DEFORMATION BEHAVIOUR OF WELDED STAINLESS STEEL – CARBON STEEL SANDWICH SHEET MATERIAL

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Ključne riječi:

Key words: stainless steel, sandwich sheet material, welding, formability

Sažetak:

Abstract: Formability of welded austenitic stainless steel (321 type) – low carbon steel (1010 type) sandwich sheet material was tested. Gas tungsten arc welding (GTAW) and shield metal arc welding (SMAW) procedures were used. After applying the GTAW welding process the weld metal hardness was found considerably higher than after using the SMAW process, due the higher consumable fraction in case of the GTAW welding procedure. The bendability of the tested weldments appeared to be satisfying, but the biaxial stretchability of the welded sandwich sheets was considerably lower compared to the base material (33 % - 45 % degradation). The stretchability degradation brought by welding was found the lowest in the samples welded by the lowest heat energy input. The strain distribution after equibiaxial stretching of the welded sheets, was very inhomogeneous due the different hardening abilities of the base and weld metal.

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1. INTRODUCTION

There is an increasing interest for replacing solid stainless steel sheets or plates by sandwich sheet composites due the opportunity of producing different types of industrial vessels with improved properties at lover cost [1, 2]. Carbon steel sheet plated with stainless steel on its one or both sides takes advantage of the corrosion resistance of the austenitic stainless steel while making use of the strength and low cost of carbon steel. Further improvements are related to the benefits as an improved heat transfer characteristics, good strength and ductility, improved electrical properties, improved vessel design at lower cost. Important point for the successful application of the joined sandwich sheets is the ability of the material to sustain different shaping demands affected by the types of acting stress systems and the ductility of weldment.

In this work AISI 1010 type low carbon steel has cladded with AISI 321 stainless steel without inter layer strip using by explosive bonding procedure. Such a safely bonded sandwich slabs were further hot rolled on continuous hot rolling mill, using on line accelerated cooling (OLAC) at the end of hot rolling line, avoiding the traditional final heat treatment of austenitic stainless steel [3]. The considered sandwich material consists of components which exhibit a good weldability and they are readily joined by standard welding processes in a wide range of applications, extending from thin sheet linings to relatively heavy section joints. The aim of this work was to study the formability of the welded stainless steel – carbon steel sandwich sheet material and the formability degradation in respect the full material, after applying the Shield Metal-Arc Welding (SMAW) and the Gas Tungsten-Arc Welding (GTAW) procedures.

2. EXPERIMENTAL WORK

2.1. Material

The stainless steel - low carbon steel sandwich slabs were produced by explosive bonding. The bonded slabs after ultrasonic control of the bonding quality was heated up to (1200 °C) and hot rolled down to 4,6 mm in 6 stand tandem rolling mill. The chemical composition of sandwich components is given in Table 1. The stainless steel layers make 10.5% - 14 % of the total thickness of the sandwich material.

Table 1. Chemical Composition of sandwich components.

	AISI	C %	Mn %	P %	S %	Si %	Cr %	Ni %
Stainless steel	321	0.10	2.00	0.040	0.030	1.00	18.00	10.00
Low-Carbon steel	1010	0.12	0.50	0.040	0.040	0.040	-	-

2.2. Welding

Two different welding procedures applied to join the tested sandwich sheet: (i) Shield Metal-Arc Welding (SMAW) and (ii) Gas Tungsten-Arc Welding (GTAW) often called Tungsten Inert Gas welding (TIG) [4]. Double square-groove butt joints were designed, as it is shown in Figure1. The samples were welded without preheat and post-weld heat treatment. Interposes temperatures are typically maintained bellow 100 – 150 °C. Austenitic, 2,5 and 3,2 mm diameters E18.8MnB20+ electrodes (ISO 3581 designation) were used in direct current-electrode positive SMAW process, and the 18/8Mn6 TIG wires in direct current-electrode negative GTAW process. The chemical composition of the used consumables is listed in Table 2.

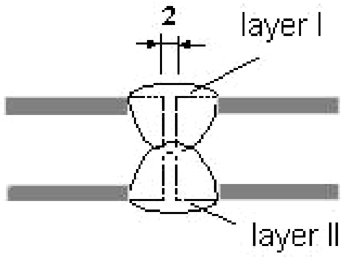

Figure 1. Sketch of the used double square-groove butt joint.

