

THE IMPACT OF GAS ON THE TRIBOLOGICAL PROPERTIES OF STEEL 16MnCr5 AFTER SURFACING WITH MICRO-JET COOLING

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Abstract

This paper presents results of experimental research concerning the impact of an innovative method of micro-jet cooling on the padding weld performed with MAG welding. It enables to steer the parameters of weld cooling in a precise manner. Micro-jet cooling is a novel method patented in 2011. In addition, various elements, which may e.g. enhance hardness or alter tribological properties, can be entered into its top surface, depending on the applied cooling gas. The micro-jet welding method is the innovative method, which reduces the intensity of abrasive wear. The method can be used as a basic finishing or a regeneration method. An innovative technology for micro-jet is used to cool the weld surface that is, using a micro-welding jet cooling. This allows accurate and complete control of the surface structure of the deposit. The material under study was steel 16MnCr5, which was subject to the welding process with different gases of micro-jet cooling. Nitrogen and air was used as a cooling gas. The main parameter of weld assessment was wear intensity. The tests were conducted in a tribological pin-on-disc type position. T-11 pin-on-disc tester allows for indicating basic wear parameters (wear intensity, wear coefficient, wear force). Based on results of experiment the application of nitrogen in micro-jet cooling of the padding weld in the welding process of steel 16MnCr5 beneficially affects resistance to abrasive wear.

Keywords: wear resistance, steel 16MnCr5, micro-jet, surfacing

1. Introduction

The welding method is used for reduction the intensity of wear process and regeneration of structural elements [1-5]. The working elements of machines operating in hard conditions are subject to intensified wear not on their full surface, but merely in specific characteristic places. These are mostly places where the biggest pressure occurs or materials causing accelerated wear get into contact (e.g. sand grains of sharp edges) [7, 8]. The micro-jet welding method is the innovative method, which reduces the intensity of abrasive wear [6-15]. The method can be used as a basic finishing or a regeneration method. An innovative technology for micro-jet is used to cool the weld surface that is, using a micro-welding jet cooling [13]. This allows accurate and

complete control of the surface structure of the deposit. The main data of the micro-jet and the welding parameters are shown in article [13-14].

2. Experimental procedure

The research incorporated steel 16MnCr5 intended for carburizing and heat improvement. It is characterised by very good mechanical properties and hardness after a proper thermo-chemical heat treatment, exceeding 60 HRC [5]. It is used for machine parts exposed to varying loads and heavy wear. In order to maintain the conditions similar to those in the actual regeneration, the panel from which the sample was cut out of carburizing, hardening and tempering. The process parameters are presented in Tab. 1.

Tab. 1. Parameters of the thermo-chemical heat treatment of 16MnCr5 steel

Type of treatment	carburization	hardening	tempering
Temperature [°C]	920°C	840°C	240°C

Upon the thermo-chemical heat treatment, the frontal area of the sample was welded with the MAG method without cooling and with micro-jet cooling. The gases used in the cooling process were nitrogen and compressed air. The main data about micro-jet (Fig. 1) and its parameters of welding were shown in Tab. 2.

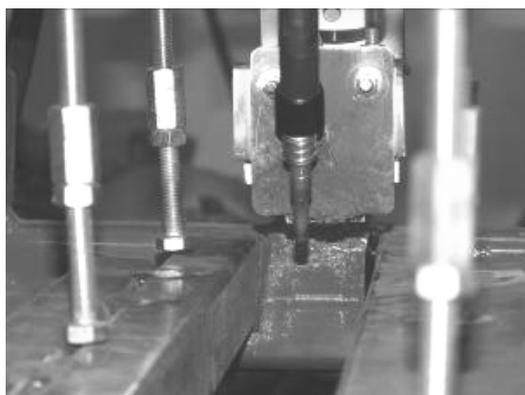


Fig. 1. Equipment for MIG welding with micro-jet injector (main view)

Tab. 2. 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
6.	Micro-jet shielded gases	compressed air, nitrogen
7.	Micro-jet gas pressure	0.4 MPa
8.	Micro-jet stream gas diameter	always 40 μm

Nitrogen and compressed air were chosen for micro-jet cooling gases (always with diameter of 40 μm of stream). Cooling gas pressure was not varied (always 0.4 MPa) in both cases for two tested micro-jet gases (compressed air and nitrogen). Velocity of the processes (both welding and micro-jet cooling) was on the same level of 150 mm/min.

In order to indicate wear intensity of the welded plate, samples in the shape of a square at the size of 4x4 mm were extracted (by electro-hollowing). The resultant samples were studied via the T-11 pin-on-disc tester (Fig. 2).

