www.czasopisma.pan.pl PAN www.journals.pan.pl

Arch. Metall. Mater. **63** (2018), 1, 83-86

DOI: 10.24425/118912

T. WĘGRZYN*#, J. KAMIŃSKA**, J. PIWNIK***, Z. STANIK*

MATHEMATHICAL EQUATIONS OF THE INFLUENCE OF MOLYBDENUM AND NITROGEN IN WELDS

The paper offers mathematical equations of the influence of micro-jet cooling on structure and impact toughness properties of metal weld deposit. Weld metal deposit (WMD) was carried out for standard MIG welding and for MIG welding with micro-jet cooling. This new method is very promising mainly due to the high amount of AF (acicular ferrite) and low amount of MAC (self-tempered martensite, retained austenite, carbide) phases in WMD. That structure corresponds with very good mechanical properties ie. good impact toughness of welds at low temperature. Micro-jet cooling after welding can find serious application in automotive industry very soon. Until that moment only argon, helium, nitrogen and gas mixtures of argon were tested for micro-jet cooling after welding. The best results of mechanical properties of WMD in presented welding method correspond with micro-jet argon cooling.

Keywords: welding, steel, micro-jet, ferrite, impact toughness, equations

1. Introduction

The industry is constantly using new technologies with new materials. Large technological progress can be seen in the automotive industry [1-4]. For the structures we need constant and reliable knowledge about the influence of alloy elements. Especially nickel, molybdenum, nitrogen and oxygen are regarded as the important elements effecting on mechanical properties and metallographic structure of low alloy welds. However there is different influence of those elements on mechanical properties of welds [5-6]. The influence of the variable amounts of molybdenum and nitrogen on impact properties of different basic electrode deposits were tested in last 15 years [7].

There were even given mathematical equations regarding impact toughness (at temperature +20°C and –40°C) of welds in terms of the amount of nitrogen and molybdenum in WMD [1].

For temperature +20°C:

$$U_{+20}^{\mathrm{Mo}} = 265 - 66 \cdot \mathrm{Mo} - 0{,}8 \cdot \mathrm{N} \tag{1}$$

and for temperature –40°C:

$$U_{-40}^{\mathrm{Mo}} = 135 - 46 \cdot \mathrm{Mo} - 0{,}45 \cdot \mathrm{N} \tag{2}$$

where:

U_{+20}^{Mo} – impact toughness of weld metal deposit at +20°C, J;

U_{-40}^{Mo} – impact toughness of weld metal deposit at –40°C, J;

Mo – molybdenum contents (in range 0.27 to 0.52%) of weld metals deposit, %;

N – nitrogen contents (in range 78 ppm to 168 ppm) of weld metals deposit, ppm.

Furthermore, on the basis of the results of the influence of the variable amounts of Mo, Ni, N, O it was not possible to obtain more than 55% of acicular ferrite in WMD that guaranties good impact toughness of WMD. New technologies are constantly being created for the production [5-9]. It has recently been invented welding with micro-jet cooling. Micro-jet technology gives chance to obtain weld that corresponds with much better mechanical properties (especially impact toughness of WMD) compared with classic welding method [10,11]. Good mechanical properties of weld correspond respectively with low-oxygen processes. Amount of nickel and molybdenum also have strong influence on metallographic structure because of the influence on acicular ferrite (AF) formation [12]. Micro-jet cooling just after welding gives a new chance to increase amount of AF in weld and consequently micro-jet cooling effects on impact toughness of weld [13-14]. The micro-jet cooling was tested for low alloy steel with various micro-jet parameters. The micro-jet cooling gives a real opportunity for professional development in the field of welding with controlling the parameters of weld structure. WMD with high amount of acicular ferrite and good impact toughness are important for automotive welding. The automotive industry has always been one of the driving forces behind innovative welding application [12-15]. The paper offers mathematical equations of the influence of micro-jet cooling on structure and impact toughness properties of metal weld deposit.

