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# ASSESSMENT OF THE TRIBOLOGICAL PROPERTIES OF HARDFACING WELDING ALLOY Fe-Mn-C-B-Si-Ni-Cr IN DRY FRICTION CONDITIONS

## BADANIA WŁAŚCIWOŚCI TRIBOLOGICZNYCH POWŁOK NAPAWANYCH Fe-Mn-C-B-Si-Ni-Cr W WARUNKACH TARCIA SUCHEGO

**Key words:**

coatings, hardfacing by arc welding, flux-cored wire, wear

**Słowa kluczowe:**

powłoki, napawanie, drut proszkowy, zużycie.

**Abstract**

The paper assesses the tribological properties of hardfacing coatings produced by gas metal arc welding. Flux-cored wires were used as a welding material. The core mixture was based on the Fe-Mn-C-B-Si-Ni-Cr alloy. Seven types of

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flux-cored wires with different compositions were prepared. The flux-cored wires had a diameter of 2.4 mm. The tribological assessment was performed with an Amsler tribotester under dry friction conditions at different unit pressures: 3, 7, and 10 MPa. The results demonstrate that the coating L-6 has good tribological properties. The overlay weld had a hardness of 49 HRC. Following friction testing, the coatings were also examined with respect to their microhardness and microstructure.

## INTRODUCTION

The analysis and assessment of the tribological properties of designed friction pairs is still one of the current problems of research on tribological processes. This entails selecting suitable materials, lubricants, and testing methods. It is vital that the test conditions of a friction pair reflect the real ones as much as possible **[L. 1]**.

One of the many methods for increasing wear resistance or recovery of friction pairs is to use hardfacing coatings. The most popular materials for hardfacing are electrodes and flux-cored or solid wires **[L. 2]**. These materials are based on Fe, Ni, Co, Ti alloys with different alloying elements such as Si, Cr, B, Mn, and V, which determines their properties. From an economic aspect, it is favourable to use Fe-based alloys. Iron-based alloys that can be used for producing coatings include Fe-Cr-C, Fe-C-Cr-Si, Fe, and Fe-Mn-C-B **[L. 3–5]**. In the production of wear resistant coatings, the objective is to increase the plasticity of surface layers, while ensuring that they have high hardness. This can be achieved by the addition of alloying elements that will increase hardness (e.g., Si, Cr) and plasticity (e.g., Ni). Alloying can be done using the majority of selected metallic elements with high concentrations depending on an economic aspect. The tribological properties of Fe-Mn-C-B alloy are improved by producing a structure that contains iron carbide $Fe_3C$ and manganese carbide $Mn_3C$ as well as iron and chromium borides, $Fe_2B$, FeB, and $Cr_2B$. They can be used as reinforcing phases in the alloy's structure due to their high hardness, wear and corrosion resistance, and thermal stability**.** The addition of manganese leads to increased plasticity of both iron carbide $Fe_3C$ and the produced eutectic alloy. It creates a solid solution with iron and extends the area of the distribution of carbides in the $Fe_3C$-$Mn_3C$ system, thus increasing their dispersion **[L. 6–9]**.

## EXPERIMENTAL DETAILS

The material for hardfacing coatings were flux-cored wires produced at the Institute of Welding Technology in Gliwice. The wires had a diameter of 2.4 mm. The metal strip was filled from 30 to 35%. Coatings were produced by gas metal arc welding (welding with $CO_2$). They were applied to S 235JR steel. Hardfacing was done by a semi-automatic method. The current was set to approx. 270 A, and the voltage was approx. 30V. The coatings had a thickness ranging between 4 and 6 mm. They were marked as L1-L6. The analysis of chemical composition of the weld metal used for producing hardfacing alloy coatings is given in **Table 1**.