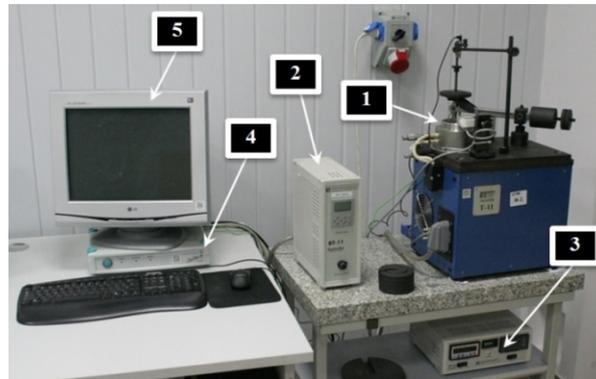


Fig. 2. Schema of the T-11 position for the tribological pin-on-disc-type test: 1 – sensors and transducers, 2 – the controller BT-11, 3 – the controller BT-03, 4 – digital amplifier 8 Spider, 5 – a set of computer

It allows for indicating basic wear parameters (wear intensity, wear coefficient, wear force). The counter-sample constituted a silicate disc (Fig 3b). It was made of a densified calcareous and sand mixture of 0-0.6 mm granularity. The application of this type of frictional vapour imitates conditions of intensive dry friction which occurs, among others, in dry material carriers (e.g. aggregate, corn grains) and the densifying process of dry materials (e.g. production of silicate bricks, pavement blocks). The unit pressure of the sample vs. the counter-sample was identical in every test and equalled $p = 1.5$ MPa. The duration time of the test was 20 min. The test was performed at 20 degrees Celsius. It was not used lubrication. Fig. 3 presents the sample and the counter-sample.

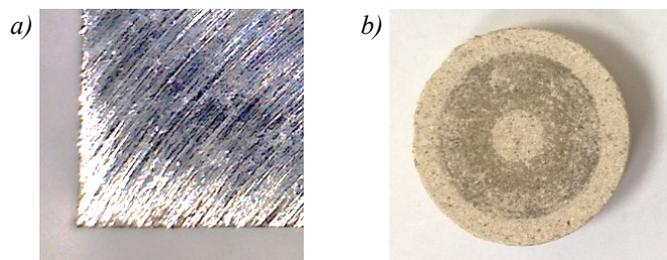


Fig. 3. View of: a) the sample, b) the counter-sample

3. Results and discussion

All tested welding processes were chosen with very similar micro-jet cooling conditions with one cooling injector. It was possible to get precisely weld cooling conditions especially in range 800-500°C (time of cooling in welding conditions: parameter $t_{800/500}$). Example of $t_{800/500}$ diagram with micro-jet cooling and standard welding without micro-jet process is presented in Figs. 4-6.

Heat transfer coefficient of tested micro-jet gases does not influences strongly on cooling conditions of welds (Fig. 7, 8). This is due to the similar conductivity coefficients ($\lambda \cdot 105$), which for compressed air and N_2 , in the 273 K are not very various, respectively: 21.26 and 23.74, J/cm·s·K. Cooling conditions are rather similar when nitrogen and compressed air are chosen as a micro-jet gas. 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 $t_{800/500}$ of standard welding is much longer in comparison with micro-jet cooling. Micro-jet cooling does not have influence on chemical composition of weld.

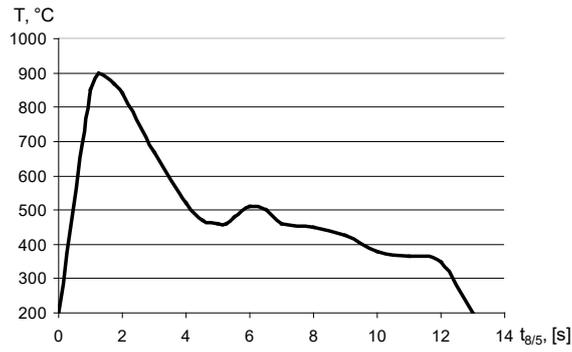


Fig. 4. Weld cooling conditions with micro-jet cooling, micro-jet gas (compressed air) pressure is 0.4 MPa, one jet installed in injector

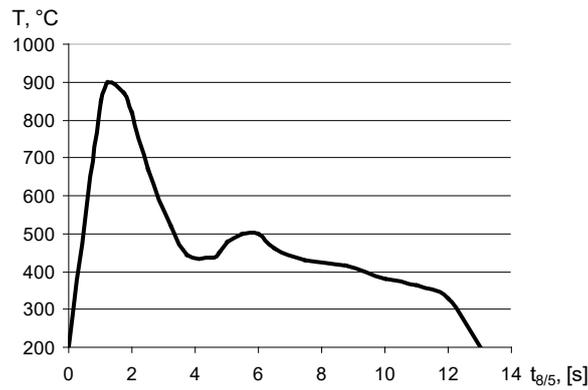


Fig. 5. Weld cooling conditions with micro-jet cooling, micro-jet gas (N₂) pressure is 0.4 MPa, one jet installed in injector