* THE SILESIAN UNIVERSITY OF TECHNOLOGY, FACULTY OF TRANSPORT, 8 KRASIŃKIEGO STR., 40-019 KATOWICE, POLAND
** WROCLAW UNIVERSITY OF ENVIRONMENTAL AND LIFE SCIENCES, DEPARTMENT OF MATHEMATICS, 53 GRUNWALDZKA STR., 50-357 WROCŁAW, POLAND
*** BIALYSTOK UNIVERSITY OF TECHNOLOGY, MECHANICAL FACULTY, 45C WIEJSKA STR., 16-351 BIAŁYSTOK , POLAND

Corresponding author: tomasz.wegrzyn@polsl.pl

2. Aim and plan of research

It was decided to investigate the properties of WMD, depending on the various parameters of the process. The present paper aims at outlining micro-jet innovations only in MIG welding process. The weld metal deposit was prepared by welding with micro-jet cooling with varied pressure of argon micro-jet cooling just after welding. To obtain various amount of acicular ferrite in weld the micro-jet injector was installed (Fig. 1). Only one parameter of micro-jet cooling was slightly varied:

– cooling steam diameter was not varied (always 50 µm),
– gas pressure was varied (between: 0.4 MPa and 0.5 MPa),
– micro-jet gases was not varied (always argon was chosen). MIG welding processes based on argon as a shielded gas.

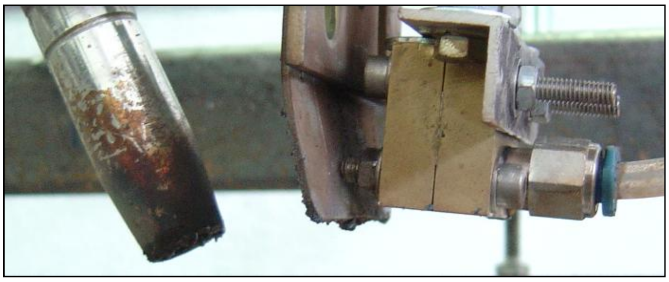

Fig. 1. Montage of MIG welding head and micro-jet injector

3. Materials to research

The basic material to research was S355J2G3 steel. Various welds of standard MIG welding were compared firstly without innovative micro-jet cooling technology. A typical weld metal deposit had rather similar chemical composition in all tested cases (Table 1). Weld metal deposit was prepared by welding with micro-jet cooling with varied micro-jet gas (argon) pressure. The main data about parameters of welding were shown in table 1.

TABLE 1

Parameters of welding process

Nº	Parameter	Value
1.	Diameter of wire	1.2 mm
2.	Standard current	220 A
3.	Voltage	24 V
4.	Shielding MIG welding gas	Ar
5.	steam diameter of micro-jet gas	50 µm
6.	micro-jet cooling gas	argon
7.	micro-jet gas pressure	from 0.3 MPa, upto 0.7 MPa
8.	Distance between welding head and micro-jet injector	6 cm

4. Results and discussion

There were mainly tested and compared welds of standard MIG welding with micro-jet technology with various micro-jet gases mixtures. A typical weld metal deposit had rather similar chemical composition in all tested cases (Table 2).

TABLE 2

Chemical composition of WMD after MIG process

No.	Element	Amount
1.	C	0.08%
2.	Mn	0.77%
3.	Si	0.39%
4.	P	0.016%
5.	S	0.017%

Various micro-jet parameters (in that case gas pressure) had some influence on intensively cooling conditions but did not have greater influence on chemical WMD composition. Metallographic structure of WMD was carried out after chemical analyses of WMD. Very precisely acicular ferrite (AF) and MAC phases (self-tempered martensite, retained austenite, carbide) content were analyzed. Examples of the results of the metallographic structure analysis are shown in table 3.

TABLE 3

Acicular ferrite and MAC phases in WMD after MIG welding with various micro-jet parameters (gas pressure)

Micro-jet gas pressure [MPa]	Acicular ferrite in WMD [%]	MAC phases [%]
without m-j cooling	45	4
0,30	45	4
0,35	52	4
0,40	61	3
0,45	67	3
0,50	70	3
0,55	71	3
0,60	66	3
0,65	57	4
0,70	46	4

Analyzing table 3 it is easy to deduce that MIG welding with micro-jet cooling could be treated as a good option. Amount of acicular ferrite in WMD after MIG welding without micro-jet cooling was only on the level of 45%. Amount of acicular ferrite in WMD after MIG welding with micro-jet cooling was always on much higher level up to 71%. Acicular ferrite with percentage above 55% was gettable only after micro-jet cooling (shown on Fig. 3, Tab. 3). Micro-jet gas pressure has strong influence on metallographic structure (Fig. 2).

