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Computer aided structure prediction of 0H18N9 and S235JR steels laser welded joints

A. Klimpel, T. Kik*, J. Górka
Welding Department, Silesian University of Technology,
ul. Konarskiego 18a, 44-100 Gliwice, Poland
* Corresponding author: E-mail address: tomasz.kik@polsl.pl

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ABSTRACT

Purpose: of these researches was to investigate possibilities of joining materials with different chemical composition and properties. CAW software to prediction of joints structure was used.
Design/methodology/approach: the quality of single- and double sided joints was assessed by metallographic examinations, hardness tests, tensile and bending tests.
Findings: a computer aided structure prediction was tested by metallographic examinations and hardness tests. Because of possibility of use these type of joints in medical equipment production tensile and bending tests and also corrosion resistance tests were preformed.
Research limitations/implications: for complete information about tested different chemical composition and properties materials joints it is needed to check others materials in place of S235JR carbon steel.
Practical implications: result of this paper is a information that is possible to join materials with different chemical composition and properties materials with different chemical composition and properties. It is also possible to precise predict structure of weld using computer software.
Originality/value: the researches were provided for welding materials used in medical equipment producing. Welded joints were tested for a corrosion resistance in typical disinfectants used in medical conditions. At the beginning computer prediction was used.
Keywords: Welding; HPDL laser; CAW; Microstructure prediction; Medical equipment

1. Introduction

Present technological development create possibilities to joining of materials with different chemical composition and properties. This type of joints is often used in production of medical equipment as well as in automotive, chemical, food and power industries [1,2,5].

In joining processes of different properties and chemical composition materials it is needed to use modern welding technologies which provide to receive high quality joints [1,2,5,6,8]. Connection of modern welding technologies with computer aided design techniques meets with specifications of quality management system requirements and “zero defects” rule [9,11,13].

In few last years thanks to dynamic growth of engineering and laser equipment, High Power Diode Laser (HPDL) found industrial application. Controlled energy distribution and different shape of laser beam spot with power density, up to 10^5 Watt per cm^2, makes these lasers very attractive heat power source [6,7,8,10]. Application of specialized CAW (Computer Aided Welding) software gives the possibilities to predict of a joint microstructure and also potential hazards connected with properties of welded materials [9,11,12,13]. In this work the HPDL laser was used for welding butt joints from S235JR carbon steel and 0H18N9 austenitic steel for medical equipment production [14].

2. Research equipment and work methodology

Main purpose of researches was to elaborate of technological conditions of HPDL laser welding of S235JR carbon steel and

0H18N9 austenitic steel butt joints. Range of researches includes:

- „Schaeffler's Diagram" CAW program use for prediction of welded joint microstructure,
- test joints welding,
- metallographic examinations,
- mechanical properties tests,
- joints corrosion resistance tests.

For welding tests were used S235JR carbon steel and 0H18N9 austenitic steel with chemical composition and properties shown in Table 1.

Table 1.
Chemical composition and properties of S235JR carbon steel and 0H18N9 austenitic steel

Material	C [%]	Si [%]	Mn [%]	P [%]	S [%]	Cr [%]	Ni [%]
S235JR	0.22	0.35	1.10	0.05	0.05	0.3	0.3
0H18N9	0.07	0.80	2.00	0.045	0.030	19.0	11.0
R_m [MPa]: S235JR - 460, 0H18N9 - 490							
R_e [MPa]: S235JR - 235, 0H18N9 - 185							

All tested joints were welded on test stand equipped in ROFIN Sinar HPDL 020 laser and CNC cross-table, Fig 1. Technical data of ROFIN Sinar HPDL 020 laser are shown in Table 2.

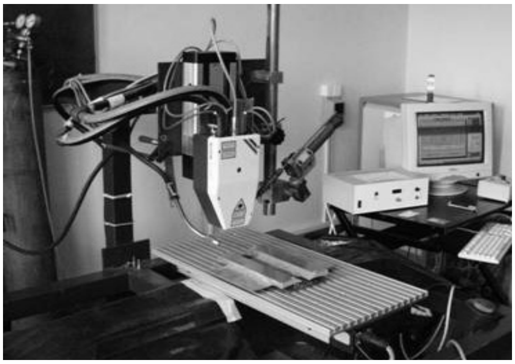


Fig. 1. HPDL laser welding test stand

Table 2.
Technical data of ROFIN Sinar DL 020 High Power Diode Laser

Wave length	808÷940 [nm]
Power range	100÷2300 [W]
Power efficiency	35 ÷50 [%]
Focal length	82 [mm] / 32 [mm]
Laser beam spot dimensions	1.8×6.8 / 1.8×3.8 [mm]
Power density range	0.8÷36.5 [kW/cm^2]

As it is known, structure of joint depends of ferrite amount which was at high temperatures (proportion of austenite-forming to ferrite-forming components). Quantitative influence of these components on microstructure, and especially ferrite amount in joints welded in precise specified thermal conditions was studied by L. A. Schaeffler [3,4].

