Arch. Metall. Mater. **62** (2017), 3, 1647-1650

DOI: 10.1515/amm-2017-0252

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# IMPACT TOUGHNESS OF STEEL WMD AFTER TIG WELDING

The material selected for this investigation was low alloy weld metal deposit after TIG welding with various amount of oxygen in weld metal deposit (WMD). After TIG process it is difficult to get proper amount of oxygen in WMD on the level much lower than 350 ppm. The highest impact toughness of low alloy WMD corresponds with the amount of oxygen in WMD above 350 ppm. In the paper focuses on low alloy steel after innovate welding method with micro-jet cooling that could be treated as a chance on rising amount of oxygen in weld. Weld metal deposit (WMD) was carried out for TIG welding with micro-jet cooling with various amount of oxygen in WMD. In that paper various gas mixtures (gas mixtures Ar-$O_2$ and Ar-$CO_2$) were tested for micro-jet cooling after TIG welding. An important role in the interpretation of the results can give methods of artificial intelligence.

*Keywords:* TIG, welding, micro-jet, oxygen in WMD, acicular ferrite, impact toughness

## 1. Introduction

In last 20 years main authors created a lot of new technologies in materials science and engineering [1-5]. It has recently been invented low alloy steel welding (only for MIG/MAG processes) with micro-jet cooling [6-9]. Laser welding and also micro-jet cooling after MIG/MAG give chance to obtain weld metal deposit with very high amount of acicular ferrite (AF) in weld metal deposit (WMD) that corresponds with much higher impact toughness of weld [10-12]. In presented paper first time TIG welding was tested with micro-jet cooling (Fig. 1).

The importance of respecting modern welding methods with low-nitrogen and low-oxygen processes (50 ppm of N, 350 ppm of O) guarantees welds with good plastic properties. Generally low-nitrogen and low-oxygen processes give a chance to obtain high amount of acicular ferrite (AF) in low alloy steel WMD that directly corresponds with high impact toughness of weld [1-5]. Having the most optimal inclusion parameters in main welding processes (SMAW, SAW, MIG, MAG) it is only possible to get maximal 55% of AF in weld, but no more. In TIG welding the acicular ferrite content is observed on lower level (at the maximum of 48%). In SMAW, SAW, MIG, MAG processes it is possible to have higher amount of AF because it corresponds with the most beneficial amount of oxygen in WMD on the level of (350 ppm-450 ppm). In simple TIG process it is not possible to get very high amount of AF because it corresponds with the much lower amount of oxygen in WMD (below 280 ppm) [4]. Micro-jet cooling just after welding gives a new chance to increase seriously high amount of AF in TIG process because of the possibility of grain refinement in WMD and it small saturation by oxygen. The micro-jet cooling was tested for low alloy steel with various micro-jet parameters (micro-jet gas pressure, stream diameter, various gas mixtures of Ar-$O_2$ and Ar-$CO_2$.

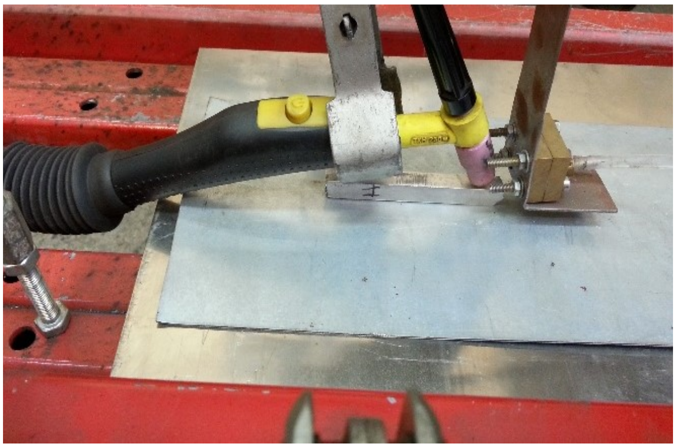

Fig. 1. TIG welding head with micro-jet injector

## 2. Plan of the research

The present paper aims at outlining micro-jet innovations only in TIG process. It was decided to investigate the proper-