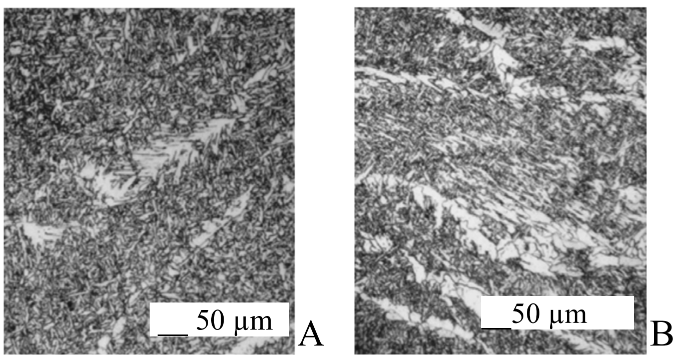

Fig. 2. Acicular ferrite in WMD (A – with m-j cooling, B – without m-j cooling)

Analysing table 3 is also possible to deduce that amount of acicular ferrite in metal weld deposit is affected by the micro-jet cooling conditions. Using the least square method there was presented that acicular ferrite amount of metal weld deposit depends on cooling conditions (micro-jet gas pressure). There was given a basic equation 3 and corresponding figure 3:

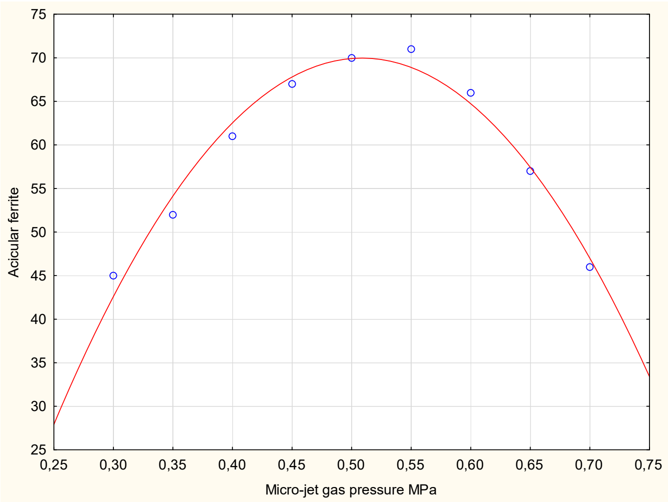

Fig. 3. Amount of acicular ferrite of WMD in terms of micro-jet gas pressure

Analyzing figure 3 and equation 3 it is easy to deduce, that micro-jet gas pressure should be in range 40 MPa – 60 MPa.

$$F = -92{,}62 + 639{,}14x - 628{,}14x^2 \tag{3}$$

where:

- F – acicular ferrite amount, %;
- x – micro-jet gas pressure, MPa.

Maximal error for equation 3 was equal 3.2%, and the least square error was equal 2.1%. Finaly Charpy V impact test of the deposited metal were carried out. For these studies there were selected samples containing the highest acicular ferrite content (Table 3). The Charpy tests were done mainly at temperature – 40°C on 5 specimens having been extracted from each weld metal (Table 4).

TABLE 4

Impact toughness of WMD after welding with micro-jet cooling

Micro-jet gas pressure [MPa]	Impact toughness (at-40°C C) [KCV, J]
0,30	40
0,35	44
0,40	50
0,45	53
0,50	57
0,55	57
0,60	49
0,65	44
0,70	40

It is possible to deduce that impact toughness at negative temperature of weld metal deposit is apparently affected by the parameters of micro-jet cooling just after welding. Using the least square method there was presented that impact toughness depends on cooling conditions (in that case: micro-jet gas pressure). There was given equations 4, 5 and corresponding Fig. 4.

For all impact toughness values (9 points, marked in red color on figure 5):

$$U = -47{,}67 + 410{,}19x - 409{,}52x^2 \tag{4}$$

– only for values of impact toughness higher than 47 J (5 points, marked in blue color on figure 5):

$$U = -130{,}8 + 746{,}86x - 742{,}86x^2 \tag{5}$$

Maximal error for equation 2 was equal 4.2 J, and the least square error was equal 3.1 J. Maximal error for equation 2 was equal 3.8 J, and the least square error was equal 3.2 J.

