Experimental Report

28/03/2014

Proposal: **1-02-143** **Council:** 10/2012

Title: Study on the application of rolling and laser processing to modify the residual stress state of multi-pass welds

This proposal is a new proposal

Research Area: Materials

Main proposer: **GANGULY SUPRIYO**

Experimental Team: GANGULY SUPRIYO
COULES Harry
SULE Jibrin

Local Contact: PIRLING Thilo

Samples: Ferritic steel (Fe, Mn, C, Ni, Mo, P, S)

Instrument	Req. Days	All. Days	From	To
SALSA	4	4	08/05/2013	12/05/2013

Abstract:

Multi-pass welding of relatively thick structures results into a non-uniform metallurgical structure and a variable distribution of residual field through the thickness and across the weld. In multi-pass welds a previously deposited pass undergoes elastic, plastic, creep and viscous deformation from the deposition of weld metal in successive passes. In ferritic steel this also leads to formation of non-uniform metallurgical phases and microstructural features through the thickness which depends on the variable thermal cycles that a particular weld bead experiences during the entire period of welding. The heat affected zone also undergoes a series of complex thermal cycles and forms different metallurgical phases with variable microstructural features. The non-uniform strain from differential thermal cycle results into formation of a variably distributed residual stress state through the thickness and across the weld. The present proposal is aimed to understand and evaluate the effect of cold working through post weld rolling and subsequent laser processing in generation recrystallised grain structiure with modification of residual stress state.

Experiment Title: Application of rolling and laser processing to modify the residual stress state in multi-pass welds

Proposal Number: 1-02-143

Instrument: Strain Analyser for Large and Small scale engineering Applications (SALSA)

Abstract: In a multi-pass weld, formation of residual stress depends on the response of the weld metal, heat affected zone and parent material to complex thermo-mechanical cycles of welding. In the present study, possibility of creating a refined and recrystallized microstructure with modified stress distribution was investigated by post weld rolling and laser processing. The 3-dimensional stress magnitude and distribution with different processing conditions were analysed using the SALSA strain scanner. Residual strain profiles across the weld and in various through thickness depth were measured in the principal strain directions in 20 mm thick steel plates. The measured strain values were corrected using a stress free reference comb of 4×4×4 mm^3 and stress in the different principal directions were analysed.

In this study, the residual strain was measured in three through thickness locations (2, 10 and 18 mm below the surface on which the final weld pass was laid). The hardening of the weld metal due to successive passes and thereafter post weld rolling and laser processing was evaluated. The results show that up to 2 mm below the weld surface, rolling was effective in improving the longitudinal residual stress distribution, modifying the stress state from tensile to compressive across the weld centre line. Laser treatment after rolling was found to reinstate the original stress state indicating application of excessive thermal energy. In as-welded state, diminishing peak stress magnitude was observed from the cap to root pass. This indicates plastic deformation by thermal straining from successive passes on previously deposited weld metal.

Background and Aim:

Multi-pass fusion welding is a widely accepted process to join thick steel sections used for different engineering applications. Fusion welding creates a graded structure with different microstructure and mechanical properties across the weld metal, heat affected zone and the parent plate. In multiple welding this is even more complicated owing to the thermal cycles introduced from the successive passes. Welding thermal cycles create a variably distributed residual stress field across the weld and through the thickness. In multi-pass welding this stress state becomes more complex due to plastic straining from the multiple thermal cycles.

The effect of such residual stresses in a welded structure could affect the integrity of a structure while in-service due to amplification of the applied stress level and also result in distortion of the structure after welding. Significant research has been focussed in the past, to mitigate weld residual stress and thereby improving the service life of a structure. These includes; post weld heat treatment, shot peening, modification of the structural configuration and the implementation of the thermal tensioning techniques [1,2,3].

The application of rolling to reduce weld residual stress and distortion for a thin plate has been in practice for sometime [4-6]. Coules et al [7] and Altenkirch et al [8] have shown that post weld rolling methods was effective in reducing residual stresses in single pass welds. Application of rolling on multi-pass welds has not yet been reported.

The grain structures in multi-pass welds are dendritic in nature. Laser heating of the weld metal after cold rolling was aimed at recrystallization of the cold worked microstructure. In addition, laser energy may result in tempering of any martensite phase that formed in the weld metal in the welding process. This will have possibly have positive impact on the toughness and thereby on the integrity of the welded structure [9].

