STEEL STRUCTURES AFTER WELDING WITH MICRO-JET COOLING

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Abstract: The paper focuses on low alloy steel after new welding method with micro-jet cooling. Weld metal deposit (WMD) was carried out for standard MIG and MAG welding and for MIG and MAG welding with micro-jet cooling. This method is very promising mainly due to the high amount of acicular ferrite in WMD. That structure corresponds with very good mechanical properties, ie. high impact toughness of welds. Micro-jet cooling after welding can find serious application in automotive industry very soon.

Key words: welding, micro-jet, impact toughness, steel

1. Introduction

Manufacturing process management (MPM) is a collection of technologies and methods used to define how products are to be manufactured. New technologies are constantly being created for the production[1-11]. 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 [1, 5]. Good mechanical properties of weld correspond respectively with low-nitrogen and low-oxygen processes. Amount of nitrogen and oxygen has strong influence on metallographic structure because of the influence on acicular ferrite (AF) formation. Amount of AF must be treated as the most beneficial structure in low alloy steel WMD that directly corresponds with high impact toughness of weld [2, 8]. Acicular ferrite is formed with non-metallic inclusion contact (nitride and oxide inclusions of welds). Even having the most optimal inclusion parameters in weld it is only possible to get maximal 55% of AF in weld, but never more (Fig.1).

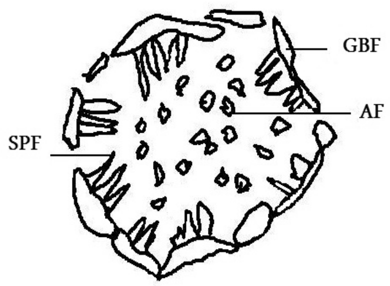

Fig. 1. Typical structure of low Alloy weld
AF- acicular ferrite, GBF - grain boundary ferrite, SPF - side plate ferrite) [1].

Micro-jet cooling just after welding gives a new chance to increase seriously high amount of AF in weld and consequently micro-jet cooling effects on impact toughness of weld [1-3]. The micro-jet cooling was tested for low alloy steel with various micro-jet parameters.

2. Aim and plan of research

It was decided to investigate the properties of the material, depending on the parameters of the process.The present paper aims at outlining micro-jet innovations only in MIG and MAG welding process. It was decided to check:

- acicular ferrite amount in WMD after micro-jet cooling,
- increase the impact toughness of WMD after micro-jet cooling.

The weld metal deposit was prepared by welding with micro-jet cooling with varied gases for both MIG/MAG welding and micro-jet cooling process. To obtain various amount of acicular ferrite in weld during welding process, the micro-jet injector was installed. Main parameters of micro-jet cooling were slightly varied:

- cooling steam diameter was varied (between: 40 μm, 50 μm, 60 μm),
- number of cooling jets was not varied (only 1 jet),
- gas pressure was varied (between: 0.4 MPa, 0.5 MPa, 0.6 MPa),
- micro-jet gases were varied (argon, nitrogen, helium, gas mixture of 90% Ar and 10% CO_2, gas mixture of 79% Ar and 21% CO_2).

MIG/MAG welding processes based on two shielded gases, respectively argon (for MIG) and gas mixture of 79% Ar and 21% CO_2 (for MAG). Figure 2 illustrates montage of welding head and micro-jet injector.

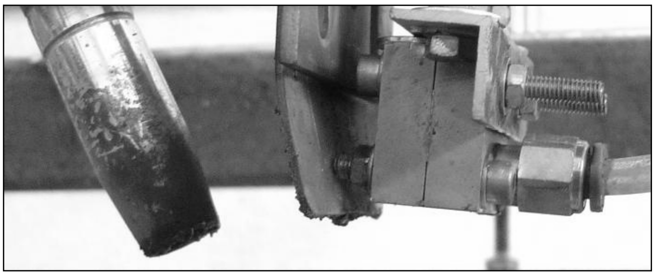

Fig. 2. Montage of welding head and micro-jet injector

3. Materials to research

The basic material to research was S355J2G3 steel. Various welds of standard MIG/MAG 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). Argon was chosen as shielded gas for MIG welding and gas mixture of 79% Ar and 21% CO_2 for MAG welding. Weld metal deposit was prepared by welding with micro-jet cooling with varied gases and gas mixtures (nitrogen, argon, helium, gas mixtures Ar-CO_2) with changing another micro-jet parameter (gas pressure). The main data about parameters of welding were shown in table 1. Cooling gas pressure was always in range 0.4 up to 0.6 MPa.

