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Nitrogen amount in weld after steel welding with micro – jet cooling

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Abstract: ***Micro-jet cooling after welding was tested only for MIG and MAG welding processes. Argon, helium and nitrogen were chosen as a micro-jet cooling gases. A paper presents a piece of information about nitrogen in weld metal deposit (WMD) after micro-jet cooling. There are put down information about micro-jet gases that could be chosen both for MIG/MAG welding and for micro-jet process. Furthermore here were given main information about influence of various micro-jet gases on metallographic structure and mechanical properties of steel welds. Mechanical properties of weld were precisely presented in terms of nitrogen amount in WMD (weld metal deposit).***

Index Terms— **welding, micro-jet cooling gases, weld, metallographic structure, nitrogen in weld**

I. INTRODUCTION

At the beginning of the 21st century it was proposed main classification of welding processes due to the content of oxygen and nitrogen in the weld. Many authors put especial attention to nitrogen and oxygen amount in MWD. Welding process was even classified respectively on [1-4]:

- low oxygen process (unless 450 ppm O in WMD)
- medium oxygen process (in range 450 up to 700 ppm O in WMD,
- high oxygen process (higher amount than 700 ppm of O),
- low nitrogen process (unless 50 ppm N in WMD)
- medium nitrogen process (in range 50 up to 70 ppm N in WMD,
- High nitrogen process (higher amount than 70 ppm of N).

Good mechanical properties of low-alloy steel weld correspond strongly with low-nitrogen and low-oxygen processes. Nitrogen and oxygen have strong influence on metallographic structure because of influence of acicular ferrite (AF) formation. Amount of acicular ferrite is treated as the most beneficial phase in steel WMD that corresponds with high impact toughness of weld [5]. Amount of AF in weld is connected with nitrogen and oxygen in WMD because of nitride and oxide inclusions presence in welds. Acicular ferrite could be formed with nonmetallic inclusion contact. Very important role plays such parameters of inclusions as: size, density, and first of all lattice parameter of nitride or oxide inclusions. In standard low-alloy steel weld it is only possible to get maximal 60 % of AF in weld, but no more [6-10]. Micro-jet cooling just after welding gives new chance to increase high amount of AF in weld in artificial way. Consequently micro-jet cooling effects on mechanical properties of weld. Actually the micro-jet cooling was tested only for low-alloy steel with three micro-jet gases (argon, helium, nitrogen) only for MIG/MAG welding with modern gas mixtures [11-12].

II. EXPERIMENTAL PROCEDURE

Steel WMD was prepared by welding with micro-jet cooling with varied gases both for MIG/MAG welding and micro-jet cooling process. To obtain various amount of nitrogen and oxygen in weld it was installed innovate welding process with micro-jet injector. Main parameters of micro-jet cooling were slightly varied:

- cooling stream diameter was varied from 40 and 50
- o number of cooling jets (1 or 2)
- gas pressure 0.4 MPa and 0,5 MPa

MIG/MAG welding process was based on two shielded gases: argon and gas mixture of 79% Ar and 21% CO2. Montage of welding head and micro-jet injector illustrates figure 1.

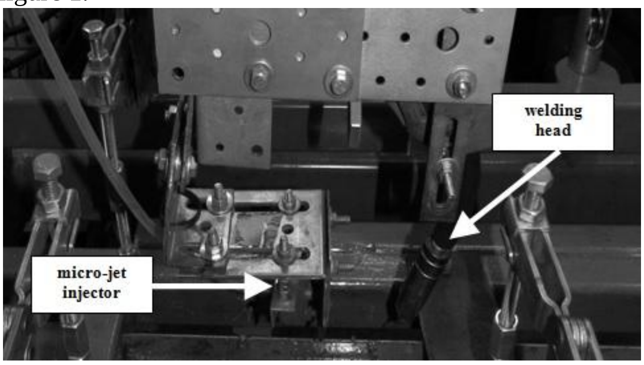

Fig. 1. Montage of welding head and micro – jet injector

Thus weld metal deposit was prepared by MIG/MAG welding with two different gases (Ar and gas mixture of 79% Ar and 21% CO_2) and with three micro-jet cooling gases (argon, helium, nitrogen). Steel S355J2G3 (Euro Norms), equivalent 765 (AISI) was chosen for this investigation, table 1.

Table 1. Chemical composition of S355J2G3 steel, [%]

C	Mn	Si	P	S	Cr	Ni	Mo	W	V	Al	Cu
0,2	1,5	0,2-0,5	max 0,04	max 0,04	max 0,03	max 0,03	-	-	-	max 0,2	max 0,3

The main data about parameters of S355J2G3 steel welding were shown in table 2.

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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 gases	Ar, 81% Ar + 19% CO_2
5.	Kind of tested micro-jet cooling gas	1 – Ar 2 – He 3 – N_2
6.	Gas pressure	0.4 MPa 0.5 MPa
7.	Number of jets:	1 or 2
8.	cooling steam diameter	40 µm 50 µm

Weld metal deposit was prepared by MIG and MAG welding with great number of micro-jet cooling parameters.

