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WELDING WITH MICRO-JET COOLING AS A WAY TO IMPROVE THE MECHANICAL PROPERTIES OF MODE OF TRANSPORTATION SHAFT SURFACE

Summary. The use of surface welding with micro-jet cooling allows to control the structure of the surface layer. It is a way to significantly increase the mechanical properties (for example hardness) of the surface layer. The effect of this is to extend the life of the kinematic pair.

The main aim of this paper was to determine the influence of using micro-jet cooling for surface welding on tribological properties (e.g., friction coefficient and weight loss). Results of traditional surface welding (without micro-jet cooling) were compared with results of surface welding with micro-jet cooling. In this case, the medium of cooling was argon and nitrogen. Hardness, time to seizure, friction coefficient, and specimen weight loss were compared. The results showed that the use of a suitable cooling medium for surface welding process could improve the tribological properties of the surface weld.

1. INTRODUCTION

Surface welding is a method of repairing the steel machine shafts. It is a very popular method because it ensures decent results in simply way, with low cost of repair. Unfortunately, the results of such a repair are not always satisfactory, and the process parameters should be selected and fixed to obtain better results.

Parameters of surface welding influence the mechanical properties of surface layer. Steering these parameters allows to obtain a layer that is characterized by strictly defined properties. One of the way of steering is forced cooling of surface layer immediately after surface welding process. It is called micro-jet cooling process.

Wear of machine parts surface is a reason of deterioration of their functional properties. The reason for this is all kinds of physical and chemical processes occurring during operation. It is also related to the working conditions. Most commonly, machines working surfaces are subject to wear by separate or simultaneous impacts. These include the processes of friction (abrasion and adhesion), shock loads, high temperatures, corrosion, erosion, and cavitation. The process of wear is formed when the material loss at the surface layer of the subject is caused by the separation of particles of the layer as a result of scratching, grinding, or scalloping (microcutting). The phenomenon of adhesion takes place in the case of metal surfaces friction without the presence of lubricants. The process of wear under the influence of shock loads occurs when the working surface is subject to instantaneous, significant mechanical stress owing to the compression force. The load can be exerted on a small part of the surface or on the whole working surface. The frequency of the load can be random or regular. This may cause elastic deformation or plastic deformation of the surface layer. The process of wear under the influence of high temperature causes a decrease in the functional properties of not only the working surface but also the whole object. The result of it is a decrease in wear resistance, corrosion resistance, strength and toughness of the object. Erosion is caused by the impact of liquid or gas stream under high pressure on the surface of the object. This process is further enhanced by the presence of particles of dust or other abrasives in gas or liquid. Increase of temperature and corrosion influence similarly. The process of cavitation wear occurs in the case of movement of the working surface of the object in liquids at high speeds. Areas of substantially lower pressure occur. In these areas, there is evaporation of the liquid, and it leads to implosion. This is owing to the release of large mechanical energy. It causes damage to the work surface roughness and leads to formation of rifts. Corrosion occurs in various forms, depending on the type of corrosive environment, the load condition, and the presence of an electric field. Besides the basic types of tribological wear, there are also other types of wear such as oxidation, scuffing, fatigue, spalling, pitting, and fretting [1, 2].

2. SURFACE WELDING

Surface welding is a process of coating of metal surfaces by forming surface weld, which has characteristics similar to the ground (where applicable to the regeneration) or which has characteristics different to the ground (in the case of its application to increase operating time). There are many kinds of surface welding methods and basic materials applied to the substrates (Tab. 1).

Table 1

Basic surface welding processes [3]

Process	Basic materials applied to the substrate	Range of layer thickness, mm
Gas surface welding	• alloys based on Fe, Ni, Cr, Co, Cu; • carbides, nitrides, oxides, and borides; • cermets	0.05 ÷ 3.5
Coated electrode surface welding	• alloys based on Fe, Ni, Cr, Co, and Cu	1 ÷ 5
Submerged arc surface welding	• alloys based on Fe, Ni, Cr, and Co	2 ÷ 20
Electroslag surface welding	• low carbon steels, • alloy steels	12 ÷ 100
Gas tungsten arc (GTA) surface welding	• Al, Cu, W, Ti, Cr, and Ni; • low carbon steels; • alloy steels; • alloys based on Ni, Cr, and Co	1.5 ÷ 5
Gas metal arc (GMA) surface welding	• Al, Cu; • alloys based on Fe, Ni, Cr, Co, Cu, and Al	0.5 ÷ 6
Arc self-shielded flux-cored wire surface welding	• alloys based on Fe, Ni, Cr, and Co	0.5 ÷ 10
Plasma surface welding	• alloys based on Fe, Ni, Cr, Co, and Cu; • oxides, nitrides, carbides, borides, carbides, and silicides; • cermets	0.2 ÷ 15
Laser surface welding		0.1 ÷ 5
Friction surfacing		0.2 ÷ 4
Explosive surface welding	• alloys based on Fe, Ni, Cr, Co, Cu, Pb, and Al	5 ÷ 35

The aim of the surface welding of machine components is to restore geometrical dimensions or give the properties of the surface layer. To achieve this in the case of steel elements, non-alloyed weld metal (ferrite-pearlite structure) or low-alloy weld metal (bainite-martensite structure) is used. Sometimes also high-alloy weld metal is used for surface welding.

