

DOI: 10.1515/amm-2016-0023

D. HADRYŚ*, T. WĘGRZYN**#, J. PIWNIK***, L. WSZOŁEK**, D. WĘGRZYN****

COMPRESSIVE STRENGTH OF STEEL FRAMES AFTER WELDING WITH MICRO-JET COOLING

Low carbon steel weld structures generally exhibit a very linear stress–strain relationship. In the study of strength of materials, the compressive strength is the capacity of a material or structure to withstand loads tending to reduce size of structure. It is mainly measured by plotting applied force against deformation in a testing machine. Compressive strength is a main key value for design of welded structures. The main goal of that paper was analysing of plastic properties of frame welds which were made with various parameters of micro-jet cooling. New technology of micro-jet welding could be regarded as a new way to improve plastic properties of welds. It allows to obtain welds with better mechanical properties in comparison to ordinary welding method. Furthermore it is possible to steering of weld structure and properties of the weld. There were given main information about influence of various micro-jet gases on metallographic and properties of structure steel welds.

Keywords: welding, micro-jet cooling, plastic properties, compressive tests, impact toughness

1. Introduction

Proper mechanical properties of weld correspond with structure of weld metal deposit (WMD). Acicular ferrite (AF) is treated as the most beneficial phase in steel WMD that corresponds with good strength and impact toughness [1-5]. Amount of AF in weld is connected with nitrogen and oxygen in WMD because of nitride and oxide inclusions of welds. Even having optimal oxide inclusion parameters in weld metal deposit it is only possible to get maximal 55 % of acicular ferrite in WMD [6-9]. Micro-jet cooling just after welding gives great chance to increase artificially high amount of AF in weld and consequently allows to get good mechanical properties of weld [10-11]. The micro-jet cooling was tested only for low alloy steel with two micro-jet gases (argon, helium) only for MIG welding. Argon and helium as micro-jet gases could give better micro-structure of WMD (having 0.08% C, 0.8% Mn) than classic MIG process (table 1) [12-16].

TABLE 1

Metallographic structure of MIG welds [1]

Micro-jet gases	Ferrite AF	MAC phases
without micro-jet	55%	3%
He	61%	5%
Ar	73%	2%

Table 1 shows that argon is more beneficial micro-jet gas cooling than helium. Also it is shown that micro-jet cooling improves acicular ferrite amount in weld. For automotive

sector material properties, production and repair technologies are extremely important [17-23].

2. Experimental procedure

The main samples used in the study based on steel frames built on a square of side 300 mm. Samples were made of closed profiles with dimensions 20 x 30 x 2 mm. Profiles are made of popular S235JR steel. In addition, each sample had the reinforcing part in the form of a diagonal. Test sample is shown in figure 1.

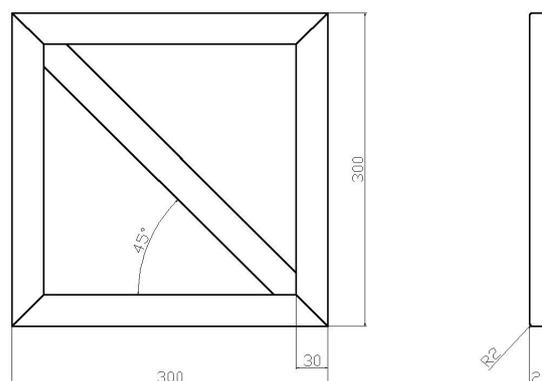


Fig. 1. Steel frame after MIG welding with micro-jet cooling

The study included load (compression) prepared samples under static conditions. It was decided that the maximum total force strength is aggravating of 100 kN (figure 2).

