SVOJSTVA SUČEONO ZAVARENOG SPOJA KOROZIJSKI OTPORNOG NEHRĐAJUĆEG ČELIKA 316 L

PROPERTIES OF BUTT WELD JOINT MADE ON CORROSION RESISTANT STAINLES STEEL 316 L

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Abstract:

The article presents an example of successful welding of stainless steel grade 316 L by using TIG welding process. The welding process influences the melting which starts in consumable material and the most heated base material. It also affects the surrounding material close to the melted material that starts to change its microstructure as a consequence of rapid heating and rapid cooling. The changed microstructure has the influence on mechanical properties and also its corrosion resistance.

Mechanical properties obtained at tensile tests, bending, hardness measurements and Charpy tests were studied after the welding on V - shaped butt joint. The microstructure of the base material, heat affected zone and the weld metal was observed and analysed by the light microscope.

Sažetak:

U radu je predstavljen primjer uspješnog zavarivanja nehrđajućeg čelika tipa 316 L sa upotrebom TIG postupka zavarivanja. Postupak zavarivanja utječe,da se počne taliti dodatni materijal i najviše zagrijan osnovni materijal. On isto utječe na materijal u okolini, koji je blizu taljenog materijala tako da počne da mijenja mikrostrukturu zbog brzog zagrijavanja i brzog hlađenja. Izmijenjena mikrostruktura utječe na mehaničke osobine i njegovo korozijsko otpornost.

Studirana su bila mehanička svojstva dobivena kod zateznog pokusa , savijanja, mjerenja tvrdoće, i Charpy pokusa po zavarivanju V – oblike sučelnog zavarenog spoja. Na optičkom mikroskopu je bila studirana i analizirana microstruktura osnovnog materijala, zone utjecaja toplote i materijala zavara .

1. INTRODUCTION

When austenitic stainless steels are subject to prolonged heating in the temperature range 425 – 815 °C, the carbon in the steel diffuses to the grain boundaries and precipitates chromium carbide [1-3]. This removes chromium from the solid solution and leaves a lower chromium content adjacent to the grain boundaries. Steels in this condition are termed 'sensitised'. The grain boundaries become prone to preferential attack on subsequent exposure to a corrosive environment

[2,3]. This type of corrosion is known as inter-granular corrosion (IC), also known in the past as 'weld decay'.

If the carbon level is below 0.030% then this inter-crystalline corrosion does not take place following exposure to these temperatures, especially for the sort of times normally experienced in the heat affected zone of welds in 'thick' sections of steel.

The lower carbon 'variants' (316 L) were established as alternatives to the 'standards' (316) carbon range grade to overcome the risk of inter-crystalline corrosion (weld decay) [3,4], which was identified as a problem in the early days of the application of these steels. This can result if the steel is held in a temperature range 450 to 850°C for periods of several minutes, depending on the temperature and subsequently exposed to aggressive corrosive environments. Corrosion then takes place next to grain boundaries.

For the above mentioned reasons the welding of the steel grade 316 L should be carried out by special attention in order not to totally demolish convenient microstructure of steel 316 L [4-7]. During the welding, the heat input should not be too high so that grains will not grow too much and destroy Charpy toughness. It is crucial to use an appropriate consumable material, which needs to be chosen carefully to enable approximately 2-10 % of delta ferrite in the weld metal after the welding, and prevent the inter-crystalline corrosion.

This article presents how to choose the right welding technology for welding and how the welding process influences the mechanical properties and the microstructure.

2. BASE AND CONSUMABLE MATERIALS

Stainless steel grade 316 L (1.4404) was used as the base material for the investigation. This steel is the low carbon molybdenum - bearing austenitic stainless steel. The molybdenum gives better overall corrosion resistance particularly to pitting and crevice corrosion in chloride environments. Thus it is extensively used in heavy gauge welded components. The austenitic structure also gives excellent toughness, even down to cryogenic temperatures, and higher creep, stress to rupture and tensile strength at elevated temperatures. The chemical composition and mechanical properties of 10 mm thick 316 L stainless steel are given in table 1 and 2.