Tab. 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.	Shielding MAG welding gas	Ar and 21% CO_2
5.	Kind of tested micro-jet cooling gas	1. Ar 2. He 3. N_2 4. 79% Ar/21% CO_2 5. 90% Ar/10% CO_2
6.	Micro-jet gas pressure	0.4 MPa 0.5 MPa 0.6 MPa
7.	steam diameter of micro-jet gas	40 µm, 50 µm, 60 µm

4. Results and discussion

There were tested and compared welds of standard MIG/MAG welding with micro-jet technology with various micro-jet gases and mixtures. A typical weld metal deposit had rather similar chemical composition in all tested cases (tables 2, 3).

Tab. 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%
6.	O	400 ppm
7.	N	50 ppm

Tab. 3. Chemical composition of WMD after MAG process

No.	Element	Amount
1.	C	0.08%
2.	Mn	0.79%
3.	Si	0.41%
4.	P	0.017%
5.	S	0.018%
6.	O	530 ppm
7.	N	50 ppm

Various micro-jet parameters had some influence on intensively cooling conditions but did not have greater influence on chemical WMD composition, except situation when nitrogen was used as a micro-jet cooling gases. For standard MIG and MAG welding and welding with two micro-jet gases: argon and helium amount of nitrogen was always on the level of 50 ppm, but for welding with nitrogen as a micro-jet gas amount of nitrogen was much higher, on the level of 70 ppm.

Metallographic structure of WMD was carried out after chemical analyses of WMD (taken from MIG and MAG processes). 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 tables 4, 5.

Tab. 4. Acicular ferrite in WMD after MIG welding with various micro-jet parameters

Micro-jet gas	Micro-jet gas pressure [MPa]	steam diameter of micro-jet gas [µm]	MAC phases [%]	Acicular ferrite [%]
-	-	-	3	55
He	0.4	40	4	60
He	0.5	40	5	61
He	0.6	40	5	57
Ar	0.4	40	3	71
Ar	0.5	40	3	73
Ar	0.55	40	3	71
Ar	0.6	40	4	68
N_2	0.4	40	4	51
N_2	0.5	40	4	53
N_2	0.6	40	4	50
79%Ar/21% CO_2	0.4	40	4	64
79%Ar/21% CO_2	0.5	40	4	60
79%Ar/21% CO_2	0.6	40	4	56
90%Ar/10% CO_2	0.4	40	3	67
90%Ar/10% CO_2	0.5	40	3	70
90%Ar/10% CO_2	0.6	40	3	63

Analyzing tables 4 and 5 it is easy to deduce that both MIG and MAG welding with argon micro-jet gas cooling could be treated as optimal. Also MIG and MAG welding with micro-jet gas mixture of 90%Ar/10% CO_2 be treated as a good option. It was decided to test this method (argon as micro-jet gas) in more precisely.. It is also shown that micro-jet gas pressure after MIG and MAG welding cannot be higher than 0.5 MPa. Micro-gas pressure for argon cooling should be on the level of 0.5 MPa for MIG process and micro-gas pressure for argon cooling should be on the level of 0.4 MPa for MAG welding process. Further next main process parameter was included (various steam diameter of micro-jet cooling gas). Examples of results are shown in tables 6, 7.

Tab. 5. Acicular ferrite in WMD after MAG welding with various micro-jet parameters

Micro-jet gas	Micro-jet gas pressure [MPa]	steam diameter of micro-jet gas [µm]	MAC phases [%]	Acicular ferrite [%]
-	-	-	3	50
He	0.4	40	4	54
He	0.5	40	5	55
He	0.6	40	5	53
Ar	0.4	40	3	64
Ar	0.5	40	3	62
Ar	0.55	40	3	59
Ar	0.6	40	4	58
N_2	0.4	40	4	41
N_2	0.5	40	4	42
N_2	0.6	40	4	40
79%Ar/21% CO_2	0.4	40	4	54
79%Ar/21% CO_2	0.5	40	4	53
79%Ar/21% CO_2	0.6	40	4	51
90%Ar/10% CO_2	0.4	40	3	60
90%Ar/10% CO_2	0.5	40	3	57
90%Ar/10% CO_2	0.6	40	3	54

Tab. 6. Acicular ferrite in WMD after MIG welding with various micro-jet parameters

Micro-jet gas	Micro-jet gas pressure [MPa]	steam diameter of micro-jet gas [µm]	MAC phases [%]	Acicular ferrite [%]
Ar	0.5	40	3	73
Ar	0.5	50	3	70
Ar	0.5	60	4	64

Tab. 7. Acicular ferrite in WMD after MAG welding with various micro-jet parameters

Micro-jet gas	Micro-jet gas pressure [MPa]	steam diameter of micro-jet gas [µm]	MAC phases	Acicular ferrite [%]
Ar	0.4	40	3	64
Ar	0.4	50	4	61
Ar	0.4	60	4	57

Analyzing tables 6 and 7 it is easy to deduce that both MIG and MAG welding (with steam diameter of micro-jet gas on the level of 0.4 µm) argon micro-jet gas cooling with could be treated as optimal.

