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Parameters of welding with micro-jet cooling

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ABSTRACT

Purpose: of that paper was analysing main welding process with parameters of micro-jet cooling. The main reason of it was investigate possibilities of getting varied amount of acicular ferrite (AF) in WMD (weld metal deposit). High amount of acicular ferrite influences positively impact toughness of weld. For optimal amount of AF it is necessary to determine the parameters (eg. number of clusters, diameter of stream) of the micro-jet.

Design/methodology/approach: During research with varied micro-jet parameters the chemical analysis, micrograph tests and Charpy V impact test of the metal weld deposit on pendulum machine were carried out. The Charpy V impact test was prepared according to standard ISO EN 148-1 Metallic materials - Charpy pendulum impact test - Part 1: Test method. Samples for impact testing were prepared according to standard ASTM A370.

Findings: Varied amount of acicular ferrite in weld metal deposit (in range 55-75%) in terms of micro-jet cooling parameters (numbers of jet, gas pressure). This high amount of acicular ferrite is unheard in weld metal deposit in another way or other methods of welding like MAG or TIG.

Research limitations/implications: That research was made for MIG method (according to PN-EN ISO 4063:2009) only. Another method of welding in this article was not tested. Other methods (for eg. MAG, TIG) have not been tested, but it is suspected that similar phenomena are taking place.

Practical implications: Micro-jet cooling it is way to get higher amount of acicular ferrite in weld metal deposit than the usual methods of welding. It is very important because it could be used to steering of weld joint structure and mechanical properties (for example impact toughness).

Originality/value: In this research new method of cooling weld joint during welding was used. At the present time use of micro-jet cooling while MIG is in the testing phase and requires an accurate diagnosis.This method is very promising and capable of industrial application, mainly due to the significant improvement of weld quality and reduces costs.

Keywords: Welding; Micro-jet cooling parameters; Weld metal deposit; Metallographic structure; Acicular ferrite; Impact toughness

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MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

Some alloy elements, especially nickel (in range 1-3%) or molybdenum (in range 0.2-0.6%), oxygen) could be treated as elements which very positively influencing on impact toughness of steel welded structures. Metallographic structure of weld metal deposit having composition of 0.08% C, 0.8% Mn, 400 ppm O and 2% Ni or 0.4% Mo could be treated as optimal, because it corresponds with high percentage of acicular ferrite AF (until 65%). In this case steel weld has good mechanical properties (especially impact toughness) [1,2]. For a long time researchers were putting main question: how to lift percentage of AF in weld above 65%. There was described great role of non-metallic inclusions during austenitic conversion, nevertheless it was impossible to exceed value of 65% of AF in WMD. New micro-jet cooling technology could be regarded as a new way to solve that problem. This paper describes the influence of artificially lifted amount of acicular ferrite in WMD (above 65%) with using micro-jet cooling with varied parameters of the process. Process was tested with varied parameters.

The influence of positively influencing elements on mechanical properties of steel car body welds such as Mn, Ni, Mo, and O were well analysed in the past 10 years [3-6]. There were suggested new welding device proposal on low and high welding processes. Oxygen for o long time was assumed as a important element influencing high amount of AF in welds because of oxide inclusions role during austenite conversion (Figures 1, 2).

