DOI: 10.21062/mft.2023.033 http://www.journalmt.com

The Effect of Mixing the Additive Material with the Substrate during the Renovation of the Foundry Mold by TIG Welding Hardfacing

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The article is focused on the effect of mixing the additional material with the substrate (base material) on the properties of the weld metal during arc welding with TIG technology. The research is aimed at the use of arc welding with TIG technology in the repair of foundry molds. These are repairs of permanent steel foundry molds. The parts of the mold in contact with the liquid metal are subjected to heat-chemical-mechanical stress. This load causes mold wear, which causes a decrease in surface quality and a change in the dimensional accuracy of the casting. The main cause of wear on the functional surfaces of the mold cavity is tribological processes. From the study of professional works dealing with mold wear [5,11,22], it is clear that one of the main parameters for determining the intensity of wear is surface hardness. The theoretical part deals with wear and the factors that affect wear. The experimental part compares the properties of one, two, and three-layer TIG welds, specifically the chemical composition, hardness, and coefficient of friction determined by the "ball-on-flat" method.

Keywords: Casting mold, Renovation, TIG welding, Hardfacing, Tribological test

1 Introduction

In the era of constantly increasing energy and material costs in industrial production, the possibility of renovating machinery and recycling material is coming to the fore. Foundry is one such area of industry. The article deals with the renovation of permanent foundry molds for casting non-ferrous metals such as aluminum alloys, copper alloys, zinc alloys, magnesium alloys, etc.

Steel foundry permanent molds are financially demanding components in the production of castings. The lifetime of the foundry mold is limited by the number of castings cast. The lifetime is mainly influenced by the combination of tribo-degradation processes and also the operating conditions during production. Tribodegradation processes include chemical processes during the interaction of the liquid metal with the functional surface of the mold, as well as abrasive, adhesive, and erosive wear of the mold. Although these are molds made of steels that resist damage even at high temperatures (the operating temperature of the mold when casting aluminum alloy is approx. 250 °C), wear is present [1, 2].

The most significant damage to the mold is in the locations of changes in dimensions, sharp shapes, or changes in the shape and cross-section of the casting. The location of the defect is in these places when the mold is repeatedly loaded by the casting process. Temperature changes cause residual stresses. Residual stresses exceeding the strength limit of the material cause cracks. Cracks usually spread to the inside of the mold. Cracks cause significant damage or destruction of the casting mold [2].

The most important damage parameters are tribological processes attacking the functional surfaces of the foundry mold, namely the mold cavity and the inlet system. The mutual action of at least two tribological elements during their relative movement (form-liquid metal) affects the wear of the contact surfaces. Form-liquid metal interactions are also important in the process of casting into metal molds. The wear process is not only present on the mold, but also the core for the production of cavities in the casting. The cores must be resistant to wear at high temperatures as well as the mold. Wear of the mold and cores mainly causes turbulence to the dispersed filling of the mold, high hydrodynamic pressures during pressure casting, and temperature stress. The wear of molds and cores is a combination of several simultaneously acting types of wear, such as erosion, abrasion, corrosion, and thermal fatigue of the mold material. Molds for casting are made of highly alloyed tool steels. Steels are complexly alloyed, especially with the elements Cr, V, Mo, or W [3, 5, 10].

Jhavar was devoted to the analysis of the wear of various types of molds and dies in his professional works. He defined different types of wear and influencing factors in casting in his works. Wear is mainly caused by abrasive, adhesive wear, erosion, and mechanical fatigue caused by temperature changes during casting and cooling. Predominant wear mechanisms may change during mold wear [2, 23].

Factors affecting wear include working temperature, atmosphere, size and shape of the contact area, pressure and heat load of the mold, the material of the mold, surface treatment of the mold cavity, speed of filling the mold with liquid metal, the shape of the mold cavity and vibration. The wear of the casting mold can also be caused by insufficient cleaning of the mold between casting cycles, or insufficient separation protection of the surface of the mold before casting. During the casting process, solid particles can become abrasive particles [2].