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ties of weld metal deposit having various amount of oxygen in WMD after TIG welding (depending on the parameters of the micro-jet cooling just after welding). The weld metal deposit was prepared by welding with micro-jet cooling with varied gas mixtures of Ar-$O_2$ and Ar-$CO_2$. To obtain various amount of oxygen in WMD and consequently higher amount of acicular ferrite in weld, the micro-jet injector was installed after welding head. Main parameters of micro-jet cooling were slightly varied:

- cooling steam diameter was not varied (always 50 µm),
- gas pressure was varied (between: 0.4 MPa and 0.6 MPa),
- micro-jet gases were varied (gas mixture of Ar-$O_2$ and Ar-$CO_2$).

TIG welding processes based on argon as a shielded gas only.

## 3. Materials to research

The basic material to research was low alloy steel S355J2G3. Various welds of standard TIG 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 various gas mixtures (mixtures Ar-$O_2$ and Ar-$CO_2$) with changing other micro-jet parameters (gas pressure, cooling stream diameter).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 | 23 V |
| 4. | Shielding MIG welding gas | Ar |
| 5. | Micro-jet cooling gas mixtures | 1. Ar<br>2. 97% Ar/3% $O_2$<br>3. 94% Ar/6% $O_2$<br>4. 90% Ar/10% $CO_2$<br>5. 80% Ar/20% $CO_2$ |
| 6. | Micro-jet gas pressure | 0.4 MPa<br>0.5 MPa<br>0.6 MPa |
| 7. | Steam diameter of micro-jet gas | 50 µm |
| 8 | Cooling streams in injector | always 1 |

## 4. Results and discussion

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

TABLE 2

Chemical composition of WMD after welding

| No. | Element | Amount |
|---|---|---|
| 1. | C | 0.07% |
| 2. | Mn | 0.84% |
| 3. | Si | 0.39% |
| 4. | P | 0.012% |
| 5. | S | 0.014% |
| 6. | N | 55 ppm |
| 7. | O | 260-420 ppm |

Various micro-jet parameters had some influence on intensively cooling conditions but did not have greater influence on chemical WMD composition (except oxygen in WMD).

Metallographic structure of WMD was carried out after chemical analyses of WMD (with various oxygen amount). Acicular ferrite (AF) in terms of oxygen amount in WMD was precisely analyzed. Examples of the results of the metallographic structure analysis are shown in (Table 3).

TABLE 3

Acicular ferrite in WMD after TIG welding with various micro-jet parameters

| Micro-jet gas mixtures | Micro-jet gas pressure [MPa] | Acicular ferrite in WMD, % | O in WMD [ppm] |
|---|---|---|---|
| without cooling | — | 43 | 260 |
| Ar | 0.4 | 50 | 260 |
| 90% Ar/10% $CO_2$ | 0.4 | 56 | 320 |
| 97% Ar and 3% $O_2$ | 0.4 | 63 | 340 |
| 80% Ar/20% $CO_2$ | 0.4 | 62 | 360 |
| 94% Ar and 6% $O_2$ | 0.4 | 57 | 390 |
| Ar | 0.5 | 42 | 260 |
| 90% Ar/10% $CO_2$ | 0.5 | 59 | 330 |
| 97% Ar and 3% $O_2$ | 0.5 | 58 | 355 |
| 80% Ar/20% $CO_2$ | 0.5 | 59 | 375 |
| 94% Ar and 6% $O_2$ | 0.5 | 52 | 420 |
| Ar | 0.6 | 54 | 260 |
| 90% Ar/10% $CO_2$ | 0.6 | 63 | 350 |
| 97% Ar and 3% $O_2$ | 0.6 | 60 | **375** |
| 80% Ar/20% $CO_2$ | 0.6 | 58 | 390 |
| 94% Ar and 6% $O_2$ | 0.6 | 51 | 440 |

Analyzing tables 3 it is easy to deduce that welding with with micro-jet cooling could be treated as a very good option. Amount of acicular ferrite in WMD after TIG welding without micro-jet cooling was only on the level of 43%. It is also shown that micro-jet cooling after TIG corresponds with 60% of acicular ferrite in WMD. Acicular ferrite with percentage above 60% was gettable after micro-jet cooling only when oxygen was on the level of 350 ppm (Table 4).

