

# The Effect of Heat Input and Shielding Gas Composition on Corrosion Resistance of TIG Weld Metal of New Lean Duplex Stainless Steel S82441

J. Niagaj<sup>1,†</sup> and Z. Brytan<sup>2</sup>

<sup>1</sup>*Institute of Welding, Str. Bł. Czesława 16-18, 44-100 Gliwice, Poland*

<sup>2</sup>*Mechanical Engineering Faculty, Institute of Engineering Materials and Biomaterials, Silesian University of Technology, Str. Konarskiego 18a, 44-100 Gliwice, Poland*

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The effects of TIG welding and post-treatment procedures on the microstructure and the pitting corrosion resistance of welded lean duplex stainless steel S82441 were investigated. Autogenous TIG welding was used with different amounts of heat input and shielding gases such as Ar, and mixtures of Ar-N<sub>2</sub> and Ar-He. The addition of 5% to 15% of nitrogen to argon practically did not affect the level of the pitting corrosion resistance. However, the application of gas mixtures (50% Ar + 50% He) resulted in a significant decrease in pitting corrosion resistance. We found that increased current (200 A and 250 A) led to lower values of CPT of welds compared with welds obtained with 50 A, 100 A and 150 A. In addition, the removal of the weld surface layer (0.2 ~ 0.3 mm thickness) in most cases not only resulted in a significant increase in resistance to the pitting corrosion but also post-treatment of weld, implying that corrosion resistance depended on factors such as surface roughness or the presence of undesirable oxides.

**Keywords:** lean duplex stainless steel, TIG, pitting corrosion, shielding gas, heat input

## 1. Introduction

Stainless steel type S82441 [1] is one of the recently developed and only a few years ago introduced to the market grade of a lean duplex stainless steel (LDSS). In comparison with the well-known and widely used standard duplex stainless steel S32205/S31803, steel S82441 contains a higher amount of manganese, but a slightly lower amount of nickel and molybdenum. In turn, compared with the lean duplex steel S32101, S82441 stainless steel contains less manganese, but more of chromium, nickel and molybdenum [2]. The lean duplex stainless steel with a composition containing approximately 24% Cr and 3.5% Ni, has strength and corrosion resistance superior to that of Type 304L stainless steel and comparable to Type 316L. The higher strength of lean duplex stainless steel family allows thinner sections of LDSS to replace components made with thicker sections of standard austenitic Cr-Ni and Cr-Ni-Mo stainless alloys. This substitution may result in considerable cost savings. The high strength, toughness, corrosion resistance, and weldability of lean duplex stainless steel family makes them a good choice for use in many industrial, load-bearing and domestic

goods applications [1-4].

One of the most important features of virtually all high-alloy steels, including duplex stainless steel, which determine the success of their use in industrial practice is not only suitable corrosion resistance of the base material, but also of their welded joints. The lean duplex stainless steels like the duplex one shows good weldability. For lean duplex as well as duplex grades it is essential to ensure that an adequate amount of austenite is formed in the weld metal and heat affected zone, in order to ensure adequate balance between austenite and ferrite phase. The second important factor that should be taken into consideration during welding of such alloys is to avoid the precipitation of detrimental phases such as intermetallics and nitrides. Additionally, the proper post-weld cleaning should be performed to ensure good corrosion properties [4].

The results of microstructure investigation and pitting corrosion resistance of the welded joints of lean duplex stainless steel S82441, according to ASTM G48, are described below, where the welded joints were made using the TIG method with various shielding gases and different amounts of heat input.