***Table 1**: Chemical composition of the stainless steel 316 L (weight %)*

C	Mn	Si	P	S	Cr	Mo	Ni	N	Fe
0,03	2,00	0,75	0,045	0,03	17,00	2,50	12,00	0,10	balance

***Table 2:** Mechanical properties of the stainless steel 316 L*

Yield Strength 0.2 % Proof (MPa)	Tensile Strength (MPa)	Elongation (%)	Vickers Hardness (HV)
170	485	40	220

TIG 19/9 NC Si solid wire was used as a consumable material at TIG welding. It is suitable for welding corrosion resistant stainless steels, for devices, vessels and parts in chemical, pharmacy and cellulose industry for temperature up to 350°C. Welded material also has oxidation resistance up to 800°C and good ductility till - 196°C. Chemical composition of 2.4 mm thick TIG 19/9 NC Si wire is presented in table 3.

***Table 3:** Chemical composition of the TIG 19/9 NC Si consumable material*

C	Mn	Si	Cr	Mo	Ni
0,025	1,75	0,80	19,0	2,75	11,5

***Table 4:** Mechanical properties of the TIG 19/9 NC Si consumable material*

Yield Strength 0.2 % Proof (MPa)	Tensile Strength (MPa)	Elongation (%)	Impact Energy KV at 20 °C (J)
> 320	550 - 650	> 30	80 J

3. EXPERIMENTAL PROCEDURE

Butt weld V - joint was made on 10 mm thick and 350 mm long sheet plate of 316 L stainless steel. Preparation of the weld groove and the weld passes building is shown in figure 1. TIG welding process (141) and 2.4 mm thick TIG 19/9 NC Si solid wire and argon 4.6 shielding gas were used for welding. The first root pass was shielded during the welding by another welder from other side by using TIG process with lower heat input and without consumable material instead of shielding by forming gas. The welding parameters are given in table 5.

***Table 5:** The welding parameters of the V shaped butt weld joint*

Welding pass	Current (V)	Voltage (V)	Welding speed (cm/min)	Heat Input (kJ/cm)
1	100	11	8	4.95
1* (for protection of root pass)	40	8	8	1.44
2 - 5	150	11,5	8	7.63
6	150	11,5	7,5	8.28

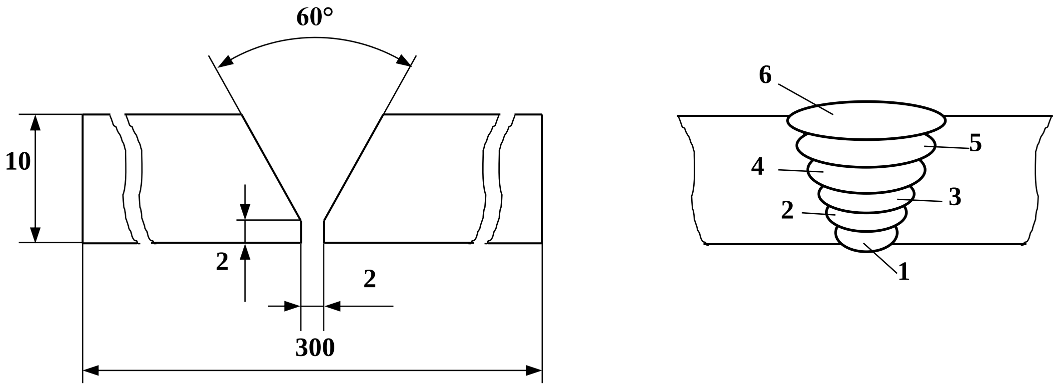


***Figure 1:** Preparation of the weld grove and the welding passes build up.*

Tensile tests

Two tensile specimens were machined from weld joint and tested at room temperature by AMSLER servo-hydraulic tensile machine by using SIST EN 10002-1:2002 standard.

