Experimental report

02/11/2020

Proposal:	**DIR-169**	**Council:**	10/2018
Title:	Residual stress measurement in transient liquid phase-bonded steel components		
Research area:	Engineering		

This proposal is a new proposal

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Samples: Medium carbon steel
Low carbon steel
Low-alloyed Steel

Instrument	Requested days	Allocated days	From	To
SALSA	4	4	18/02/2020	22/02/2020

Abstract:

Transient liquid phase bonding (TLPB) has a great potential to develop lower Residual stresses (RS) compared with arc welding processes. In TLPB, the whole joint is pre-heated to the process temperature - below the melting point of the base metal, held constant at this temperature during a pre-set time, and subsequently cooled to ambient temperature at a controlled cooling rate. The way in which heat is delivered allows the development of much lower cooling rates at the joint, which enables an increase in austenite transformation temperature, helping to relieve RS associated with this phase transformation.

The outcome of the present experiment is to determine up to which extent diminishing cooling rates - by means of the TLPB process - reduces the development of RS at the joint and the heat affected zone in these welds. In order to carry out this experiment, we propose to measure RS with SALSA stress scanner in TLP-bonded steel bars of different grades - low carbon, medium carbon and low-alloyed steels - in the as-welded condition, for the longitudinal, hoop and radial directions.

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Introduction

Hot-wrought steel bars (Ø 25 mm) were welded by means of the transient liquid phase bonding (TLPB) process. Three different steel grades were used as base metals: ASTM A29 1015 (low carbon, Yield strength (YS) = 300 MPa), 1040 (medium carbon, YS = 425 MPa), and 4140 (low-alloyed, YS = 675 MPa).

Amorphous metallic foils (25 µm thick) METGLAS® SA1 ($Fe_{92}Si_5B_3$ in wt.%) were used as filler material, which were placed between the bars to be welded.

Regarding the thermomechanical parameters of the TLPB process, it was carried out at process temperature T_P = 1300 ºC – which was held constant at this temperature during t_H = 7 minutes, with an applied pressure of 4 MPa.

Experimental

The 211 Fe peak was measured using a layout with 2θ = 93º and a gauge volume of 2 × 2 × 2 mm^3.

Residual stresses (RS) scanning was performed in each weldment in the radial direction (RD), hoop direction (HD), and axial direction (AD), as it is shown in Fig. 1. It is worth noting that based on RD scanning results, a symmetry pattern was observed with respect to the XY plane and the Z axis (see section Results). Therefore, the scanned area of HD and AD was reduced having in mind the abovementioned symmetries.