<sup>†</sup> Corresponding author: Jerzy.Niagaj@is.gliwice.pl

**Table 1 Chemical composition of lean duplex stainless steel S82441**

Chemical composition, wt%									
C	Si	Mn	P	S	Cr	Ni	Mo	Cu	N
0.025	0.36	3.00	0.022	0.001	23.92	3.66	1.61	0.39	0.279

**Table 2 Welding joint parameters**

Current, A	Heat input, kJ/mm				
	Ar	Ar + 5%N <sub>2</sub>	Ar + 10%N <sub>2</sub>	Ar + 15%N <sub>2</sub>	Ar + He
50	0.11	-	-	-	-
100	0.27	0.26	0.26	0.26	-
150	0.45	0.42	0.44	0.43	-
200	0.65	0.65	0.65	0.65	0.72
250	0.89	-	-	-	-
300	1.17	-	-	-	-

## 2. Experimental Procedure

### 2.1 Materials

The research was carried on using sheets of lean duplex stainless steel grade S82441 of the thickness 6.0 mm, with the chemical composition presented in the Table 1. The Pitting Resistance Equivalent Number PREN calculated according to the formula:  $PREN = \%Cr + 3.3 \times (\%Mo) + 16 \times (\%N)$  for a given melt is equal to  $PREN = 33.7$ . During TIG welding respective shielding gases were applied: pure technical argon EN ISO 14175-I1-Ar, the mixes of argon and nitrogen (5, 10 and 15 %) with designations according to standard: EN ISO 14175-N2-ArN-5, EN ISO 14175-N2-ArN-10 and EN ISO 14175-N2-ArN-15, and also a mixture of argon and helium in the relation 50/50 with designation EN ISO 14175-I3-ArHe-50.

### 2.2 Procedures

The welding joints were produced using sheet plates grade S82441 with the dimensions 100x50x6 mm on the TIG mechanized welding stand consisting of welding source power Lorch V40, a welding trolley Promotech DC20 with the precisely adjustable travel speed of torch and an attachment device to position welded pieces. The welding speed of all samples was constant and the current intensity was changed in the range from 50 to 300 A (Table 2).

All welds were made in the manner that the beginning and the end did not go beyond the limits of the sample. Thus, during the corrosion testing according to ASTM G48 the ferric chloride solution affected only the face of welded joints. Used dimensions of the samples are not in accordance with the standard ASTM G48, but their

choice is explained by the fact that the use of standard samples with dimensions of 50 × 25 mm would require cutting them from the welded joint, and then during corrosion test the corrosive medium would affect both the joint surfaces and the surfaces of the weld cross section, which in the real conditions would never happen and could distort obtained results.

Additionally the various parts of the sample surface were treated in a variety of ways prior to corrosion testing: 1) etching (abbreviation E) with a commercially available etching paste, 2) cleaning with a wire brush (abbreviation B+E), and then etched with the paste, 3) machining (abbreviation M) by milling surface layer removing depth of 0.1 ~ 0.3 mm (max. 0.5 mm) from the face of the weld. The milling was applied in aim to mechanically remove of oxides and other surface contamination that might occur on the surface of the weld face and would not be removed by brushing and pickling treatment. The roughness of a surface worked in different ways was measured in terms of the Ra parameter.

The study of corrosion resistance of the welded joints of S82441 stainless steel was performed according to the requirements of ASTM G48 standard using the method E, which concerns a test method to determine the critical pitting temperature (CPT) for stainless steel (Method E – Critical pitting temperature test for stainless steels). Test samples were prepared in accordance with the specifications in point 7 of the ASTM G48, and then exposed to a corrosive solution of the following composition: 68.72 g of  $FeCl_3 \cdot 6H_2O$ , 16 ml of concentrated HCl; 600 ml of distillate  $H_2O$ . The exposure time was set to 24 h. The test was performed in a climatic chamber at three temper-