Bending tests

Four bending specimen were machined from weld joint. One specimen was used for testing of the root of weld joint, another specimen was used for testing of the face of weld joint and other two specimens are used for side bending tests. All bending tests were made according to SIST EN ISO 7438:2000 standard.

Hardness tests and microstructure analysis

A metallography specimen was prepared using grinding, polishing and etching from the butt weld joint for microstructure analysis in Nikon optic microscope EPIPHOT 300 by using magnifications 200 and 500. Later, the metallographic specimen was used for Vickers hardness measurements on Shimadzu HMV 2000 by using load of 9.81 N. The hardness measurements were carried out according to standard EN 288 in root region and face region of the weld joint.

Charpy testing

Charpy specimens with ISO V groove were machined from base material, heat affected zone and weld metal. Charpy testing was performed according to the EN 10045 standard by using AMSLER pendulum RPK 300. Charpy specimens were tested at room temperature and at -60 °C temperature in all regions of the weld joint.

4. RESULTS AND DISCUSION

In figure 2 is presented macro metallographic sample of the weld joint on 316 L stainless steel.

Figure 2: *Macro metallographic sample of the weld joint on 316 L stainless steel*

Results of the tensile tests

Tensile testing was performed at room temperature. The results of tensile testing of the weld joint are presented in Table 6 and broken specimens after testing are shown in Figure 3. All fractures of the tensile specimens happened in the base material, so the weld joint is the overmatch. This means that the weld join is stronger when comparable to the base material. The tensile strength of the tested specimens is between 550 and 650 MPa, what is normal for a base material (see table 2).

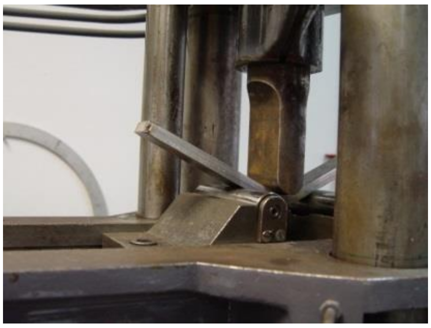
Table 6: *Results of tensile testing*

Specimens	Dimensions (mm)	Tensile strength (MPa)	Location of fracture
1	13,0 × 10,6	619	Base material
2	14,7 × 10,6	587	Base Material

Figure 3: Tensile specimens after testing.

Results of the bending tests

Bending tests were performed at room temperature. All specimens were bended for angle 180°. On the surface where was region of the tensile stresses were no mistakes in all specimens.



Root

Face

Side (specimens 1, 2)

Figure 4: *Bending specimens during and after testing*

Table 7: *Results of bending testing*

Specimens	Dimensions (mm)	Dimension of the punch, angle (mm, °)	Location of fracture
Root	29.6 × 10.6	D = 30 mm, α = 180°	Without defects
Face	30.0 × 10.6	D = 30 mm, α = 180°	Without defects
Side 1	10.6 × 9.6	D = 30 mm, α = 180°	Without defects
Side 2	10.6 × 9.9	D = 30 mm, α = 180°	Without defects

Results of hardness testing

Hardness testing was performed at room temperature by using Vickers intender and load of 9.81 N. Hardness were measured in root and face region of the weld joint. All results was below of 250 HV1