In standard MIG welding process (without micro-jet cooling) there were usually gettable higher amounts of grain boundary ferrite (GBF) and site plate ferrite (SPF) fraction meanwhile in micro-jet cooling both of GBF and SPF structures were not dominant in all tested cases (with all micro-jet gases and gas mixtures). In all tested cases there were observed also MAC (self-tempered martensite, retained austenite, carbide) phases on the small level of 3-5%. Acicular ferrite with percentage above 70% was gettable only after argon micro-jet cooling (shown on Fig. 3, tab. 4). There was observed that gas pressure on the level of 0.4 MPa and 0.5 MPa could be treated as optimal in all tested cases. Micro-jet gas pressure has influence on metallographic structure (Fig. 3).

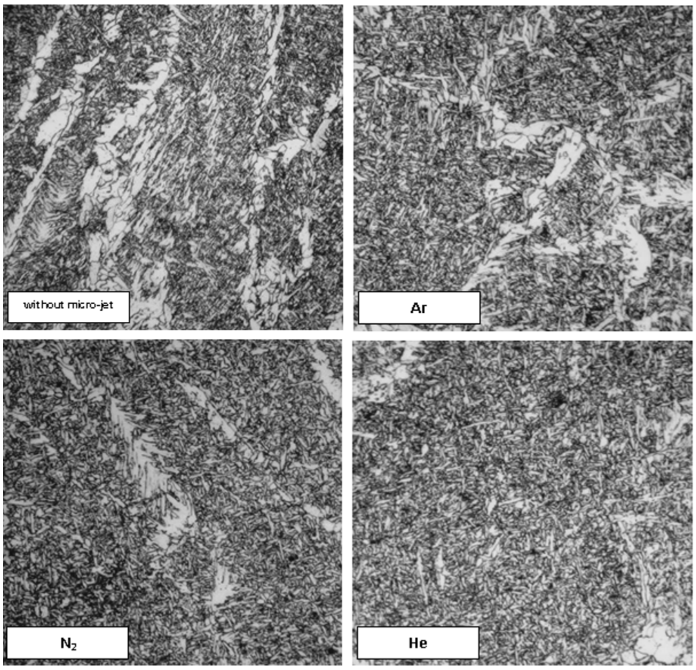

Fig. 3: Acicular ferrite in weld (55-73%) in terms on micro-jet gases (micro-jet gas pressure 0.5 MPa, steam diameter of micro-jet gas on the level of 0.4 µm), magnification ×200.

Heat transfer coefficient of various micro-jet gases influences on cooling conditions of welds. This is due to the conductivity coefficients (λ x105), which for Ar, N_2, He in the 273 K are various, respectively: 16.26, 23.74, 143.4 J/(cm·s·K). Cooling conditions are rather similar when nitrogen and argon are chosen as a micro-jet gas. Helium could give stronger cooling conditions and that fact translates high amount of MAC phases in MWD (5%). Gas mixtures of argon with oxygen or carbon dioxide could be regarded as good choice (69% of acicular ferrite). There were no observed nitrides in MWD, so after welding with nitrogen as a micro-jet gas, higher amount of nitrogen is connected only with nitrogen as a interstitial effect in material. After that the chemical analysis, micrograph tests and Charpy V impact test of the deposited metal were carried out. For these studies were selected samples containing the biggest acicular ferrite content (tables 4, 5). The Charpy tests were done mainly at temperature + 20°C, 0 and - 40°C on 5 specimens having been extracted from each weld metal (tables 8, 9).

It is possible to deduce that impact toughness at negative temperature of weld metal deposit is apparently affected by the kind of micro-jet gas or gas mixture in cooling injector. Argon as a micro-jet gas again must be treated as an optimal one, nitrogen could be treated as a wrong micro-jet gas choice. Gas mixtures of argon with carbon dioxide on the level of 10% could be regarded also as a good choice. Impact toughness of WMD in both cases is comparable. For the economic reasons gas mixture of argon with carbon dioxide could be recommended as a micro-jet cooling gas. In welded structures there are

Tab. 8. Impact toughness for MIG welding with varied micro-jet gases

Micro-jet gas	Temp. [°C]	Impact toughness [KCV, J]	Acicular ferrite [%]
without micro-jet	- 40	45	55
N_2		below 40	53
Ar		57	73
He		47	61
without micro-jet	0	66	55
N_2		42	53
Ar		81	73
He		67	61
without micro-jet	+20	168	55
N_2		142	53
Ar		181	73
He		173	61
79% Ar and 21% CO_2	- 40	47	64
90% Ar and 10% O_2		49	70
79% Ar and 21% CO_2	0	71	64
90% Ar and 10% O_2		73	70
79% Ar and 21% CO_2	+20	177	64
90% Ar and 10% O_2		180	70