Thus it is easy to deduce that micro-jet cooling has strong influence on metallographic structure (Fig. 2).

TABLE 4

Optimal parameters of micro-jet cooling

| Micro-jet gas mixtures | Micro-jet gas pressure [MPa] |
|---|---|
| 80% Ar/20% $CO_2$ | 0.4 |
| 90% Ar/10% $CO_2$ | 0.6 |
| 97% Ar and 3% $O_2$ | 0.6 |
| 97% Ar and 3% $O_2$ | 0.6 |

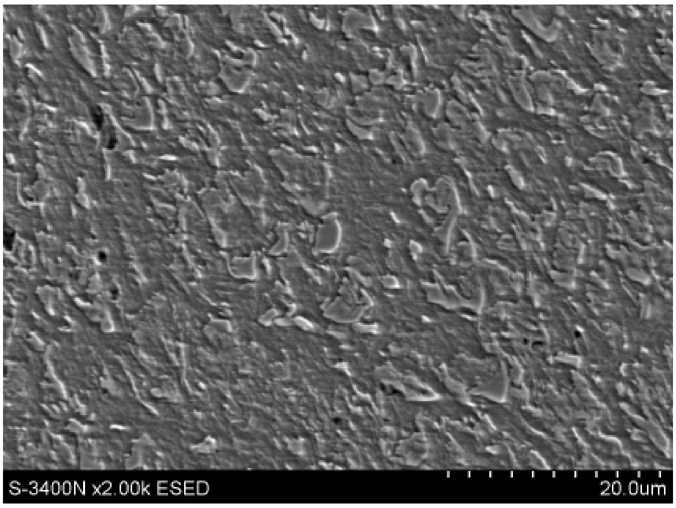


Fig. 2. Acicular ferrite in weld metal deposit after micro-jet cooling, magnification ×2000

After microscope analysis, 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 5).The Charpy tests were done mainly at temperature -40°C on 5 specimens having been extracted from each weld metal (Tables 4,5).

TABLE 4

Impact toughness for TIG welding

| Temp. [°C] | Impact toughness [KV, J] |
|---|---|
| –40 | below 47 |
| –30 | below 47 |
| –20 | 65 |
| 0 | 90 |
| 20 | 180 |

Simple TIG welding does not allow getting impact toughness 3 class (47 J at –30°C). TIG welding with micro-jet cooling allows getting even impact toughness 4 class (47 J at –30°C)

It is possible to deduce that impact toughness at negative temperature (–40°C) of weld metal deposit is apparently affected by the oxygen amount in WMD, that strongly corresponds with micro-jet cooling parameters. Argon with minimal amount of oxygen or carbon dioxide could be regarded as a very good choice. It is easy to assume that an important role in the interpretation of the results can give methods of artificial intelligence.

TABLE 4

Impact toughness for TIG welding with varied micro-jet gases

| Oxygen amount in WMD | Temp. [°C] | Impact toughness [KV, J] |
|---|---|---|
| 260 | –40 | below 47 |
| 340 | –40 | 59 |
| 370 | –40 | 56 |
| 390 | –40 | 49 |
| 430 | –40 | below 47 |

## 5. Conclusions

This investigation has proved that the new micro-jet technology has the potential for growth. It might be great achievement of welding technology in order to steer weld metal structure and impact toughness. The New welding 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 TIG welding process;
- micro-jet cooling after welding can prove amount of ferrite AF, the most beneficial phase in low alloy steel weld metal deposit;
- argon mixtures with small amount of oxygen or carbon dioxide could be treated as proper micro-jet cooling media in welding process;
- oxygen in WMD after TIG process should be in range (340-390) ppm

## REFERENCES

[1] T. Hao, H. Tang, W. Jiang, X. Wang, Q. Fang, Mechanical Spectroscopy of Equal-Channel Angular Pressed Fe-Cr Alloys and Tungsten **60** (3), 2101-2106 (2015).