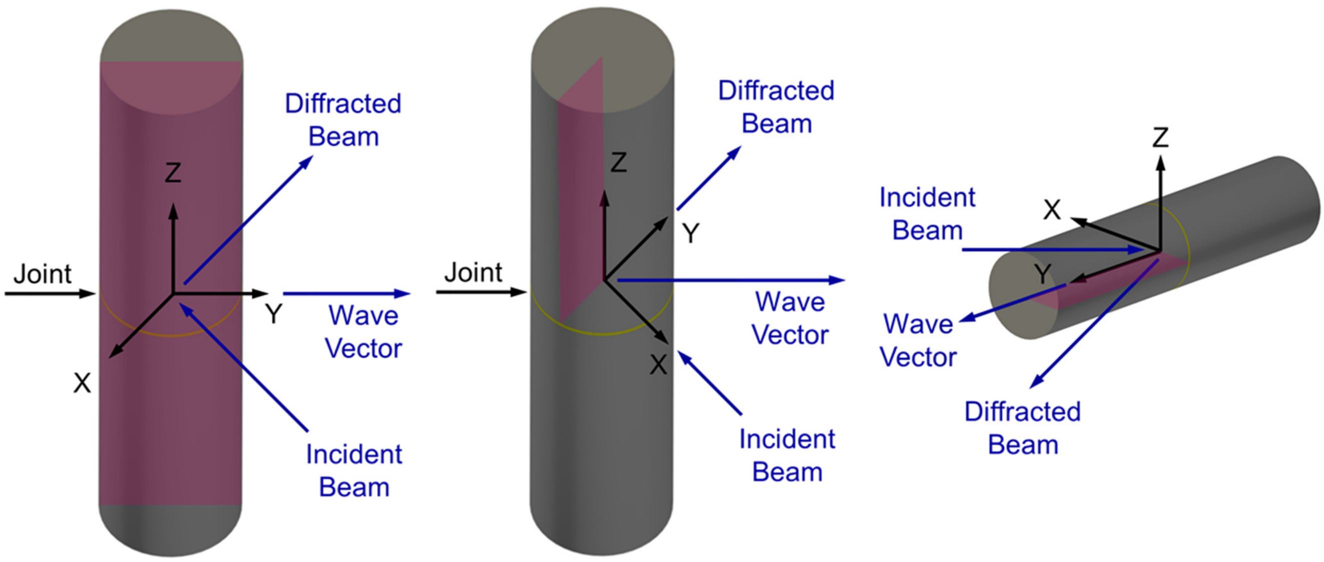

Fig. 1. RS scanning layout for each measured direction. From left to right: RD, HD and AD. Light red areas show the scanned area in each layout.

In addition, comb reference samples were measured to determine the strain free lattice spacing (d_0). A sample for each steel grade was cut from other weldment performed identically to that who was measured. The size of each of cube was 3 x 3 x3 mm^3, to allow the whole neutron gauge volume to fit inside it.

Results

Fig. 2 shows the measured 2θ at the selected points in RD for the 1010 and 4140 steel weldments. Based on the minimum and maximum values of 2θ, a symmetry plane at Y = 0 – the joint plane, and Z = 0 – the axis of revolution, can be observed. Therefore, HD and AD scans were carried out only in second quadrant of the YZ and XY planes, respectively.

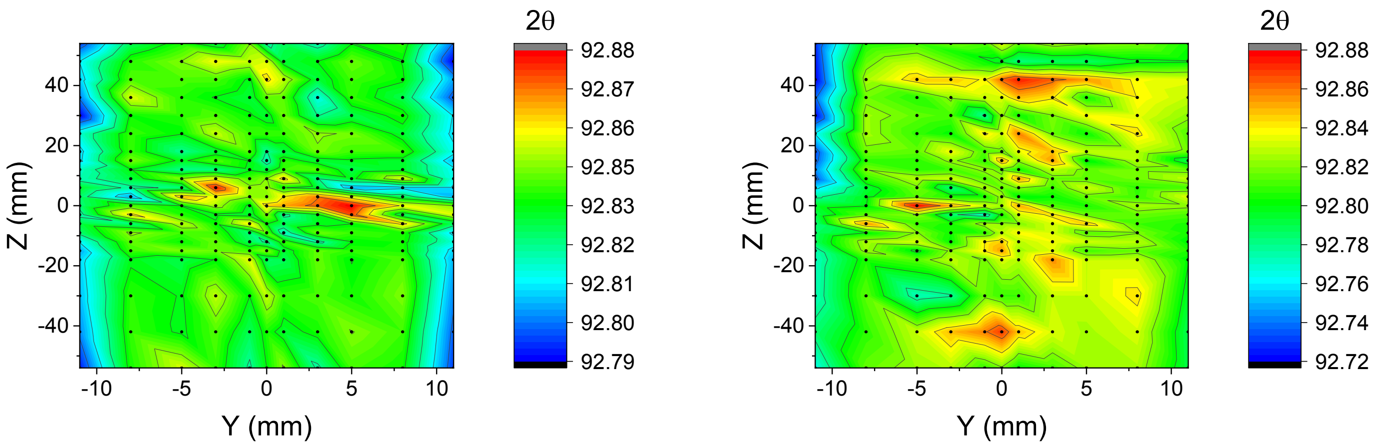

Fig. 2. Measured 2θ at the selected points (black dots) in RD for the 1010 (left) and 4140 (right) steel weldments.

Fig. 3 shows the resulting RS for the 1010 steel weldment. A compressed core is observed, particularly at the joint and/or its neighboring region (the joint position is Y = 0 in AD scan, and Z = 0 in HD and RD scan). The observed peak value is 61% of the YS of the base metal.