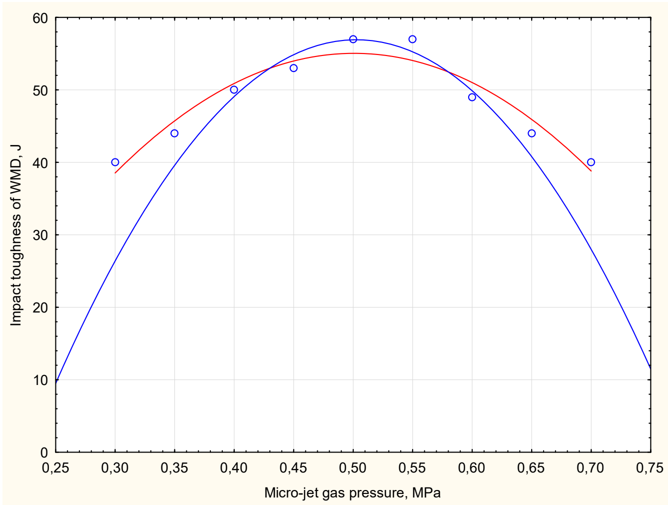

Fig.4. Impact toughness of WMD in terms of micro-jet gas pressure

Analyzing figure 4 and equations 4, 5 it is possible to deduce, that micro-jet gas pressure should be in range 40 MPa – 60 MPa.

5. Conclusions

This investigation has proved that the new micro-jet technology has the potential for growth. It may be great achievement of welding technology in order to steer weld metal structure, impact toughness and strength. The new technology with micro-jet cooling may have many practical applications in many fields, like for example in automotive industry or to repair damaged metal elements. On the basis of investigation it is possible to deduce that:

– micro-jet cooling could be treated as an important element of MIG welding process;
– micro-jet cooling after welding can prove amount of ferrite AF, the most beneficial phase in low alloy steel weld metal deposit;

- micro-jet cooling after welding can prove impact toughness of WMD;
- micro-jet gas pressure should be on the level of 0.5 MPa.

REFERENCES

[1] P. Czech, G. Wojnar, R. Burdzik, et al., Journal of Vibroengineering **16** (4), 1619-1639 (2014).

[2] H. Madej, P. Czech, Maintenance And Reliability 4 (2010).

[3] B. Szczucka-Lasota, Arch. Metall. Mater. **61** (3), 1431-1436 (2016). DOI: 10.1515/amm-2016-0234.

[4] Z. Stanik, Mechatronic Systems, Mechanics And Materials II Book Series: Solid State Phenomena **210**, 58-64 (2014).

[5] P.J. Van der Wolk, Modelling CCT-diagrams of engineering steels using neural networks, Delft University Press (2001).

[6] J. Labaj, G. Siwiec, L. Blacha, R. Burdzik, Metalurgija **53** (2), 215-217 (2014).

[7] G. Golanski, J. Jasak, J. Slania, Kovove Materialy-Metallic Materials **52** (2), 99-106 (2014).

[8] G. Golański, P. Gawień, P. Słania, Arch. Metall. Mater. **57** (2), (2012).

[9] A. Lisiecki, Applications of Lasers (2013).

[10] L.A. Dobrzański, J. Trzaska, A.D. Dobrzańska-Danikiewicz, Use of Neuronal Networks and Artificial Inteligence Tools for Modeling, in: s. Hashmi (Ed.), Comprehensive Materials Processing, Elsevier science & Technology (2014).

[11] A. Kurc-Lisiecka, W. Ozgowicz, W. Ratuszek, J. Kowalska, 203-204, 105-110 (2013), Doi 10.4028/www.scientific.net/SSP.203-204.105.

[12] B. Szczucka-Lasota, B. Gajdzik, T. Węgrzyn, Ł. Wszołek, Metals **7** (9), 339, 1-9, (2017) doi:10.3390/met7090339.

[13] D. Hadryś, Arch. Metall. Mater. **60** (4), 2525-2528 (2015).

[14] T. Węgrzyn, J. Piwnik, B. Łazarz, W. Tarasiuk, Mechanika **21** (5), 419-423 (2015).

[15] B. Szczucka-Lasota, B. Gajdzik, T. Węgrzyn, Time Efficiency in Lean Manufacturing on Long Weld Steel after micro-jet cooling, in: M. Jabłoński (ed.) Strategic Performance Management. New Concepts and Contemporary Trends, Chapter 19, Editor: Nova Science Publishers, Inc., New York, 327-342 (2017).