Scientific Journal of Silesian University of Technology. Series Transport
Zeszyty Naukowe Politechniki Śląskiej. Seria Transport

Volume 102 **2019**

p-ISSN: 0209-3324

e-ISSN: 2450-1549

DOI: https://doi.org/10.20858/sjsutst.2019.102.17

Journal homepage: http://sjsutst.polsl.pl

Article citation information:
Szczucka-Lasota, B., Węgrzyn, T., Lukaszkowicz, K. Low alloy steel shaft surface regenerative welding with micro-jet cooling. *Scientific Journal of Silesian University of Technology. Series Transport*. 2019, **102**, 205-215. ISSN: 0209-3324.
DOI: https://doi.org/10.20858/sjsutst.2019.102.17.

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LOW ALLOY STEEL SHAFT SURFACE REGENERATIVE WELDING WITH MICRO-JET COOLING

Summary. In this paper, the effect of surface preparation after innovating welding technology with micro-jet cooling was reported. Substantial information about parameters of steel machine elements surfacing with the micro-jet cooling process was given. Recorded evidence concerning the influence of various micro-jet parameters on the metallographic structure of the machine shaft after surface welding was taken. There were tested metallographic and tribology properties of welds. The tribology interactions of a solid shaft surfaces were examined after surface welding.
Keywords: welding, micro-jet cooling, metallographic structure, wearing

1. INTRODUCTION

The purpose of metal surfacing is to obtain the best possible coating of the welding element. Usually, after regeneration, machine components regain good operating properties. Crankshafts are subjected to wear due to prolonged friction with cooperating parts. For

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example, the shaft of the gearbox should be regenerated in many vehicles after passing 150 Mm, and the shafts of mining heading machines regenerate only after 4 months of intensive exploitation, unless the head of the combine has contact with hard increments (then exploitation time of mining combine elements will be even shorter) [1,2]. The surface welding process is mainly and often used to apply hardness or wear-resistant layer of base metal [3]. It is a very important method of extending the life of machines, tools, and construction equipment. The main goal of the paper is to explore the possibilities of surfacing with micro-jet cooling. For welding, the machine parts with the use of micro-jet cooling, only welding processes in which no slag is formed can be used. The biggest application of micro-jet cooling takes place in the Metal Inert Gas (MIG), Metal Active Gas (MAG) and Tungsten Inert Gas (TIG) processes. The metallographic structure was analysed in terms of micro-jet parameters. For getting various amounts of ferrite, bainite and martensite in this welding method, it is necessary to determine the main parameters of the process such as:

- the diameter of the stream of the micro-jet injector.
- type of micro-jet gas or gas mixture.
- micro-jet gas pressure.
- a number of jets.

Welding with micro-jet technology was very carefully tested for low alloy welding [4,5]. In low alloy steel weld, mechanical properties of weld correspond with the chemical composition and metallographic structure [6,7]. In the case of hardfacing, it is important to obtain a martensitic structure in order to increase the hardness of the coating and their resistance to abrasive wear [8-10].

The goal of this paper is to describe the possibilities of shaft MAG surface welding process with micro-jet cooling, which allows obtaining the various content of ferrite, martensite, bainite. In the case of ferrite, it is important that the grain is not as small as possible, which translates into better tribological properties of regenerated shafts and does not lead to fissures. In weld metal deposit there are three morphological varieties of ferrite: grain boundary ferrite, side place ferrite and acicular ferrite, which is the most advantageous due to the small grain size.

2. MATERIALS AND METHOD

A test stand for hardfacing was made. To obtain the various amount of ferrite, martensite and bainite in shaft surface weld, it was installed through a welding process with micro-jet injector with a variable number of micro-streams. The diameter of streams was on the level of 50 μm and 60 μm. To analyse the surface welding with micro-jet cooling, there were chosen shafts of 40NiCrMo6 steel with a diameter of 34 mm. An example of a machine shaft supplied for regenerative welding with the use of micro-jet cooling is shown in Figure 1.

Surface weld was prepared by welding with micro-jet cooling with varied parameters. Two micro-jet gases (nitrogen and helium) were tested in the cooling process just after surface welding. There were also other varied important micro-jet parameters: gas pressure, micro-jet gas pressure and micro-jet diameter. The main data about the parameters of welding were shown in Table 1. MAG surface welding process with micro-jet cooling was carefully tested. Helium was chosen for the micro-jet cooling because of its good cooling properties. Nitrogen was used for the micro-jet cooling, under the assumption that there could be observed slight nitriding of the surface welds.

Fig. 1. A machine shaft supplied for regenerative welding with the use of micro-jet cooling

Tab. 1

Parameters of the welding process.