3. FATIGUE WEAR AND CONTACT WEAR

The main factors dependent on the fatigue strength of surface welded machine components are surface welding conditions, defects in surface welds, internal stresses in the element and the structure of surface welds (related to the mechanical properties of the layer). Surface welding conditions (e.g. welding method, welding technique, and surface weld thickness) usually affect the number and type of defects (presence of notches). Internal stresses in the surface welded machine components are connected to the structure of the surface weld and the surface treatment surface weld layers. Internal stresses are the cause of the occurrence of cracks during operation, particularly brittle fracture, fatigue cracks, and corrosion cracks [4]. Defects in surface welds (blisters, slag, and local discontinuities) formed at the beginning of pass in surface welding have a major effect on the fatigue strength of the surface welded shafts. Especially in the case of coated electrodes, surface welding and submerged arc surface welding defects in the form of slag between the pass are the cause of reduced strength of the surface weld. Contact durability of surface welded components depends on wear. The wear is a function of the load, the properties of the weld, and environmental conditions. Contact durability of surface welded components depends also on the level of acceptable consumption. The load is expressed by the pressure of Hertz, and the method of its calculation depends on the individual models. Properties of surface weld are described by their hardness and structure. The operating conditions are described by the presence of the lubricant and the effect of lubrication on the friction coefficient [4]. In general, contact durability of the surface welded components is proportional to the hardness increase of surface welds and inversely proportional to the pressure increase and the coefficient of friction. It is shown in Fig. 1.

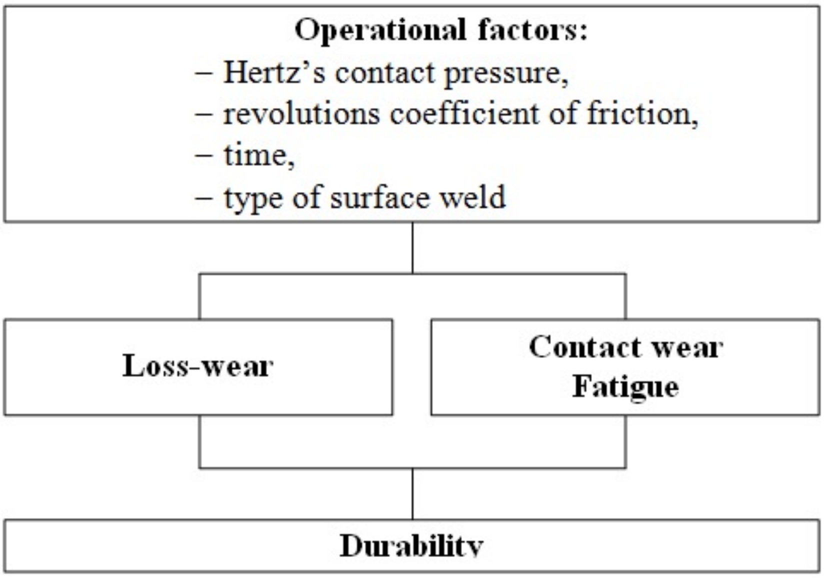

Fig. 1. Tribological system scheme

Load of surface welded machine component determines the wear of the welded surface layer. This can be described using a Lorenc curve. The following ranges may be indicated:

- lapping period with the degressive course - in this period, fit-of-surface micro-geometry can be observed,
- period of normal operation with stabilized wear (curve is linear), and

- period of catastrophic wear with the progressive course - in this period, sudden increase in damage and very fast exponential increase of wear in consumption can be observed.

4. EXPERIMENTAL PROCEDURE

Investigation of seizure resistance on the Amsler machine has been carried out. This attempt involves testing of material strength (metals and alloys) in terms of seizure resistance in the conditions of sliding friction on the Amsler machine. It is used on the material constituting the sliding friction associations of machine parts (e.g. wheel gears, bushings of bearings, and shafts pivots). The test consists of friction of specimen with a counterspecimen under defined conditions. On the basis of the test, the seizure resistance of the friction component is determined [5].