**Table 1. Analysis of chemical composition of weld metal used for producing hardfacing alloy coatings.**
Tabela 1. Analiza stopiwa powłok napawanych

| Content wt % | Specimen designation | | | | | |
|---|---|---|---|---|---|---|
| | **L-1** | **L-2** | **L-3** | **L-4** | **L-5** | **L-6** |
| C | 2.80 | 1.60-1.80 | 1.99 | 1.70 | 1.60 | 1.63 |
| Si | 2.30 | 2.67 | 2.70 | 2.32 | 1.91 | 2.46 |
| Mn | 10.75-13.04 | 0.17 | 5.77 | 3.12 | 5.94 | 7.29 |
| Cr | 10.97 | 16.28 | 13.92 | 15.89 | 15.35 | 16.24 |
| Ni | 8.36 | 8.25 | 11.00 | 10.50 | 10.21 | 17.68 |
| B | 1.96 | 1.94 | 2.13 | 2.19 | 2.24 | 1.79 |
| Fe | Rest | | | | | |

The tribological tests were performed using a modified Amsler tribometer. Test specimens were cut out by electroerosion. Then, their surface was subjected to grinding. The combination of friction type pair is shown in **Figure 1**. The measured roughness parameter $R_a$ was 0.579 µm. The tested friction pair had the following parameters:

– Type of contact: distributed (mandrel-disk),
– Type of motion: sliding,
– Mandrel dimensions: a 10 mm square,
– Diameter and thickness of the disk: 90 x10 mm
– Hardness: 49-52 HRC,
– Slipping velocity: 0.4 m/s,
– Contact pressure: 3,7,10 MPa
– Contact lubrication: no lubricant (dry friction)
– Number of repetitions: 3-5,
– Measurement time: 6 hrs,
– Ambient temperature: 23±1$^{o}$C,
– Wear was measured by the gravimetric method.

In order to reject gross error, test results were rated using the Dixon test.

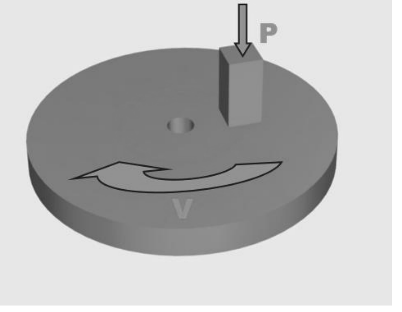



**Fig. 1. The combination of friction type pair**
Rys. 1. Skojarzenie pary trącej

Prior to friction, the coatings were subjected to hardness measurement using a Rockwell hardness tester. The measurement consisted in applying load to the surface of a specimen using a diamond indenter with an angle of 120º. It was repeated 5 times for each specimen. The microhardness of coatings was measured with a ZWICK 3212002/00 microhardness tester. The measurement was made on the cross section of metallographic specimens at various depths using a Vickers diamond indenter. The load was set to 50 N. Next, microscopic examination of the surface of the metallographic specimens taken from the cross section was performed. Following their sealing with thermo-hardening phenolic resin, the metallographic specimens were subjected to grinding on a Buetler-manufactured grinding and polishing machine using abrasive paper of varying gradation **(**starting from 120 µm). Finally, they were polished with MD Floc diamond paste (3 µm). The prepared metallographic specimens were subjected to chemical etching with Mi1Fe (4% solution of nitric acid $HNO_3$ in alcohol) and Mi20Fe (5g $CuCl_2$, 40ml HCl, 55ml distilled $H_2O$). The microstructure was examined with a MEF 4M metallographic microscope. Friction surfaces were examined with a Nikon Eclipse MA 200 metallographic microscope. Surface profiles were analysed using a Surtronic 3+ profilometer. The surface was scanned on a measuring length of 4 mm.