No.	Parameter	Value
1.	Diameter of wire	1.2 mm
2.	Standard current	220 A
3.	Voltage	24 V
4.	Shielding welding gas	80%Ar+20%CO_2
5.	Kind of tested micro-jet cooling gas	1 – He 2 – N_2
6.	Micro-jet gas pressure	0.4 MPa 0.5 MPa
7.	Micro-jet diameter	50 μm 60 μm

3. RESULTS AND DISCUSSION

A goal of the study was to examine the varying structure of the typical surfacing shaft after welding. Steels with a carbon content of about 0.3% should be preheated to a temperature of about 200℃. The possibility of welding cracks in these steel grades is caused by the presence of such structures in Weld Metal Deposit (WMD) as martensite, bainite and grain boundary ferrite. Such a structure can promote cracking after welding. Nevertheless, it was decided to check the possibility of surface welding steel shaft without preheating due to the use of micro-jet cooling, thinking that it might reduce the size of ferrite significantly. Micro-jet gas could have both influence on cooling conditions and the chemical WMD composition (nitrogen amount in WMD) (Figures 2, 3 and 4).

Important $t_{8/5}$ welding parameter, which informs about the cooling time between 800 and 500°C, where the most important austenite transformation occurs, is the largest (on the level of 10 sec) when micro-jet cooling is not used.

In the case of $t_{8/5}$ welding parameter, it is much smaller (on the level of 6 sec) when nitrogen micro-jet cooling is used.

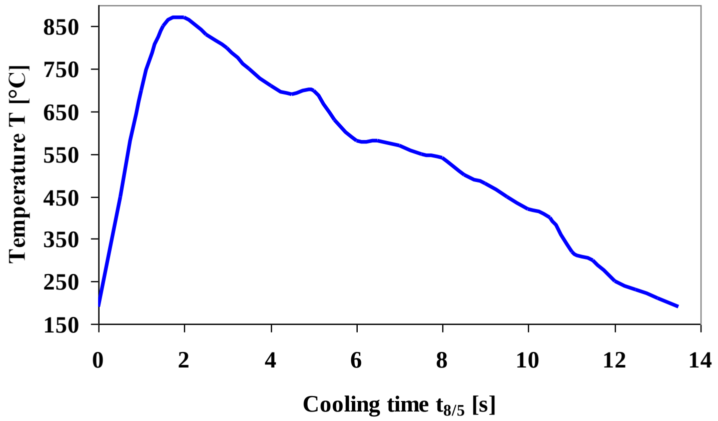

Fig. 2. Weld cooling conditions without micro-jet cooling

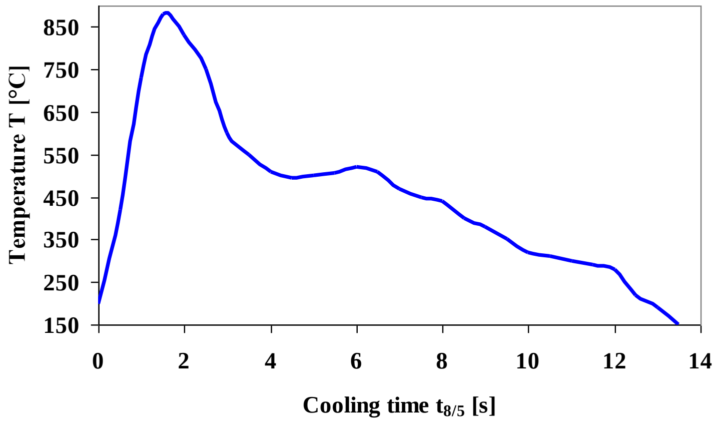

Fig. 3. Weld cooling conditions with micro-jet cooling, micro-jet gas (N_2) pressure is 0.5 MPa, one jet installed in the injector

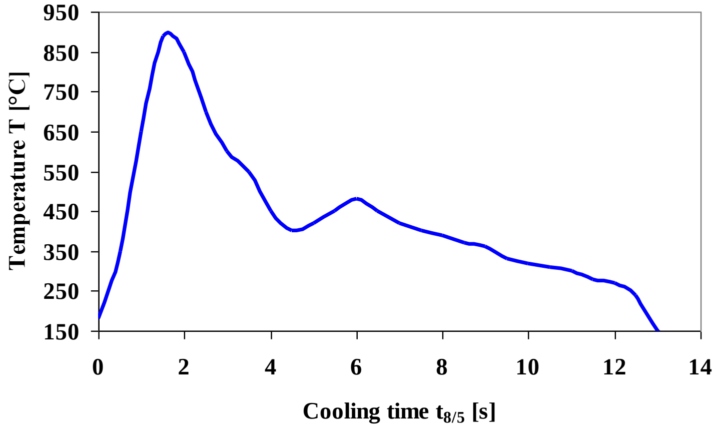

Fig. 4. Weld cooling conditions with micro-jet cooling, micro-jet gas (He) pressure is 0.5 MPa, one jet installed in injector

