



EFFECTS OF HIGH CONCENTRATION HYDROGEN DURING GMA WELDING OF DUPLEX STAINLESS STEEL

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Abstract

In our research the effects of high concentration hydrogen (argon + 13.5 % to 15.0 % hydrogen) in the shielding gas was compared to pure argon in case of gas metal arc welding of LDX 2404 lean duplex stainless steel. The hydrogen in the shielding gas increased the weld bead width, penetration depth and the average arc voltage too. In the microstructure and hardness distribution no significant differences were observed with the addition of hydrogen in the argon shielding gas.

Keywords: duplex stainless steel, gas metal arc welding, hydrogen, arc voltage, weld geometry

1. INTRODUCTION

Duplex stainless steels (DSS's) are one type of corrosion resistant stainless steels which contain approximately equal amount of ferrite and austenite phases. One special type of DSS's called lean duplex stainless steel (LDX), which has got the expression "lean" after their reduced nickel and molybdenum content. The reason of development of LDX's was the extensive fluctuation of nickel and molybdenum prices on the metal stock market experienced at the beginning of the 21st century [1]. Nowadays, beside the extensive spreading application of high strength steels in automotive industry [2, 3] the development of LDX's has a great attention and lean duplex started replacing regular austenitic (e.g. AISI 316 and 304) grades [4-7]. The welding of DSS's is often related with complex issues due to their double phase microstructure, however nowadays it can be stated DSS's generally demonstrate decent weldability [8]. During the gas metal arc (GMA) welding of DSS's, 1-2 % active component (CO₂ or O₂) or higher concentration of helium (up to 30 %) beside argon (Ar) is recommended to be used as shielding gas [9]. In some cases smaller concentration (1-5 %) of nitrogen is also recommended because of nitrogen's strong austenite forming ability [10-14]. One of the biggest challenges during welding of DSS's is to keep the phase balance in the weld metal (WM) and heat affected zone (HAZ). The usage of hydrogen (H₂) in the shielding gas in welding of austenitic stainless steels is widely used (mainly during gas tungsten arc (GTA) welding) [15-17], however the usage of hydrogen during the welding of DSS's is generally not recommended because of the possibility of hydrogen embrittlement or hydrogen cracking [18-19]. The interaction between hydrogen and duplex stainless steel is based on a complex mechanism, which can be originated from the dual phase microstructure of DSS's. The diffusivity of hydrogen is much higher in ferrite, than in austenite. The effective diffusivity of hydrogen in duplex steel containing 44 % austenite is reduced 400 times in comparison with fully ferritic steel [20]. This means the transport of hydrogen through DSS's occurs mainly through the ferrite matrix and austenite works as a hydrogen trap. It also means the transport paths of hydrogen in the ferrite phase are not straight because they must pass around the austenite grains [20]. The shapes of these paths are more complicated in case of the weld metal. The duplex weld microstructure consists of Widmanstätten austenite leading to more



tortuous paths [21]. On the other hand hydrogen-associated degradation of mechanical properties is much higher in ferrite, than in austenite [21]. In order to investigate the effects of hydrogen from the shielding gas Ogawa and Miura [22] performed GTA welding on different DSS's with shielding gas hydrogen content varies from 0 to 10 % in argon. With higher ferrite ratios cracking occurred during welding with 2-10 % hydrogen content, however preheating to 200°C and solution heat treatment were confirmed to be effective for crack prevention. Kordatos et al. investigated [23] the effect of 10 % hydrogen (beside 90 % argon) in shielding gas during GTA welding of 2507 type (EN 1.4410) super duplex stainless steel. The ferrite content increased due to the decreasing atomic nitrogen content in the weld metal. The hardness of the weld metal increased to the effect of hydrogen and hydrogen addition had a deleterious effect to the pitting corrosion. In case of usage of hydrogen in the backing gas, Westin et al. [24] experienced the best pitting corrosion resistance with using 90 % N₂ +10 % H₂ backing gas besides the mechanical properties had no significant change.

2. EXPERIMENTAL METHODS

The used base metal (BM) was 3 mm thick 2404 type (EN 1.4662) lean duplex stainless steel plate (*Figure 1*) with low nickel and molybdenum, however high nitrogen content (*Table 1*). The plate was welded in solution annealed condition as came from the manufacturer. The used filler material for bead-on-plate run welds was G 22 9 3 NL type (AWS A5.9 ER2209) duplex stainless steel welding wire with the diameter of 1.2 mm.