Tab. 9. Impact toughness for MAG welding with varied micro-jet gases

Micro-jet gas	Temp. [°C]	Impact Toughness [KCV, J]	Acicular ferrite [%]
without micro-jet	- 40	below 40	50
N_2		below 40	42
Ar		57	64
He		47	55
without micro-jet	0	61	55
N_2		below 40	53
Ar		73	73
He		64	61
without micro-jet	+20	164	55
N_2		141	53
Ar		180	73
He		171	61

79% Ar and 21% CO_2	- 40	below 40	54
90% Ar and 10% O_2		47	60
79% Ar and 21% CO_2	0	66	54
90% Ar and 10% O_2		69	60
79% Ar and 21% CO_2	+20	173	54
90% Ar and 10% O_2		177	60

some general types of tests performed: impact toughness, structure, fractografphic studies and strengths. Fractographic study allowed to conclude, that micro-jet cooling has influence on inclusion size (Fig. 4 and 5).

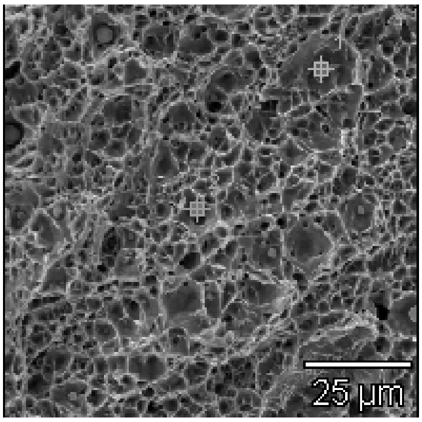

Fig. 4. Inclusion ray microanalysis in WMD in terms of micro-jet gases parameters (Ar - micro-jet gas, micro-jet gas pressure 0.4 MPa, micro-steam diameter 40 μm)

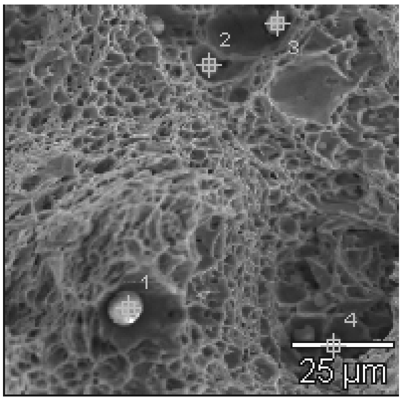

Fig. 5. Inclusion ray microanalysis in WMD in terms of micro-jet gases parameters (N_2 - micro-jet gas, micro-jet gas pressure 0.4 MPa, micro-steam diameter 40 μm)

Based on observations of figures 3-5 it may be clearly stated that the micro-jet cooling affects the structure. Acicular ferrite easier is formed because of the smaller inclusions presence. After the structural analysis strengths of WMD was carried out (Fig. 6).

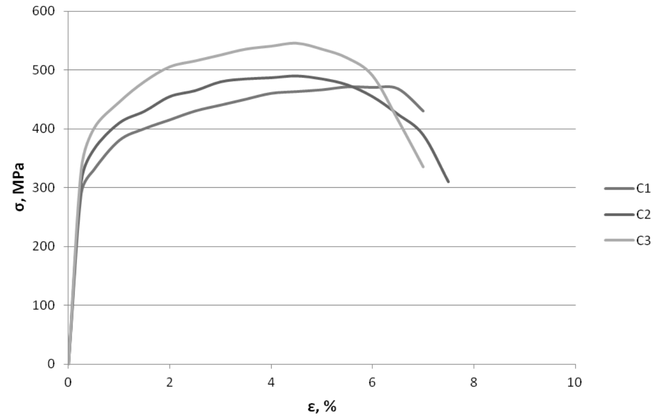

Fig. 6. Stress-strain curves showing MAG deposits:
C1 – without micro-jet cooling,
C2- Ar as a micro-jet gas, micro-jet gas pressure 0.4 MPa, micro-steam diameter 40 μm,
C3- N_2 as a micro-jet gas, micro-jet gas pressure 0.4 MPa, micro-steam diameter 40 μm.

It is shown that strength of tested deposits is on the comparable level of 500 MPa. Much greater differences were observed for impact toughness of various tested deposits.

5. Conclusions

The micro-jet injector gives a real opportunity for professional development in the field of welding with controlling the parameters of weld structure. These 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 MAG 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 could be treated as an optimal micro-jet gas in welding process;
- nitrogen also could not be treated as a proper gas for micro-jet welding, because of higher percentage of N in MWD and good strength of WMD;
- micro-jet gas pressure should be on the level of 0.4 MPa;
- optimal micro-steam diameter should be on the level 40 μm.

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