Table 2. Chemical composition of the welding consumables (wt %)

ISO 3581 Designation	Welding Process	C, (%)	Cr, (%)	Ni, (%)	Mn, (%)
E18.8MnB20+	SMAW	0.12	19	9	7
18/8Mn6	GTAW	0.12	19	9	7

The heat inputs of 13.4, 8.4 KJ/cm using 2.5-mm wire, 17.9, 12.2 using 3.2-mm wire for SMAW and 22.5, 18.8 KJ/cm for the GTAW were applied for layer I and layers II, respectively. These two procedures were used to join the sandwich sheet samples for the uniaxial tension test, as well as, for biaxial stretching. Also, all the welding joints checked up using by liquid penetrates and radiographic control, avoiding using samples for further testing with any defects at the surfaces or across the bulk. Experimental joints welded by GTAW process were marked as T, samples welded by SMAW process using 2.5 mm and 3.2 mm diameter electrodes were marked as R and D, respectively.

2.3. Testing

Hardness measurement. The hardness profiles of the weldments were determined using by Vickers, HV10, procedure.

Tensile testing. Sheet specimens with a gauge length of 100 mm are tested on "AMSLER" tensile testing machine, at a crosshead rate of 10 mm/min. The tensile strength (UTS) of the butt-welded joints was determined using by specimens, shaped, as it is shown in Figure 2.

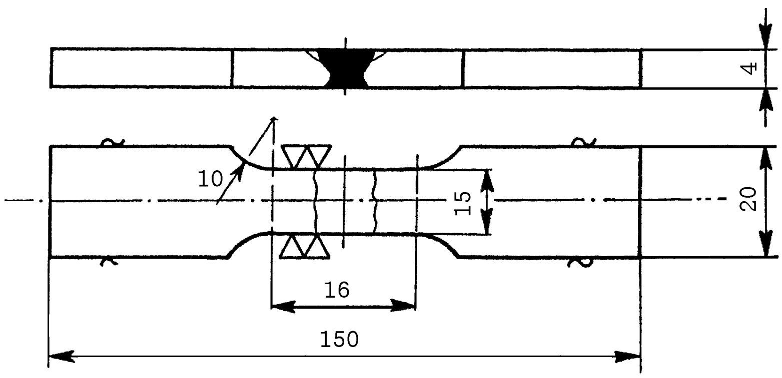

Figure.2. Tensile specimens used for UTS measurement in butt-welded joint.

Bend test. Face bend test and root bend test (three-point bend) made, using 12 m diameter deflector bar.

Dome test - Biaxial stretching. Gridded rectangular blanks of 150mm were firmly clamped and stretched in a "Hille" hydraulic press, over a 75 mm diameter hemispherical punch (Figure 3).

The punch rate was 8 mm/min. As a lubricant polyethylene foil was used. During stretching, the load-punch displacement was recorded. The sheet blanks were prepared from the as received material, but some of them were cut on halves and than joined the two halves, applying the considered welding processes.

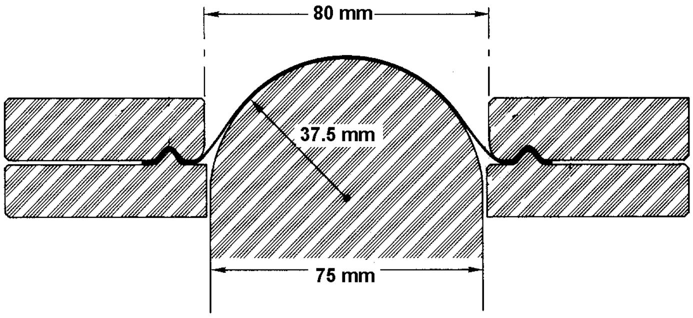

Figure 3. Sketch of the equibiaxial stretching over hemispherical.

3. RESULTS AND DISCUSSION

Table 3 shows that the ultimate tensile stresses (UTS) are very close for all three types of specimens (marked as T, R and D), ranged to 440MPa ÷ 450 MPa. In all cases fracture occurs in the position of base metal, implying deformation concentration in the softer base metal, what is assumed to be the reason for the same UTS values?