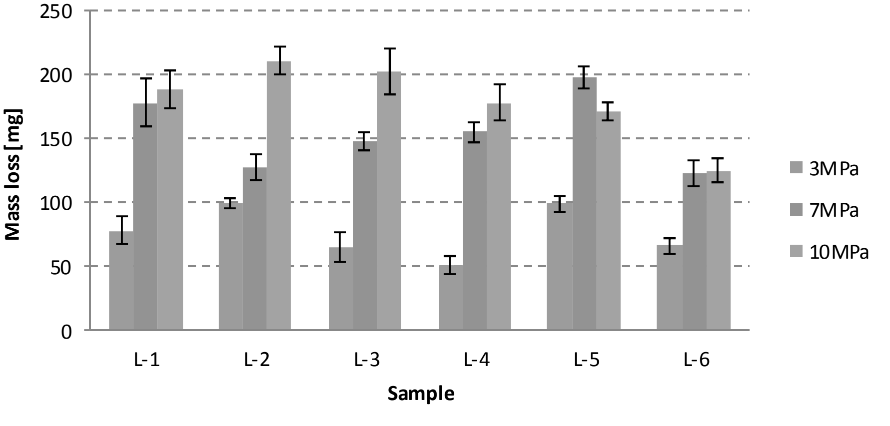
## RESULTS AND DISCUSSION

The experiments were performed on hardfacing coatings before and after tribological tests. The L-1 coating had the highest hardness, amounting to 60 HRC. The second highest hardness specimen was L-2 with a hardness of 56 HRC. The lowest hardness specimens were L-3 with a hardness of 51 HRC and L-4 and L-5 with a hardness of 50 HRC. The L-6 coating had the lowest hardness equal to 49 HRC. The L-1 specimen had a high carbon content, 2.8 wt%, and a low nickel content – 8.36 wt%, compared to lower hardness specimens. In contrast, the lowest hardness specimen, L-6, had a low carbon content but a high content of nickel.

## Tribological tests

The process of wear depends on friction pair material, contact temperature, roughness, surface hardness, unit pressures, and sliding velocity. **Figure 1** shows the results of mass loss (mass decrement is given in milligrams) after tribological tests performed on the L1-L6 coatings and their corresponding counter-specimens (C45 steel). At 3 MPa, the L-4 coating had the lowest mass loss equal to 51 mg. With the unit pressures set to 7 MPa, it was the L-6 coating that has the lowest mass loss of 123 mg. The L-6 coating also exhibited the lowest mass loss of 125 mg at 10 MPa. The standard deviation of mass loss ranged from 3 mg to 19.19 mg. When analysing the data from **Figure 2**, it can be observed that good tribological properties were exhibited by the L-6 coating. This coating had a hardness of 49 HRC, which is lower than in the case of other coatings. The results of tribological tests for higher hardness coatings, L-1 and L-2, reveal chipping of coating particles, which affects the measured wear values.

a)



b)

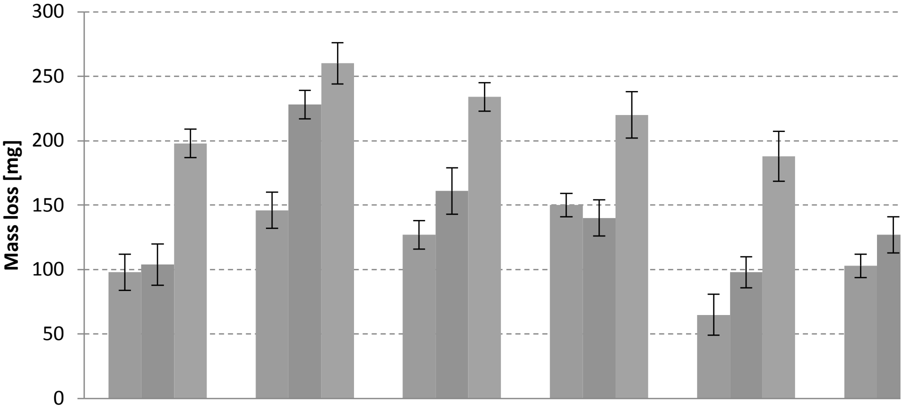



**Fig. 2. Mass loss of the coatings (a), and counterbodies (b)**
Rys. 2. Zużycie wagowe powłok (a) oraz przeciwpróbek (b)

**Figure 3** illustrates variations in the friction coefficient measured in the tribological tests for the L-6 coating at unit pressures set to 3, 7, and 10 MPa. When the applied load is set to 3 MPa, the mean friction factor is 0.39; at 7 MPa – it is 0.51, and at 10 MPa – it is 0.59. The friction coefficient increases with an increase in the unit pressures.

