M. RADOŃ, Z. A. OPIEKUN, A. DEC

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STRUCTURAL ANALYSIS OF SHEET NICKEL WELDED JOINTS

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The paper presents an analysis of structure nickel sheet welded joints made by applying Gas Tungsten Arc Welding (GTAW) method. Based on results of metallographic examination, HV5 hardness measurements, Energy dispersive spectroscopy (EDS) and X-ray diffraction (XRD) analysis of the welds it was found that the joints were characterized with a three-zone structure with large columnar dendrites in the welds. Columnar dendrites show a mosaic substructure with uniformly distributed carbides of M3C type rich in nickel.

Keywords: nickel, sheet, GTAW welding, X-ray analyses, welded joint structure

INTRODUCTION

Nickel is a ferromagnetic metal which, unlike other elements of the iron group (iron, cobalt), has in the solid state only one type of crystalline structure, namely the face-centered cubic lattice (A1).

High resistance of nickel to corrosion in aggressive atmospheres, seawater, and organic acids make it a particularly suitable material for welded structures such as seawater desalting plants, caustic soda production lines, and food industry equipment, especially for production of fruit juices and preserves.

The precondition for good weldability of nickel is high purity of the metal. Sulfur and phosphorus make welded nickel joints susceptible to hot cracking and therefore the content of those elements should be limited to the level of 0,01 % at the most. Presence of oxygen which is responsible for grain coarsening and triggers hot-shortness, should be limited to the level of 0,02 % maximum. It is also necessary to keep content of fusible elements such as lead, tin, zinc, cadmium, bismuth, and antimony in nickel on the level not higher than 0,02 %.

Presence of carbon induces susceptibility of nickel to cold brittleness and its content should be kept below a maximum of 0,1 % [1, 2].

The nickel grades most widely used for welded structures are Nickel 200 and Nickel 201 (designation as per IAI) or VDM Nickel 99,2 number 2.4066 and VDM LC-Nickel 99,2 number 2.4068, respectively (as per VDM Metals) [3].

The objective of the study reported in this paper was to carry out a structural analysis of welded joints of sheet nickel grade VDM LC-Nickel 99,2 (Nickel 201). Structural examination covered welded tee joints and butt joints of sheet nickel specimens with thickness of 2 mm and 6 mm made with the use of GTAW method in protective atmosphere of argon with filler in the form of nickel wire containing an addition of titanium.

RESEARCH MATERIAL AND METHODOLOGY

The material subject to the research were welded joints of specimens of sheet nickel with thickness of 2 mm and 6 mm, marketed by VDM Metals under trade name VDM LC-Nickel 99, numbered 2.4068 as per EN 10204/01.05. Chemical composition of the sheet metal was determined by means of spectral analysis using Q4 TASMAN optical emission spectrometer (Bruker). Chemical composition of 2 and 6 mm sheet nickel: 0,015 % C; 0,08 % Mn; 0,04 % Si; 0,002 % Ti; 0,004 % Cu; 0,12 % Fe; 0,02 % Mg; <0,0018 % S; Ni bal. The filler metal used to make the welded joints had the form of wire with diameter of Ø 1,6 mm and Ø 2,4 mm manufactured by Special Metals and designated Nickel Filler Metal 61 1,6 mm and Nickel Filler Metal 61.093x36, respectively, as per AWS5.14-ERNi-1.

All the welded joints analyzed as part of the present study were made by applying GTAW method and using infusible electrode WT20/2.4. As the shielding and plasma-forming gas, argon with purity of 99,9995 supplied at rate of 10 - 12 l/min (as per EN-ISO 144175-1) was used in every cases. Table 1 shows the welding parameters for nickel sheets.