Schaeffler's diagram permits to estimate/predict microstructure of welded joint depending on chemical compositions of welded materials [3,4,15]. On vertical axis of this diagram was placed a nickel equivalent as a relation [15]:

$$(Ni) = \%Ni + 30\%C + 0.5\%Mn \tag{1}$$

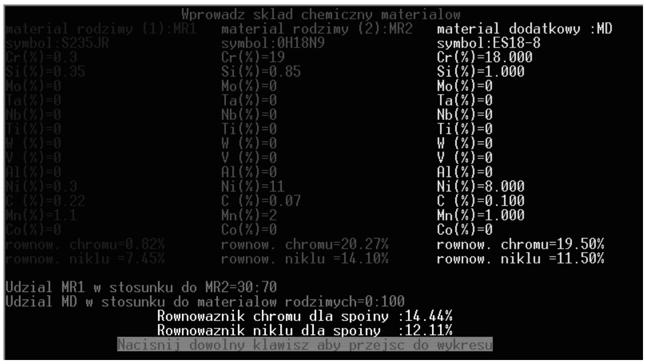
On horizontal axis - chromium equivalent:

$$(Cr) = \%Cr + \%Mo + 1.5\%Si + \%Nb \tag{2}$$

Schaeffler's diagram does not take into consideration of nitrogen which austenite-forming influence is significant [3,4]

"Schaefler's Diagram" CAW software allows to estimate microstructure of designed joint based on chemical compositions of welded materials, additional material and other materials used in welding process. After start of this applications user can read basic information about program and short descriptions of Schaeffler's diagram rules. Data input for calculations is possible by two ways: based on data in program database (selection from database) and also as typed from computer keyboard. There is also possibility to update database with new materials [15].

After selection of welded materials and additional material, chromium and nickel equivalents for welded materials were calculated by program, Fig 2. Results of calculations are also displayed in graphical form, Fig. 3.



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                      Wprowadz sklad chemiczny materialow
material rodzimy (1):MR1   material rodzimy (2):MR2   material dodatkowy :MD
symbol:S235JR              symbol:0H18N9              symbol:ES18-8
Cr(%)=0.3                  Cr(%)=19                   Cr(%)=18.000
Si(%)=0.35                 Si(%)=0.85                 Si(%)=1.000
Mo(%)=0                    Mo(%)=0                    Mo(%)=0
Ta(%)=0                    Ta(%)=0                    Ta(%)=0
Nb(%)=0                    Nb(%)=0                    Nb(%)=0
Ti(%)=0                    Ti(%)=0                    Ti(%)=0
W (%)=0                    W (%)=0                    W (%)=0
V (%)=0                    V (%)=0                    V (%)=0
Al(%)=0                    Al(%)=0                    Al(%)=0
Ni(%)=0.3                  Ni(%)=11                   Ni(%)=8.000
C (%)=0.22                 C (%)=0.07                 C (%)=0.100
Mn(%)=1.1                  Mn(%)=2                    Mn(%)=1.000
Co(%)=0                    Co(%)=0                    Co(%)=0
rownow. chromu=0.82%       rownow. chromu=20.27%      rownow. chromu=19.50%
rownow. niklu =7.45%       rownow. niklu =14.10%      rownow. niklu =11.50%

Udzial MR1 w stosunku do MR2=30:70
Udzial MD w stosunku do materialow rodzimych=0:100
                   Rownowaznik chromu dla spoiny :14.44%
                   Rownowaznik niklu dla spoiny  :12.11%
              Nacisnij dowolny klawisz aby przejsc do wykresu
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Fig. 2. „Schaeffler's Diagram" CAW program, data input screen

„Schaefler's Diagram" CAW program takes into consideration possibilities of: hot cracking, sigma-phase embrittlement, hardening cracks and grain over-growth. Additional informations marked on diagram are areas of different microstructures of welded joints (austenite, ferrite, martensite) [20].

After a preliminary tests of S235JR carbon steel and 0H18N9 austenitic steel butt joints welding process, an optimal parameters were established:

- laser beam power: 2300 [W],
- welding speed: 0.2 [m/min],
- laser beam spot width: 1.8 [mm],
- focal length: 82 [mm],
- shielding gas: argon – 8 [l/min].

Welded joints series made during the tests:

- butt joint of 3.0 [mm] 0H18N9 austenitic steel and S235JR carbon steel sheets; double-sided welding,
- butt joint of 3.0 [mm] 0H18N9 austenitic steel to 2.0 [mm] thick S235JR carbon steel sheets; single-sided welding.