Investigations were made with technically dry friction. In this case, the friction surfaces have adsorbed fluids from atmosphere and their reaction products with friction surface components (e. g. nitrogen, oxygen, water, as well as oxides, hydroxides and other compounds).

When critical force pressure is exceeded, a surge in frictional resistance, wear intense, and deterioration of the friction surfaces occurs. This is owing to the rapid expansion of adhesive connections between vertices of mating surface roughness. Research regarding seizure resistance was carried out on Amsler type A-135 slip-rolling machine, which is shown in Fig. 2a and 2b. The sample and counterspecimen are made of two different materials that are used to work in real conditions (Fig. 2c). In the case where the test materials have different hardness, the specimen is made of a material with a lower hardness than the material of the counterspecimen.

Hardness and structure of the specimen material and counterspecimen material should be prepared by identical processes (e.g., heat treatment). The state of the materials should include at least the part of the specimen volume or counterspecimen, which will be put to friction. The surface specimen and counterspecimen must be carefully and thoroughly prepared. Surface roughness R_a of specimens is 0.63 (specimens and counterspecimens after fine grinding).

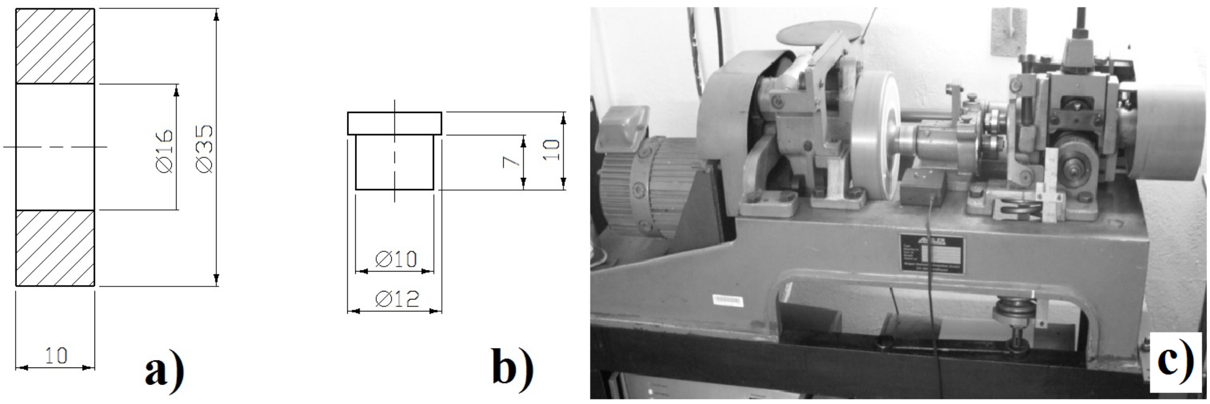

Fig. 2. Counterspecimen (a) and specimen (b) for Amsler type A-135 slip-rolling machine investigation (c)

The Amsler-type machine is used in the present study under unidirectional sliding. The rotating sample is mounted in the holder (Fig. 3a). It provides the correct set of the sample relative to the counterspecimen and repeatability of load conditions. The stationary counterspecimen is mounted to the bottom spindle by tightening the nut. Fig. 3b shows the way of mounting of specimen and counterspecimen on Amsler machine.

The comparative study is performed in two successive cycles. During the test, the value of downforce of sample to counterspecimen should be increased:

- in range of 20.0÷196.2 N with dry friction pressure is increased every 30 seconds by the value of 10 N,
- in range of 200.0÷1962.0 N with dry friction pressure is increased every 30 seconds by the value of 50 N.

If seizure occurred at a lower load range, further tests at an increased range is not performed. In comparative studies, the speed of 0.37 m/s (spindle speed machines of 3.3 s-1) should be set. If at this speed there will be no seizure, testing should be performed at a speed of 0.74 m/s (spindle speed machine 6.6 s-1). During the tests, the following were recorded [6]:

- coefficient of friction,
- the value of downforce specimen to counterspecimen, and
- testing time.

After obtaining the seizure limit, the machine should be stopped. Specimen and counterspecimen should be removed and cleaned and their surface should be observed to determine their resistance to seizure.