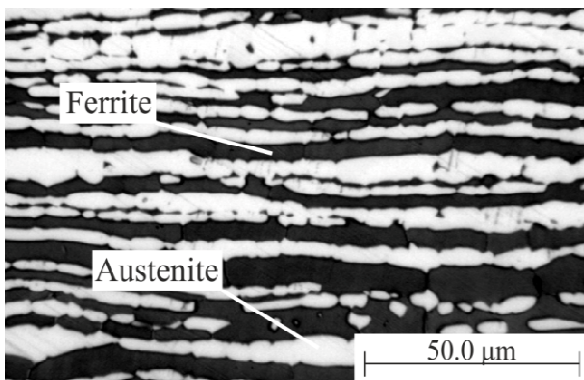


Figure 1 Microstructure of LDX 2404 base material (colour etched)

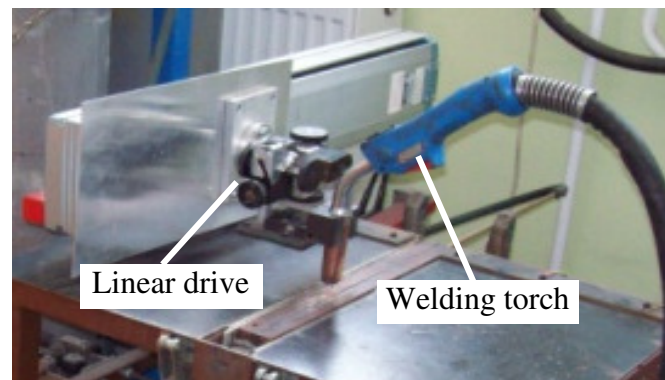


Figure 2 The automated assembly with the welding torch and linear drive

Table 1 The nominal chemical compositions of the LDX 2404 plate and the ER2209 welding wire

Material	Chemical composition of the used materials, nominal values (wt.%)						
	C	N	Cr	Ni	Mo	Others	Fe
LDX 2404	0.02	0.27	24	3.6	1.6	3Mn Cu	Bal.
ER 2209	<0.015	0.15	22.5	8.8	3.2	2Mn	Bal.

The welding process was performed on a Rehm Megapuls 300 type machine automated with a Yamaha F1405-500 type linear drive (*Figure 2*). The linear drive ensured the constant welding speed and constant nozzle gap. The fixed parameters of the welding processes are as follows: welding speed=4.7 mm·s⁻¹, wire feed speed=3.6 m·min⁻¹, current=130 A, arc voltage=20.7 V, shielding gas volume=12 l·min⁻¹ and the nozzle distance=10 mm. The welding was performed with direct current, wire positive (DC+). The steel plates were cleaned with acetone just before welding. The position of the plates was fixed by a clamp device. On one plate 100 mm long weld seams were



made. Before the next welding sequence the plates were cooled down to room temperature on air. The welding process variables were the 5 different shielding gas mixtures with hydrogen content; 0 %, 13.5 %, 14.0 %, 14.5 %, 15.0 % next to argon (specimens designated as H0, H13.5, H14.0, H14.5 and H15.0, respectively). High concentration of hydrogen in shielding gas was used in order to investigate the effects which can be originated only from the hydrogen in the shielding gas and to get major differences compared to pure argon. The external weld geometry measurements were done using a calliper in 10 points. For metallographic examination sections perpendicular to the weld seams were saw cut under constant cooling. The cross section were mounted into epoxy resin and grinded up to 2400 grit paper and after polished with 3 μ m diamond suspension. The used etchant contained 100 ml distilled water, 18 ml hydrogen chloride (HCl) and 1 g potassium pyrosulfite (K₂S₂O₅). This etchant makes the ferrite phase appear darker and the austenite phase lighter because of the sulphide layer. The used optical microscope was Olympus PMG3 and the stereomicroscope was Olympus SZX16. For Vickers hardness measurements (HV10) KB Prüftechnik KB750 type equipment was used. The hardness measurements were performed in cross sectional specimens along a line 1 mm deep from the plate surface. The ferrite content measurement of the BM and WM was done using JMicroVision 1.2.7 image analyzer software on 10 metallographic images e.g. *Figure 1* with ~ 0.36 mm² areas typical to the microstructure.

3. RESULTS AND DISCUSSION

During all the welding processes smoke and soot formation were experienced. In case of hydrogen in the shielding gas metal splashes and unstable electric arc were observed. The unstable electric arc led to big differences in the weld geometry.

3.1 Changes in the weld seam geometry

Compared to pure argon (H0) the high concentration of hydrogen increased the weld bead width and penetration depth and decreased the height (*Figure 3* and *Figure 5*).

