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Innovative surface welding with micro-jet cooling

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ABSTRACT

Purpose: of that paper was analysing main surfacing welding process with parameters of micro-jet cooling. The main reason of it was investigate possibilities of getting varied amount of martensite and bainite in surface weld of machine shafts. For getting various amount of martensite and bainite in this method it is necessary to determine the main parameters of the process such as. number of jets, diameter of stream of the micro-jet injector, type of micro-jet gases, micro-jet gas pesure.

Design/methodology/approach: During research with varied micro-jet parameters the chemical analysis, micrograph tests and hardness test of the metal weld were carried out.

Findings: There were gettable varied amount of martensite and bainite in weld surface metal in terms of micro-jet cooling parameters (numbers of jet, gas pressure). Possibilities of steering the structure (varied amount of martensite and bainite in this case) using micro-jet technology must be treated as an innovate way for MIG/MAG welding.

Research limitations/implications: That research was made for MIG/MAG method (according to PN-EN ISO 4063:2009) only. Another method of welding in this article was not tested. Other methods (for eg. 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 various amount of martensite and bainite in surface weld 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 hardfacing or wearfacing).

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 in welding regeneration.

Keywords: Welding; Micro-jet cooling parameters; Surfacing; Metallographic structure

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MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

Some alloy elements, especially nickel (in range 1-2%) or chromium (in range 1-2%), carbon (in range 0.15-0.2%) could be treated as elements positively influencing hardfacing or wearfacing of machine shafts. Metallographic structure of surface weld could be treated as optimal, because it corresponds with high percentage of martensite and bainite. For a long time researchers were putting main question: how to steer percentage of both structures [1-8]. It could be important problem steel welding and in surface regeneration for classic and new materials like TRIP steel. TRIP steel is a high-strength material typically used in the automotive industry (Fig. 1).

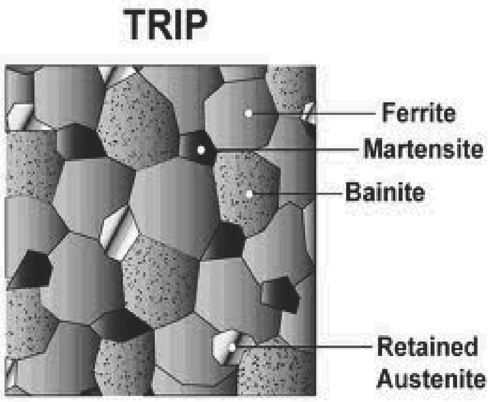


Fig. 1. Equipment for MIG welding with micro-jet injector [9]

TRIP steel has a triple phase microstructure consisting of ferrite, bainite, and martensite (during plastic deformation and straining, the metastable austenite phase is transformed into martensite). This transformation allows for higher strength keeping good ductility. Micro-jet technology gives chance to weld properly that material. In that paper there were put especial attention to weld surfacing during shaft regeneration

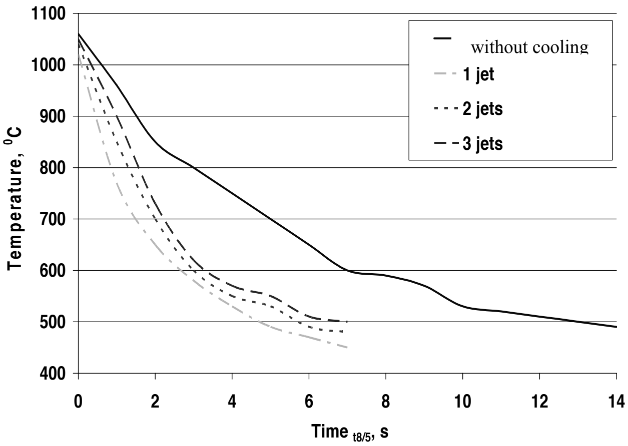


Fig. 2. Weld cooling conditions in terms of number of jets in micro-jet cooling after welding [18]

It was tested how to steer percentage and of martensite amount in the shaft weld surface. However it is very difficult to count precisely the value of martensite amount in weld [8, 17].