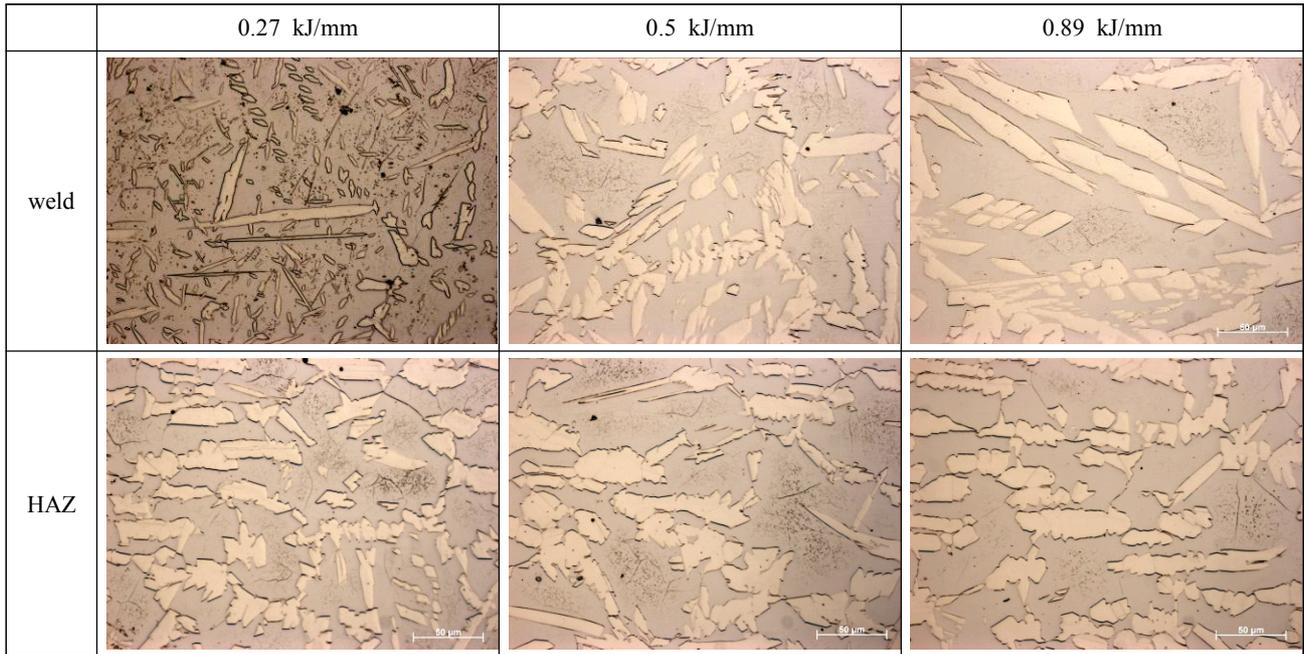


Fig. 1 The microstructure of the TIG welds and the HAZ metal made with argon shielding gas at different heat input.