* HIGHER SCHOOL OF LABOUR SAFETY MANAGEMENT, KATOWICE, POLAND

** SILESIA UNIVERSITY OF TECHNOLOGY, 8 KRASIŃSKIEGO STR., 40-019 KATOWICE, POLAND

*** BIALYSTOK UNIVERSITY OF TECHNOLOGY, BIALYSTOK, POLAND

**** UNIVERSITY DA BEIRA INTERIOR, COVILHA, PORTUGAL

Corresponding author: tomasz.wegrzyn@polsl.pl

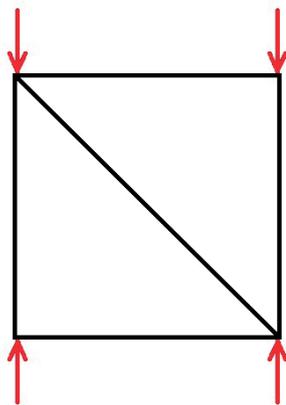


Fig. 2. Frame montage in testing machine

Frames were prepared by welding with micro-jet cooling with gas mixtures both for standard MIG welding and MIG welding with micro-jet cooling. To obtain various amount of acicular ferrite in weld it was installed welding process with micro-jet cooling. Main parameters of micro-jet cooling were slightly varied:

- cooling steam diameter (40 μm and 50 μm),
- gas pressure (0.4 MPa and 0.5 MPa),
- helium and argon were chosen as micro-jet gases.

Montage of welding head and micro-jet injector illustrates figure 3.



Fig. 3. Montage of welding head and micro-jet injector

The main data about parameters of welding were shown in table 2.

 TABLE 2
 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 welding gas	argon
5.	Kind of tested micro-jet cooling gas	argon, helium
6.	Gas pressure	0.4 MPa; 0.5 MPa
7.	Number of micro-jets:	1
8.	cooling steam diameter	40 μm ; 50 μm

Thus welding structure (frame) was prepared by MIG welding with micro-jet cooling with great number of .

3. Results and discussion

There were tested and compared various welds of standard MIG welding with innovative micro-jet cooling technology. A typical weld metal deposit had similar chemical composition in all tested cases. Micro-jet gas could have only influence on more or less intensively cooling conditions, but does not have any influence on chemical WMD composition (table 3).

 TABLE 3
 Chemical composition of WMD

comment	Element	Amount
in all tested cases	C	0.08%
in all tested cases	Mn	0.79%
in all tested cases	Si	0.39%
in all tested cases	P	0.017%
in all tested cases	S	0.018%

After chemical analyses the metallographic structure of WMD was carried out. Example of this structure was shown respectively in tables 4.

 TABLE 4
 Metallographic structure of WMD

Micro-jet gas	Gas Pressure MPa	Cooling steam diameter, μm	Ferrite AF	MAC phases
without micro-jet	-	-	55%	4%
argon	0.4	40	66%	2%
argon	0.4	50	73%	2%
argon	0.5	40	71%	2%
argon	0.5	50	65%	2%
helium	0.4	40	63%	3%
helium	0.4	50	67%	3%
helium	0.5	40	65%	3%
helium	0.5	50	61%	3%

Table 4 shows that in all cases micro-jet cooling is more beneficial than simple MIG welding without micro-jet cooling because of AF amount. There were also observed MAC (self-tempered martensite, retained austenite, carbide) phases on various level. In standard MIG welding process (without micro-jet cooling) there are usually gettable higher amounts of grain boundary ferrite (GBF) and site plate ferrite (SPF) fraction meanwhile after micro-jet cooling WMD both of GBF and SPF structures were not so dominant. Ferrite with percentage above 70% was gettable only in one case after MIG welding with argon as a micro-jet gas (fig.4). The higher amount of MAC phases was observed for more intensive helium micro-jet cooling.

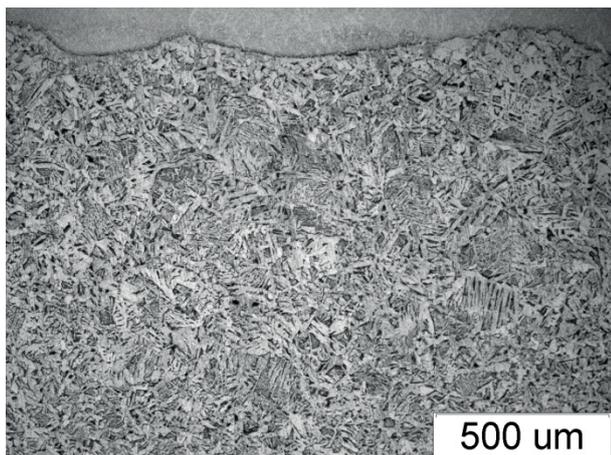


Fig.4. High amount of acicular ferrite in weld (above 70%) after argon micro-jet cooling