In the case of $t_{8/5}$ welding parameter, it is also smaller (on the level of 4 sec) when helium micro-jet cooling is used. Heat transfer coefficient of tested micro-jet gases influences on cooling conditions of welds (Figures 3 and 4). This corresponds to varied martensite content. This is due to the different conductivity coefficients ($\lambda \cdot 105$), which for N_2 and Ar, in the 273 K is on the level of 23.74 J/cm·s·K. Helium gives much stronger cooling conditions due to the higher conductivity coefficients ($\lambda \cdot 105$), which for He is 143.4 J/cm·s·K. A typical WMD had similar chemical composition in all tested cases. The chemical composition of WMD after MAG welding with and without micro-jet cooling is presented in Table 2.

Tab. 2

Chemical composition of Weld Metal Deposit (WMD)

No.	**Element**	**Amount**
1.	C	0.31%
2.	Mo	0.2
3.	Mn	0.67%
4.	Si	0.17%
5.	P	0.014%
6.	S	0.011%
7.	Cr	1.8%
8.	Ni	1.36%
9.	Cu	0.07%
10	Al	0.22%
11.	V	0.01%
12.	N	55-70 ppm

For standard MAG welding without micro-jet cooling and for MAG welding with helium micro-jet cooling, the amount of nitrogen was always on the level of 55 ppm. For MAG welding with nitrogen micro-jet gas cooling, the amount of nitrogen was much higher, on the level of 70 ppm. After chemical analyses, the metallographic structure was given. Presence of such structures in WMD as martensite, bainite and grain boundary ferrite were identified. Weld cracks were not observed in all examined cases, especially where micro-jet cooling was used. An additional success of the research was the possibility of controlling the martensite content. For the sake of transparency in the interpretation of results, it was decided to compare only the content of martensite in the weld. A piece of information about martensite amount in WMD is shown in Tables 3 and 4.

Tab. 3

Martensite in surface weld (helium used as a micro-jet gas)

Micro-jet diameter, μm	Micro-jet gas pressure, MPa	Number of jets	Martensite aprox, %
-	-	-	45
50	0.4	1	50
50	0.4	2	60
50	0.5	1	55
50	0.5	2	65

60	0.4	1	55
60	0.4	2	65
60	0.5	1	60
60	0.5	2	65

Tab. 4

Martensite in surface weld (nitrogen used as a micro-jet gas)

Micro-jet diameter, μm	Micro-jet gas pressure, MPa	Number of jets	Martensite aprox, %
-	-	-	45
50	0.4	1	50
50	0.4	2	55
50	0.5	1	55
50	0.5	2	60
60	0.4	1	55
60	0.4	2	60
60	0.5	1	60
60	0.5	2	65

Micro-jet cooling does not have a greater influence on the chemical composition of the weld. In the case of nitrogen micro-jet cooling, there was additionally observed traces of nitrides. It was observed that the micro-jet cooling is able to increase the content of martensite to 65% and seriously reduce the size of ferrite grains (Figures 5 and 6).

It is not so easy to precisely count martensite amount such as other typical low alloy steel weld phases: acicular ferrite, grain boundary ferrite, side plate ferrite for low alloy welding [11]. Martensite amount was only estimated. Cooling allows for the increase of the content of the martensite in the weld from 45% to 65%. After microscope observation, a microhardness was carried out (Figures 7, 8 and 9). Standard surface welding could not guaranty high hardness (Figure will be able to be integrated in 8).

Fig. 5. Martensite (approximately 45%) in weld after MAG welding without micro-jet cooling (big size of ferrite grains)

Fig. 6. Martensite (approximately. 65%) in weld after MAG welding with micro-jet cooling (ferrite grain of various sizes)

Surface weld hardness of the shaft was decreased in terms of the distance from weld face; the maximum value was much below 450 HV. Much higher hardness values were observed after welding with helium micro-jet cooling (Figure 8).

Surface shaft welding with helium micro-jet cooling allowed to excide hardness even above 450 HV. The effect of nitrogen micro-jet cooling on steel WMD hardness is shown in Figure 9.