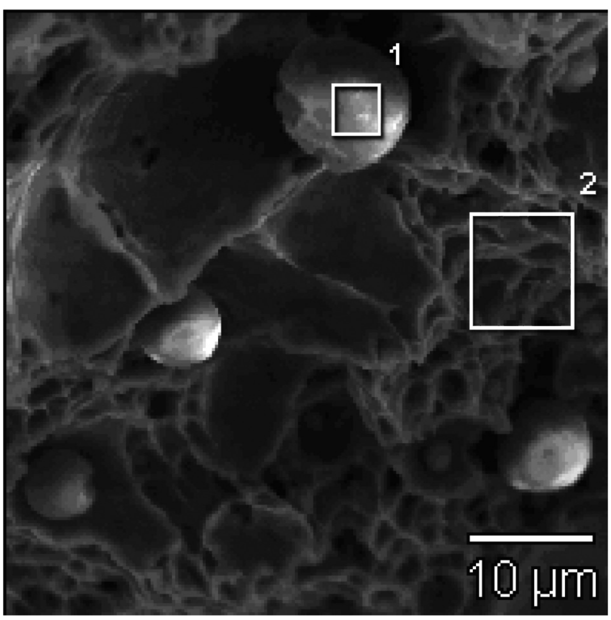

Fig. 1. Big oxide inclusions in weld, the oxygen amount (740 ppm)

However nickel, molybdenum and manganese could have independently the positive influence on impact properties of steel welds. In main publications it is presented that amount of this elements must be content in characteristic ranges (Ni content should not exceed 3%, Mo content should not exceed 0.5%, Mn should not exceed 0.9% and O amount absolutely should not be greater than 500 ppm) [5-8]. Weld metal deposit with mentioned chemical composition has positive influence on the acicular ferrite formation in welds. Welding parameters, metallographic structure and chemical composition of weld metal deposit are regarded as the important factors influencing the impact toughness of deposits [9,10,12]. The influence of the most beneficial amounts of nickel, molybdenum and oxygen (oxide inclusions) could guarantee even 65% of acicular ferrite in weld, but no more [2,11,14]. It was observed that oxygen amount and further oxide inclusions in steel metal weld deposit have main influence on the transformation austenite→acicular ferrite (AF). The quality, quantity, type and size of oxide inclusions determine the formation of acicular ferrite (Figures 1, 2) [4-9].

Amount of AF strongly depends especially on size of oxide inclusions and lattice parameters of ferrite and oxygen. Nevertheless amount of 65% of acicular ferrite is very difficult to exceed.

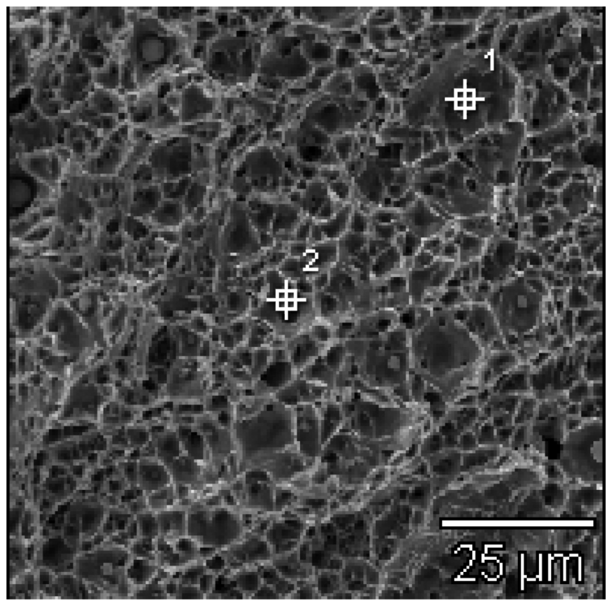

Fig. 2. Small oxide inclusions in weld, the oxygen amount (380 ppm)

To obtain much higher amount of acicular ferrite in weld metal deposit it was installed welding process with micro-jet injector (3 cooling streams of argon with diameter of 40 µm). Welding conditions with micro-jet cooling were similar like in standard welding procedure [2,6,15,16]. There was even gettable the same percentage of total ferrite percentage as a sum of its main morphology forms (Fig. 3):

- fraction of grain boundary ferrite (GBF),
- fraction of side plate ferrite (SPF),
- fraction of acicular ferrite (AF).

