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TIG WELDING OF ADVANCED HIGH STRENGTH STEEL SHEETS

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Abstract
To reduce self-weight, car manufacturers and machine part producers tend to parts made of high strength steels and advanced high strength steels. The load bearing capacity of these components depends largely on the quality of the welds, therefore the joining of such high strength steels sheets by automatized tungsten inert gas (TIG) welding without filler metal was investigated. The selected steel grades were transformation induced plasticity (TRIP) steel (with 1000 MPa ultimate tensile strength) and twinning induced plasticity (TWIP) steel (with 800 MPa ultimate tensile strength). The weldability of both steel grades without filler metal and without pre heating and post weld heat treatment was investigated also in dissimilar joints. The visual and metallographic examinations, hardness measurements and tensile testing showed that the usability of this welding process to weld good TWIP-TWIP joints is good, to TRIP-TRIP joints is limited and to TRIP-TWIP joints is poor.

Keywords: *Advanced high strength steel, Transformation induced plasticity steel, Twinning induced plasticity steel, Tungsten inert gas welding, Quantitative metallography.*

1. INTRODUCTION

To decrease self-weight of steel structures and machine parts manufacturer tends to use steel grades with higher and higher strength. Although structural steels can have very high ultimate tensile strength (S700, S960...S1300QL [1]) their welding is difficult, and the formability and fatigue properties of the joints are not very high [2-5]. At applications where safety and toughness is especially important -like in car bodies- other types of high strength steels (HSS) or advanced high strength steels (AHSS); like dual phase, transformation induced plasticity (TRIP) and twinning induced plasticity (TWIP) steel grades are used [6, 7].
The TRIP and TWIP AHSS grades have large plasticity which makes them ideal for the production of difficult car body parts and they have also very good tensile properties to increase passenger safety and to decrease the weight of the vehicle. However the welding of these steel grades has challenges because of the high alloying element content and small grain size and in case of TRIP steel the four-phasic microstructure[8]. So far gas metal arc welding (GMAW) [9] also with flux cored wire [10] resistance spot welding [11-13] and laser beam welding [14-18]of these AHSS sheets have been studied. But studies about the tungsten inert gas welding (TIG) or gas tungsten arc (GTA) welding of AHSS steels is rear and their mostly about low alloy HSSs [19]. Therefore in our current study we intend to determine the weldability of high alloy TRIP and TWIP steels.

2. MATERIALS AND METHODS

To investigate the possibility of robotized TIG welding neither filler metal (142 process) nor preheating or post weld heat treatment was used during the tests.
The AHSS types investigated in this study were one TRIP steel and one TWIP steel. The steel grades were: Zn-coated HCT800T (1.0948) steel, commercial name TRIP 800 and 22Mn0.6C steel, commercial name TWIP 1000 with the nominal 800 MPa and 1000 MPa ultimate tensile strength (UTS) respectively. The chemical composition and main properties of the used AHSSs are listed in *Table 1*. The TWIP steel had fully austenitic microstructure, the trip steel contained 60.2% ferrite, 25.4% bainite, 2.4% martensite and 12.2% austenite. The microstructure of the used base AHSSs are shown in *Figure 1*.

Table 1 Chemical composition and main properties of the used materials

Materials	**Chemical composition [wt. %]**							**Sheet thickness [mm]**	**Tensile properties**				**grain size, d [μm]**
	C	**Mn**	**Si**	**Al**	**Ni**	**Cr**	**Fe**		**UTS [MPa]**	**YS [MPa]**	**$A_{11.3}$ [%]**	**Z [%]**	
TRIP 800	0.27	2.1	1.52	0.25	-	-	bal.	1.5 ± 0.05	795±6	490±14	21±1	9±1.5	2.6
TWIP 1000	0.51	15.0	0.46	1.00	-	13.0	bal.	1.0 ± 0.05	1030±12	540±15	52±2	8.5±1	4.9