To obtain various amount of martensite in weld metal it was installed welding process with micro-jet injector (various cooling streams of micro-jet gas, various gas pressure of cooling stream and with constant diameter dimension of 40 μm). Welding conditions with micro-jet cooling were similar like in standard welding procedure [10-16]. Microjet-technology it and main parameters were well tested for low alloy welding structure [18-20]. Firstly it was chosen was chosen optimal injector respectively with one, two and three jets (Fig. 2).

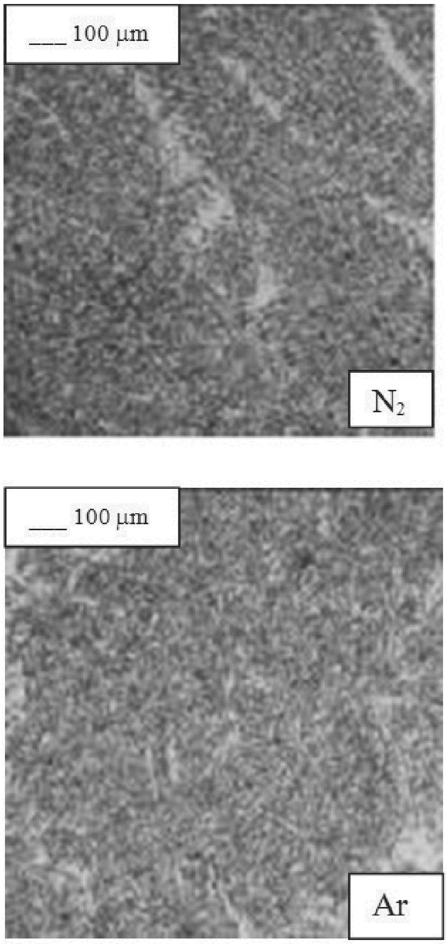
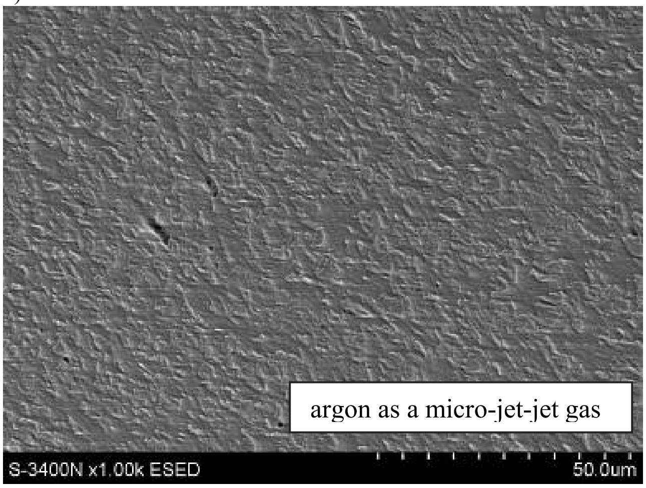


Fig. 3. Acicular ferrite in weld (68-73%) in terms on micro-jet gases (argon, nitrogen), magnification × 200 [19]

It was observed, that it is not an important difference between number of juts installed in injector, but micro-jet cooling is totally different in comparison with standard MIG welding. Secondly that was tested, that argon and nitrogen used in micro-jet injector have similar effect during cooling after welding. It was also tested that helium is cooling with stronger effect, and that microstructure in terms of micro-jet gases has influence on the metallographic structure of low alloy steel (Fig. 3).