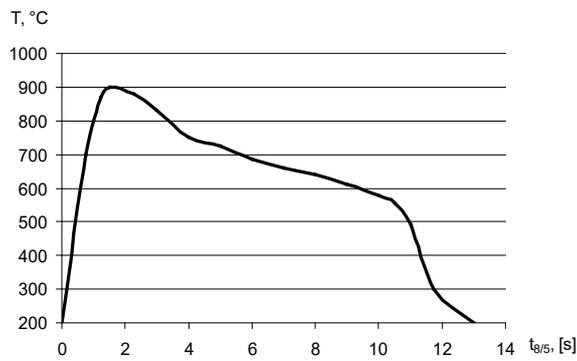


Fig. 6. Weld cooling conditions without micro-jet cooling

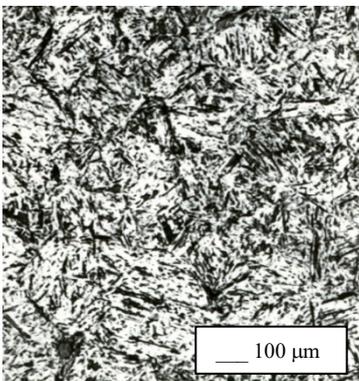


Fig. 7. Martensite (approx. 75%) in weld after welding with microjet cooling (nitrogen as microjet gas)

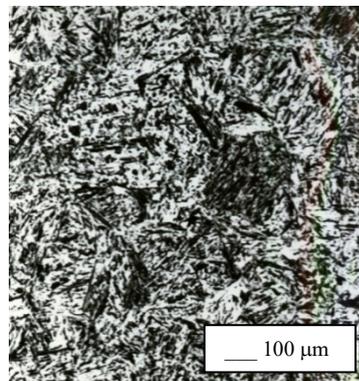


Fig. 8. Martensite (approx. 70%) in weld after welding with microjet cooling (air as microjet gas)

For standard surface MIG welding and surfacing without micro-jet cooling amount of nitrogen in weld was always on the level of 50 ppm. For welding with air as a micro-jet gas amount of nitrogen in WMD was much higher, on the level of 65 ppm. For welding with nitrogen as a micro-jet gas amount of nitrogen in WMD was the highest, even on the level of 70 ppm. Sometimes there were observed traces of nitrides in weld metal deposits, when nitrogen was used as a micro-jet gas. There was carried out metallographic structures for MAG surfacing with micro-jet cooling. In all cases, martensite was the main phase that only was strongly varied; it is shown in Tab. 3 and Fig. 7, 8.

Tab. 3. Martensite in weld after micro-jet cooling

Micro-jet gas pressure	Micro-jet gas	Martensite approx., %	nitrides
–	–	60	–
0.4 MPa	nitrogen	75	–
0.4 MPa	air	70	traces

Martensite amount is not on the same level in all tested cases that is shown in Figs. 7, 8.

It is not so easy to count martensite amount 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 (Tabs. 2, 3). The tested samples were measured for distribution of microhardness of the surface layer. The results are shown in Figs. 9-11.

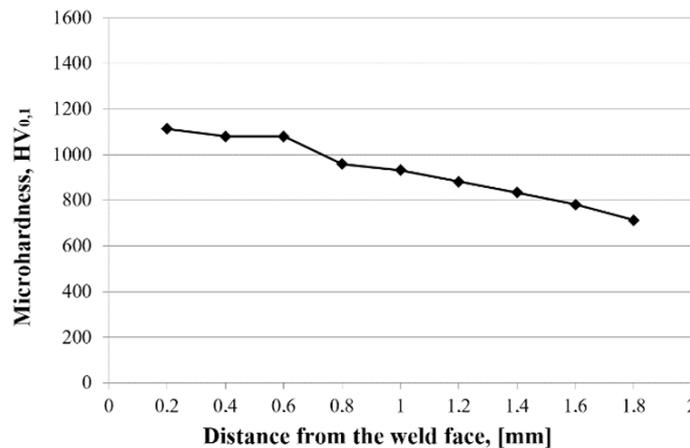


Fig. 9. Hardness of standard weld without micro-jet

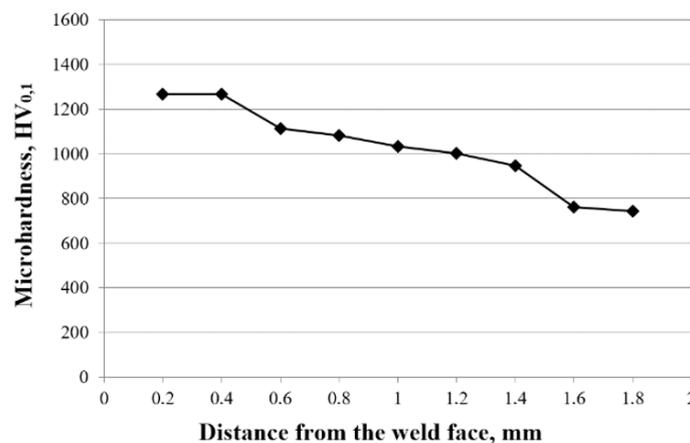


Fig. 10. Hardness of weld after micro-jet cooling, one cooling jet, nitrogen as a micro-jet gas