Hardness was tested according to PN-EN 1043-1 standards on Brickers 220 hardness tester with load - 5 kg (HV5), Fig. 7. Mechanical properties were tests according to PN-EN 895 standards on Instron 4210 test-machine. Bending tests were provided on Losenhausen test-machine according to PN- EN 910 standard. Bending tests were provided on 10 millimeters bend-plunger. Results of these tests were shown in Tables 3 and 4.

3. Results of researches

Results of prediction of welds microstructure in “Schaeffler’s Diagram” CAW program indicate that microstructure of weld is austenitic with small amount of martensite.

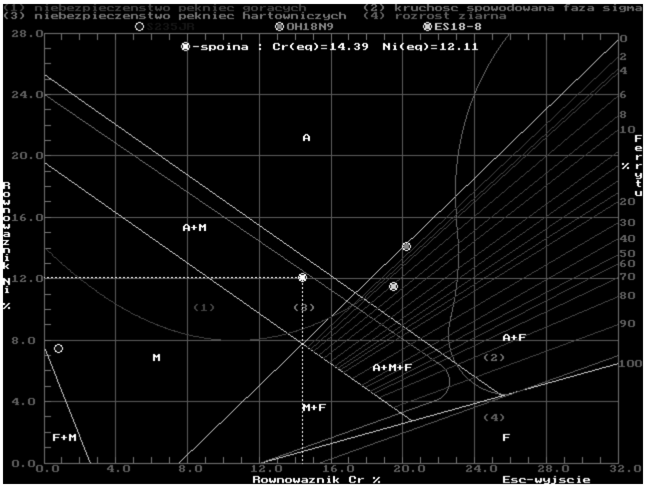

Fig. 3. „ Schaeffler’s Diagram” CAW program, prediction results for 0H18N9 and S235JR steels welding

Macrostructure examinations were provided on OLYMPUS SZX12 microscope with 10x magnification, Fig. 4.

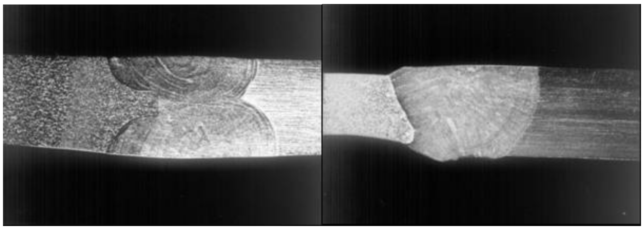

Fig. 4. Macrostructure of double-sided welded butt joint of 3.0 [mm] thick of 0H18N9 austenitic steel and S235JR carbon steel sheets and single-sided butt joint of 3.0 [mm] 0H18N9 austenitic steel to 2.0 [mm] thick S235JR carbon steel sheets, HPDL laser welded (laser beam power: 2.3 [kW], welding speed: 0.2 [m/min], laser beam spot width: 1.8 [mm]), magnification: 10x

Microscopy examinations were provided on OLYMPUS PMEU 3 microscope with magnifications: 100 and 200x, micro-etching in $FeCl_3$, Fig. 5,6.

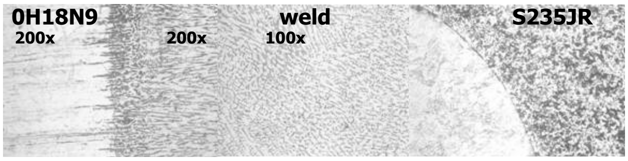

Fig. 5. Microstructure of double-sided welded butt joint of 3.0 [mm] thick of 0H18N9 austenitic steel and S235JR carbon steel sheets (Laser beam power: 2.3 [kW], welding speed: 0.2 [m/min], laser beam spot width: 1.8 [mm]), magnification: 200x, 100x

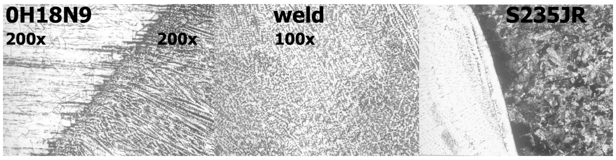

Fig. 6. Microstructure of single-sided welded butt joint of 3.0 [mm] 0H18N9 austenitic steel to 2.0 [mm] thick S235JR carbon steel sheets (laser beam power: 2.3 [kW], welding speed: 0.2 [m/min], laser beam spot width: 1.8 [mm]), magnification: 200x, 100x

Table 3.
Results of tensile strength tests of 0H19N9 austenitic steel and S235JR carbon steel sheets butt joints according to PN-EN 895 standard (laser beam power: 2.3 [kW], welding speed: 0.2 [m/min], laser beam spot width: 1.8 [mm])