Surface shaft welding with nitrogen micro-jet cooling allowed to excide hardness even above 450 HV. This is translated by increased nitrogen content in WMD (from 55 ppm to 70 ppm). Finally, tribological tests were done using the Amsler machine. Results of the Amsler tests are shown in Table 5.

Tab. 5

The tribological test results

Properties	Sample of surface weld without micro-jet cooling	Sample of surface weld with helium micro-jet cooling	Sample of surface weld with nitrogen micro-jet cooling
Critical Force	300 N	300 N	300 N
Critical unit pressure	9.74 N/mm^2	9.74 N/mm^2	9.74 N/mm^2
Blurring time	10 s	25 s	25 s
Friction coefficient	0.548	0.397	0.380
Weight loss [g]	0.0160 g	0.0009 g	0.0006 g

Based on the results stated in Table 6, it was found that the highest resistance to abrasive wear has the sample taken after welding with micro-jet cooling. Favourable micro-jet gases are nitrogen or helium.

After hardness analysis, Charpy V impact test of the deposited metal was carried out. The Charpy tests were done at temperature +20°C on 5 specimens having been extracted from each weld metal (Table 6).

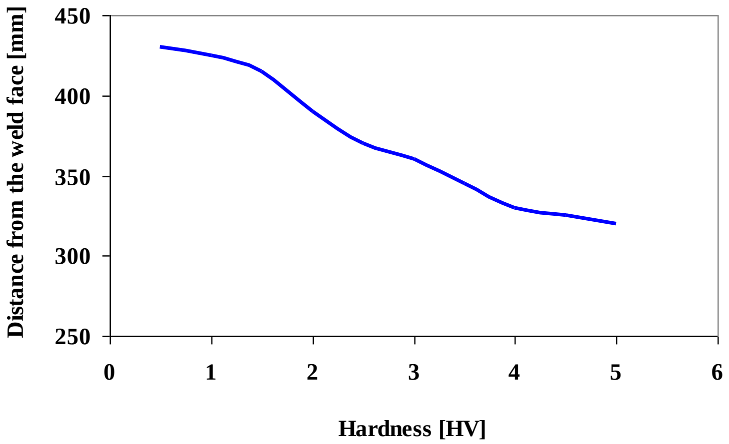

Fig. 7. Hardness of standard MAG steel weld without micro-jet cooling

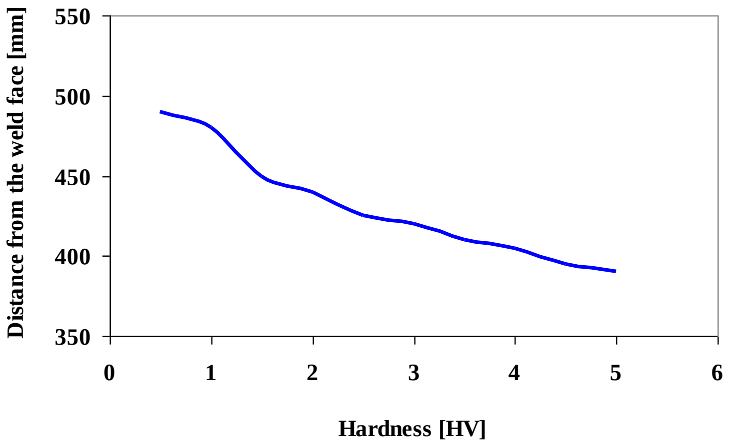

Fig. 8. Hardness of weld after with micro-jet cooling with helium used as micro-jet gas

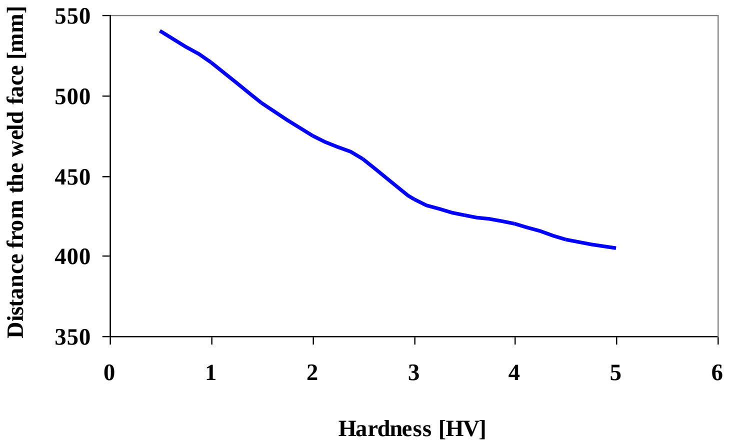

Fig. 9. Hardness of weld after micro-jet cooling with nitrogen used as a micro-jet gas