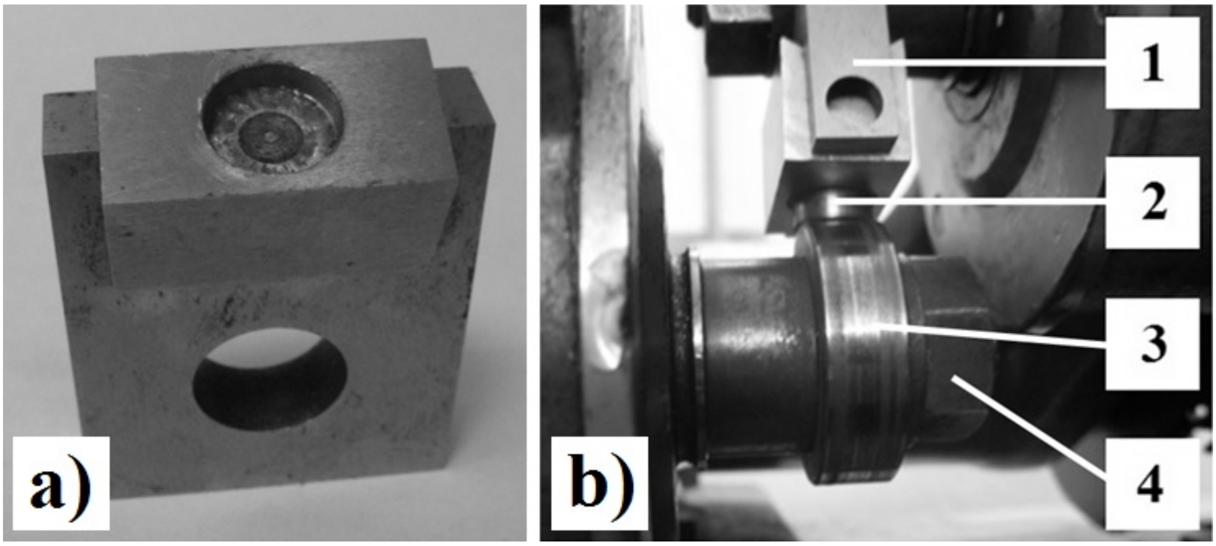

Fig. 3. Holder of specimen (a) and the way of mounting of specimen and counterspecimen on Amsler machine (b): 1 - specimen holder, 2 - specimen, 3 - counter specimen, 4 - machine spindle

5. SPECIMENS AND COUNTER SPECIMENS

The basic material for the specimens was S355JR steel. This is a grade of steel-on-steel constructions, and it is one of the most popular steel grade. Chemical composition and mechanical properties of this steel are presented in Tables 2 and 3.

Table 2

Chemical composition of S355JR steel

Chemical element	Content, %
C	max. 0.2
Mn	1.0 ÷ 1.5
Si	0.2 ÷ 0.55
P	max. 0.04
S	max. 0.04
Cr	max. 0.3
Ni	max. 0.3
Al	max. 0.02
Cu	max. 0.3

Table 3

Mechanical properties of S355JR steel

Yield stress	Tensile strength	Elongation, A_{80}	Hardness
355 MPa	490 ÷ 630 MPa	14 ÷ 18%	140 ÷ 190 HB

Next surface welds were done with MIG surface welding method (Metal Inert Gas). Specimens made with traditional MIG method were compared with specimens made with using MIG method with micro-jet cooling [7 - 14]. Micro-jet cooling is one of the forced cooling methods. This method of cooling could be used to cooling welds immediately after welding, and it allows to minimize heat transfer to the welded elements [15]. The heat is absorbed by the cooling medium [16, 17]. Using of micro-jet cooling for surface welding influences properties of the surface layer.

Three types of specimens were made for investigations:

- specimens welded with traditional MIG method (without micro-jet cooling),
- specimens welded with MIG method with using micro-jet cooling with argon (Ar) as cooling medium, and
- specimens welded with MIG method, but using micro-jet cooling with nitrogen (N_2) as cooling medium.

Specimens were made with parameters of surface welding presented in Table 4. Chemical composition of surface weld is presented in Table 5. Stand for orbital surface welding with micro-jet cooling is shown in Fig. 4.

Table 4

Parameters of surface welding process

Parameter	Value
Diameter of wire	1.2 mm
The length of the electrode free outlet	12 mm
Electrode classification	F-42 MIG The surface weld is crack-free, machinable and corrosion-resistant. It contains chromium, nickel and molybdenum. It is transferred to elements exposed to abrasive wear in combination with moderate impact stress.
Standard current	220 A
Voltage	24 V
Speed of surface welding	70 mm/min
Shielding welding gas	Ar
Flow of shielding welding gas	27 dm^3/min
Micro-jet cooling medium	Ar, N_2
Micro-jet cooling medium pressure	0.7 MPa
Diameter of micro-jet cooling stream	40 μm
Number of micro-jet cooling stream	1

The content of elements such as C, Mn, Si, P, S and O is identical in all studied welded surfaces. The difference appears in the content of nitrogen in the welded surface. In the case of surface welding process with micro-jet cooling when nitrogen was used as a cooling medium, its content was higher than other cases (70 ppm). It can be assumed that the nitrogen in the welded surface came from the cooling medium. Nitrides were found in the welded surface material. Nitrides are a high hardness compounds. This caused an increase in the overall hardness of the welded surface.