Table 3. Welding conditions and mechanical properties of weldments

Welding method	Consumable (ISO3581)	Weld. current (A)	Arc voltage (V)	Welding speed (cm/min)	Heat input (KJ/cm)	UTS (MPa)	Bend test	
							Face bend	Root bend
GTAW	18/8Mn6 ∅2.5 mm (T)	120	22	I layer-7	22.5	450	good	good
				II layer-8.4	18.8			
SMAW	E18.8MnB20+ ∅2.5 mm (R)	80	28	I layer-10.0	13.4	440	good	good
				II layer-16.0	8.4			
	E18.8MnB20+ ∅3.2 mm (D)	110	28	I layer-10.3	17.9	445	good	good

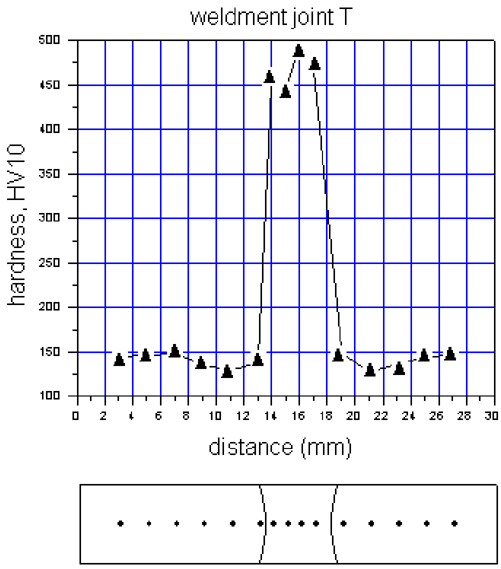

Figure 4. Hardness variation of welding joint after applying the GTAW process (T sample).

The hardness variation across the welded specimens after applying the GTAW welding procedure (T samples) and SMAW procedure (R and D samples) is shown in Figures 4 and 5, respectively. The base metal hardness was ranged to ~ 140-150 HV, while the hardness markedly increased in the weld metal, reaching ~ 240 HV in R samples, ~ 270 HV in D, or even ~ 500 HV in the case of T samples. The considerably higher hardness attained in the latest sample is attributed to the higher consumable fraction after applying the GTAW welding procedure compared to the SMAW process.

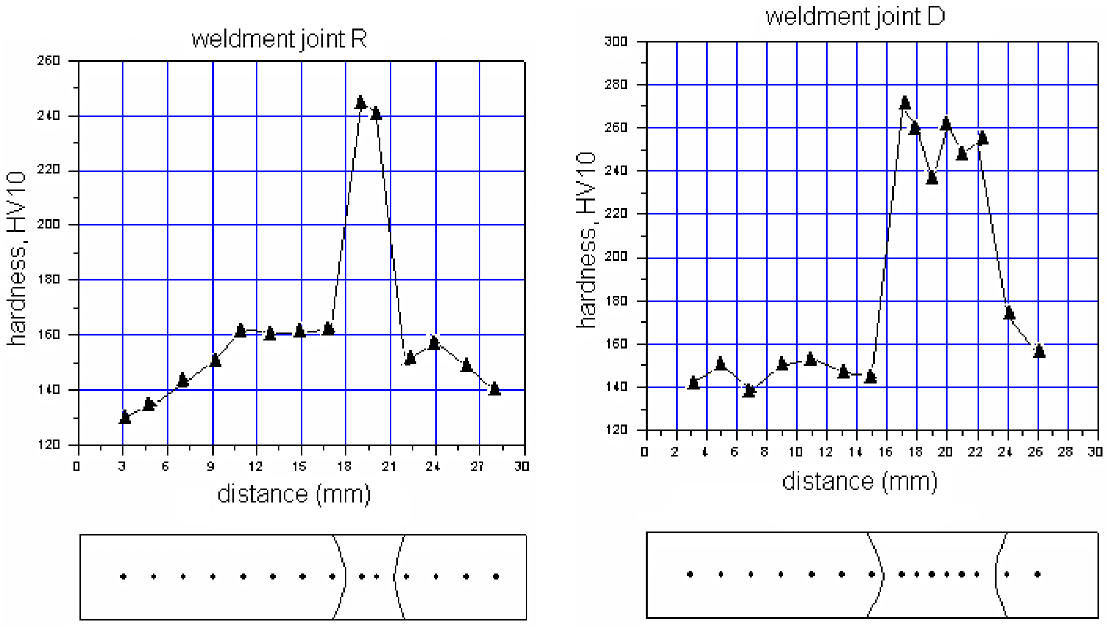

Figure 5. Hardness variation of welding joints after applying the SMAW process (R and D samples).