Method of forming a metallographic structure of weld metal deposit is described by the following steps:

- during continuous cooling austenite is formed first the below-solidus grain boundary ferrite,

- next the plate ferrite is formed, the plates are oriented almost perpendicular to the interior of the former austenite grains,
- at the end the fine-grained acicular ferrite is formed inside the grains,
- some relatively small amounts of austenite can be transformed at lower temperatures in the bainite and martensite,
- very small amounts of austenite may remain in the metallographic structure as the so-called retained austenite.

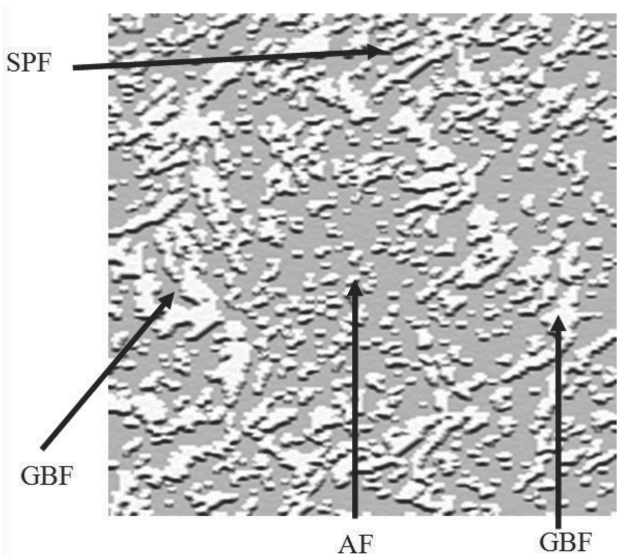

Fig. 3. Fraction of ferrite in weld metal deposit, GBF - grain boundary ferrite, SPF - side plate ferrite, AF - acicular ferrite

2. Experimental procedure

The innovative technology of welding using a micro jet cooling (innovative ability of cooling) allows for precise and fully controlled the control structure of the weld. Adjusting the structure of weld obtained through the application of the aforementioned technologies will ensure the high quality of connection of welding such as: increasing the content of ferrite AF for welds low carbon and low will provide appropriate (required) mechanical properties of joints. To achieve this must be applied time chilling bead or's root of the weld, which you can obtain using the cluster micro stream medium cooling that is using the "device to the micro jet cooling". Thanks to the unique technologies as media outlets you can apply any fluid (liquid or gas). However, it should be noted that the multitude of variables (the diameter outflow jet, the number of jet cooling, the flow rate of the fluid, the distance of the device to the micro jet cooling of the face of the weld, the angle of inclination of the device surface welding of the material, the distance of the device of the cooling from the head or helmet and the geometry of the layout of jet cooling), originating from the same device and affecting the process of cooling involves very detailed study.

This method is for the bonding of steel made of various metals and alloys (e.g. steel, aluminum alloys, titanium alloys, alloy of copper and other). Adjustment of structure is to ensure a high quality welding connection can also improve weldability of materials. For the calculation of the initial micro jet device picked argon as the cooling medium. Argon picked due to a lack of potential for oxidation and nitriding of the weld. In the absence of satisfactory results in further proceedings will be able to use other media refrigeration such as nitrogen or helium. Cooling medium will be produced in a device with the installation of micro jet. The device is an integral part of the complex of the welding head. It is characterized by high intensity over the heat through the reaping very high coefficient of heat exchange between the weld and the micro-liquid 's [13,16,17]. Weld metal deposit was prepared by welding with micro-jet cooling with varied geometrical parameters. The main data about parameters of welding were shown in Table 1.

