. These facts increase the importance of residual stress measurement of welded joints of heavy gauge steel plates. The aim of this study is to clarify the effect of weld bead shape on residual stress distribution in steel welded joints made using the same weld heat input SAW but different weld bead shape.

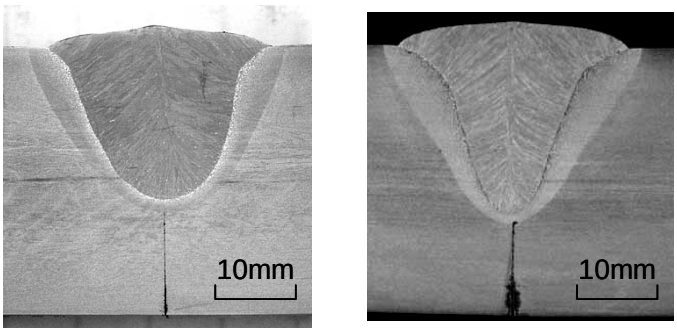


Figure 1 Weld bead shape manufactured under the same weld heat input

Experimental procedure

Two welded joints having different weld bead shapes were prepared with the same weld heat input. The material used was API X70 steel plate with 26.8 mm thickness. Four electrode submerged arc welding (4E-SAW) was applied to manufacture double-sided weldments. For one sample, conventional SAW was applied to both the backing and finishing sides, and for the other sample, conventional SAW was applied to backing side and SP-SAW was applied to finishing side. In addition, restraining plates were attached to the specimens perpendicular to the transverse direction to control the amount of contraction in this direction and eliminate this potential difference from the analysis..

Residual stress measurements of 4E-SAW joints were conducted using SALSA, neutron diffraction equipment at ILL. Welded joint samples for residual stress measurement were prepared as shown in Figure 2. In addition, a 'comb' was cut from the welded joint to measure the stress free reference lattice spacing variation across the welded region. Sample settings and measurement points are shown in Figure 3. Stress measurements were made at only one side of the weld center line (assuming a symmetric distribution of stress either side of the weld-line), in order to reduce measurement time. Residual strains along the longitudinal, transverse and through-thickness directions were measured with gauge volume of 2 mm × 2 mm × 2 mm at all measurement points using a neutron beam having a wavelength of 1.64 Å. The (211) diffraction plane was used for the measurements and diffraction elastic constant of 210 GPa and Poisson's ratio of 0.30, for (211) , were used for residual stress calculation.