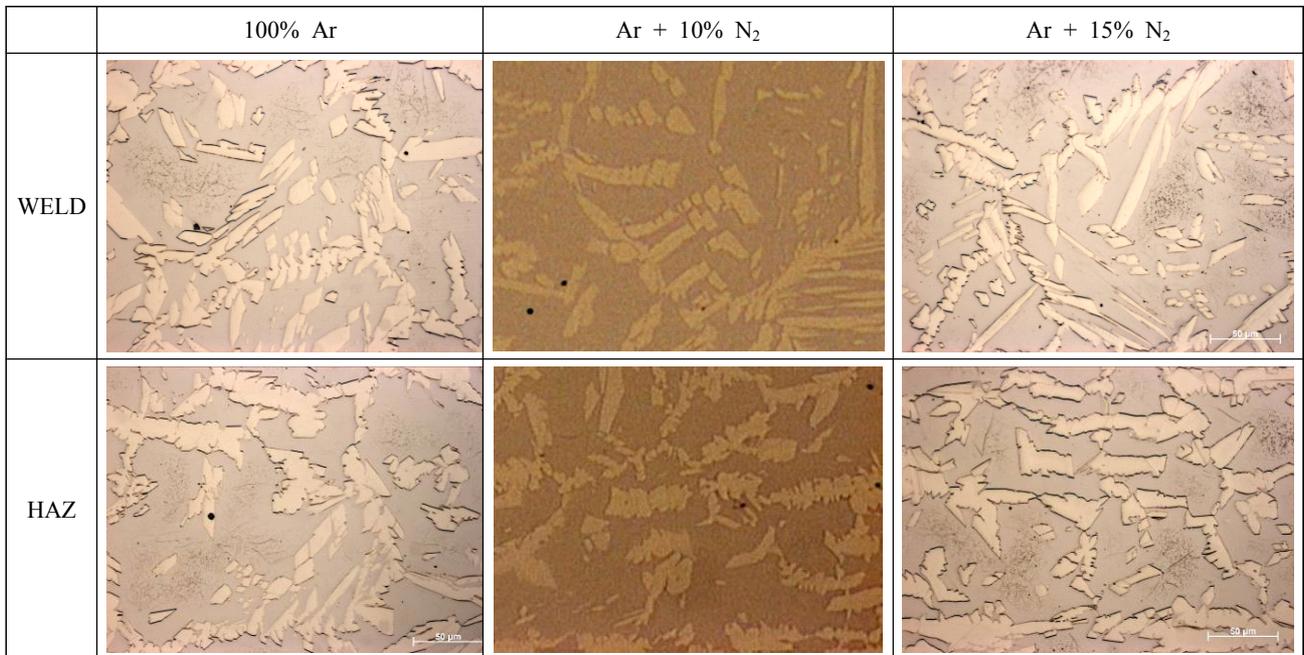


Fig. 2 The microstructure of the TIG welds and the HAZ metal made with different nitrogen addition in argon shielding gas at the current intensity of 100 A.

atures: 15, 25, and 35 °C. The presence of pits at the weld start and crater on test welds were not taken into account because in these areas the welding process was not stable.

Testing of microstructure was performed in the cross-section of welded samples.

### 3. Results and Discussion

#### 3.1 Microstructure

Microstructure analysis shows (Fig. 1), that Less austenite is evident than the ferrite in the materials of all the joints. Noteworthy, however, is that with less heat in-

**Table 3 Results of corrosion test according to ASTM G48 at 15 °C**

Welding current, A	Surface treatment	Presence of pits after corrosion test at 15 °C				
		Ar	Ar + 5% N <sub>2</sub>	Ar + 10% N <sub>2</sub>	Ar + 15% N <sub>2</sub>	Ar + He
50	E	no	-	-	-	-
	M	no	-	-	-	-
	B+E	no	-	-	-	-
100	E	no	●	no	no	-
	M	no	no	no	no	-
	B+T	no	no	no	●	-
150	E	no	no	●	no	-
	M	no	no	no	no	-
	B+T	no	no	no	no	-
200	E	●	no	no	no	●●●
	M	●	no	no	no	●●●
	B+T	no	no	no	●●	●●
250	E	●	-	-	-	-
	M	●	-	-	-	-
	B+T	●	-	-	-	-
300	E	no	-	-	-	-
	M	no	-	-	-	-
	B+T	no	-	-	-	-

no – lack of pits, ● – single pits, ●● – medium amount of pits, ●●● – high amount of pits

put (0.27 kJ/mm) austenite grains are smaller, more dispersed and evenly distributed in the weld material. The structure of the heat affected zone (HAZ) is practically the same.

The microstructures of the weld metal show (Fig. 2) that the addition of nitrogen up to 15% (85% Ar + 15% N<sub>2</sub>) does not cause a greater amount of austenite in comparison with the structure of the weld metal made with technically pure argon shielding gas (100% Ar). The structure of the HAZ is practically the same.

### 3.2 Pitting corrosion resistance

The results of the CPT determination according to ASTM G48 are shown in Tables 3 and 4, which provide data of the tests carried out at temperatures of 15 and 25 °C, while test temperature 35 °C was not included because all samples had been attacked by pitting corrosion.