Tab. 6

Impact toughness for MIG welding with varied micro-jet gases

Welding process	Impact toughness KV [J]
MAG	70
Mag with helium micro-jet cooling	75
Mag with nitrogen micro-jet cooling	65

The impact toughness of all WMD is comparable among themselves. The impact toughness of this steel (with 0.31% C) is not very high, however, the influence of micro-jet cooling on the elastic properties of steel can be lightly noticed. Helium micro-jet cooling shreds the ferrite grain, which can lead to a small increase in impact strength. Cooling with nitrogen micro-jet cooling allows nitrogen to be increased in WMD, which adversely affects elastic properties of the material. Helium with minimal could be regarded as a good choice.

After the impact toughness analysis, a fractography test was conducted. Fractographic methods are routinely used to determine the cause of failure in engineering structures. Figure 10 presents a typical fracture of the WMD after MAG welding without micro-jet cooling. Figure 11 shows a typical fracture of the WMD after MAG welding with helium micro-jet cooling.

Comparing both drawings, it is possible to deduce that after welding with helium micro-jet cooling fracture of WMD is more ductile than after welding with nitrogen micro-jet cooling.

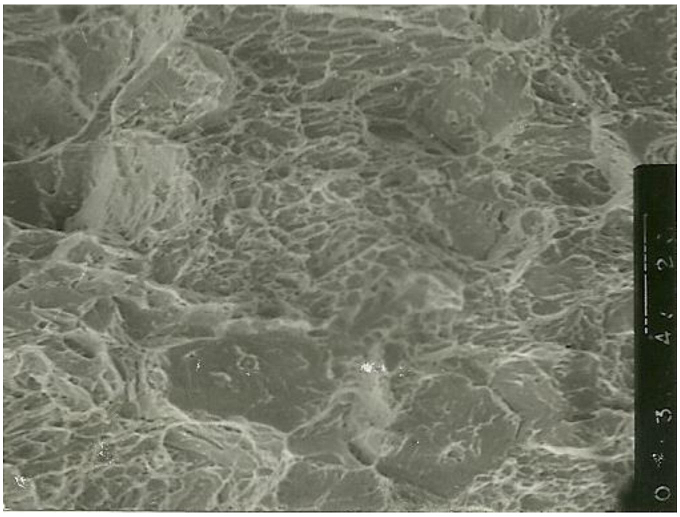

Fig. 10. Scanning electron micrograph of small-sized inclusions in the WMD after welding with nitrogen micro-jet cooling

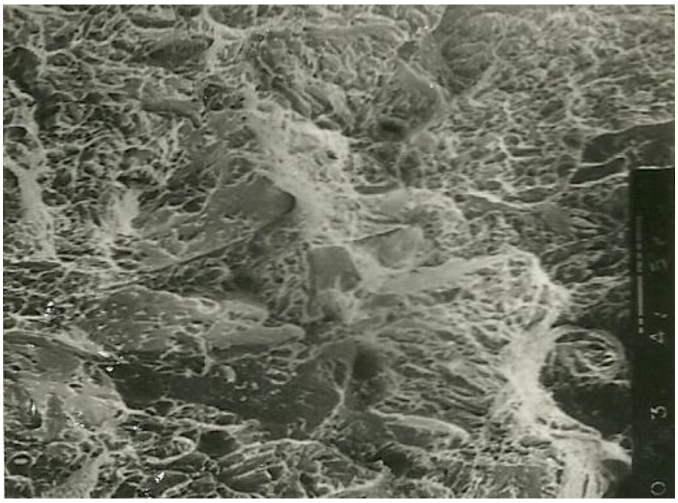

Fig. 11. Scanning electron micrograph of small-sized inclusions in the WMD after welding with helium micro-jet cooling

4. CONCLUSIONS

The micro-jet surfacing technology was tested for surface welding with various micro-jet parameters. Micro-jet technology could be treated as a very beneficial process during shaft surfacing. Structure change was observed, especially the increase in martensite content and ferrite fragmentation in the metal deposit.

On the basis of the 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 harness by various micro-jet parameters.
- there is no great difference between the influence of argon and helium on cooling conditions.
- nitrogen used for micro-jet cooling (instead of argon and nitrogen) is responsible for the highest hardness in all tested.
- there were observed traces of nitrides when nitrogen was used for micro-jet cooling (instead of argon when nitrides were not observed).
- the highest resistance to abrasive wear has the sample taken after welding with micro-jet cooling.
- micro-jet cooling does not have a noticeable influence on the impact toughness of WMD.

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Received 09.10.2018; accepted in revised form 29.12.2018