For the welding tests 100×50 mm pieces were cut mechanically from the sheets without edge chamfering. The AHSS sheets were cleaned before the welding with acetone. The sheets were mechanically clamped and butt welded perpendicular to the roll direction to 100×100 mm specimens. For the welding tests a REHM Invertig.Pro® digital 350 AC/DC welding machine automated with a Yamaha F1405-500 type linear drive was used. The welding torch was perpendicular to the sheets the working distance to the thicker sheet was 4 mm. The tungsten electode was Ø 2.4 mm, WT20 type (~2% ThO_2) with 30º bevel-angle. As shielding gas 99.996 % argon was used both face and root side. During the welding process the sheets were not in direct contact to each other, at the end of the sheets 1 mm gap was left to provide co-axial joints and the sheets were mechanical clamped during welding. The height step (in case of the TWIP-TRIP joint) was on the torch side. The polarity for the welding tests was DC+. Preliminary welding tests were made with different parameters, than visually examined. During parameter optimization the specimens were evaluated on the basis of the macroscopic joint appearance, full weld penetration and absence of visible weld defects (cracks, burn through etc.). The welding parameters which were evaluated to be the best according to the visual examinations are listed in *Table 2*.

Table 2 The TIG welding parameters for the AHSSs

Joint type	**Current [A]**	**$V_{welding}$ [$cm \cdot min^{-1}$]**	**Ar_{face} [$l \cdot min^{-1}$]**	**Ar_{root} [$l \cdot min^{-1}$]**
TRIP TRIP	35	8	12	8
TRIP TWIP	39	8	12	8
TWIP TWIP	39	8	16	8

The specimens for microscopic examination were mechanically cut in cross sections, mounted in metallography resign and mechanically grinded on SiC papers P80, P120, P320, P600, P1200, and P2500 with continuous water rinsing. Finally the specimen were polished with 1 μm and 0.5 μm particle size Al_2O_3 suspension. After etching the specimens were investigated with Olympus PMG3 optical microscope. Tensile tests were made with MTS 810 universal materials testing machine. To prepare the tensile specimen the sheets were grinded to achieve even sheet thickness and cross section area. Hardness measurements were made with Buehler 1010 Vickers hardness tester on specimens prepared for metallographic investigations. Nickel and chromium equivalents ($Ni_{eq.}$, $Cr_{eq.}$) were determined according to *Equation 1 and 2.*

$$Ni_{eq.}=\%Ni + 30\times\%C + 0.5\times\%Mn + 30\times\%N \tag{1}$$
$$Cr_{eq.}=\%Cr + 1.4\times\%Mo + 1.5\times\%Si + 0.5\times Nb + 2\times\%Ti \tag{2}$$

The $Ni_{eq.}$ and $Cr_{eq.}$ values and the predicted phases after welding according to Schäeffler diagram – presuming 50-50% intermixture of the two sheet parts in the weld pool – are listed in *Table 3*.

Table 3 The $Ni_{eq.}$ and $Cr_{eq.}$ values and the predicted phases of the weldments

Joint type		$Cr_{eq.}$	$Ni_{eq.}$	predicted microstructure
TRIP	TRIP	0,69	9,15	austenite+martensite
TRIP	TWIP	7,19	15,98	martensite
TWIP	TWIP	13,69	22,80	austenite

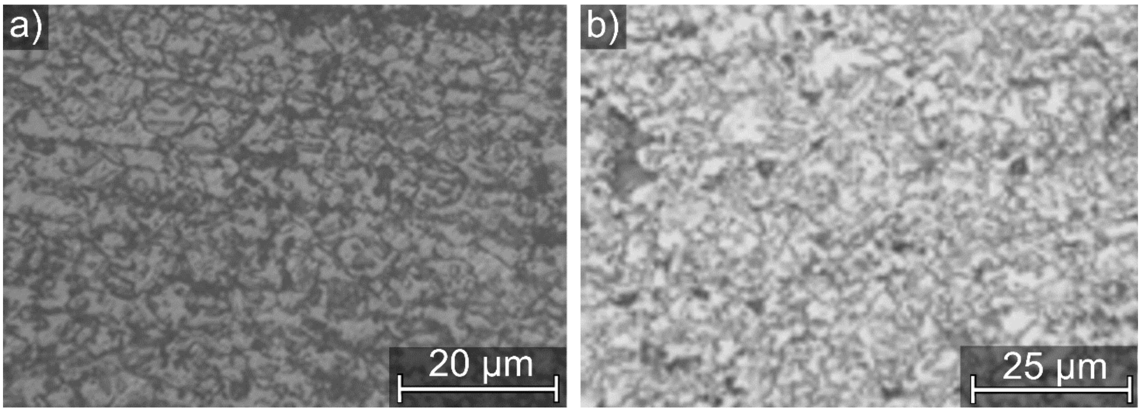

Figure 1 Light microscope micrographs of the: a) TRIP 800 and b) TWIP 1000 AHSSs

3. RESULTS AND DISCUSSION

The visually best looking joints of each type (welded according the parameters of *Table 2*) are shown in *Figure 2*. No visible weld defects could be detected, therefore these joints were investigated further in details. The microhardness profiles and the corresponding micrograps of the selected joints are shown in *Figure 3* and the results of the tensile tests are listed in *Table 4*.