Counterpecimens have been made with 100Cr6 steel. This is a high-quality steel for making rings, rolling bearings, shafts less than 30 mm in diameter, treadmills and slides. Chemical composition of this steel are presented in Tables 6.

Table 5

Chemical composition of surface weld

Surface welding process	Without micro-jet cooling	With micro-jet cooling	
Cooling medium	-	Ar	N_2
Element	Content in surface weld		
C	0.08%		
Mn	0.79%		
Si	0.39%		
P	0.017%		
S	0.018%		
O	390 ppm		
N	50 ppm	50 ppm	70 ppm

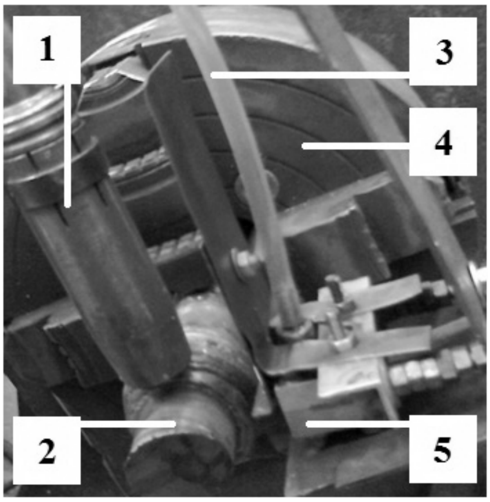

Fig. 4. Stand for orbital surface welding with micro-jet cooling; 1 - welding head, 2 - shaft, 3 - cooling medium hose, 4 - turning handle, 5 - micro-jet nozzle

Table 6

Chemical composition of 100Cr6 steel

Chemical element	Content, %
C	0.95 ÷ 1.1
Mn	0.25 ÷ 0.45
Si	0.15 ÷ 0.35
P	max. 0.025
S	max. 0.025
Cr	1.3 ÷ 1.65
Ni	max. 0.3
Cu	max. 0.3

6. RESULTS AND DISCUSSION

Different kinds of specimen were tested and compared. Welds were made with ordinary MIG welding method and with MIG welding method with micro-jet cooling of surface welds (cooling mediums: argon and nitrogen). The results are shown in Figures from 5 to 8 and in Table 7. The results are the average of five tests.

In all cases, critical downforce had the same value, and it was about 300 N because seizure appears before load increase. In all tests, critical pressure was 9,74 N/mm^2.

