

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-O₂ and Ar-CO₂) 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

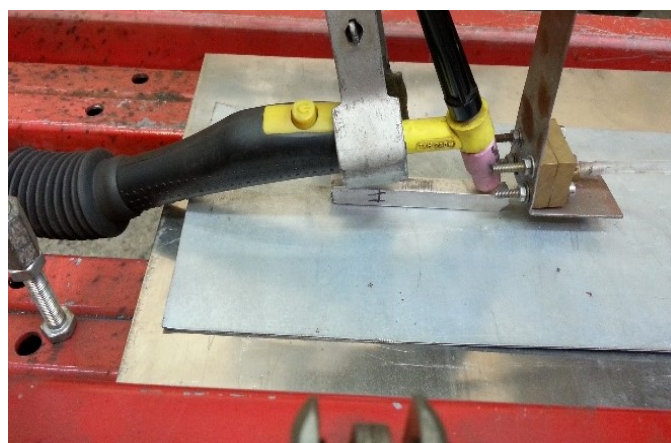


Fig. 1. TIG welding head with micro-jet injector

chance to increase seriously high amount of AF in TIG process because of the possibility of grain refinement in WMD and its 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-O₂ and Ar-CO₂).

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-O₂ and Ar-CO₂. 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-O₂ and Ar-CO₂).

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-O₂ and Ar-CO₂) 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 2. 97% Ar/3% O ₂ 3. 94% Ar/6% O ₂ 4. 90% Ar/10% CO ₂ 5. 80% Ar/20% CO ₂
6.	Micro-jet gas pressure	0.4 MPa 0.5 MPa 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

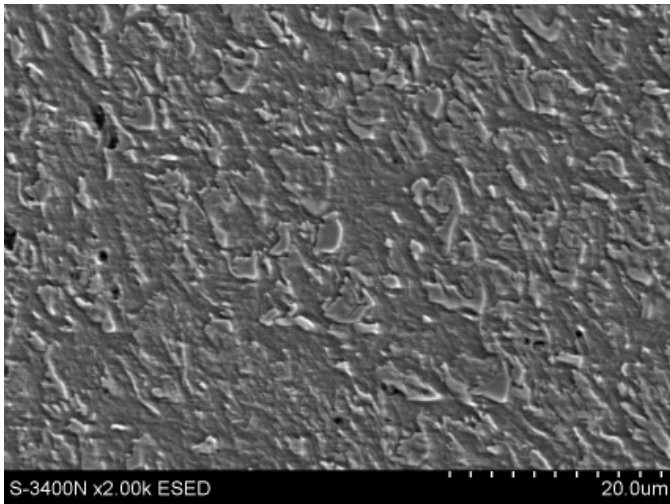
Analyzing tables 3 it is easy to deduce that welding with micro-jet cooling could be treated as a very good option. Amount of acicular ferrite in WMD after TIG welding without micro-jet cooling was only on the level of 43%. It is also shown that micro-jet cooling after TIG corresponds with 60% of acicular 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 $\times 2000$

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. [$^{\circ}\text{C}$]	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. [$^{\circ}\text{C}$]	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

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