Table 1.
Parameters of welding process

No.	Parameter	Value
1.	Principal diameter of wire	1.2 mm
2.	Standard current	220 A
3.	Voltage	24 V
4.	Shielding welding gas	Ar Ar + 1.5% O 82% Ar + 18% CO_2
5.	Number of tested micro-jet cooling stream jets	1- stream, 2 - streams situatet paralel, 3 - stream (situated in equilateral triangle with sides 6 mm, Fig. 4)
6	Micro-jet welding shielded gas, gas pressure	Ar, 0.4 MPa
7	Standard of welding wire	EN 440: G4S:1

Welding technology with micro-jet injector is an automatic process where welding head with micro-jet moves thanks to a special carriage. The essential element of that apparatus is welding equipment with welding head. It moves automatically and it's linear velocity may be regulated. Welding head is interconnected with micro-jet accessory which has possibility of regulating the most important geometrical parameters of device (distance of micro-jet from the weld metal deposit and welding head, glacing angle micro-streams over the weld metal deposit).The study was carried out for low alloy steel S355J2G3 (with thickness of 2 mm) on a special prepared research station. Welding process ensures the cooling of the overall joint. Only argon was chosen for micro-jet cooling (with diameter of 40 µm of stream). Cooling gas pressure was 0.4 Pa. At higher pressure coolant jet was the 'blown" weld, as shown in Figure 4.

There were tested welding conditions with installed micro-jet injector. Cooling jets were situated in equilateral triangle with sides 6 mm. Equipment for MIG welding with micro-jet cooling and testing stand is presented in Figure 5. Velocity of welding process Velocity of the processes (both welding and micro-jet cooling) were on the same level of 150 mm/min (because of great number of other parameters of micro-jet cooling).

Fig. 4. Weld distortion by over-pressure jet cooling

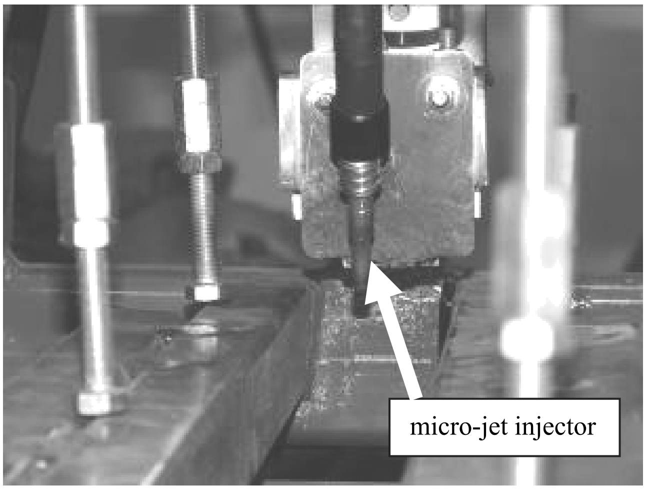

Fig. 5. Equipment for MIG welding with micro-jet injector (main view)

3. Results and discussion

All tested welding processes were chosen with very similar micro-jet (Fig. 2) cooling conditions: with one injector (A), two injectors (B, C), and three injectors (A, B, C). It was possible to get precisely weld cooling conditions especially in range 800-500°C (Figure 6).

The data presented in Figure 6 shows that the largest decrease of the temperature was observed for the 3 jets (layout as shown in Figure 4). However, the cooling in this case was too intense and did not result in a significant increase of ferrite AF. In the case of one hole cooling, decrease of the temperature was too slow. The optimal course of cooling was achieved using two cooling holes (B and C as shown in Figure 4). The results presented in Figure 7 are the mean of the results. Each time, with different amounts of the cooling holes made six measurements.

Microjet cooling does not have influence on chemical composition of weld. A typical weld metal deposit had chemical composition which was shown in Table 2.