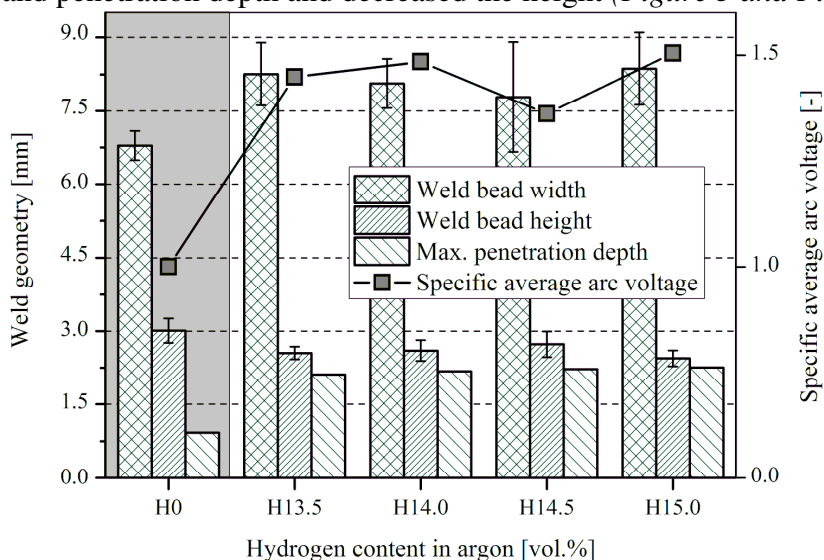


Figure 3 Weld geometry and average arc voltage values as a function of the H₂ content in the shielding gas

The biggest increase (compared to H0) in the average weld bead width is 23 % and the biggest increase in the penetration depth is 244 %, which were measured with H15.0 shielding gas. These values are in good correlation with the increasing average arc voltage, registered by the welding equipment. Compared to H0 shielding gas the arc voltage increased by 51 % in case of H15.0. The increasing arc voltage resulted in the bigger penetration depths and wider weld beads. The changes in the weld geometry and penetration depth occur in

the changes of the form factors. The external form factor can be calculated as the ratio of bead width and the height and the internal form factor as the width over the penetration depth (*Figure 4*). With high concentration in the shielding gas the external form factor increased with 28-52 % and

the internal form factor decreased with 47-52 %.

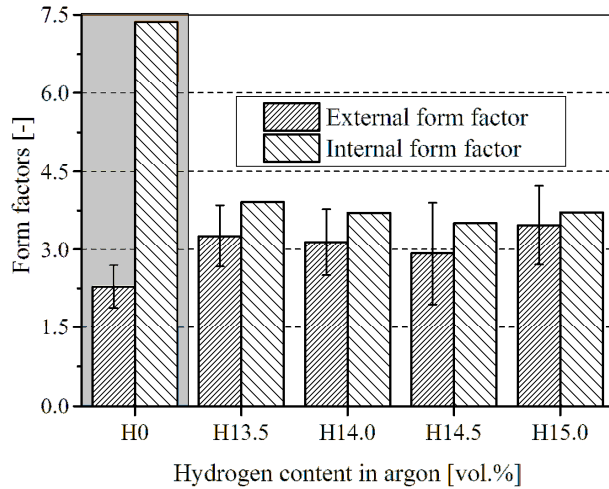


Figure 4 External and internal form factors as a function of hydrogen in the shielding gas