In standard low alloy MIG welding process (without micro-jet cooling) there were usually gettable higher amounts of GBF (grain boundary ferrite) and SPF (side plate ferrite) fraction meanwhile in micro-jet cooling both of GBF and SPF structures were not dominant in all tested cases (with argon, nitrogen, helium as micro-jet gas). In all tested cases there were observed also MAC (self-tempered martensite, retained austenite, carbide) phases. Acicular ferrite with percentage above 70% was gettable only after argon micro-jet cooling (shown on Figure 4). The higher amount of MAC phases was especially gettable for nitrogen micro-jet cooling and for standard MIG (Table 3). The main reason of that investigation was to get varied amount of martensite and bainite in surface weld of machine shafts. For various amount of martensite and bainite it is necessary to determine the main parameters (eg. number of jets, diameter of stream) of the micro-jet injector.

a)



b)

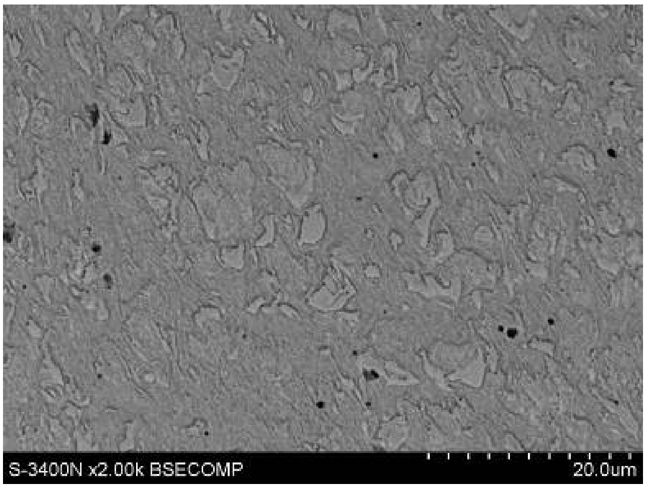


Fig. 4. AF in weld metal deposit after micro-jet cooling (argon), magnification: a) × 1000, b) × 2000 [19]

Thus in low alloy MIG welding process (without micro-jet cooling) there are gettable much higher amounts of GBF and SPF meanwhile in welding with micro-jet cooling acicular ferrite with percentage above 70% was dominant. Analysing low alloy welding with micro-jet cooling information it is possible to foresee that micro-jet technology could by capable of steering structure in other materials. Possibilities of steering the structure (varied amount of martensite and bainite) using micro-jet technology might be treated as an innovate way for MIG/MAG surface welding of machine elements, such as shafts.

3. Experimental procedure

The innovative micro-jet technology was used in investigation i.e. weld surfacing using a micro jet cooling. It allows precisely and fully controlling the structure of the surface weld. Machine shafts were surfacing using typical welding parameters Weld metal deposit was prepared by welding with micro-jet cooling with varied geometrical parameters. The main data about micro-jet (Fig. 2) and its 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 mixture	82% Ar + 18% CO_2
5.	Number of tested micro-jet cooling stream jets	1- stream, 2 - streams
6	Micro-jet shielded gases,	Ar N_2
7	Micro-jet gas presure	0.4 MPa 0.5 MPa
8	Micro-jet stream gas diameter	always 40 µm

Welding technology with micro-jet injector is an automatic process where welding head with micro-jet injector moves thanks to a special carriage. The essential element of that apparatus is connected with welding head (Figure 5). It moves automatically and it's linear velocity may be regulated. The study was carried out for low shaft steel 18H2N2 (with diameter of 80 mm) on a special prepared research station. Welding process ensures the cooling of the overall joint. Nitrogen and argon were chosen for micro-jet cooling gases (always with diameter of 40 µm of stream). Cooling gas pressure was twice varied (0.4 MPa and 0.5 MPa) in both cases for two tested micro-jet gases (argon and nitrogen). Velocity of the processes (both welding and micro-jet cooling) were on the same level of 150 mm/min.