III. RESULTS AND DISCUSSION

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

Table 3. Chemical composition of WMD

Welding process	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%
MIG welding (Ar), without micro-jet cooling	N	50 ppm
MIG welding (Ar), He as micro-jet gas	N	50 ppm
MIG welding (Ar), Ar as micro-jet gas	N	50 ppm
MIG welding (Ar), N_2 as micro-jet gas	N	70 ppm
MAG welding (79% Ar and 21% CO_2) without micro-jet cooling	N	55 ppm
MAG welding (79% Ar and 21% CO_2), He as micro-jet gas	N	55 ppm
MAG welding (79% Ar and 21% CO_2), Ar as micro-jet gas	N	55 ppm
MAG welding (79% Ar and 21% CO_2), N_2 as micro-jet gas	N	75 ppm

For standard MIG and MAG welding (without micro-jet cooling) there were observed comparable amount of nitrogen (on the comparable level of 50-55 ppm). For MIG and MAG welding processes with micro-jet cooling there were also observed comparable amount of nitrogen (on the level of 50-55 ppm) only when argon and helium were installed as micro-jet gases. For MIG and MAG welding processes with nitrogen micro-jet cooling there were also observed increased amount of nitrogen (on the level of 70-75 ppm). After chemical analyses the metallographic structure was carried out. Example of acicular ferrite amount was shown in table 4 (a detailed analysis of all micro-jet parameters after MIG welding), and in table 5 (simplified version).

Table 4. Metalographic structure of MIG welds

Micro-jet gas	Micro-jet gas pressure [MPa]	Micro-jet diameter [µm]	Number of jets	Ferrite AF
-	-	-	-	55%
He	0.4	40	1	60%
He	0.4	40	2	57%
He	0.4	50	1	61%
He	0.5	40	1	61%
He	0.5	50	1	59%
Ar	0.4	40	1	71%
Ar	0.4	40	2	69%
Ar	0.4	50	1	73%
Ar	0.5	40	1	73%
Ar	0.5	50	1	72%
N_2	0.4	40	1	53%
N_2	0.4	40	2	47%
N_2	0.4	50	1	51%
N_2	0.5	40	1	50%
N_2	0.5	50	1	49%

It was easy to deduce, that cooling process cannot be to intensive. Thus one jet should be always installed in cooling injector. Micro-jet gas pressure should be on the level of 0.4 MPa, and micro-jet diameter should be equal 50 µm. The same good results could be obtained when micro-jet gas pressure is on the level of 0.5 MPa, and micro-jet diameter is equal 40 µm. For MAG welding process with micro-jet cooling parameters were not varied. Only one cooling jet was always installed in injector. Micro-jet gas pressure was on the level of 0.4 MPa, and micro-jet diameter was always equal 50 µm. In all tested cases (after MAG welding) there were also measured MAC phases (self-tempered martensite, retained austenite, carbide).

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Table 5. Metallographic structure of MAG welds

Micro-jet gases	Ferrite AF	MAC phases
without micro-jet	53%	4%
He	59%	3%
Ar	63%	2%
N_2	53%	5%

Tables 4, 5 shows that in all cases argon is more beneficial micro-jet gas cooling than helium and nitrogen. Nitrogen as micro-jet gas could be treated as a wrong choice. In standard MIG/MAG 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 so dominant in all tested cases (with both argon and helium as micro-jet gases). Acicular ferrite with percentage above 70% was gettable only in one case after MIG welding with argon micro-jet cooling (shown on figure 3, table 4). The higher amount of MAC phases was especially gettable for more intensive nitrogen micro-jet cooling in MAG process (table. 3, 4).

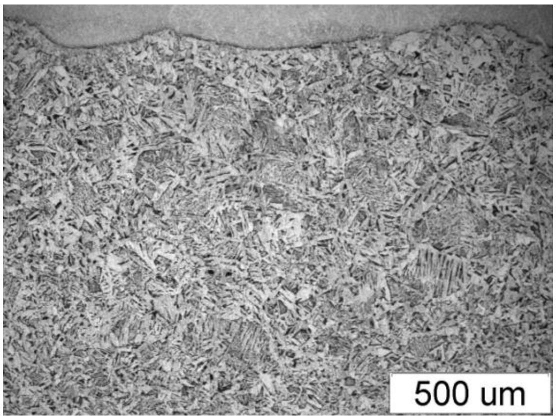

Fig. 3. High amount of acicular ferrite in weld

After microstructure studies the Charpy V impact toughness of the deposited metal were carried out (5 specimens). The impact toughness results are given in table 6. The Charpy tests were only taken at temperature - 40° C and +20° C.

Table 6. Metallographic structure of MAG welds

Welding method	Micro-jet gas	Impact toughness KCV, J (at - 40° C)	Impact toughness KCV, J (at +20° C)
MIG	-	43	181
MAG	-	below 40	175
MAG	Ar	54	183
MIG	Ar	59	195
MAG	He	46	186
MIG	He	51	182
MAG	N_2	below 40	152
MIG	N_2	below 40	155

It is possible to deduce that impact toughness both at ambient and 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 than helium, however micro-jet cooling with helium gives much better results than simple MIG/MAG welding without micro-jet cooling.

IV. SUMMARY AND CONCLUSIONS

In low alloy steel welding there are two general types of tests performed: impact toughness and microstructure. Acicular ferrite and MAC phases (self-tempered martensite, upper and lower bainite, retained austenite, carbides) were analyzed and counted for various deposits. This two tests (microstructure and impact toughness) proved that micro-jet technology gives beneficial modification in impact toughness of welds. The innovative micro-jet technology was recognized both for MIG and MAG welding. On the basis of investigation it is possible to deduce that micro-jet technology could be important complement of both welding methods: MIG and MAG. An important part of the article was to analyze the content of nitrogen in the weld and and relate it with the content of acicular ferrite in WMD and the toughness of weld.

Final conclusions:

a) micro-jet cooling could be treated as an important element of both MIG and MAG welding process,
b) micro-jet cooling after welding can prove amount of ferrite AF, the most beneficial phase in low alloy steel WMD,
c) argon could be treated as optimal micro-jet gas for low alloy steel welding processes both for MIG and MAG,
d) micro-jet injector after welding has only influence on more or less intensively cooling conditions, but does not have strong influence on oxygen amount in WMD,
e) Micro-jet injector after welding has influence on nitrogen amount in WMD only when nitrogen is used as micro-jet gas.

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