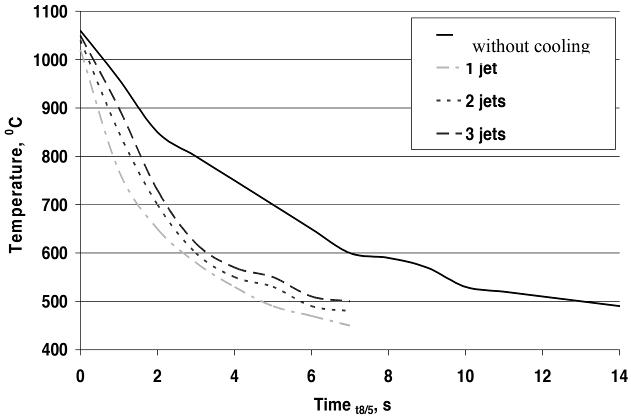

Fig. 6. Weld cooling conditions without cooling and with micro-jet injector

Table 2.
A typical chemical composition of weld

No.	Element	Amount
1.	C	0.08%
2.	Mn	0.79%
3.	Si	0.39%
4.	P	0.017%
5.	S	0.018%
6.	O	380 ppm
7.	N	85 ppm

There were typical analysed structures for MIG welding with micro-jet cooling. Example of this structure was shown on Figure 5.

Table 3.
Metallographic structure of weld

Number of jets	Ferrite AF	MAC phases
-	55%	3%
1 (A)	68%	2%
2 (B, C)	73%	2%
3 (A, B, C)	70%	3%

In standard MIG welding process (without micro-jet cooling) there were usually gettable higher amounts of GBF and SPF fraction meanwhile in micro-jet cooling both of GBF and SPF structures were not dominant in all tested cases (with one, two, three jets). In all tested cases there were observed also MAC (self-tempered martensite, retained austenite, carbide) phases. High percentage of AF ferrite was gettable only for welding with micro-jet cooling (Table 3). Acicular ferrite with percentage above 70% was gettable only after micro-jet cooling (shown on Figures 7, 8, Table 3).