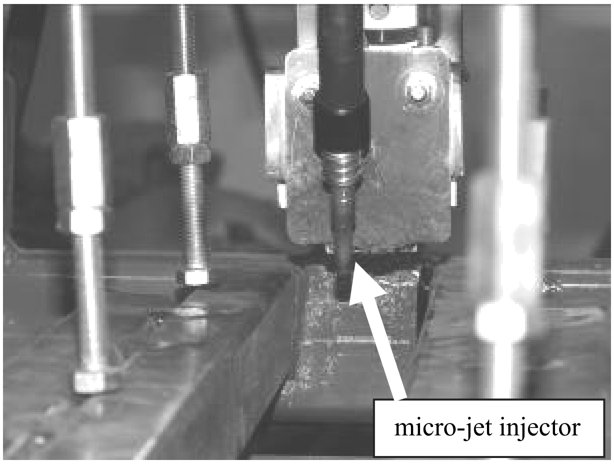


Fig. 5. Equipment for MIG welding with micro-jet injector (main view)

A purpose of the study was to examine the varying structure of the typical surfacing shaft after welding, Figure 6.

Fig. 6. Shaft after surface welding

3. Results and discussion

All tested welding processes were chosen with very similar micro-jet cooling conditions: with one injector and couple of injectors. It was possible to get precisely weld cooling conditions especially in range 800-500 °C (time of cooling in welding conditions: parameter $\mathbf{t_{800/500}}$). Example of $\mathbf{t_{800/500}}$ diagram with micro-jet cooling and standard welding without micro-jet process is presented in Figures 7, 8, 9.

Heat transfer coefficient of tested micro-jet gases does not influences strongly on cooling conditions of welds (Figures 7, 8). This is due to the similar conductivity coefficients ($\lambda \cdot 105$), which for Ar and N_2, in the 273 K are not very various, respectively: 16.26 and 23.74, J/cm·s·K. Cooling conditions are rather similar when nitrogen and argon are chosen as a micro-jet gas.

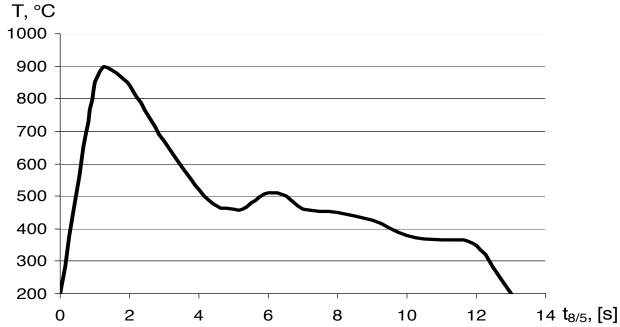


Fig. 7. Weld cooling conditions with micro-jet cooling, micro-jet gas (Ar) pressure is 0.4 MPa, one jet installed in injector

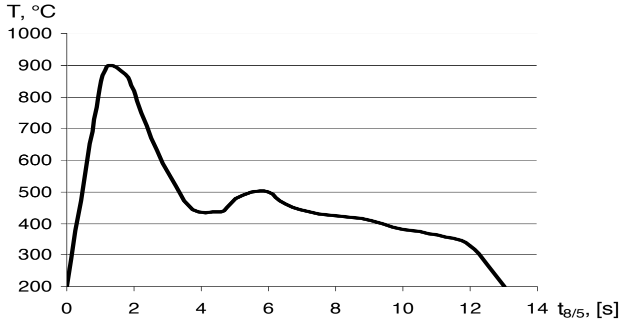


Fig. 8. Weld cooling conditions with micro-jet cooling, micro-jet gas (N_2) pressure is 0.4 MPa, one jet installed in injector