To the knowledge of the investigators, this research is novel whereby local mechanical tensioning by post weld rolling and laser heating was applied in a multi-pass weld to mitigate the residual stress and to create a stress free recrystallized grain structure with compositional homogeneity.

The work was performed both in ferritic and austenitic steel. The results observed in the low carbon steel is reported here.

1 Experimental:

1.1 Material

The material used in this study was API 5L X100 grade pipeline steel plate and the filler wire was Union NiMo (1mm diameter). An optimised tandem GMAW power source was used for welding.

Table 1 shows the chemical compositions of the pipeline steel plate and the filler wire. The shielding gas used is 92% Ar and 8% O_2 at flow rate of 30 l/min.The dimension of the test piece is (300 x 150 x 20) mm which was machined out from the X100 pipeline steel plate. A narrow groove (10° included angle) bevel was used with backing bar as shown in

Figure **1**. A 5 mm gap was maintained between the plates. Six passes were deposited to fill the entire groove.

Chemical composition (wt %)														
	C	Si	Mn	P	Mo	Ni	Al	B	Cu	Nb	Ti	V	Cr	S	Others
X100	0.06	0.25	1.79	0.016	0.16	0.13	0.03	<0.0005	0.27	0.03	0.01	0.04	0.03	<0.003	
Filler wire	0.12	0.4 -0.8	1.3 - 1.9	0.015	0.25 - 0.65	0.8 -1.3	-	-	0.3	-	-	-	0.15	0.018	0.25

Table 1: Showing composition of the pipeline steel plate and the filler wire

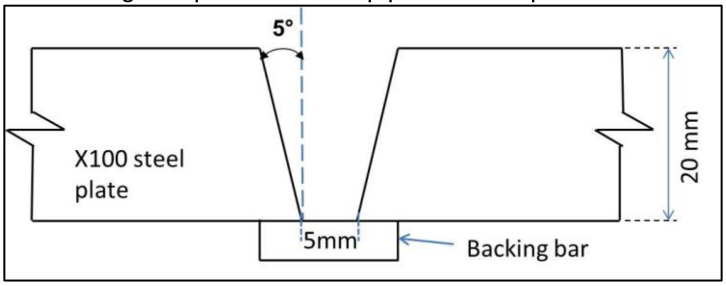

Figure 1: Pipeline steel plate set-up with backing bar

The as welded plates were rolled with 150 kN normal load using a flat roller and then treated with a selected laser processing parameters where the laser power was maintained at 3 kW, travel speed of 0.3 m/min and beam diameter of 20 mm. The laser parameters were derived after performing series of experiments to control the maximum temperature within a specific range.

1.2 Measurement of residual strain

The lattice spacing (d) of {211} crystallographic plane was measured for all the principal strain directions as this family of crystallographic planes closely follows the macroscopic straining pattern of BCC crystal structures [10]. The measurement were made using a neutron incident beam of 1.648 Å wavelengths, which gives a diffraction angle (2Ө) of 87.62^{o}. Through-thickness wall scanning method was used to position the gauge volume accurately. The gauge volume dimension was determined from the slits on the incoming beam and a collimator in front of the detector. The longitudinal strain direction was measured using a 2 × 2 × 2 mm^3 gauge volume while the transverse and the out-of-plane directions were measured using a 2 × 20 × 2 mm^3 gauge volume. The increase in gauge volume along the welding direction during measurement of transverse and normal directions was based on the assumption that the stress state would remain identical in the longitudinal direction.

2 Result and Discussion:

The residual stresses analysed across the weld are shown in fig. 2. The residual stress state in the as welded samples

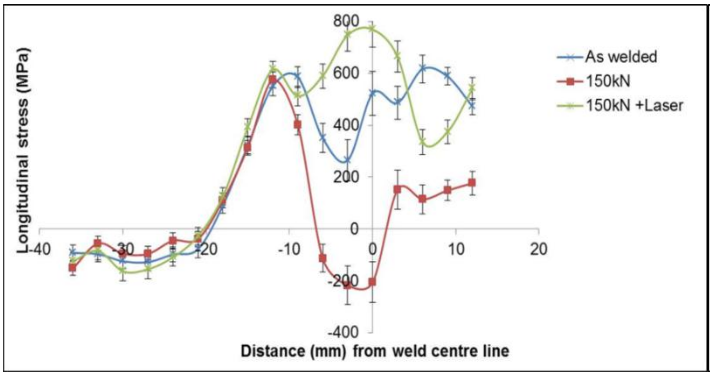

Fig. 2 – Residual stress profile across the weld in specimens with different processing conditions. Measured 2 mm below the top surface.