Structural analysis of welded joints made that way was carried out on metallographic sections prepared by cutting the joints transversally, polishing mechanically the obtained cross-sections, and including them in elec-

Table 1 **Welding parameters of nickiel sheets**

Type of welded joint	number of stich	filer wire / mm	U/ V	I/ A	Vs / mm/s
tee joint / 2 mm	1	Ø 1,6	12	220	56
tee joint / 6 mm	1	Ø 1,6	12	220	56
	2	Ø 2,4	14	240	51
butt joint/ 6 mm	1	Ø 1,6	14	245	68
	2	Ø 2,4	14	240	98
	3	Ø 2,4	14	242	87

where: U – current / V, I – voltage / A, v_s – welding speeed / mm/s

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M. Radoń, (e-mail: m.radon@prz.edu.pl), Z. A. Opiekun, A. Dec, Department of Casting and Welding, Rzeszow University of Technology, Rzeszow, Poland

trically conducting mass Duroplast Schwarz (ATM). All sections were etched twice, with Adler's reagent and Kalling's reagent. Microstructure of welded joints was observed with the use of VEGA3 XMH scanning electron microscope (Tescan) equipped with INCA x-act (Oxford Instruments) adapter for chemical composition analysis. The welds were examined on D8 ADVANCE X-ray diffractometer (Bruker). Measurements of HV5 hardness of the joints were carried out on ZHV10 hardness tester (Zwick Roell).

RESEARCH RESULTS

Microstructure, results of X-ray microanalysis and hardness measurements

Examination of microstructure of sheet nickel welded joints was carried out with the use of scanning electron microscope (SEM), whereas the quantitative point-like X-ray microanalysis in micro-areas of the joints was performed using INCA X-Act adapter (Oxford Instruments). Hardness measurements were taken on ZHV10 hardness tester tipped with Vickers indenter at the load of 50 N (HV5) along lines on transverse cross-sections of the welded joints. Figures 1–3 and Table 2 shows results of the measurements.

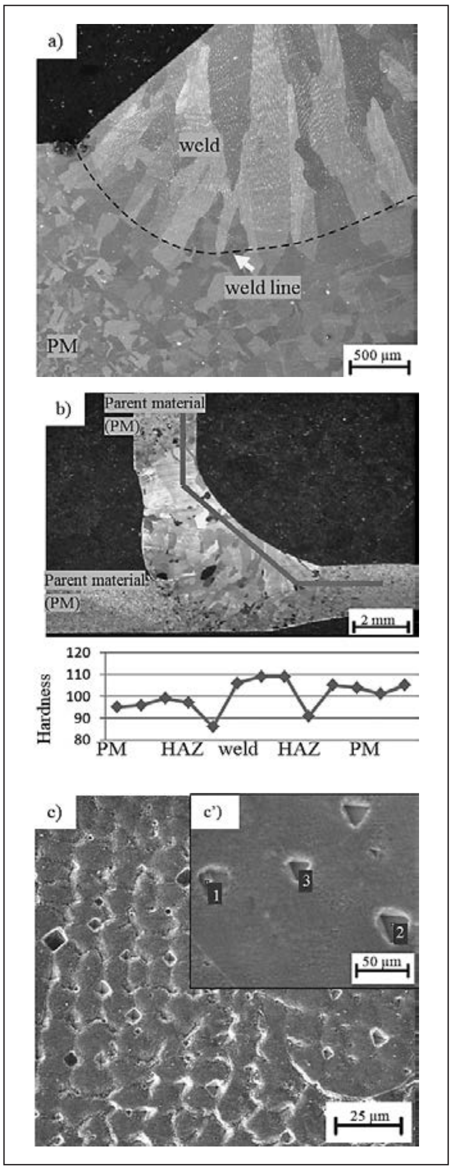

Figure 1 (a) Macrostructure of a welded tee joint on 2-mm thick nickel sheet specimens: (b) macrostructure with marked line along which HV5 hardness; (c, c') microstructure of the joint with marked elements.

In the Table 2 presented content of alloying elements marked in micro-areas 1, 2, and 3, form Figure 1 c, c'.

X-ray examination

To examine structure of sheet nickel welded joints, D8 ADVANCE diffractometer (Bruker) was used. The X-ray qualitative phase analysis was carried out in Bragg-Brentano focusing geometry. Some of the identified reflections on the analyzed X-ray diffraction pattern are slightly shifted towards values lower than those quoted under ICSD Collection Code 108174 – Figure 4.