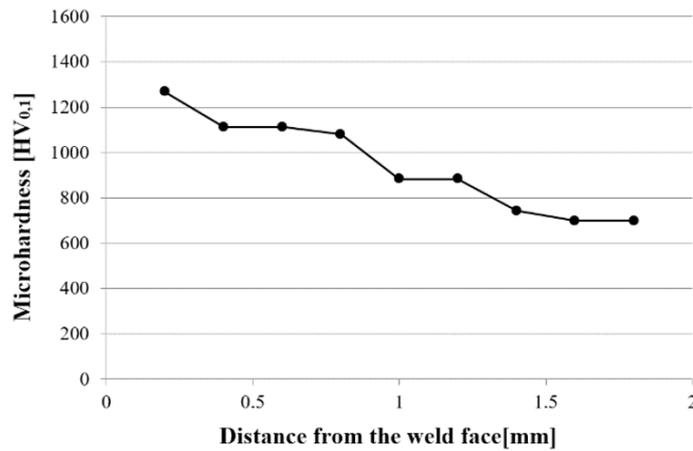


Fig. 11. Hardness of weld after micro-jet cooling, one cooling jet, air as a micro-jet gas

The obtained results constitute an average out of 5 tests conducted on 5 samples that were put to the same welding procedure and the same thermo-chemical heat treatment. These results are included on the Fig. 12.

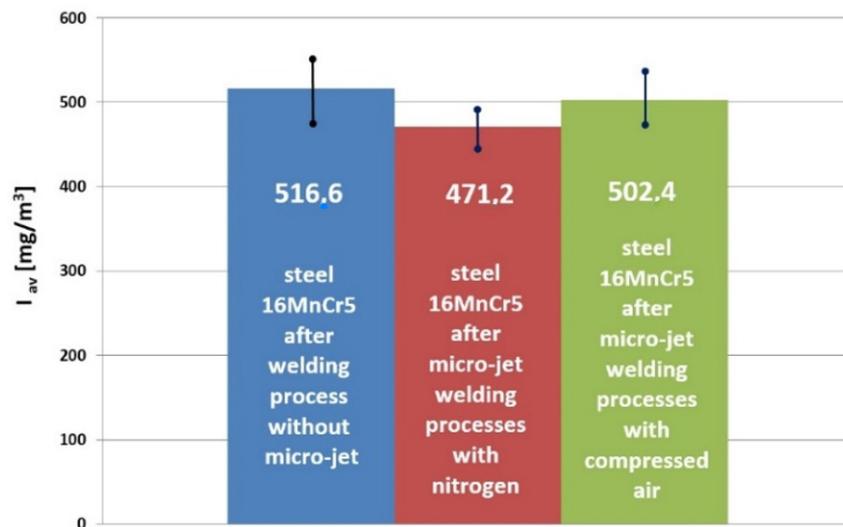


Fig. 12. Compilation of results for steel after welding process with micro-jet cooling and without cooling

All results (friction coefficient, friction force) are included in Tab. 4.

Tab. 4. Compilation of results obtained in the research at the T-11 position

Research material	I_{av} [mg/m ³]	μ_{av}	T_{av} [N]
steel 16MnCr5 after welding processes without micro-jet	516.6	0.47	13.11
steel 16MnCr5 after micro-jet welding process with nitrogen	471.2	0.46	13.43
steel 16MnCr5 after micro-jet welding process with compressed air	502.4	0.46	14.02

4. Conclusions

Micro-jet technology could be very beneficial during steel 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 various cooling media (air and nitrogen) were tested. 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 an important element of MAG welding process,
- it is possible to steer the metallographic structure (martensite, nitrides),
- it is possible to steer the weld hardness by various micro-jet parameters,
- there is not great difference between the influence of air and nitrogen on cooling conditions,
- nitrogen used for micro-jet cooling (instead of air) is responsible of higher hardness in all tested cases because of respectively higher amount of nitrogen in weld metal deposit,
- there were observed traces of nitrides when nitrogen was used for micro-jet cooling (instead of air when nitrides were not observed),
- the application of nitrogen in micro-jet cooling of the padding weld in the welding process of steel 16MnCr5 beneficially affects resistance to abrasive wear.

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