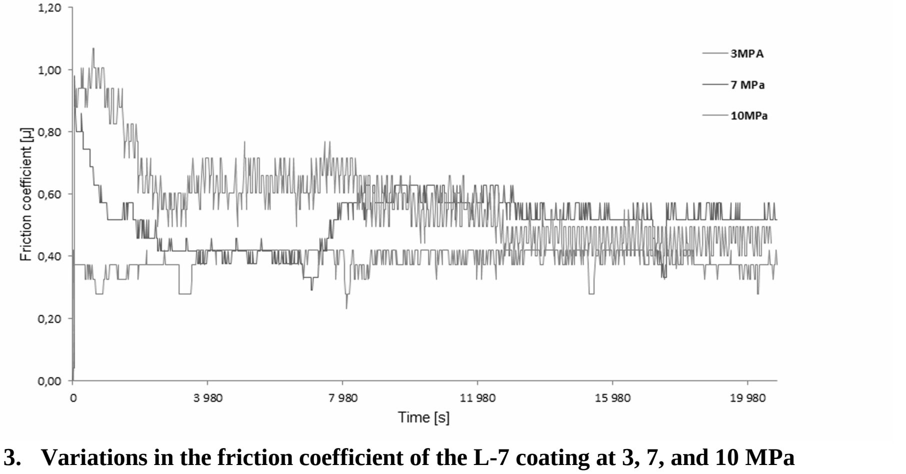
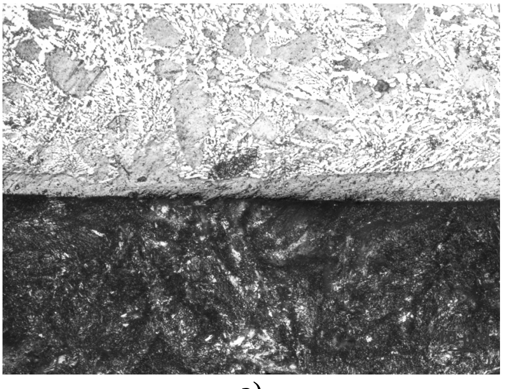



**Fig. 3. Variations in the friction coefficient of the L-7 coating at 3, 7, and 10 MPa**
Rys. 3. Przebieg zmian współczynnika tarcia dla powłoki L-7 przy naciskach jednostkowych 3, 7, 10 MPa

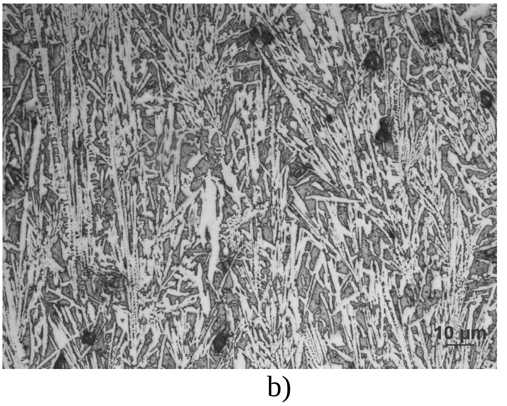
At the beginning of the process, it can be observed that the friction coefficient suddenly increases for all applied values of unit pressures, which points to the grinding of the friction pair elements. After that, the friction factor becomes more stable.

## Metallographic and microhardness tests

The microstructural tests were performed on the L-6 coating due to its high tribological properties. The microstructure of the L-6 coating is shown in **Figure 4**. The microstructure of the base metal consisted of ferrite and pearlite. The hardfaced layer has a dendrite structure with crystals of different sizes and distributions. In places, the austenite-martensite structure reveals the presence of needle-shaped crystals of carbides (carbide eutectics).



a)




b)

**Fig. 4. Microstructure of the L-6 coating in: overlay/substrate weld joint (a), hardfaced layer (b)**

Rys. 4. Mikrostruktura powłoki oznaczonej jako L-7, gdzie: miejsce połączenia napoiny z materiałem rodzimym (a), warstwa napawana (b)

The distribution of microhardness in the L-6 coating is shown in **Fig. 5**. The microhardness of the hardfacing alloy coating varies between 452 and 504 $HV_5$. The interface has a microhardness ranging from 136 to 163 $HV_5$, while that of the core ranges from 126 to 131 $HV_5$. The highest microhardness value, 504 $HV_{5,}$ is measured at a distance of 1.82 mm from the surface.