Table 2 **Content of alloying element marked in micro-areas 1, 2 and 3 (from fig. 1 c, c')**

Marked locations	Composition / %		
	C	Ti	Ni
1	7,41 (28,04)*	1,55 (1,47)	91,05 (70,50)
2	6,0 (23,72)	1,06 (1,05)	92,94 (75,23)
3	6,8 (25,3)	1,35 (1,26)	91,85 (73,44)

*Numbers in parentheses denote element content in atomic %

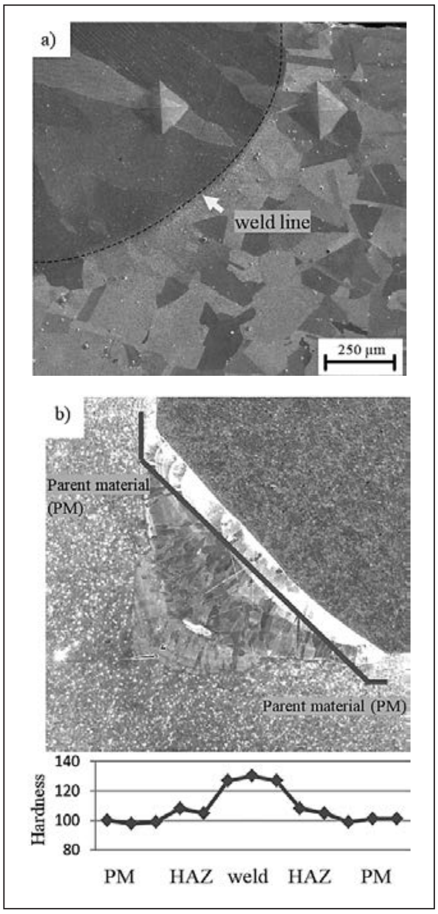

Figure 2 (a) Macrostructure of a welded tee joint on 6-mm thick nickel sheet; (b) weld microstructure

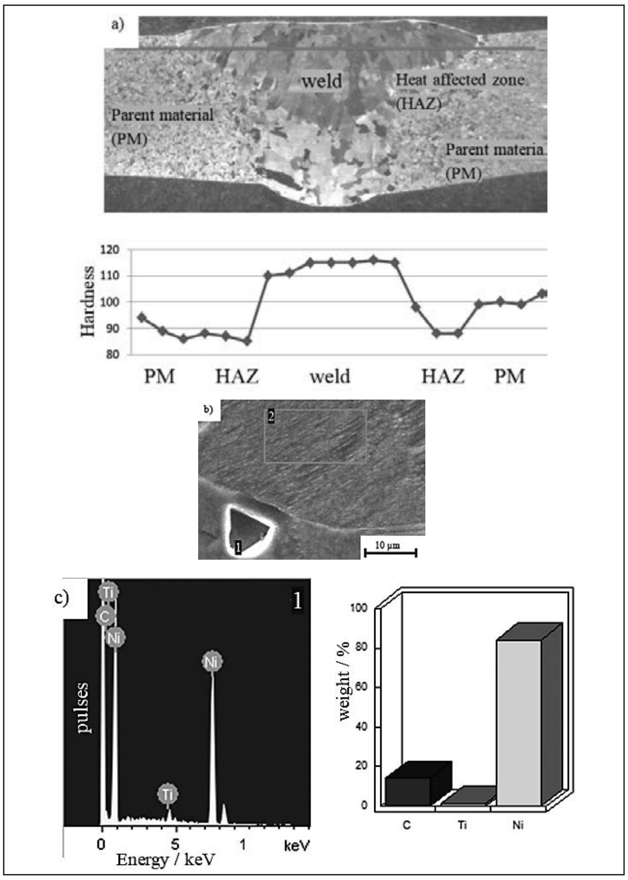

Figure 3 (a) Macrostructure of a welded tee joint on 6 mm thick nickel sheet specimens with marked line along which HV5 hardness; (b) microstructure of the joint weld with marked micro-areas in which chemical composition was determined; (c) images of scattered X-radiation together with element content values in micro-areas 1.