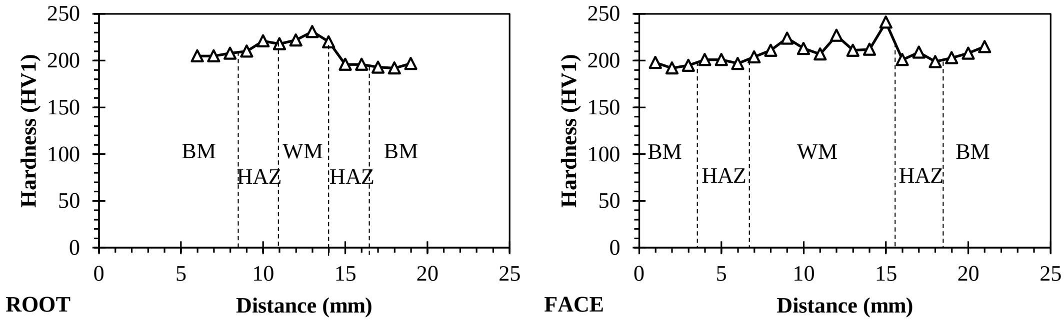


Figure 5: *Results of hardness measurements in root and face region of the weld joint*

4. Results of Charpy testing

Charpy tests were performed at room temperature and at -60 °C where weld metal, heat affected zone and base material were tested. The results of Charpy tests are presented in figure 6. The worst results are attained in the weld metal at –60 °C. The biggest deviations of the results of the Charpy tests were seen in heat affected zone because of V shape of weld joint. This is especially expressive at -60 °C for HAZ material (middle figure). Charpy impact toughness is good within all regions of weld joint at tested temperatures, since the impact energy is high enough.

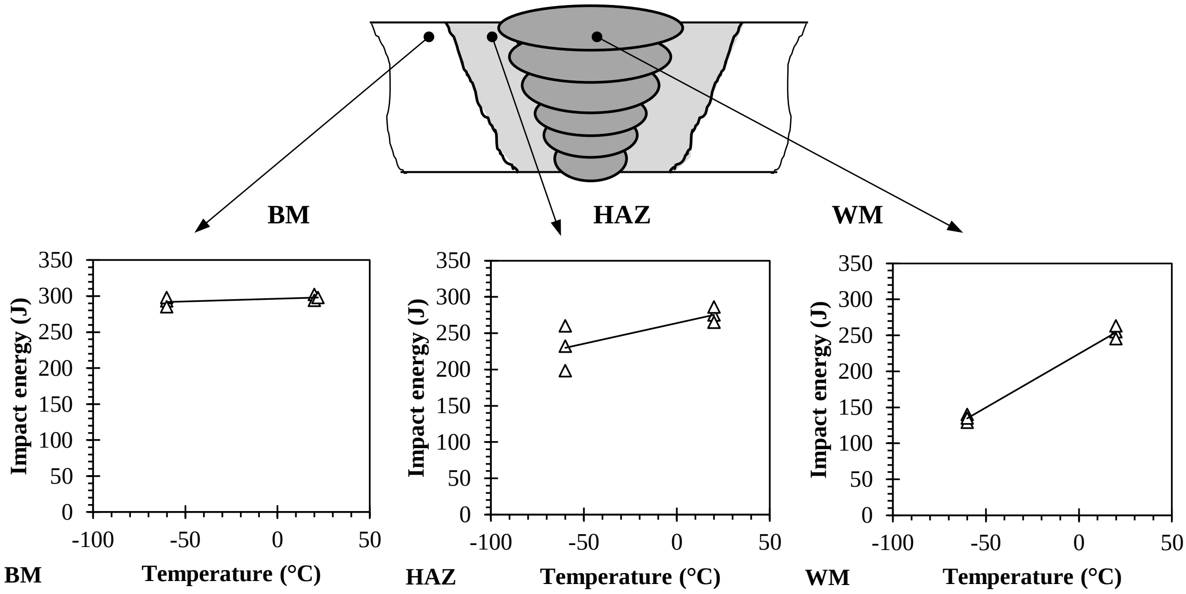


Figure 6: *Results of Charpy tests of base material - BM, heat affected zone - HAZ and weld metal - WM*

Results of microstructure analysis

Microstructure of the base material, heat affected zone and weld metal were observed by using the light microscope at magnification 200×. The microstructure of the base material is an austenitic average size of the grains of 20-30 μm. The microstructure in HAZ remains to be austenitic with bigger grain size. The average size of grains is 50-60 μm and the biggest grains are located near the fusion line. In the weld metal the solidification after the welding was quick. In the weld metal it is possible to detect some delta ferrite. The microstructure of the base material is shown in the left side in figure 7. The middle figure represents the microstructures of the heat affected zone with fusion line and some weld metal. The right figure represents the microstructure of the weld metal.