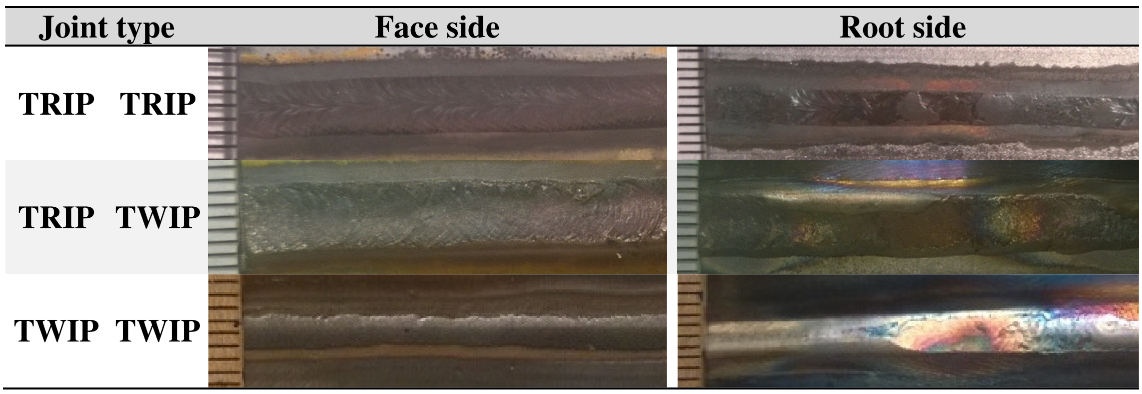

Figure 2 Macroimages of the weld beads

In case of the TRIP-TRIP joints the weld metal in the fusion zone had fine martensitic microstructure (as expected from Table 3) with considerable hardness of ~500 HV01. The heat affected zone (HAZ) had coarser grain structure with martensite and retained austenite. The tensile properties of the joints showed decreased UTS~760 MPa (due to coarse grain structure in the HAZ) with ~8% fracture elongation which is lower than the base material but for most engineering applications it could be acceptable. Note that at lower root side shielding gas flow rates < 7 $l \cdot s^{-1}$ a slight discoloration alongside the weld occurred originating from the Zn-coating of the sheets and at too high flow rates > 9 $l \cdot s^{-1}$ the melt-through was not sufficient. Altogether it is possible to automatize the welding of TRIP to TRIP steel sheets for mass production.