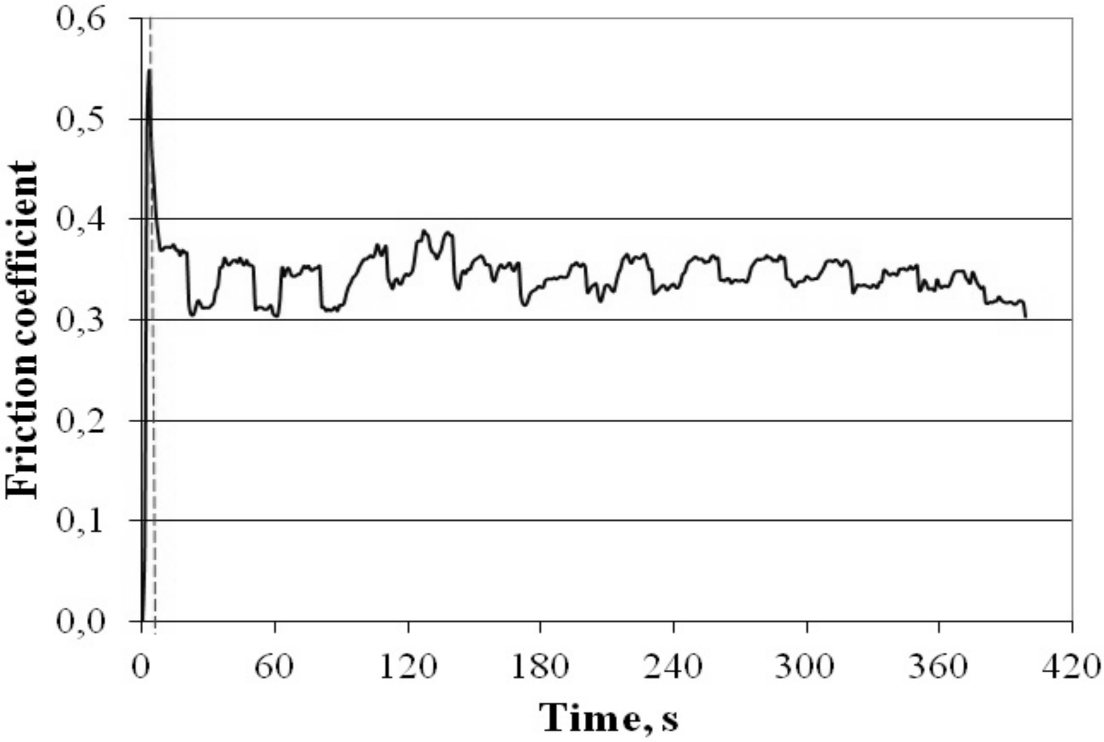

Fig. 5. Example of results for specimen made with traditional MIG surface welding method

It was found that the lowest resistance to abrasive-adhesive wear shows a specimen was made with ordinary MIG surface welding method. Average hardness of specimens made with that method was approximately 45 HRC. Time to seizure was about 10 seconds, and friction coefficient was approximately 0.548. During testing average specimens weight loss was approximately 0.0160 g.

Use of micro-jet cooling for surface welding improves properties of surface layer and resistance to abrasive-adhesive wear. Changes after using micro-jet cooling for surface welding are considerable, and the changes were noticed for hardness of specimen, time to seizure, friction coefficient and specimen weight loss.

Average hardness of specimens made with micro-jet cooling with argon was approximately 50 HRC. Hardness increased by 5 HRC in comparison to samples produced without forced cooling. Time to seizure extended twice, and it was approximately 20 seconds. Friction coefficient was decreased, and it was approximately 0.548. During testing average specimens, weight loss was approximately 0.0013 g, and it was lower in value in comparison with specimens made without micro-jet cooling for surface welding.

Average hardness of the specimens made with micro-jet cooling with nitrogen was approximately 52 HRC. Hardness increased by 7 HRC in comparison with samples produced without forced cooling and increased by 2 HRC in comparison with samples produced with micro-jet cooling with argon. Time to seizure extended to 25 seconds in comparison with samples produced without forced cooling (150%), and it was longer by approximately 5 second in comparison with samples produced with micro-jet cooling with argon. After the use of nitrogen for micro-jet cooling, friction coefficient was decreased too, and it was approximately 0.380. The decline was even greater than in the case of argon.

During testing, average specimen weight loss was approximately 0,0005 g, and it was the lowest value in all investigations.

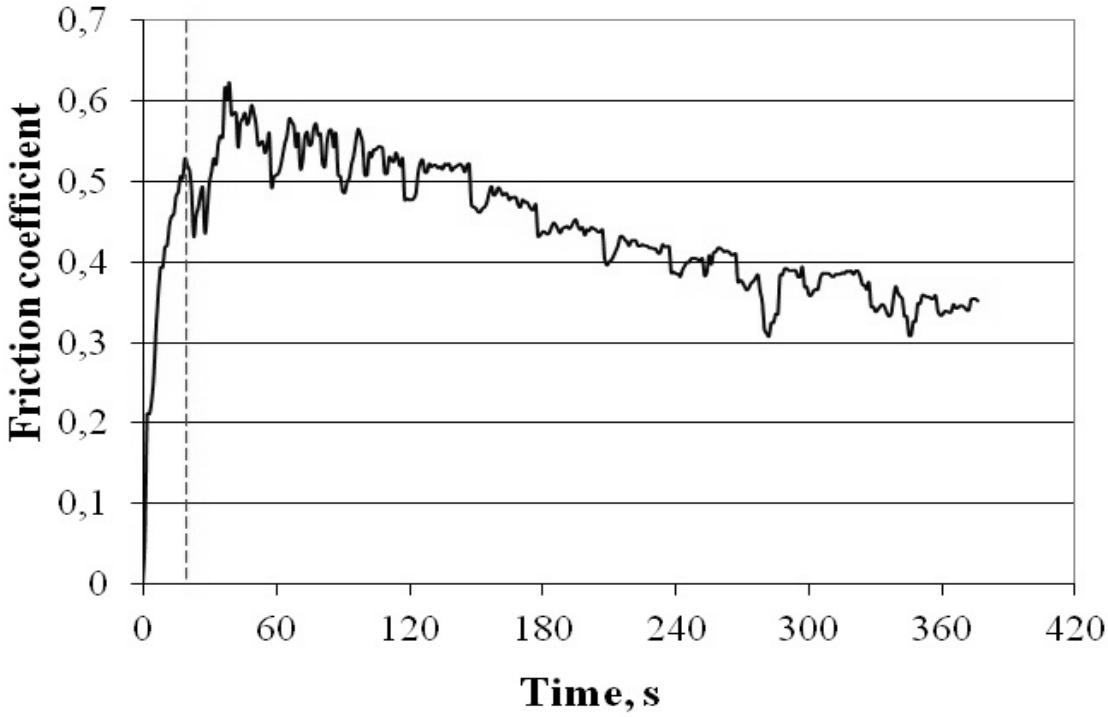

Fig. 6. Example of results for specimen made with MIG surface welding method with micro-jet cooling by argon