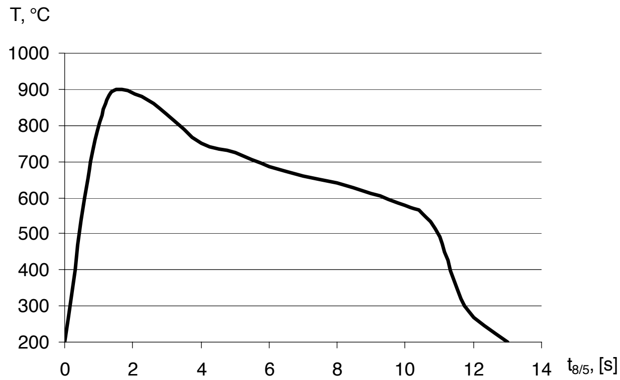


Fig. 9. Weld cooling conditions without micro-jet cooling

Helium could give possibly stronger cooling conditions, but in that article helium was not tested in any investigation. Nevertheless weld cooling conditions for case without micro-jet cooling is evidently different. Cooling time $\mathbf{t_{800/500}}$ of standard welding is much longer in comparison with micro-jet cooling. Micro-jet cooling does not have influence on chemical composition of weld. A typical weld metal deposit had chemical composition which was shown in Table 2.

Table 2.
A typical chemical composition of weld

No.	Element	Amount
1.	C	0.15%
2.	Mn	0.4%
3.	Si	0.15%
4.	P	0.014%
5.	S	0.011%
6.	Cr	1.8%
7.	Ni	1.9%

For standard surface SMAW welding and surfacing with micro-jet cooling (argon as a micro-jet gas) amount of nitrogen in weld was always on the level of 50 ppm. For welding with nitrogen as a micro-jet gas amount of nitrogen was much higher, even on the level of 70 ppm. Generally there were not observed nitrides in weld metal deposits. There was carried out metallographic structures for MIG surfacing with micro-jet cooling in terms on micro-jet parameters (Tables 3, 4). In all cases martensite was the main phase that only was strongly varied; it is shown in Tables 3, 4 and Figures 10, 11.

Table 3.
Martensite in weld (argon as a micro-jet gas)

Micro-jet gas presure	Number of jets	Martensite aprox, %	nitrides
0.4 MPa	0	50	-
0.4 MPa	1	60	-
0.4 MPa	2	70	-
0.5 MPa	0	60	-
0.5 MPa	1	70	-
0.5 MPa	2	80	-

Table 4.
Martensite in weld (nitrogen as a micro-jet gas)

Micro-jet gas presure	Number of jets	Martensite Aprox, %	nitrides
0.4 MPa	0	50	-
0.4 MPa	1	60	-
0.4 MPa	2	70	traces
0.5 MPa	0	60	-
0.5 MPa	1	70	traces
0.5 MPa	2	80	traces

Martensite amount is not on the same level in all tested cases, that is shown in Figures 10, 11.

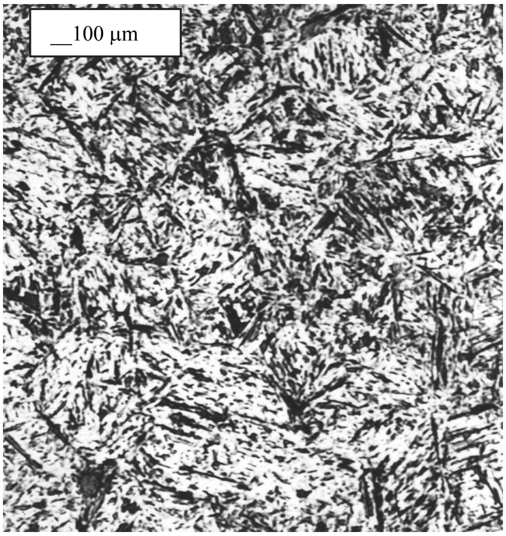


Fig. 10. Martensite (aprox. 80%) in weld after welding with microjet cooling (nitrogen as microjet gas), magn, 200x

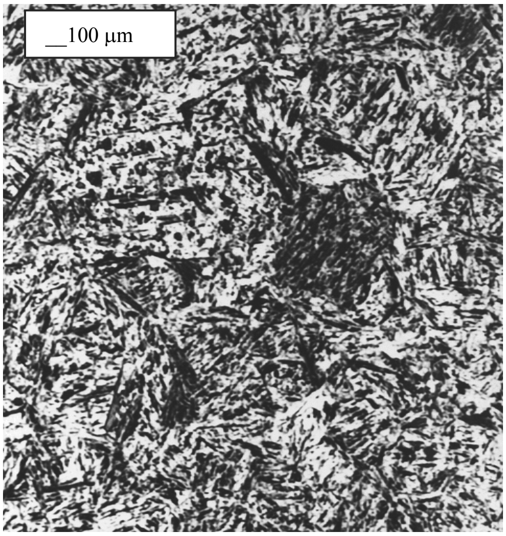


Fig. 11. Martensite (aprox. 70%) in weld after welding with microjet cooling (argon as microjet gas), magn, 200x