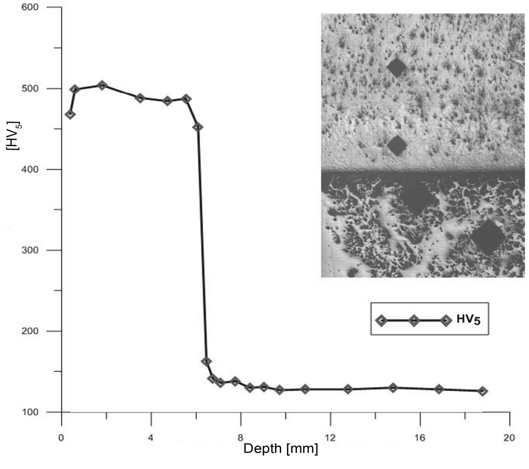
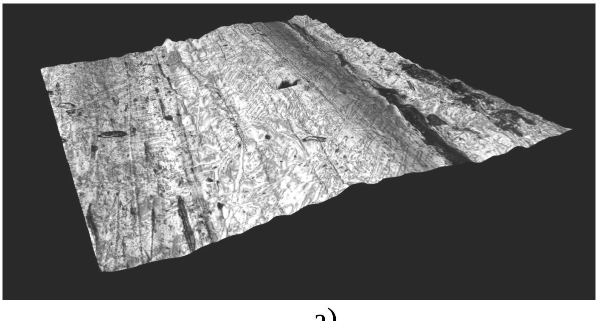


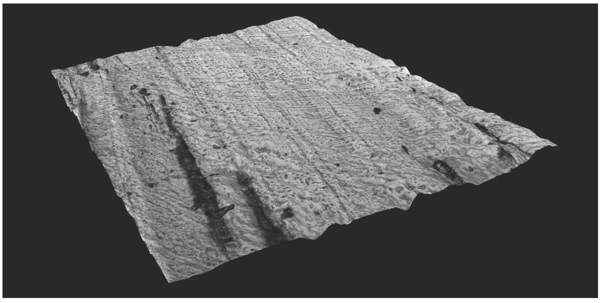

**Fig. 5. Microhardness distribution**
Rys. 5. Rozkład mikrotwardości

## Surface examination after friction

Next, we examined the surface after friction. We also measured basic parameters of the surface profile. **Figure 6** shows the structure of the surface after friction under unit pressures set to 3, 7, and 10 MPa, respectively.



a)



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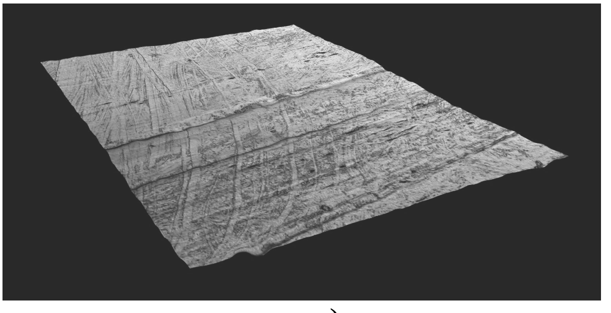

c)

**Fig. 6. Surface topography L-7 after friction at unit pressures set to: 3 MPa (a), 7 MPa (b), and 10 MPa (c) (× 100)**

Rys. 6. Widok struktury stereometrycznej powierzchni po tarciu przy naciskach jednostkowych: 3 MPa (a), 7 MPa (b), 10 MPa (c) (pow. ×100)

The microscopic surface examination helped identify mechanisms of surface wear. Surface waviness with clear microcuts can be observed. After friction, under unit pressures 3, 7, and 10 MPa, the surface roughness has clearly visible microcuts (**Figs. 6a, b, c**).