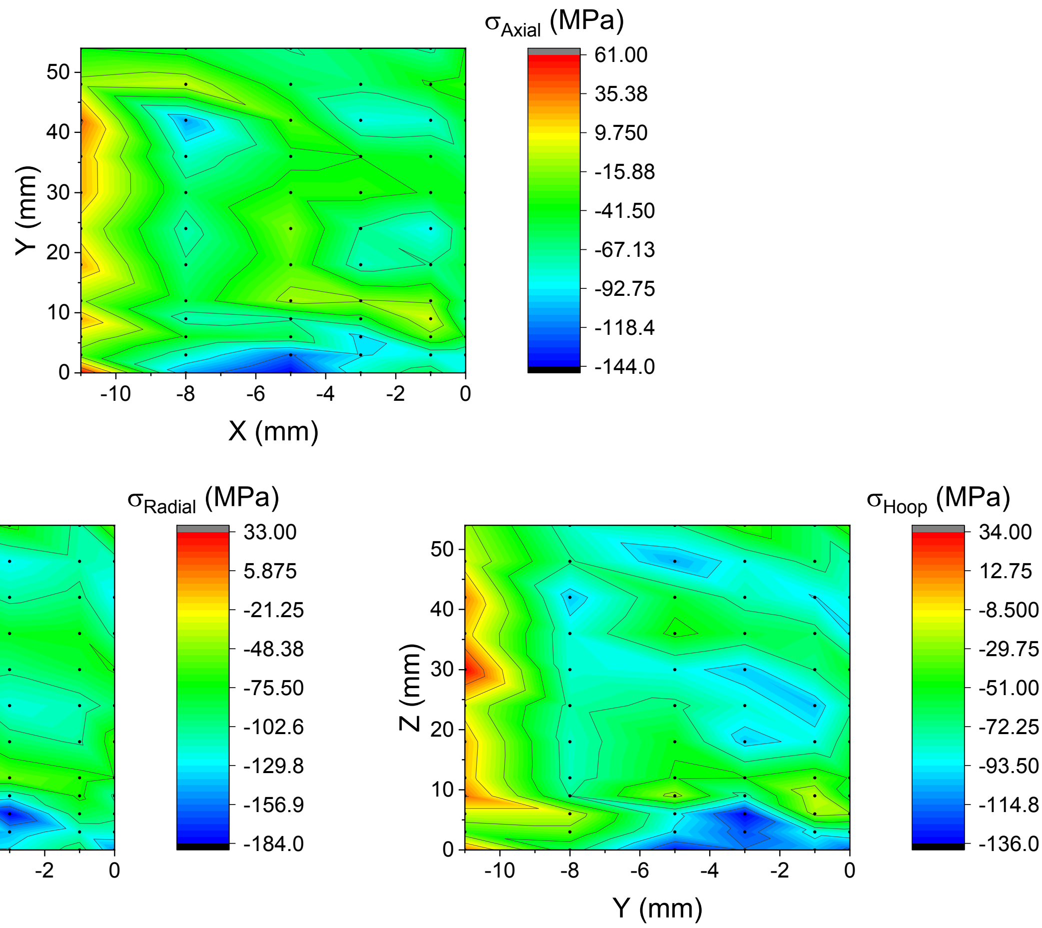

Fig. 3. RS mapping for the 1010 steel weldment.

Fig. 4 shows the resulting RS for the 4140 steel weldment. Again, A compressed core is observed. However, and in addition to the joint and/or its neighboring region, peaks and dips in compression are also detected up to 40 mm from the joint. Regarding its peak value, it is 55% of the YS (675 MPa).