It is not so easy to count martensite amont such as other typical weld phases: acicular ferrite, grain boundary ferrite, side plate ferrite. Martensite amount was only estimated. Nevertheless it is possible to present, that micro-jet technology is capable of structure steering (Tables 3, 4). After microscope observation a micro hardness was carried out (Figs. 12-17). Standard surface welding could not guaranty high hardness (Fig. 17).

Hardnes was decreased in terms of the distance from weld face, the maximum value was much below 500 HV. Much higher hardness values were observed after welding with micro-jet cooling (Fig. 13).

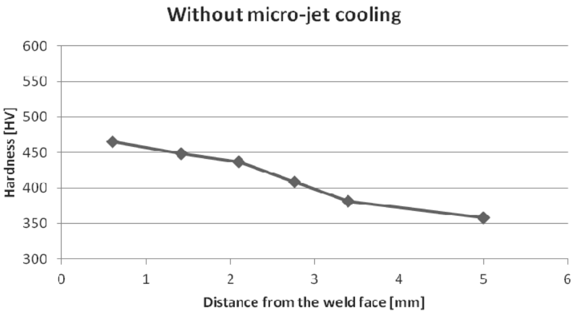


Fig. 12. Hardness of standard weld without micro-jet

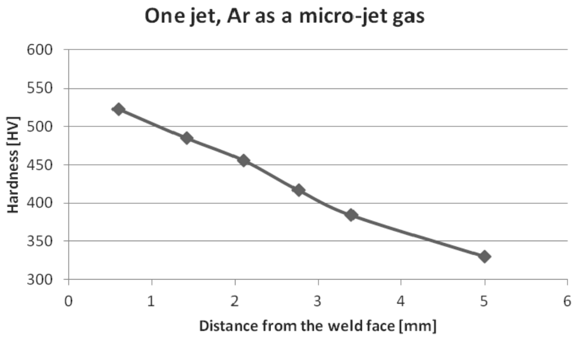


Fig. 13. Hardness of weld after micro-jet cooling, one cooling jet, argon as a micro-jet gas

Welding with micro-jet cooling (by argon) with one jet allowed to excide hardness under 500 HV. Respectively higher hardness values were observed after welding with two jets instaled in injector (Fig. 14).

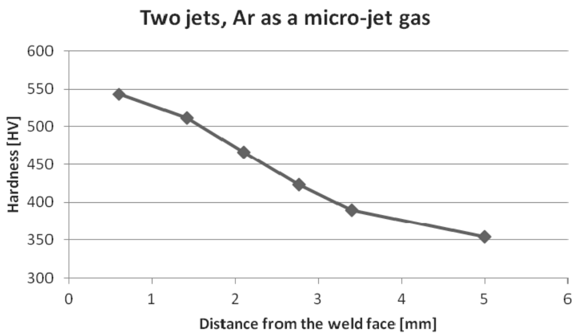


Fig. 14. Hardness of weld after with micro-jet cooling, two cooling jet, argon as a micro-jet gas

Welding with micro-jet cooling (by argon) with one jet allowed to excide hardness on the level of 545 HV. A little higher hardness values were observed after welding with micro-jet injector using nitrogen as a cooling gas (Fig. 15).