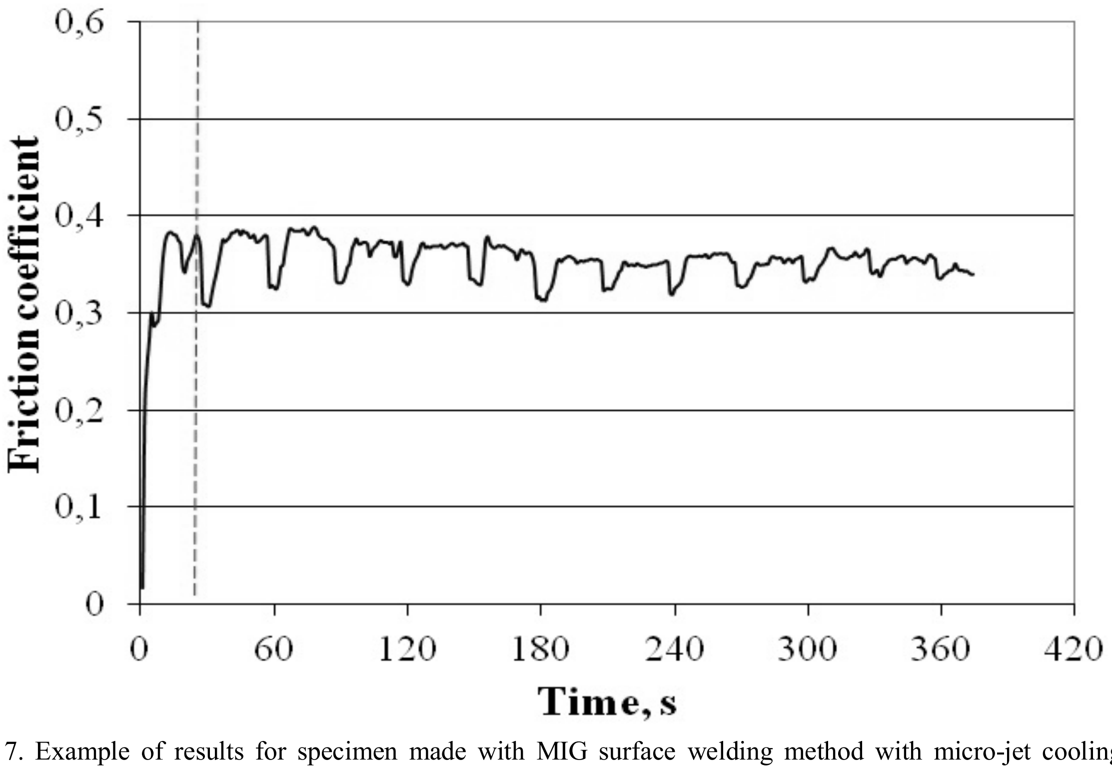

Fig. 7. Example of results for specimen made with MIG surface welding method with micro-jet cooling by nitrogen surface of specimen made with MIG surface welding method with micro-jet cooling by nitrogen after test