Heat transfer coefficient of various micro-jet gases mixtures influences on cooling conditions of welds. This is due to the conductivity coefficients ($\lambda \cdot 10^5$), which for Ar and He in the 273 K are various, respectively: 16.26 and 143.4 J / (cm·s·K). Helium could give stronger cooling conditions and that fact translates higher amount of MAC phases in MWD and lower of AF.

After microstructure study, the behavior of the frames during compression tests were carried out (figure 5).

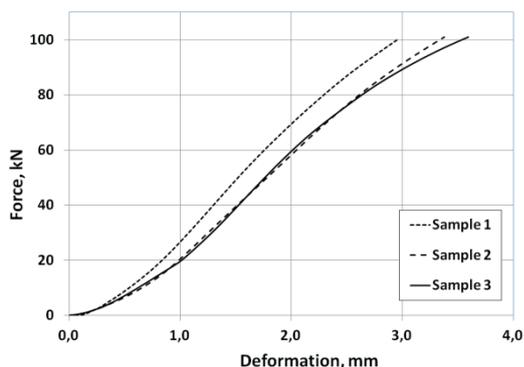


Fig. 5. Frame deformation welded with (1 MIG without micro-jet cooling, 2 MIG with helium micro-jet cooling, 3 MIG with helium micro-jet cooling)

It is easy to deduce that micro-test cooling proves plastic properties of weld structure. Both micro-jet gases (argon and helium) give comparable results. To get more information about plastic properties of tested structures Charpy V impact toughness of the deposited metal was carried out (with 5 specimens of WMD) (table 5). The Charpy tests were only carried out at temperature - 40° C. The impact toughness results is given in table 5.

TABLE 5

Impact toughness of welds

Welding method	Micro-jet gas	Test temperature, °C	Impact toughness KCV, J
MIG without micro-jet cooling	-	- 40	43

MIG with micro-jet cooling	helium	- 40	52
MIG with micro-jet cooling	argon	- 40	59

It is possible to deduce that impact toughness at negative temperature of weld metal deposit is apparently affected by the kind of micro-jet cooling gas. Micro-jet technology always strongly proves impact toughness of WMD. Argon must be treated as better micro-jet gas mixture than helium.

4. Summary and conclusions

In low alloy steel welding there are two general types of tests performed: strengths (in tension or compression), impact toughness and structure. Acicular ferrite and MAC phases (self-tempered martensite, upper and lower bainite, retained austenite, carbides) were analyzed and counted for each weld metal deposit. All this tests (compression, microstructure and impact toughness) proved that micro-jet technology gives beneficial modification in mechanical properties of welds.

5. Final conclusions:

- 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 WMD,
- argon could be treated as better micro-jet cooling gas than helium.d

REFERENCES

- [1] T. Węgrzyn, Proposal of welding methods in terms of the amount of oxygen, Archives of Materials Science and Engineering **47**(1), 57-61 (2011).
- [2] R. Burdzik, Implementation of multidimensional identification of signal characteristics in the analysis of vibration properties of an automotive vehicle's floor panel, Eksploatacja i Niezawodność – Maintenance and Reliability **16**(3), 439-445 (2014).
- [3] B. Slazak, J. Slania, T. Węgrzyn, A.P. Silva, Process stability evaluation of manual metal arc welding using digital signals, Materials Science Forum, Trans Tech Publications, Switzerland **730-732**, 847-852 (2013).
- [4] T. Węgrzyn, J. Mirosławski, A. Silva, D. Pinto, M. Miros. Oxide inclusions in steel welds of car body. Materials Science Forum **6**, 585-591 (2010).
- [5] T. Kasuya, Y. Hashiba, S. Ohkita, M. Fuji, Hydrogen distribution in multipass submerged arc weld metals, Science and Technology of Welding&Joining **6**(4), 261-266 (2001).
- [6] J. Slania, Influence of phase transformations in the temperature ranges of 1250-1000°C and 650-350°C on the ferrite content in austenitic welds made with T 23 12 LRM3 tubular electrode. Archives of Metallurgy and Materials **50**(3), 757-767(2005).
- [7] K. Krasnowski, Influence of stress relief annealing on mechanical properties and fatigue strength of welded joints of thermo-mechanically rolled structural steel grade S420MC.