Mold wear can be reduced by applying thin separation layers to the mold cavity using PVD or CVD technologies. However, these coatings can be damaged during manufacturing and will also be subject to wear. According to Cander, the cost of making the mold represents up to 30% of the production cost of the casting. According to Chen, up to 80% of molds for automotive components are repaired. The topic of finding new possibilities for repairs and renovations is therefore highly relevant. TIG technology is one of the options for quickly and cheaply repairing a foundry mold [6].

The experimental part of the article is therefore focused on the possibility of using multi-layer TIG welding for mold repairs. UTP-A 696 additive material was used for welding. TIG UTP-A 696 wire is designed for welding with high resistance to wear corresponding to the properties of high-speed steels. Resistance to abrasion, pressure, impacts, and temperature up to 600 °C. The UTP-A 696 material was selected based on the results of experiments comparing several TIG welding additive materials.

The evaluation of the weld properties was carried out based on a comparison of the wear resistance of the weld, hardness, and mixing of the material with the substrate (mold material) after welding.

2 Experimental samples

The experimental part aimed to perform a comparison of the useful properties of the made hard-facings (wear resistance and high hardness) in single-layer, two-layer, and three-layer hard-facings. A sample (base material, substrate) made of low-carbon steel S355JR (standard EN 10025-2, Mat. No. 1.0045) with dimensions of 120×40×20 mm was used as a substrate for making comparative welds. Steel S355JR is a structural carbon steel with guaranteed weldability. The carbon equivalent according to the chemical composition from the inspection certificate is C_{EV}=0.422%. The chemical composition of steel S355JR from the inspection certificate is in Tab. 1.

***Tab. 4** Chemical composition S355JR from the inspection certificate*

Chemical composition from inspection certificate (wt %)				
C	**Mn**	**Si**	**Cu**	**Nb**
0.170	1.490	0.013	0.020	0.020
Al	**S**	**P**	**Fe**	**C_{EV}**
0.035	0.003	0.011	balance	0.42 %

The hard-facings were made using the TIG welding technology (141 according to the standard ISO STN EN 4063). Additional material UTP-A 696 (Mat. No. 1.3348) TIG wire with a diameter of ø1.6 mm was chosen for the production of hard-facings. UTP-A 696 weld metal has a high resistance to wear, pressure, and shocks. The additive material creates a wear-resistant martensitic hard-facing structure. The hard-facing can be processed by grinding using sintered carbide tools. The chemical composition of hard-facing additive material UTP-A 696 is shown in Tab.1. [9, 10, 14].

***Tab. 5** Chemical composition of hard-facing additive material UTP A 696*

C	**Si**	**Mn**	**Cr**
1.0	0.2	0.2	4.0
Mo	**V**	**W**	**Fe**
8.5	2.0	1.8	balance

The welding inventor Fronius MagicWave 2200 was used for welding the welds. A tungsten electrode with a diameter of ø2.4 mm was used for welding. Argon with a purity of 99.996% was used as a protective atmosphere. Arc polarity (DC-) was set for welding. All welding beads were made with the welding current I_Z=120 A. The average value of the welding voltage was U_Z=12.7 V. The average current value was read from the display of the welding machine after welding. The interpass temperature was

200 °C. The value of the interpass temperature is recommended by the manufacturer of the additive material.

Three experimental hard-facings were made to evaluate the mechanical properties and mixing of the material. The single-layer hardfacing was made of a total of 6 weld beads in one layer. The two-layer hard-facing was made of 12 weld beads. The first layer was composed of 6 and the second of 6 weld beds. The three-layer coating was made of a total of 18 weld beads, 6 beads in each layer. The length of each weld bead was 100 mm. The welding scheme and the procedure for laying the weld beads are shown in Fig. 1. [18].