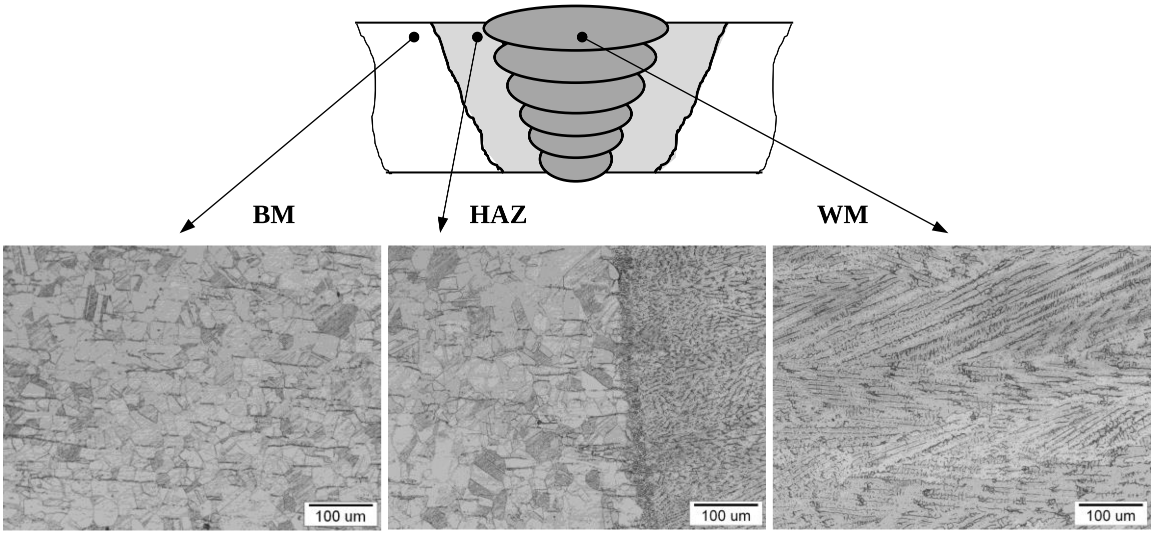


Figure 7: *Microstructure of base material, heat affected zone and weld metal; (magnification 200×)*

Schaeffler diagram is shown in figure 8. Three points are marked in the diagram, where the first one represents the base material – steel 316 L, the second point represents the consumable material TIG 19/12/3 NC Si and the third one represents the probable microstructure of the weld metal.

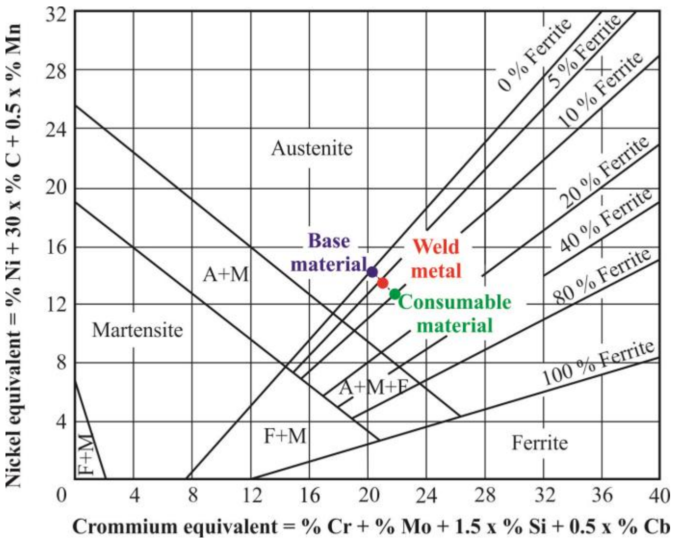


Figure 8: *Schaeffler diagram for base and consumable material and weld metal of the weld joint*