[2] R. Burdzik, Z. Stanik, J. Warczek, Method of assessing the impact of material properties on the propagation of vibrations excited with a single force impulse, Archives of Metallurgy and Materials **57**, 2, (2012).

[3] B. Szczucka-Lasota, B. Formanek, A. Hernas, K.K. Szymański, Oxidation models of the growth of corrosion products on the intermetallic coatings strengthened by a fine dispersive $Al_2O_3$, Journal of Materials Processing Technology **164-165**, 935-939 (2005).

[4] R. Burdzik, Ł. Konieczny, Z. Stanik, P. Folęga, A. Smalcerz, A. Lisiecki, Analysis of impact of chosen parameters on the wear of camshaft, Archives of Metallurgy and Materials **59**, 3, (2014).

[5] R. Burdzik, Ł. Konieczny, Research on structure, propagation and exposure to general vibration in passenger car for different damping parameters, Journal of Vibroengineering **15**, 4, (2013).

[6] 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, (2013).

[7] 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, June 2013, Doi 10.4028/www.scientific.net/SSP.203-204.105

[8] B. Formanek, K. Szymański, B. Szczucka-Lasota, New generation of protective coatings intended for the power industry, Journal of Materials Processing Technology **164-165**, 850-855 (2005).

[9] G. Peruń, Z. Stanik, Evaluation of state of rolling bearing mounted in vehicles with use of vibration signals, Archives of Metallurgy and Materials **60** (3), 1679-1683 (2015).

[10] G. Siwiec, Elimination of aluminium during the process of Ti--6Al-4V alloy during in a vacuum induction furnace, Archives of Metallurgy and Materials **57** (4), 951-956 (2012).

[11] A. Lisiecki, Titanium Matrix Composite Ti/TiN Produced by Diode Laser Gas Nitriding, Metals **5** (1), (2015).

[12] A. Lisiecki, Welding of thermomechanically rolled fine-grain steel by different types of lasers, Arch. Metall. Mater. **59** (4), (2014).

[13] G. Golański, A. Zieliński, J. Słania, J. Jasak, Mechanical Properties of VM12 steel after 30.000hrs of ageing at 600°C temperature, Archives of Metallurgy and Materials **59**, 2 (2014).

[14] G. Golański, P. Gawień, P. Słania, Examination of Coil Pipe Butt Joint Made of 7CrMoVTib10 – 10(T24) Steel After Service, Archives of Metallurgy and Materials **57**, 2, (2012).

[15] T. Wegrzyn, J. Piwnik, D. Hadryś, Oxygen in steel WMD after welding with micro-jet cooling, Archives of Metallurgy and Materials **58**, 4, (2013).

[16] T. Wegrzyn, J. Piwnik, D. Hadryś, Acicular ferrite in micro welding technologies, Archives of Metallurgy and Materials **59**, 2 (2014).

[17] T. Węgrzyn, J. Piwnik, B. Łazarz, W. Tarasiuk, Mechanical properties of shaft surfacing with micro-jet cooling, ISSN 1392-1207. MECHANIKA **21**(5), 419-423 (2015).

[18] J. Piwnik, D. Hadryś, G. Skorulski, Plastic properties of weld after micro-jet cooling, Journal of Achievements in Material and Manufacturing Engineering **59**, 1 (2013).

[19] T. Węgrzyn, J. Piwnik, B. Łazarz, D. Hadryś, Main micro-jet cooling gases for steel welding, Archives of Metallurgy and Materials **58**, 2, (2013).