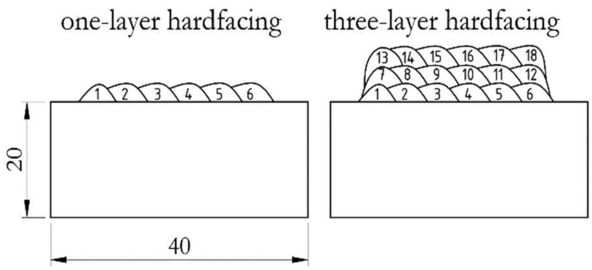

Fig. 2 *Scheme of TIG welding for a one-layer and three-layer hardfacing*

The raw surface of the welds after welding is shown in Fig. 2.

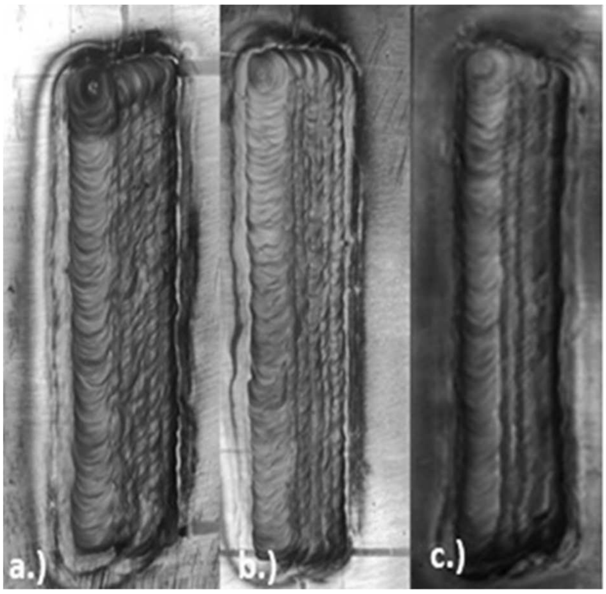

Fig. 3 *Hard-facing made with TIG technology: a.) one-layer b.) two-layer c.) three-layer*

3 Experimental measurements

Visual and penetrant testing was performed after welding and cooling the weld to check the quality and integrity of the hard-facings. There were no defects or cracks in the weld. The non-destructive evaluation of the weld was in quality B according to EN ISO 5817.

Rockwell hard-facing hardness was measured on the grinding surface of the hard-facing for the roughness of R_a = 3.6 μm.

The hardness of the material is one of the properties by which we can decide on the suitability of the steel for the given application. The hardness test was performed on the AQUASTYL RB-1E/AQ device. The hardness was measured in all hard-facing layers, even in the case of multi-layer hard-facings. 12 measurement points were distributed evenly over the surface of the grinding sample. The surface for measurement was prepared by grinding. Hardness was measured according to the following procedure. When measuring the surface of the last hard-facing layer, the surface was only leveled by grinding. When measuring the hardness of the penultimate hard-facing layer, the surface was ground to the thickness of the last layer. The thicknesses of the grinding removed layer were measured from the macrostructure of each hard-facing. Average hardness values are shown in Tab. 3. The hardness variance during measurement was ±1 HRC.

Tab. 6 *Average hardness on the layer*

Experimental sample	Layer	Hardness HRC
One-layer	1st	60
Two-layer	1st	61
	2 nd	63
Three-layer	1 st	63
	2 nd	63
	3 rd	64

The analysis of the chemical composition of the surface layers was performed on metallographic cuttings. A desktop CCD spark optical emission spectrometer Q2 ION BRUKER was used to determine the chemical composition.

The mixing of the hard-facing material with the base material was evaluated using the chemical analysis of the individual hard-facing. Chemical analysis was performed on the ground surfaces for each layer. The material removal thickness by grinding was the same as for the hardness measurement. The chemical composition of the layer was calculated by averaging 5 measurements. In the case of a one-layer hard-facing, the coating was ground down to the level of the surface of the base coating. This measurement is in Tab. 2 named layer 0th. The results of the chemical composition for all experimental samples and all hard-facing layers are shown in the Tab. 2.