#### 3.2.1 Test temperature of 15 °C

Even a quick look at the results summarized in Tables 3 and 4 shows that at temperature of 15 °C, the vast majority of welded joints has not corroded. Some occasional individual pits were found in the welded joints obtained

using the mixture of argon with nitrogen as a shielding gas. Regularly occurred single pits at this temperature were found during welding at 100% argon shielding with increased current intensity up to 200 A (Table 3). Pitting also occurred in the welded joints made at a current intensity of 250 A, but at 300 A the pits did not appear. These results are difficult to explain at this stage of the research, because the surface of the welded joint produced using the current intensity of 300A was clearly overheated and had traces of hard removable oxide layer, and nevertheless has not been attacked by corrosion. The appearance of the pits at a current intensity of 200 A and 250 A on both cleaned and milled surfaces is also understandable, because the joints have been made without a filler metal, but with the amount of heat input 0.65 and 0.89 kJ/mm respectively, which is within the recommended for the duplex stainless steel range 0.5 ~ 1.5 kJ/mm [4].

The highest amount of pitting at temperature of 15 °C was found in the welded joints produced using as a shielding gas the mixture of argon + helium in a ratio of 50/50 (Table 3). The addition of helium to the shielding gas is often recommended during welding of all duplex stain-

**Table 4 Results of corrosion test according to ASTM G48 at 25 °C**

Welding current, A	Surface treatment	Presence of pits after corrosion test at 25 °C				
		Ar	Ar + 5% N <sub>2</sub>	Ar + 10% N <sub>2</sub>	Ar + 15% N <sub>2</sub>	Ar + He
50	E	●	-	-	-	-
	M	no	-	-	-	-
	B+E	●●●	-	-	-	-
100	E	●●●	●●●	●●●	●●●	-
	M	no	●●	no	no	-
	B+E	●●●	●●●	●●●	●●●	-
150	E	●●●	●●●	●●	●●	-
	M	●	●●	●●●	●●	-
	B+E	●●●	●●●	●●●	●●●	-
200	E	●●●	●●●	●●	●●●	●●●
	M	●	●●●	●●	●●●	●●●
	B+E	●●●	●●●	●●●	●●●	●●●
250	E	●●●	-	-	-	-
	M	●●	-	-	-	-
	B+E	●●●	-	-	-	-
300	E	●●●	-	-	-	-
	M	●●	-	-	-	-
	B+E	●●	-	-	-	-

no – lack of pits, ● – single pits, ●● – medium amount of pits, ●●● – high amount of pits

less steels, so such a high susceptibility to pitting corrosion of welded joints made with the shielding gas of a mixture of Ar + He is quite surprising.

### 3.2.2 Test temperature of 25 °C

Tests of resistance to pitting corrosion in the tested welded joints at 25 °C shows (Table 4), that the pits are formed in almost all samples regardless applied of the welding parameters and the shielding gases. An exception was revealed for the samples with milled surface obtained at a current intensity of 100 A, which has no pitting, except one welded joint made with a shielding of 5% Ar + N<sub>2</sub> (Fig. 3). The interesting thing is that after the removal of a metal layer of the thickness 0.2 ~ 0.3 mm from the weld surface, the corrosion does not occur at all, although not machined weld are closely dotted with pitting corrosion. The reasons of such situation may be two: the presence of structural changes near the surface or the presence of irremovable chemical compounds, such as manganese oxide [5]. However, verification of these assumptions, requires more detailed study. At the present state of research, such behaviour can be attributed to the low surface roughness of milled surface Ra = 0.4 ~ 0.5

µm in respect to not welded surface area, where etching increase the roughness to Ra = 3.0 µm and the face of weld Ra = 1.0 µm. It is well known that lower surface roughness improve corrosion resistance of stainless steel, thus chloride ions difficultly accumulate and slowly destroy the passive film on the surface.