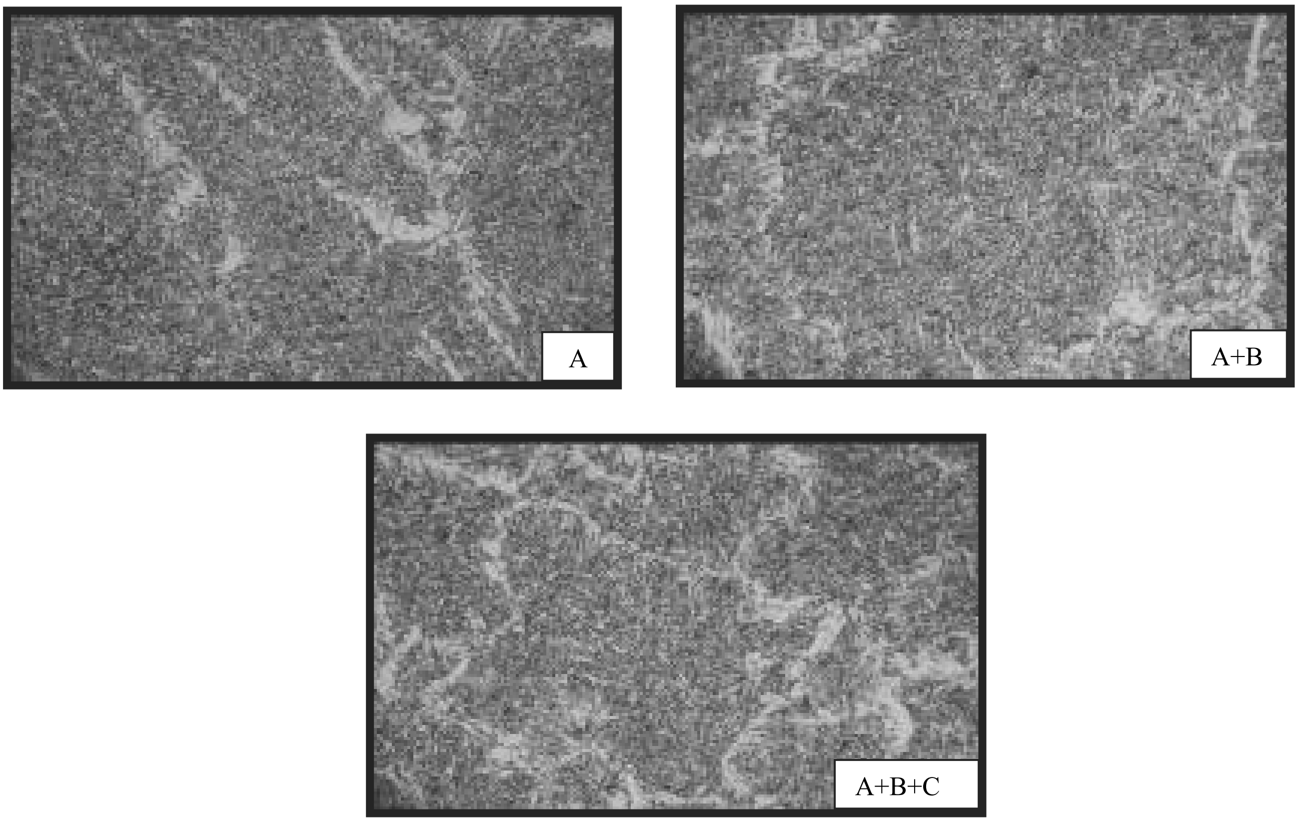

Fig. 7. Acicular ferrite in weld (68-73%) in terms on micro-jets number in injector cooling: A, A+B, A+B+C, magnification × 200

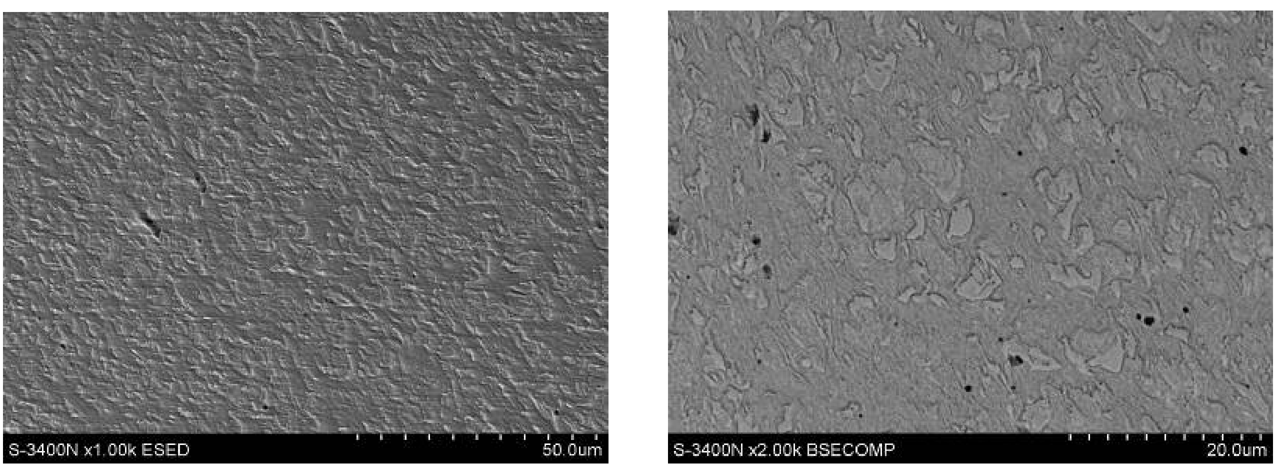

Fig. 8. Acicular ferrite in weld metal deposit after micro-jet cooling (two streams A+B), magnification: a) × 1000, b) × 2000

After that the chemical analysis, micrograph tests and Charpy V impact test on pendulum machine of the deposited metal were carried out. The Charpy V impact test was preformed according to standard ISO 148-1 Metallic materials - Charpy pendulum impact test - Part 1: Test method [18-20]. Samples for impact testing were prepared according to standard ASTM A370.