Tab. 7 *Chemical composition hard-facing layers*

Sample	Layer	C	W	V	Mn	Si	Cr	Mo	Ni	Cu	Fe
One-layer	0th	0.38	-	0.89	0.83	0.29	1.83	3.07	0.06	0.11	92.2
	1st	0.42	-	1.09	0.86	0.26	2.05	3.57	0.05	0.11	91.4
Two-layer	1st	0.75	-	1.08	0.50	0.32	3.31	5.71	0.08	0.16	86.9
	2nd	0.78	-	1.07	0.45	0.34	3.45	6.30	0.06	0.15	87.9
Three-layer	1st	0.57	-	1.08	0.55	0.40	2.96	4.93	0.09	0.16	88.4
	2nd	0.8	-	1.08	0.40	0.30	3.50	6.50	0.07	0.15	85.4
	3rd	0.87	0.98	1.56	0.40	0.30	3.30	7.40	0.12	0.17	83.2

The course of the content of chemical components in individual layers for three-layer hard-facing is shown in Fig. 3.

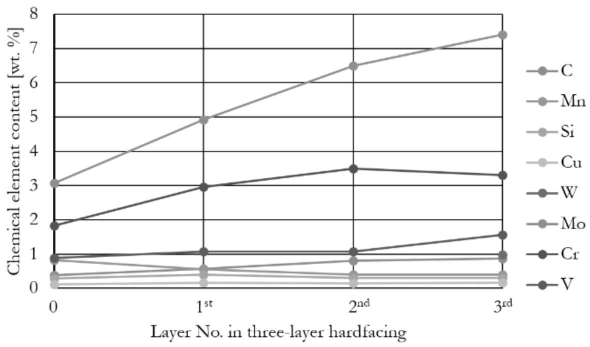

Fig. 3 *The content of steel chemical components in the individual layers of the three-layer hard-facing*

The process of material mixing can be seen from the course of the chemical composition in the individual layers (Fig. 3). The approximately identical chemical composition of the hard-facing with additional material was only achieved in the third layer of the hard-facing. However, it is necessary to take into account not only the mixing but also the burning of individual chemical elements during welding.

A tribological test of the hard-facing properties was carried out next. The "ball on flat" method was used for the tribological test. The coefficient of friction can be determined by a tribological test for a tribological pair under specific conditions. The friction coefficient is defined as the ratio of the frictional force and the normal force acting perpendicular to the surface on which the body moves. It is a dimensionless quantity. The value of the coefficient of friction can range from 0 to 1. A friction coefficient value of 0 means that there is no friction between the tribological pair. If the friction coefficient is 1, friction is very high. In terms of measurement, the coefficient of friction depends on several factors such as the internal material structure, contact surface pressure, sliding speed, temperature and humidity, surface roughness, and material pair. The coefficient of dry friction of the mold and hard deposits was experimentally determined by the "ball-on-flat" method. The tribological pair during the test was composed of a hard-facing surface (UTP-A 696) and a hardened steel ball with a diameter of Ø3mm. The hardness of the hardened ball was 64 HRC. A hardened steel ball is pressed against the tested surface with a determined force and performs a linear movement along the segment. The line segment length of ball motion was 50 mm and the forces during the test were F=10 N. The movement of the pin with the ball on the hard-facing surface is linear and continuous. The "ball on flat" tribological test was made at a temperature of 20 °C under normal atmospheric conditions. The pin with ball speed was 0.017 $m.s^{-1}$, and the duration of the test was 5000 s. The time course of wear coefficient values for one-layer, two-layer, and three-layer hard-facing under a load of 10N are shown in Fig. 3 [9, 13, 20, 22].