## CONCLUSIONS

The tests demonstrated that it is possible to produce flux-cored wires with the core mixture Fe-Mn-C-B-Si-Ni-Cr. Such prepared welding materials can be used for coating and recovery of worn-out components by gas metal arc welding. The results of the tribological tests under dry friction conditions demonstrate that the L-6 coating had the good tribological properties. All tested coatings show a higher mass loss with increasing unit pressures. However, at unit pressure set to 7 and 10 MPa, these differences are insignificant. The friction coefficient and surface temperature increase with an increase in the surface pressures. The hardfacing coating has a dendritic structure. In places, the austenite-martensite structure shows the presence of needle-shaped crystals of carbides (carbide eutectics). The microhardness of the hardfacing coating varies between 452 $HV_5$ and 504 $HV_5$.

## REFERENCES

1. Gidikova N., Ciaś A., Petkov V., Madej M., Sułowski M., Valov R.: Wear resistant chromium coatings modified with diamond nanoparticles, Archives of metallurgy and materials, Vol. 52, 2014, p. 1513–1516.
2. Adamiec P., Dziubiński J.: Wytwarzanie i właściwości warstw wierzchnich elementów maszyn transportowych, Wyd. Politechniki Śląskiej, Gliwice 2005.
3. Granat K.: Wieloskładnikowe stopy Fe-C-Cr-Si odporne na zużycie przeznaczone na odlewy i warstwy napawane, Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław 2005.
4. Badisch E., Katsich C., Winkelmann H., Franek F., Manish Roy: Wear behavior of hardfaced Fe-Cr-C alloy and austenitic steel under 2-body and 3-body conditions at elevated temperature, Tribology International, 2010, p.1234–1244.
5. Napiórkowski J., Pękalski, G., Kołakowski K.: Badanie struktur i zużywania powłok napawanych w glebowej masie ściernej, Tribologia, tarcie, zużycie, smarowanie, Nr 3, 2012, p. 111–117.
6. Pashechko M., Lenik K.: Segregation of atoms of the eutectic alloys Fe-Mn-C-B-Si-Ni-Cr at friction wear, Wear, Vol. 267, 2009, p. 1301–1304.
7. Pashechko M., Dziedzic K., Barszcz M.: Study of the structure and properties of wear-resistant eutectic Fe-Mn-C-B-Si-Ni-Cr coatings, Powder metallurgy and metal ceramics, nr 7-8, Vol. 52, 2013, p. 469–476.
8. Pashechko M., Dziedzic K., Barszcz M.: Badania struktury i właściwości warstw wierzchnich powłok ze stopów eutektycznych Fe-Mn-C-B, Inżynieria materiałowa, nr 2, Vol. 33, 2012, p. 82–85.
9. Pashechko M., Dziedzic K., Barszcz M.: Właściwości tribologiczne powłoki eutektycznej Fe-Mn-C-B-Si-Ni-Cr, Inżynieria powierzchni, nr 1, 2011, p. 40–45.

## Streszczenie

**Praca przedstawia badania właściwości tribologicznych powłok otrzymanych metodą napawania łukowego w osłonie gazowej GMA. Jako materiał spawalniczy wykorzystano druty proszkowe (rdzeniowe). Mieszankę rdzeniową wykonano na podstawie stopu Fe-Mn-C-B-Si-Ni-Cr. Opracowano siedem rodzajów drutów proszkowych o różnych składach. Średnica drutów proszkowych wynosiła 2,4 mm. Badania tribologiczne przeprowadzono na tribotesterze Amslera w warunkach tarcia suchego przy różnych naciskach jednostkowych 3, 7 i 10 MPa. Wykazały one, że dobrymi właściwościami tribologicznymi cechowała się powłoka L-6 o twardości napoiny 49 HRC. Powłoki po tarciu poddano również badaniom mikrotwardości oraz mikrostrukturalnym.**