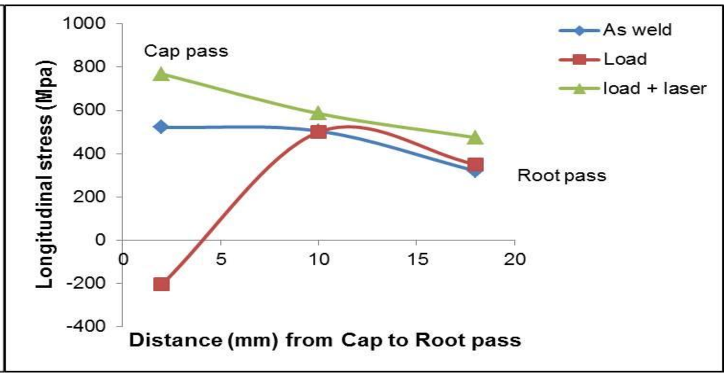

Fig. 3 – Variation of peak residual stress magnitude through the thickness of same specimens shown in fig. 2.

showed the familiar distribution of tensile type in and around the weld while it reduces sharply and become compressive in the far field parent metal. Application of rolling dramatically changed the stress state and distribution. Plastic deformation associated with the rolling changed the tensile stress to the desirable compressive type while application of post weld heating by laser reinstated the stress state.

Fig. 3 shows that the peak magnitude of the tensile residual stress in as-welded condition reduces through the thickness. This could be attributed to the fact that, the thermal straining from subsequent passes tends to reduce the stress of the previous pass. As shown in fig. 3, the effect of the rolling load and laser processing are significant up to about 5 mm below the weld surface. This was also confirmed from through thickness which clearly indicated the extent of cold working.

2.1 Application of rolling

As shown in, post rolling (measurement taken at 2 mm below the top surface) has changed the longitudinal residual stress state to compressive around the weld metal (peak tensile residual stress of 522 MPa to compressive stress of 205 MPa). When a material is put in service, the in-service stress combines with the locked in residual stresses. Therefore, the presence of this compressive stress component is beneficial since it enhance fatigue life. Application of rolling to the welded joints causes yielding of material in the weld region, thereby, relieving the residual stresses that may exist in the region. This agrees with the work reported by Coules et al [11], Altenkirch et al [8] and Wen et al [12].

The extent to which plastic straining is produced by a roller depends on the roller dimension and the contact area (in this case the weld metal). As can be seen in fig. 2, the compressive region is narrower than the width of roller (30 mm wide roller was used in the experiments). This is because the roller makes contact with the top of the weld which is narrower as compared to the width of roller. In this study, rolling causes plastic deformation in a 19 mm wide region around the weld.

2.2 Laser treatment after rolling

As can be seen in fig. 2, laser treatment after cold rolling reinstated the longitudinal residual stress state with a peak magnitude of 770 MPa indicating an excessive thermal energy input in a spatially constrained region resulting inhomogeneous plastic deformation and tensile residual stress. Reinstating the original stress profile is detrimental to the integrity of the structural weld as they increase the susceptibility of a welded structure to in-service failure mechanisms e.g. fatigue and stress corrosion cracking. Therefore, it can be concluded that in its present state, the application of the thermal energy through laser processing was excessive. Further studies needed to understand the interaction of the thermal energy with the cold rolled microstructure and also how effectively it can be applied to refine the microstructure but avoiding re-formation of the residual stress state.

3 Conclusion

Following conclusions were made from the experiments:

- Up to about 4 mm below the top surface, rolling was effective in improving the longitudinal residual stress distribution, modifying the stress state from tensile to compressive across the weld centre line.
- Application of thermal energy by laser in its present state is excessive and further study needed to ensure avoiding reformation of the residual stress state.
- In as-welded state, through the thickness (cap to root pass), reduction of the peak magnitude of the longitudinal residual stress was observed. This indicates thermal straining by successive passes on previously deposited weld metal.

Reference

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