Namely, the hardness of the weld metal mostly depends on the base metal portion melted in the weld metal (compared to the portion of the filler material) and also on the metallurgical reactions in the melting pool. The bendability of the tested weldments appeared to be satisfying in all cases. Cracks were not detected on the tensile surfaces after bending more than 140° in both face and root bend tests.

Table 4 and Fig. 6 show the load and dome heights (indentation depth) attained during equibiaxial stretching of the bulk sandwich material (base material) and the welded samples. The given results, showing degradation of dome heights in case of welded samples, make clear that the biaxial stretchability of the welded sheet samples is decreased in a great deal.

The biaxial ductility decreased for ~ 33 % in the case of R weldments, and in cases of T and D weldments for ~ 43 % and ~ 45 %, respectively. The necessary stretching load is also lowered according to the lower degree of stretching attained in the welded sheets. So, it seems that the SMAW welding process for the R condition (see Table 3.1) allow much better biaxial stretching properties of the tested sandwich sheets than after the D welding condition or after the T condition applied by the GTAW welding procedure.

It was assumed that the superior stretchability brought by the R procedure is due the lowest heat energy input and appropriately the narrowest heat affected zone (HAZ). This effect can be recognized as a shortest range of the risen hardness for sample R in respect to T and D (Figures 4 and 5).

Table 4. Degradation of load and depth

Sample	Load, kN	Dome height, mm	Load degradation, %	Dome height degradation, %
Base material – A	78	42	-	-
weldments R	57	28	26.9	33.3
weldments T	51	24	34.6	42.8
weldments D	44	23	43.6	45.2

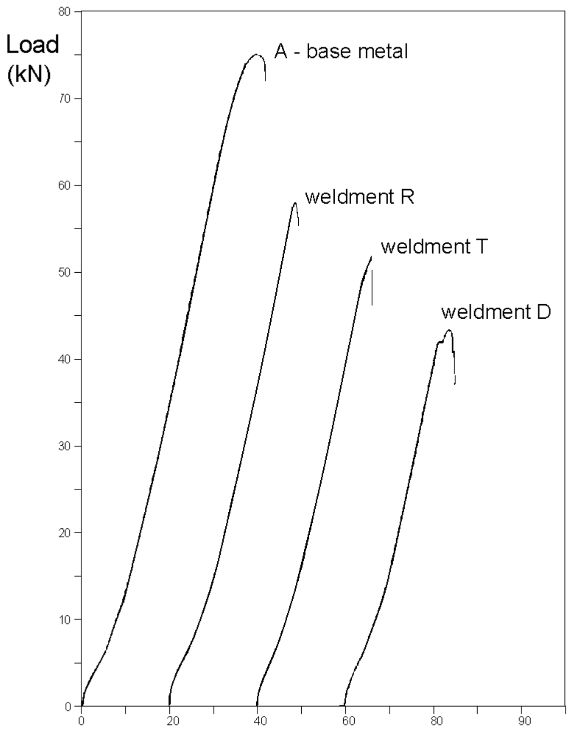

Figure 6. Load and dome height curves for the sandwich sheet materials and welded sheet samples after applying different welding procedures.

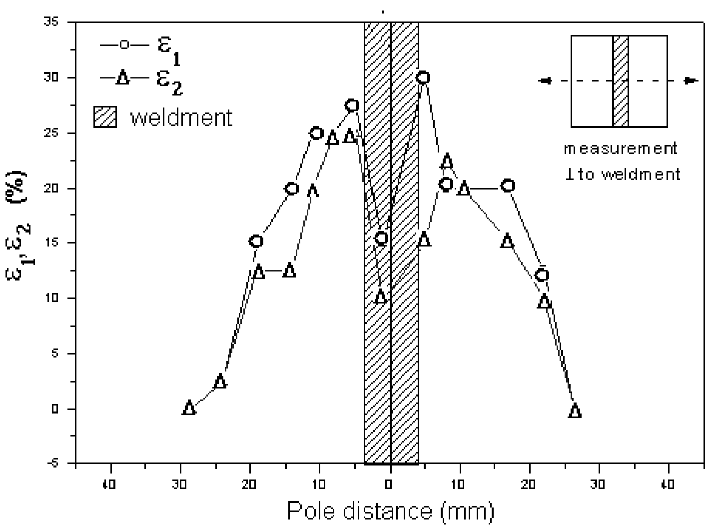

Figure 7. Strain distribution for weld metal R-90°

It should be also noted, that considering the influence of the heat energy input on the level of biaxial stretchabilty, in case of the T samples it could be further improved, as in the GTAW process the energy input can be more concentrated, i.e. the heat affected zone more reduced.