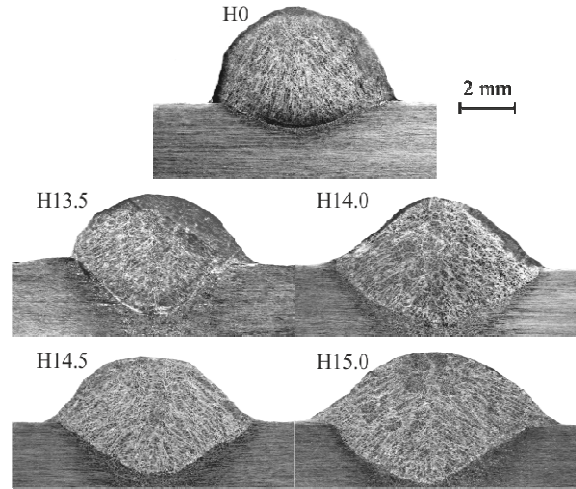


Figure 5 Macro images of the etched cross sections of the welded specimens

3.2 Changes in the hardness distribution and the microstructure of the welds

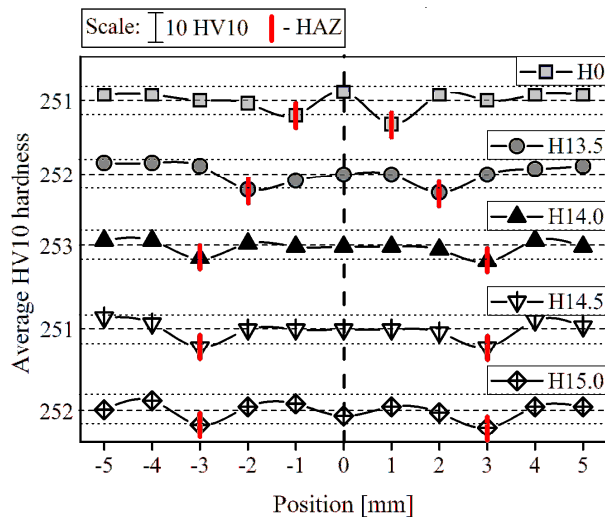


Figure 6 Hardness distribution in the different shielding gas welded WM and HAZ

The average hardness values have not changed to the effect of hydrogen in the shielding gas (Figure 6). The average hardness of the LDX 2404 base material is 252 ± 5 HV10 which is the same in the WM with all of the shielding gases. Also in all cases a small decrease (5 HV10 average) in the hardness was experienced in the HAZ. In the microstructure no significant differences can be discovered as a function of the applied shielding gas. In the WM oblong, radial ferrite grains can be seen symmetric to the centre line (Figure 7). In the HAZ coarse ferrite grains are formed. The maximum width of the HAZ is about 1000 μm in case of H15.0.

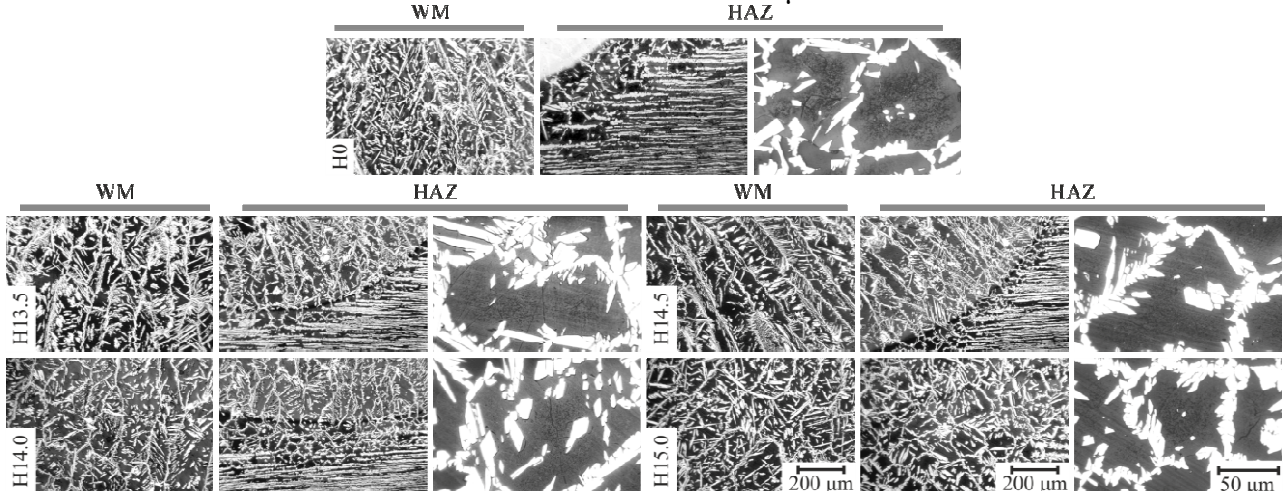


Figure 7 Microstructure of the WM and HAZ of the specimens



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The ferrite content in the LDX 2404 base material is 49 ± 2 in area %. The measured ferrite contents of the welds are as follows: H0= 55 ± 2 area %, H13.5= 51 ± 2 area %, H14.0= 50 ± 2 area %, H14.5= 50 ± 2 area % and H15.0= 51 ± 2 area %. With hydrogen in the shielding gas the ferrite content of the WM is similar to the BM but in case of argon shielding gas the ferrite content is slightly bigger. The lower ferrite content in case of H0 shielding gas can be originated from the lower heat input during welding (lower arc voltage value) as every DSS solidifies as δ -ferrite.

CONCLUSIONS

In our research LDX 2404 lean duplex stainless steel was welded with GMA technique with different shielding gas mixtures containing high concentration of hydrogen. The welding parameters stayed constant during the experiments, the hydrogen content beside argon varied from 0 % to 15.0 %. The effects to the welding process, weld geometry, hardness distribution, ferrite content and microstructure were investigated. The following conclusions can be drawn:

- hydrogen in the shielding gas increased the weld bead width (max. 23 % in case of H15.0) and the penetration depth (max. 244 % in case of H15.0),
- hydrogen in the shielding gas increased the average arc voltage during welding (max. 51 %),
- hydrogen increased the external form factor (28-52 %) and decreased the internal form factor (47-52 %),
- the hardness values did not change with the hydrogen in the shielding gas and remained near the BM's hardness which is 250 ± 5 HV10,
- in the HAZ the hardness values decreased in all cases with average 5 HV10,
- in the microstructure no significant differences can be seen as a function of the hydrogen content in the shielding gas,
- the ferrite content was the biggest, 55 ± 2 area %, in case of pure argon (H0) shielding gas, in all other cases the ferrite content in the WM is similar to the BM's, which is 49 ± 2 area %.

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