- Archives of Metallurgy **54**(4), (2009).
- [8] T. Węgrzyn, Mathematical equations of the influence of molybdenum and nitrogen in welds. International Society of Offshore and Polar Engineers IV, 263-267 (2002).
- [9] R. Burdzik, Research on the influence of engine rotational speed to the vibration penetration into the driver via feet - multidimensional analysis, Journal of Vibroengineering **15**(4), 2114-2123 (2013).
- [10] R. Burdzik, P. Fołęga, B. Łazarz, Z. Stanik, J. Warczek, Analysis of the impact of surface layer parameters on wear intensity of friction pairs. Arch. Metall. Mater. **57** (4), 987-993, (2012).
- [11] G. Golański, J. Słania, Effect of different heat treatments on microstructure and mechanical properties of the martensitic GX12CrMoVNbN91 cast steel. Archives of Metallurgy and Materials **58**(1), 25-30 (2013).
- [12] T. Węgrzyn, J. Piwnik, R. Wieszala, D. Hadryś, Control over the steel welding structure parameters by micro-jet cooling, Archives Of Metallurgy And Materials **57**(3), 679-684 (2012).
- [13] K. Lukaszewicz, A. Kriz, J. Sondor, Structure and adhesion of thin coatings deposited by PVD technology on the X6CrNiMoTi17-12-2 and X40 CrMoV5-1 steel substrates, Archives of Materials Science and Engineering **51**, 40-47 (2011).
- [14] A. Lisiecki, Diode laser welding of high yield steel. Proceedings of SPIE, Laser Technology, Applications of Lasers 8703, 22 (2012).
- [15] A. Lisiecki: Welding of titanium alloy by Disk laser. Proceedings of SPIE, Laser Technology, Applications of Lasers, 87030 (2013).
- [16] P. Fołęga. FEM analysis of the options of using composite materials in flexsplines. Archives of Materials Science and Engineering **51**(1), 55-60, (2011)
- [17] Ł. Konieczny, R. Burdzik, B. Łazarz, Application of the vibration test in the evaluation of the technical condition of shock absorbers built into the vehicle, Journal of Vibroengineering **15**(4), 2042-2048 (2013).
- [18] R. Burdzik, Ł. Konieczny, T. Figlus, Concept of On-Board Comfort Vibration Monitoring System for Vehicles, Communications in Computer and Information Science **395**, 418-425 (2013).
- [19] G. Siwiec, Elimination of Aluminum during the Process of Ti-6Al-4V Alloy, Smelting in a Vacuum Induction Furnace, Archives of Metallurgy and Materials **57**(4), 951-956 (2012).
- [20] L. Blacha, R. Burdzik, A. Smalcerz, T. Matuła, Effects of pressure on the kinetics of manganese evaporation from the OT4 alloy, Archives Of Metallurgy And Materials **58** (1), 197-201 (2013).
- [21] G. Siwiec, B. Oleksiak, A. Smalcerz, J. Wieczorek. Surface tension of Cu-Ag alloys, Archives of Materials and Metallurgy **58** (1), 193-195 (2013).
- [22] B. Oleksiak, A. Blacha-Grzechnik, G. Siwiec: Application of the flotation process in the silver recovery from the wastes generated during the silvery semi-products manufacturing. Metalurgija **51** (3), 298-300 (2012).
- [23] A. Kurc-Lisiecka, W. Ozgowicz, W. Ratuszek, J. Kowalska, Analysis of Deformation Texture in AISI 304 Steel Sheets, Solid State Phenomena **203-204**, 105-110 (2013).