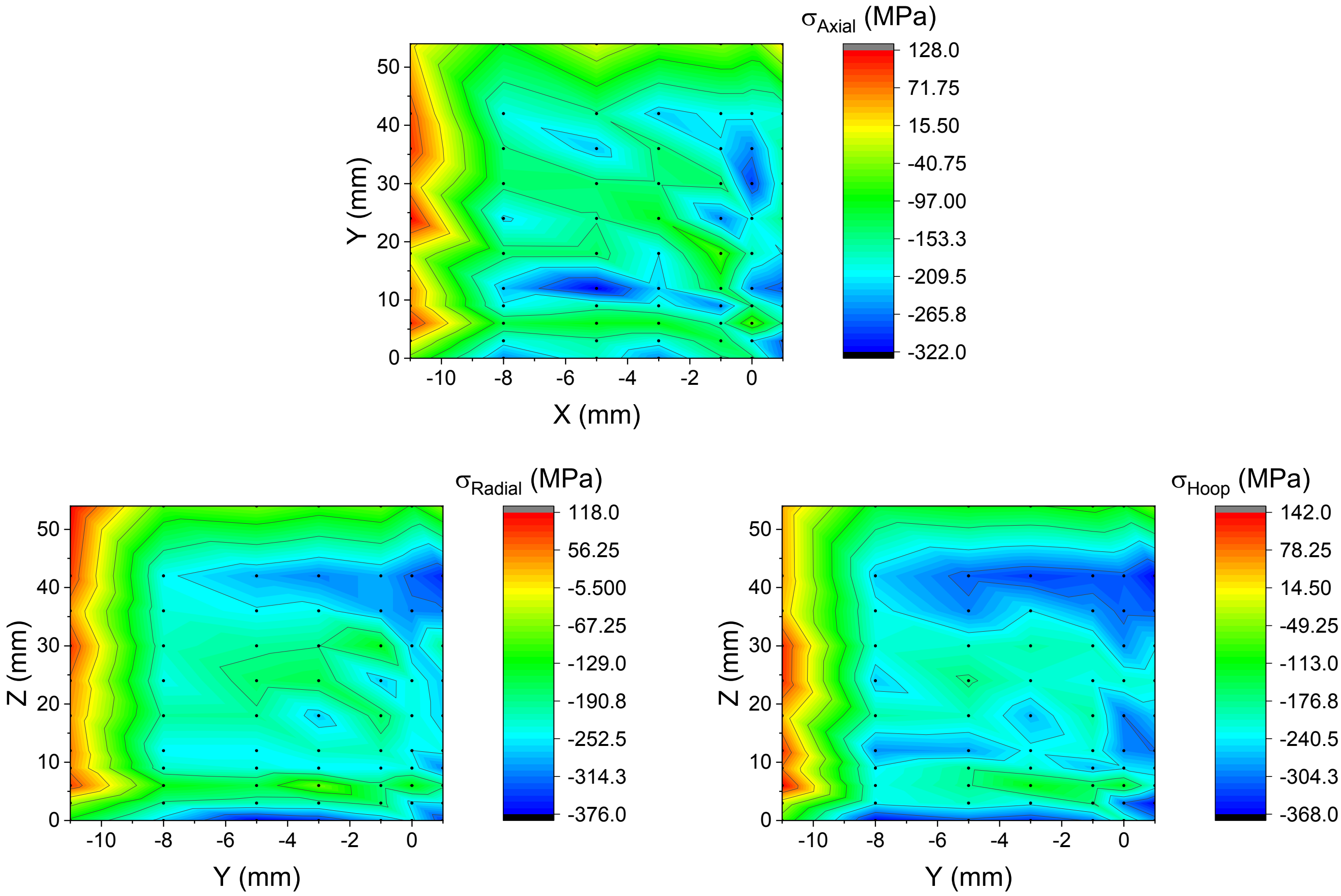

Fig. 4. RS mapping for the 4140 steel weldment.

Conclusions

TLPB process exhibits clearly different RS patterns compared with the commonly used arc welding techniques, in which RS typically reach the yielding point of the base metal – in tension. And this is directly related to the way in which heat input is carried out.

Since the whole joint in simultaneously heated to T_P , held t_H at this temperature, and subsequently cooled down to room temperature, a compressed core is obtained on the welded bars. This is similar to what happens is normalizing and quenching processes. In addition, and in the as-welded condition, the measured peak values attained ≈ 60 % of the YS of the base metal. This is due to the way in which heat is delivered, which allows the development of much lower cooling rates at the joint – particularly in the 800-500 ºC temperature range (TLPB ~ 6 min vs. 3 – 50 secs in arc welding processes). As a result, it enables an increase in the austenite transformation temperature, helping to relieve RS associated with this phase transformation.

However, the observed fluctuations on the measured compression patterns should be further analyzed. In particular, by studying the thermal cycle of the TLPB process by numerical simulation, which will allow to take into account particular details of the process (e.g.: heat input by induction heating).

Finally, it is worth noting the outstanding performance of SALSA strain imager. This was particularly evident when measuring in the AD layout – in which both the incident and diffracted neutron beam had to go through several cm of steel – without affecting the measurement. In these measuring conditions, any type of X-ray diffraction method is unsuitable, and the reported RS results could only be obtained by neutron diffraction. In addition, it is noteworthy the available neutron flux, hexapod sample positioning system and sample aligning devices.