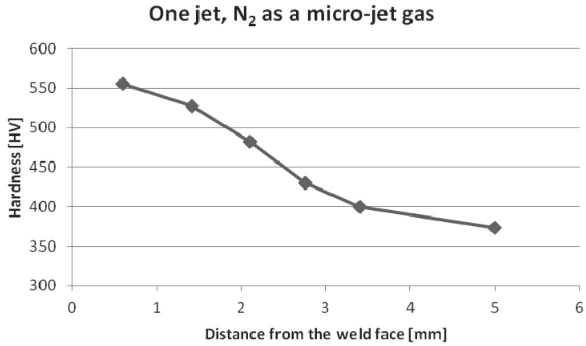


Fig. 15. Hardness of weld after micro-jet cooling, one cooling jet, nitrogen as a micro-jet gas

Welding with micro-jet cooling (by nitrogen) with one jet allowed to excide hardness under 550 HV. Respectively higher hardness values were observed after welding with two jets instaled in cooling injector (Fig. 16).

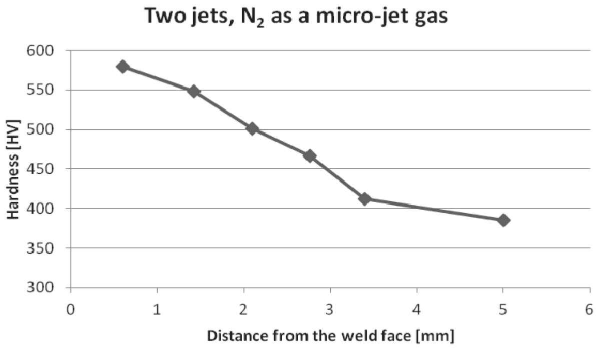


Fig. 16. Hardness of weld after micro-jet cooling, two cooling jet, nitrogen as a micro-jet gas

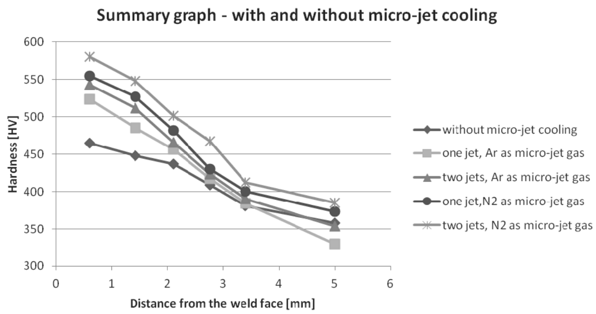


Fig. 17. Steering of weld hardness after processes with various micro-jet parameters

Welding with micro-jet cooling (by nitrogen) with two jets allowed to excide hardness on the level of 580 HV. Figure 10 presents comparison of all weld hardness values in terms of micro-jet parameters (micro-jet gas and number of jets). It is possible to present, that micro-jet technology is capable of hardness steering (Fig. 17).

The micro-hardness inside the martensitic regions after welding with micro-jet cooling are higher than in standard weld, i.e. between 580 than 475 HV compared to 470 HV. The micro-jet surfacing technology was tested for surface welding with various micro-jet gases and other micro-jet parameters.

4. Conclusions

Micro-jet technology could be very beneficial during shaft surfacing. Micro-jet injector has many parameters, such as: the diameter of 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). In this investigation only some of micro jet parameters were tested: number of jets, gas pressure, and various cooling media (argon and nitrogen). However, the preliminary results shows validity of theoretical assumptions and it will be possible to apply this technology in industry very soon.

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,
- it is possible to steer the metallographic structure (martensite, bainite, nitrides),
- it is possible to steer the weld harness by various micro-jet parameters,
- two micro-jets in cooling injector could be treated as optimal solution for hard surface welding,
- there is not great difference between the influence of argon and nitrogen on cooling conditions,
- nitrogen used for micro-jet cooling (instead of argon) is responsible of higher hardness in all tested cases because of respectively higher amount of nitrogen in weld metal deposit,
- nitrogen used for micro-jet cooling (instead of argon) is responsible of higher amount of martensite in weld metal deposit,
- there were observed traces of nitrides when nitrogen was used for micro-jet cooling (instead of argon when nitrides were not observed).

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