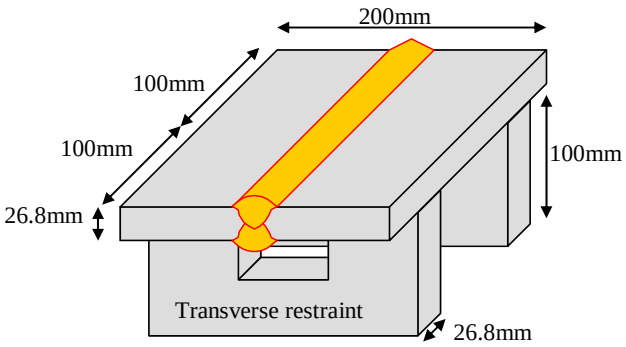


Fig. 2 Appearance of sample for residual stress measurement

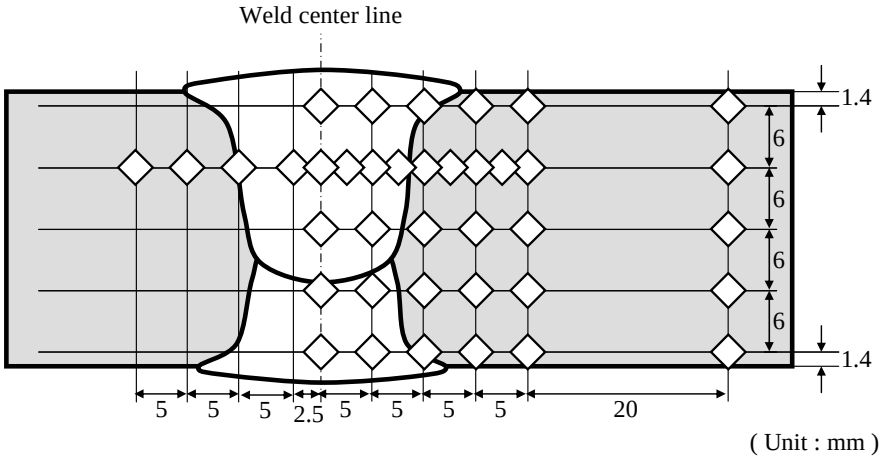


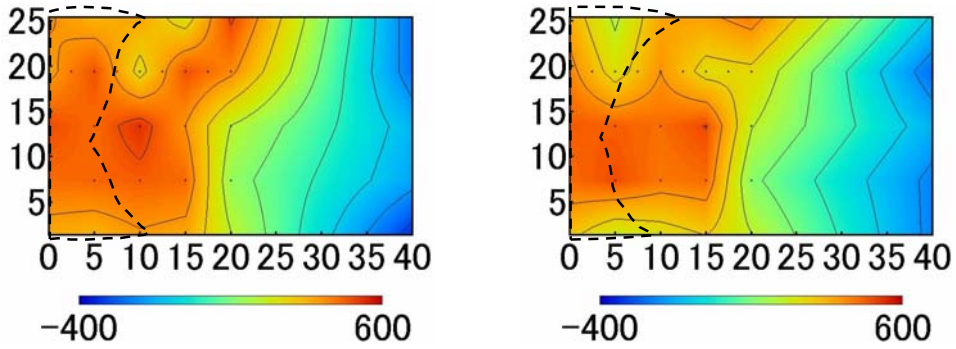
Figure 3 Measurement points of residual strain

Results

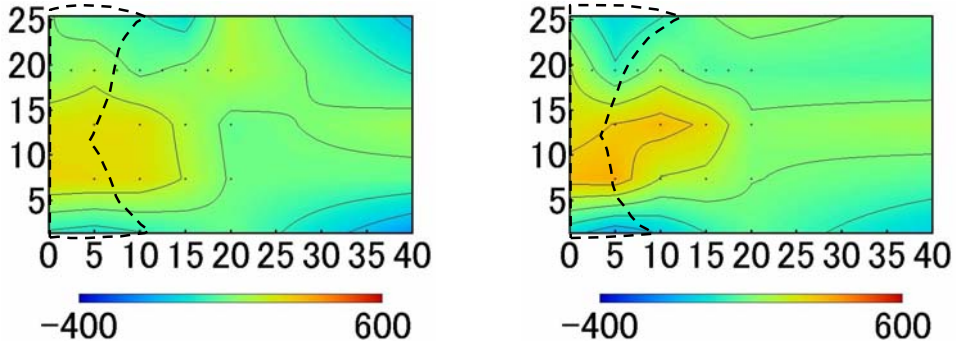
Fig.4 (a), (b), (c) respectively show longitudinal / transverse / through-thickness residual stress across one side of the weld cross section. Longitudinal residual stress in two welded joints appeared similar to each other. Tensile residual stress in weld metal and neighboring HAZ were high, especially tensile residual stress over 500 MPa was observed 5 ~ 10 mm away from the fusion boundary at mid-thickness region. On the other hand, compressive residual stress over 250 MPa was observed 40 mm away from the fusion boundary. Transverse residual stress in

both welded joints had maximum value around its penetration tip of finishing weld and overall distribution of residual stress was similar in both. However, maximum value of transverse residual stress for SP-SAW (358 MPa) was higher than that for conventional SAW (289 MPa).

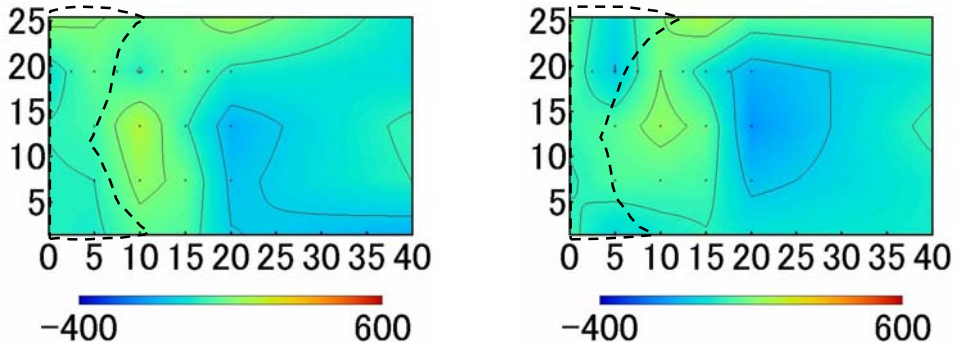
Through thickness residual stress in both welded joints had maximum value 5 mm away from the weld center line at mid-thickness. Maximum values of through thickness residual stress for both welded joints were less than 200 MPa and are much smaller than longitudinal residual stress and transverse residual stress.



(a) Longitudinal residual stress



(b) Transverse residual stress



(c) Normal residual stress

Figure 4 Residual stress distribution of welded joints;
Left : Conventional SAW Right : SP-SAW

Conclusions

The effect of weld bead shape on residual stress distribution in welded joint of heavy gauge steel plate was investigated with neutron diffraction. Residual stress distribution of conventional SAW and SP-SAW showed a similar tendency with regard to all three stress components and no significant difference was observed.