Samples prior to testing in accordance with the standard [14,15] were subjected to machining. The notch was made by milling. Used how to retrieve sections of sample and execution weighting had no impact on material properties. Due to the fact that the results obtained with impact notched bending samples are comparable only in the case tests of samples of identical size and shape notch and under the same conditions, and therefore all samples used in the tests were performed using the same tools. This is necessary because the dimension of the notch, and its shape significantly affect the acquisition values of toughness.
Charpy V impact test was carried out in such a way that the hammer blow was to the middle notch, and the axis lying in the plane of movement of the hammer and the blame was directed to the supports.

The impact toughness results is given in Table 4 and Figure 9. The Charpy tests were done mainly at temperature + 20°C and -40°C on 5 specimens having been extracted from each weld metal.

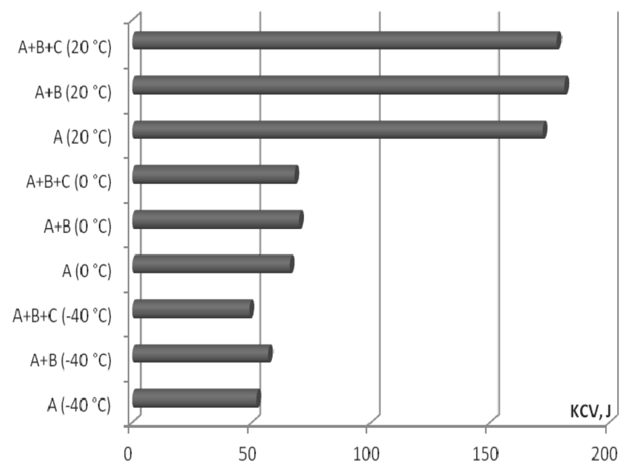

Fig. 9. Impact toughness and amount of AF ferrite for welding with shielding gas Ar

It is possible to deduce that impact toughness at negative temperature of weld metal deposit is apparently affected by the number of micro-jets in cooling injector. Two micro-jets in cooling on injector could be treated as an optimal.

In welded structures there are two general types of tests performed: impact toughness and structure. Acicular ferrite and MAC phases (self-tempered martensite, upper and lower bainite, retained austenite, carbides) were analysed and counted for each weld metal deposit. MAC phases were on the similar level of 2-3% in terms on cooling intensity in tested deposits Total amount of ferrite was on the similar level of 70% for varied number of micro-jets in cooling injector, but the levels are not exactly the same. Also in this case two micro-jets in injector could be treated as optimal. The main marked difference in tested deposits with micro-jet system cooling was observed in AF amount. Because of the AF percentage in deposits with two micro-jest in cooling injector there are gettable respectively optimal impact toughness properties.

Table 4.
Impact toughness and amount of AF ferrite for welding with shielding gas Ar

Number of micro jets	Test temperature, °C	Impact toughness KCV, J
A	- 40	52
A+B	- 40	57
A+B+C	- 40	49
A	0	66
A+B	0	70
A+B+C	0	68
A	+20	172
A+B	+20	181
A+B+C	+20	178

4. Conclusions

Using of micro jet cooling during welding with shielding gas influence on increase of ferrite AF amount. Nowadays tests of this new technology are made. It is difficult, because a lot of micro jet variables are in this investigation (the diameter outflow jet, the number of cooling jet, the flow rate and the pressure of the cooling medium, the distance between the micro jet injector and the weld, the angle of inclination between the micro jet injector and the material surface during welding, the distance between the micro jet injector and weld arc, the geometry of the jet cooling layout). However, the preliminary results shows validity of theoretical assumptions and it will be possible to apply this technology in industry.

On the basis of investigation it is possible to deduce that:

- micro-jet-cooling could be treated as a important element of MIG welding process,
- micro-jet-cooling after welding can prove amount of acicular ferrite, the most beneficial phase in low alloy steel weld metal deposit,
- high amount of acicular ferrite can guarantee respectively good impact toughness properties,
- because of using micro-jet after welding it could be possible to steer the metallographic structure,
- two micro-jets in cooling injector could be treated as optimal.

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