The surface analysis of all the samples at all tested temperatures shows that the pits are always found in the weld metal. There was no presence of pits outside the melt line, and therefore do not have them either in the heat affected zone (HAZ) or in the base material. At current intensity levels 50 and 100 A, pits are uniformly distributed on the surface of the welded joints and have a shape close to circular. At a current intensity rate of 150 A and higher, pitting mostly arranged in the vicinity of the melt line and have an elongated shape mapping the weld shape during microstructure solidification (in the shape of a Christmas tree). This fact supports the assumption that the main cause of pitting corrosion is structural changes that are taking place in the steel S82441 during autogenous welding. In contrast to the results presented in the work [5], proving the increase of corrosion resistance of the welds made in Ar with 2% of N<sub>2</sub>, and the present study

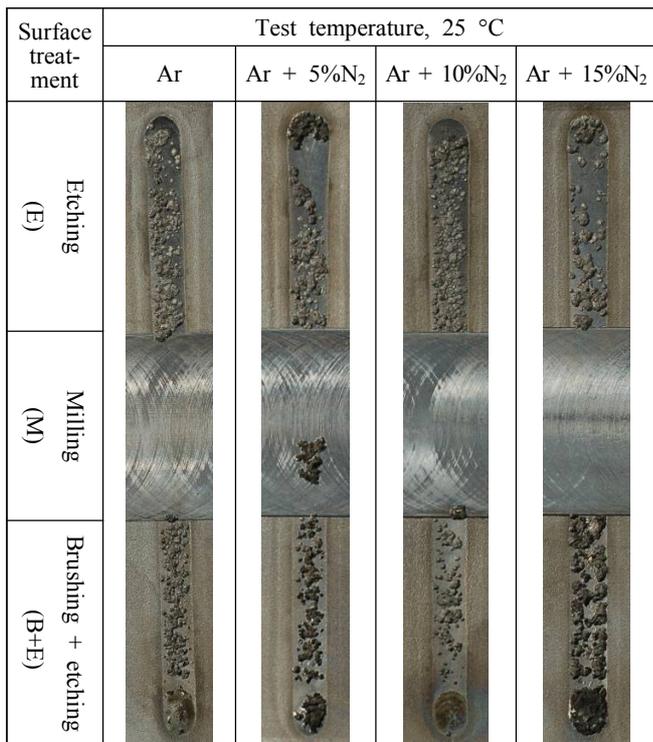


Fig. 3 Corrosion test at 25 °C according to ASTM G48 after various surface treatments of welded joints made using Ar and Ar+N<sub>2</sub> as a shielding gas at the current intensity of 100 A.

where the addition of 5%, 10% and 15% of the nitrogen to shielding gas not caused virtually any effect on the resistance to pitting corrosion evaluated by ASTM G48 method, whatever applied welding parameters in the presented study (Table 4 and Fig. 3-5). There were no observed differences in the corrosion resistance of the welded joint surface treated only with the pickling paste or wire brush and etching pastes. This shows that a properly used pickling paste provides the required surface cleanliness of the S82441 stainless steel welded joints after TIG welding and the additional surface wire brushing is not necessary. Performed studies show in most cases that removal of the weld surface layer by milling resulted in a strong increase in the resistance to the pitting corrosion. Depending on applied welding parameters the complete lack of pitting was observed (Fig. 3) or a significant reduction in their amount (Fig. 4 and 5).

#### 4. Conclusions

The pitting corrosion tests of TIG autogenous weld of lean duplex stainless steel S82441 shows that the addition to argon of 5 to 15% of nitrogen practically does not affect the level of the pitting corrosion resistance. This confirms the lack of differences in the microstructure of the weld