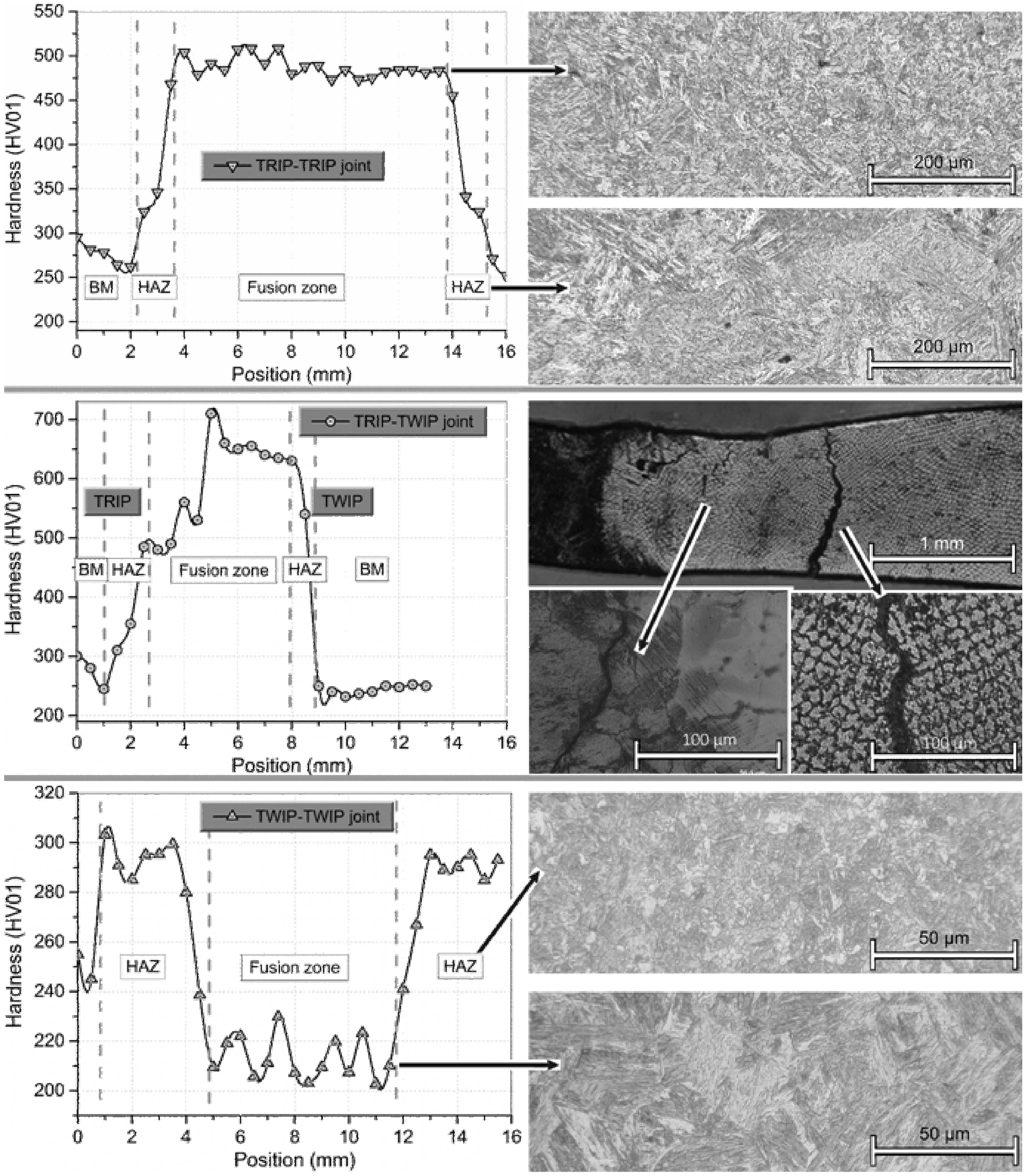

Figure 3 The hardness profiles of the welded joints and the corresponding optical microscope micrographs of the different zones

In case of the TRIP-TWIP weld metal, coarse dendritic microstructure was found and although they appeared visually good there were intergranular cracks in the weldment indicating cracking while solidification. The hardness profile showed excessive increase in hardness up to 700 HV01 in the weld metal. Tensile specimens cold not been made from the joints, because they broke brittle during machining. As a conclusion it is not recommended to weld this combination of AHSSs without any filler metal or special heat treatment considerations.
In case of the TWIP-TWIP joint the fusion zone contained some bainite and had a lower hardness values (~ 210 HV) than the base material. The HAZ had finer grains also with some bainite and had higher hardness values (~290 HV) than the base material. The tensile tests showed about 950 MPa UTS with considerable (~22 %) fracture elongation (about 43% of the base material), and ductile fracture. Therefore the weld can be qualified as a good joint and it is most suitable for robotized TIG applications.

Table 4 The Tensile properties of the TIG welded specimens for the AHSSs

Joint type		**UTS [MPa]**	**$A_{11.3}$ [%]**
TRIP	TRIP	762± 20	8.16±1.37
TRIP	TWIP	-	-
TWIP	TWIP	949±105	21.59±6.31

CONCLUSIONS

In our research the applicability of TIG welding without filler material (142 welding process) without excess preheating or post weld heat treatment to join TRIP 800 and TWIP 1000 thin AHSS sheets was investigated for the purpose of future robotization for mass production (for e.g. car body parts welding). From the above mentioned investigations the following conclusions can be drawn:

- TRIP-TRIP joints can be made with adequate quality but the welding process is sensitive to the shielding gas flow rate.
- To weld TRIP-TWIP joints 142 process is not recommended, to achieve crack free joints special heat treatment sequence needs to be developed, but it will be most likely not economic for mass production
- TWIP-TWIP welds had the best mechanical and ductile properties, it is the easiest to make therefore recommended for automation.

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