The HAZ influence on the stretchability of welded sheets can be recognized easily by following the strain distribution normally to the weld metal. Such measurements are shown in Figure 7 for the R sample. The measurements in the transverse direction indicate an abrupt drop of the radial and circumferential strain components in the area of the weld metal. The noticed effect indicate that during equibiaxial stretching of the welded sheets, the deformation distribution is very inhomogeneous, as the weld metal do not straining equally with the base material, because the different structure and mechanical properties compared to the base material.

In Figure 8 comparison is made between the strain distribution in the base material and in the weldments (along the weld metal). The area difference under the strain distribution curves for the base material and the weldments basically reflect the stretchability difference of those materials [10]. Considering the strain distribution in Figure 8, besides the higher strains attained in the base material compared to the weldments, it is interesting to note that the ability of the strain distribution of the tested weldments basically in accordance with the considered effect of the heat energy input influences. It seems that the largest area appeared under the R-sample's strain distribution curve, followed by areas under curves for T and D samples.

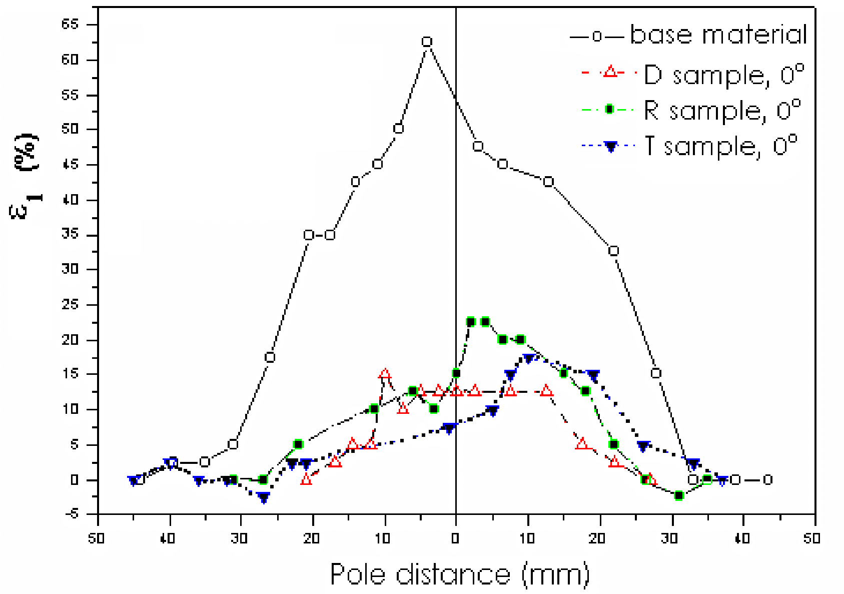

Figure 8. Comparison of strain distributions across the dome attained in the base material and the sheet samples welded by T, R and D procedures.

Such a formability limitation of welded sheets was recognized in suiting the so called Tailor Welded Blanks (TWB's), for forming application in the car industries [5,6,8,9]. Today they are joined by laser welding, producing the most localized HAZ [5, 7] and offers a good way to save the formability potential of the base material.

4. SUMMARY

Formability of welded austenitic stainless steel (321 type) – low carbon steel (1010 type) sandwich sheet material was tested. Two welding procedures were applied: gas tungsten arc welding (GTAW) and shield metal arc welding (SMAW). The sandwich sheets were tested using by uniaxial and equibiaxial stretching in order to asses the basic mechanical properties and stretching behavior of the welded sheets.

After applying the GTAW welding process the weld metal hardness was found considerably higher than after using the SMAW process, what is assumed to be due the higher consumable fraction in case of the GTAW welding procedure compared to the SMAW one.

The equibiaxial stretching tests have shown that the biaxial formability of the welded sandwich sheets is considerably lower compared to the formability of the base material (33% - 45% is lower compared to the base material). Also it was found that the ductility degradation brought by welding of the tested sandwich sheet material was the lowest in the samples welded by the lowest heat energy input, i.e. the most suppressed range of the heat affected zones.

The strain distribution measurements revealed that during equibiaxial stretching of the welded sheets, the deformation distribution is very inhomogeneous, as a result of the interplay of the deformation properties of the harder weld metal and the softer - more ductile sandwich base material.

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