CONCLUSIONS

Specimens of pure nickel (99,5 % Ni) sheet with thickness of 2 mm and 6 mm of were welded with the use of GTAW method in atmosphere of argon and nickel filler with increased content of titanium (about 3,45 % Ti). The welded joints are characterized with a three-zone structure, comprising the weld, the heat-affected zone (HAZ), and the parent material (PM). The sheet nickel (PM) has a structure composed of fine equiaxial nickel grains with dimensions 30 - 40 µm. The elements appearing in chemical composition of the sheet metal, such as Fe, Mg, Ti, C, and other present in trace quantities, combined concentration of which represents about 0,5 % of the material, constitute a solid solution of nickel. Hardness values of the sheet metal (PM) used for welding tests were found to be on the level of 100 HV5.

Macrostructure of welds displays large columnar dendritic grains emerging in the course of their cellular crystallization. Columnar grains of the welds show a mosaic dendritic structure with regularly distributed carbide precipitates, typically in the form of equilateral triangles. Both X-ray elemental concentration analysis (EDS) in micro-areas and X-ray qualitative phase analysis (XRD) indicate that the phases precipitated in dendritic substructure of welds are carbides rich in nickel of M_3C with atomic composition close to $(Ni_{74}Ti)_3C$. Dispersively distributed carbides in columnar dendrites contribute to weld hardness increase to the level of about 130 HV5. It follows from some reports [4–6] that formation of cellular crystallization interface depends on the ratio G_T/V, where G_T is the temperature gradient value at the crystallization interface (weld line — weld material–parent material borderline) and V is the crystal growth speed, and on the initial concentration c_0 of the component in the alloy. For pure nickel, concentration factor c_0 may be omitted, therefore cellular course of solidification of the weld and size of columnar dendrites depends on the ratio G_T/V and the size of partially melted grains on the weld–PM boundary. Columnar dendrites of the weld nucleate on partially melted large nickel grains on the line at which the weld fuses into PM. It is a natural tendency of crystals toepitixial grow in direction opposite to the effluent heat stream. If the speed of travel of the argon-shielded welding arc plasma stream is V_s, then the speed of growth V_c of weld crystals can be determined from the relation $V_c = V_s \cdot \cos(\alpha)$ where α is the included angle between vectors V_s and V_c. Value of the temperature gradient G_T at the weld line (weld material - PM boundary) depends on value of the welding energy linear density E_{lin}. An increase of E_{lin} value results in an increase of liquid nickel pool actual temperature T_{Ni} by a value depending on the temperature gradient G_T at the weld line, $T_{Ni} = T_{fus,Ni} + G_T \cdot x$, where $T_{fus,Ni}$ is the fusion point of nickel and x is the distance of a given point in liquid metal from the weld line which, as a consequence, leads to directional crystallization with formation of thick columnar dendrites in welds.

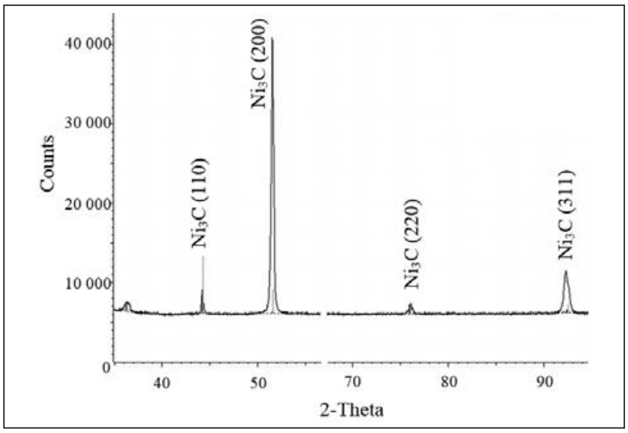

Figure 4 X-ray diffraction pattern from carbide phase occurring in welded sheet nickel joints.

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Note: Jan Snakowski is responsible for English language, Rzeszów, 2021.