The content of the delta ferrite was measured in the base material and the weld metal by using the delta ferrite meter (Ferritgehaltmesser 1.054). Delta ferrite was measured in weld metal in vertical and horizontal direction and in base material in horizontal direction. The content of the delta ferrite in the base material was 0.45 % and the average content of the delta ferrite in the weld metal was 5,3 %, which is in good coloration to the results in Schaeffler diagram. The results of delta ferrite measurements are given in Figure 9. Content of delta ferrite is below of 6 % what is acceptable level to be safe to the inter-crystalline cracking, so weld join has enough high corrosion resistant.

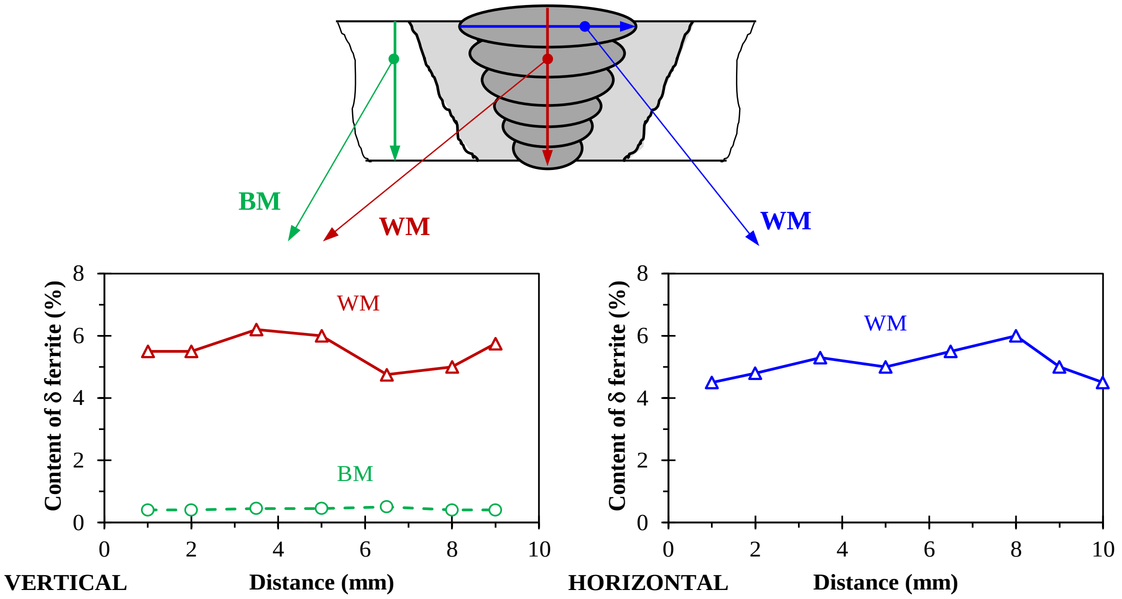


Figure 9: *Results of delta ferrite measurements*

5. CONCLUSIONS

The results of mechanical testing and delta ferrite measurements confirm that welding technology was chosen correctly.

Tensile strength of weld join is higher than tensile strength of base material so all tensile specimens were broken in base material.

Maximal hardness in weld join is below of 250 HV1 so weld joint can be resistant more to inter - crystalline cracking.

The worst impact energy is in weld metal, but high enough for safe operation of weld joint.

Content of delta ferrate in weld metal is below of 6 % that means weld joint is enough corrosion resistant to the inter-crystalline cracking.

6. REFERENCES

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