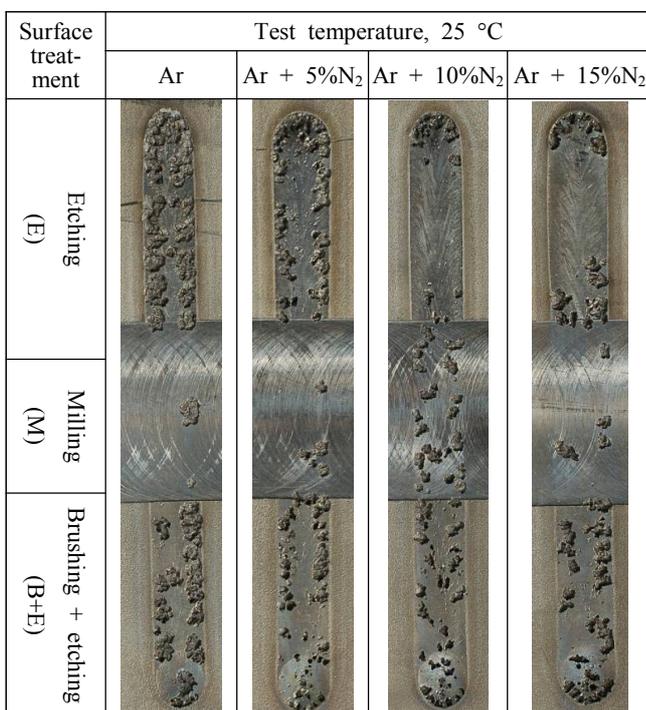


Fig. 4 Corrosion test at 25 °C according to ASTM G48 after various surface treatments of welded joints made using Ar and Ar+N<sub>2</sub> as a shielding gas at the current intensity of 150 A.

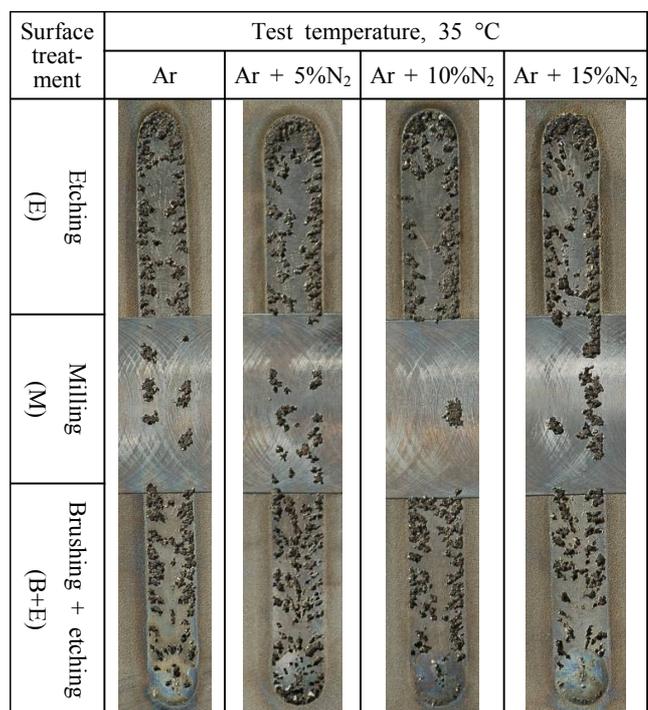


Fig. 5 Corrosion test at 35 °C according to ASTM G48 after various surface treatments of welded joints made using Ar and Ar+N<sub>2</sub> as a shielding gas at the current intensity of 150 A.

metal, namely, there was no increase in the proportion of austenite increase with increasing nitrogen content in the shielding gas composition. The structure of the HAZ is practically the same. When comparing the welding process with shielding gas of 100% Ar, the application of the gas mixture of 50% Ar + 50% He cause a significant decrease in the resistance to pitting corrosion. Increasing the welding current intensity from 50 to 300 A and accordingly the amount of heat input from 0.11 to 1.17 kJ/mm did not influence on the pitting corrosion resistance. However, it was found, that the joints made with the high current intensity 200 A and 250 A shows somewhat lower values of CPT compared to welds made with 50, 100, and 150 A. It may be associated with smaller and more dispersed austenite grains arising when using lower values of heat input. The removal of the weld surface layer of a thickness 0.2 ~ 0.3 mm, in most cases resulted in a significant increase in the resistance to the pitting corrosion, which shows that corrosion resistance is not only affected by the weld microstructure, but also other surface factors like surface roughness or the presence of undesired oxides, which determination and an explanation will be

carried out in the next stage of the research.

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