Type of welded joint	Specimen designation	Tensile strength [MPa]	Break place
0H18N9 (thickness =3mm) + S235JR (thickness =3mm)	R1	392	bbw
	R2	388	bbw
0H18N9 (thickness =3mm) + S235JR (thickness =2mm)	R1	391	bbw
	R2	378	bbw

bbw – break beyond weld (for all specimens breaks presents in S235JR carbon steel)

Table 4.
Results of bending tests of 0H19N9 austenitic steel and S235JR carbon steel sheets butt joints according to PN-EN 910 standard (laser beam power: 2.3 [kW], welding speed: 0.2 [m/min], laser beam spot width: 1.8 [mm])

Type of welded joint	Specimen designation	Bend angle [°]	Remarks
0H18N9 (g =3mm) + S235JR (g =3mm)	FBB1	130	wcas
	RBB1	130	wcas
	FBB2	130	wcas
	RBB2	130	wcas
0H18N9 (g =3mm) + S235JR (g =2mm)	FBB1	80	ciw
	RBB1	40	ciw
	FBB2	75	ciw
	RBB2	45	ciw

FBB – bending form weld face, RBB – bending from root of weld, wcas – without cracks and scratches, ciw – cracks in weld

Because welding tests were provided for medical equipment manufacturing, all welded joints were corrosion-resistance tested. Corrosion-resistance tests were provided according to FAMED

S.A. manufacturer directions (according to PN IEC–601–1+A3 standards).

Four different type of disinfectants were used in medical corrosion tests:

- Aldizol: PZH HB/899/95/96,
- Aldweir: PZH HB/413/93,
- Septacid: PZH: HB/623/98,
- Descosal P: PZH: HB/564/00/01.

Specimens were 200 times plunged into these disinfectants with 15 minutes time intervals and then dried. According to standard this examinations define which of these disinfectants causes faster corrosion. After this procedure all specimens were examined on microscope. Corrosion tests of welded joints indicate that 0H18N9 austenitic steel and weld is corrosion-resistant. S235JR carbon steel indicates low resistance on corrosive influence of disinfectants. Theirs influence provides to pitting corrosion and in the case of Descosal P disinfectant also uniform corrosion.

Results of hardness test and measurements points distribution on welded joint shows Figure 7.

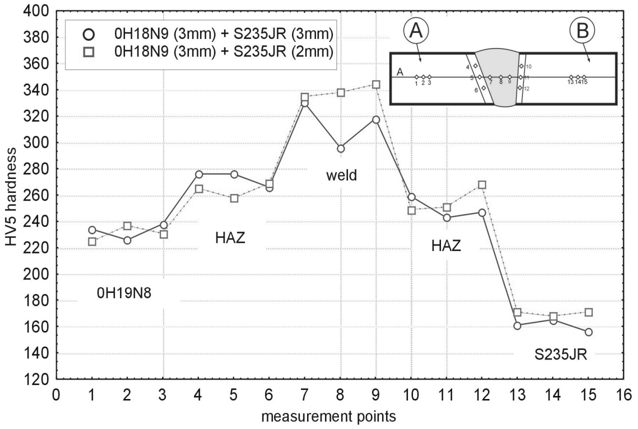

Fig. 7. Hardness distribution on 0H18N9 austenitic steel and S235JR carbon steel HPDL laser welded butt joints (Laser beam power: 2.3 [kW], welding speed: 0.2 [m/min], laser beam spot width: 1.8 [mm])

4. Conclusions

0H18N9 austenitic steel and S235JR carbon steel sheets HPDL laser welding tests indicate that is possible to produce high quality butt joints.

To provide high quality full penetrated butt joints of 3.0 [mm] thick of 0H18N9 austenitic steel and S235JR carbon steel sheets is necessary to use double-sided laser welding technique. Single-sided technique of laser welding of butt joint of 2.0 [mm] S235JR carbon steel sheet to 3.0 [mm] 0H18N9 austenitic steel sheet provide high quality joints as well.

To predict the microstructure of welds "Schaeffler's Diagram" CAW program was successfully used. Predicted microstructure was the same as results of metallographic examinations and hardness tests, Fig. 5, 6, 7. Microstructure of welds is austenitic with small isles of martensite precipitations. This is a source of increase of hardness of weld metal up to 340 HV5, Fig. 7. Increase of hardness of the weld metal is because of admixture in weld pool of S235JR carbon steel and austenitic steel. Tensile and bending tests proved high quality of welded joints, Tables 3, 4.

Medical corrosion resistance tests proved that 0H18N9 austenitic steel sheet and its HAZ and the weld metal are resistant for disinfectants influence. On the side of S235JR carbon steel sheet and its HAZ uniform corrosion and pitting corrosion take place.

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