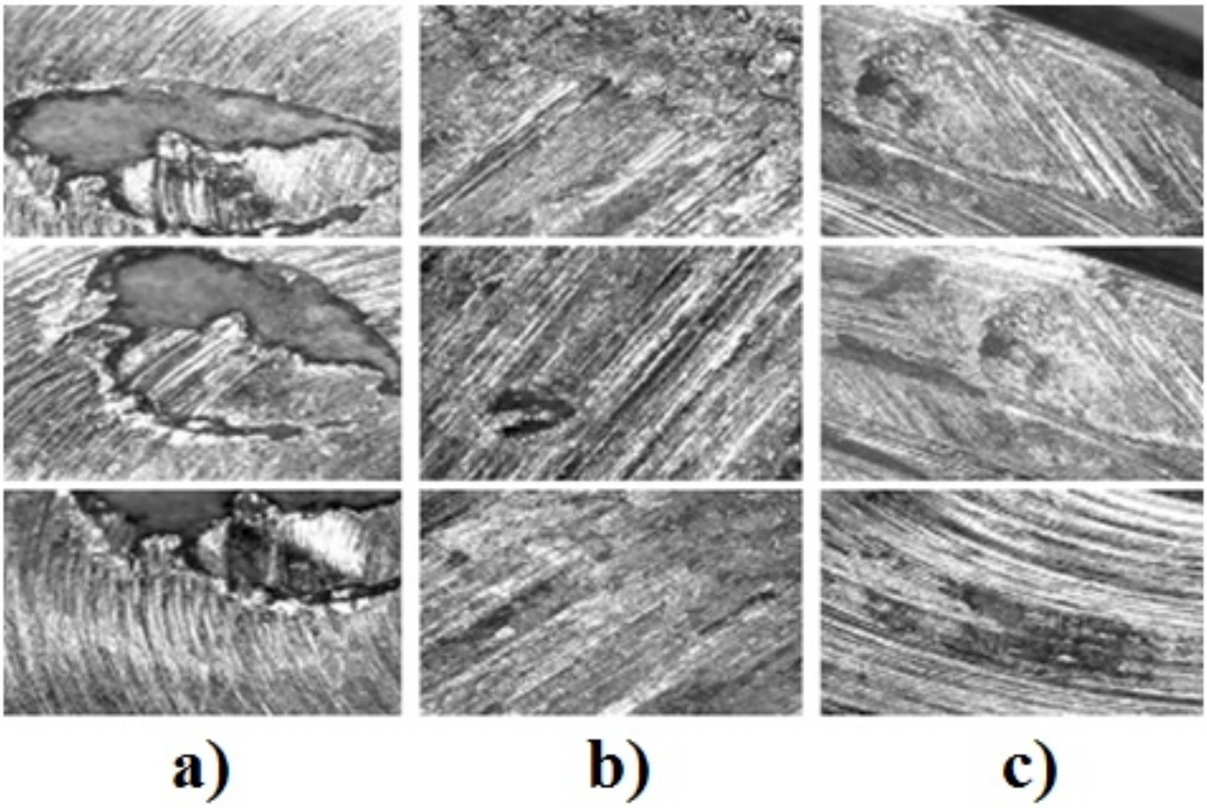

Fig. 8. Example of surface of specimen after test: a) made with traditional MIG surface welding method, b) made with MIG surface welding method with micro-jet cooling by argon, c) made with MIG surface welding method with micro-jet cooling by nitrogen after test

Table 7

Summary of investigation results

Surface welding process	Without micro-jet cooling	With micro-jet cooling	
Material of rotating specimen surface	Surface weld		
Cooling medium for micro-jet cooling	-	Argon	Nitrogen
Hardness of specimen surface	45 ± 3 HRC	50 ± 3 HRC	52 ± 2 HRC
Material of counterspecimen	Steel 100Cr6		
Hardness of counterspecimen surface	62 ± 2 HRC		
Time to seizure, s	10	20	25
Friction coefficient	0,548	0,529	0,380
Specimens average weight loss, g	0,0160	0,0013	0,0005

7. CONCLUSIONS

The aim of this paper was to determine the influence of using micro-jet cooling for surface welding on tribological properties of surface welds under dry sliding. Surface welds were made with MIG surface welding method with micro-jet cooling and without this kind of cooling. It was shown that the use of a suitable cooling medium for surface welding process could improve the tribological properties of the surface weld.

Surface welding was done with traditional MIG surface welding method and surface welding with MIG surface welding method with using micro-jet cooling. Different kinds of cooling medium were used, such as argon and nitrogen.

It was found that the use of micro-jet cooling for surface welding process influences parameters of welded surface layer.

On the basis of this investigation, it is possible concluded the following:

- micro-jet cooling could be treated as an important element of MIG surface welding process,
- micro-jet technology in surface welding could improve properties of surfaces made with welding processes,
- argon and nitrogen could be treated as micro-jet cooling mediums in surface welding process,
- using of micro-jet cooling for surface welding causes increase of surface hardness,
- using of micro-jet cooling for surface welding extends the life of surface welded layer,
- using of micro-jet cooling for surface welding causes decrease of friction coefficient,
- using of micro-jet cooling for surface welding causes decrease of weight loss, and
- improving the layer is more effective when nitrogen is used than in the case of argon.

From this, it can be concluded that the use of micro-jet cooling for surface welding improves the abrasive-adhesive properties of the surface weld. This causes a prolongation of the time after which the seizure occurs but does not increase the critical downforce at which the seizure occurs. In this case, conditions were constant, except surface hardness. It could be the reason of changes in tribological properties. The higher the hardness of surface weld, the better the tribological properties of the welded layer.

Further research on surface welding is needed, especially for other materials, for other elements geometry, and others applications (exposure to vibration, impact of energy absorption, and maintenance of construction at low temperature).

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