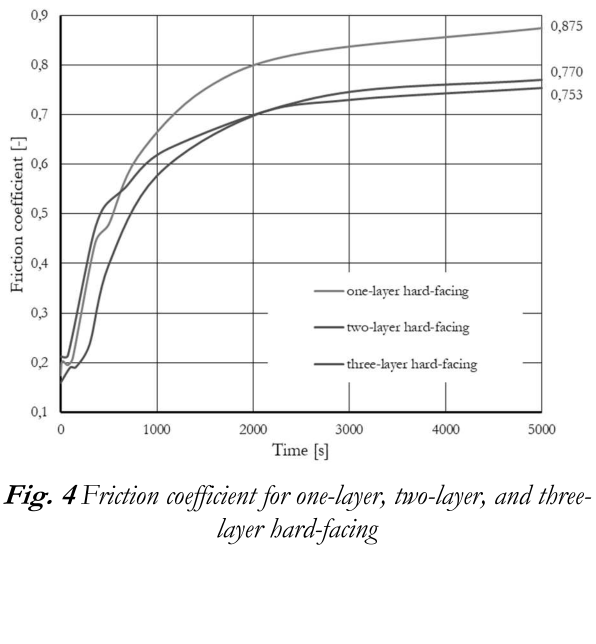

Fig. 4 *Friction coefficient for one-layer, two-layer, and three-layer hard-facing*

The friction coefficient for a one-layer hard-facing sharply increased from 0 to 1000 s, reaching a value of 0.670 at 1000 s. A coefficient of friction of 0.875 was reached in 5000 s at the end of the test. The friction coefficient of the two-layer hard-facing reached a value of 0.625 at the time of 1000 s. The coefficient increased more moderately than in the case of a single-layer hard-facing in the time interval from 0 to 1000 s. The coefficient of friction at the end of the test at 5000 s was 0.770. The friction coefficient of the three-layer hard-facing reached a value of 0.576 at the time of 1000 s. The friction coefficient of the three-layer hard-facing reached a value of 0.753 in 5000 s. The course of the friction coefficient for a three-layer hard-facing is very close to the course of the friction coefficient for a two-layer hardfacing. It is caused by only a small change in the chemical composition due to the mixing of the base material with the hard-facing material.

From the point of view of wear, it can be said that the three-layer or two-layer hard-facing surface achieved better results compared to the single-layer hard-facing surface.

The comparison of tribological properties was also carried out on the surfaces created by grinding the hard-facing to the required weld layer. A comparison of the tribological properties of a one-layer, two-layer, three-layer hard-facing and the properties of the first and second layer in a three-layer hard-facing are shown in Fig. 4.

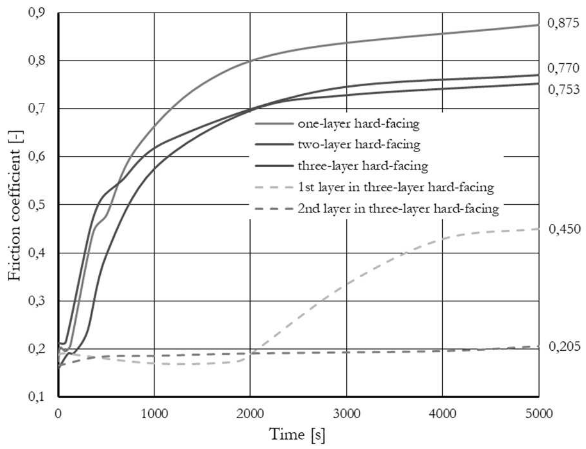

Fig. 5 *The friction coefficient for single-layer hardfacing surface and three-layer hard-facing ground to the first layer*

Significant differences in the friction coefficient can be seen in Fig. 4. The friction coefficient of the first and second layers of a three-layer hard-facing is significantly lower than that of a one-layer and two-layer hard-facing. The lowest friction coefficient was achieved in the second layer of the three-layer coating. The friction coefficient of the three-layer hard-facing reached a value of 0.205 at the time of 5000 s. The lowest friction coefficient also means the best resistance to wear. The course of the friction coefficient in the second layer of the three-layer hard-facing has a constant course and as a result, is approximately 60% lower than the surfaces of all hard-facing despite the same hardness. The low friction coefficient was achieved due to the heat treatment (annealing) of the layer during TIG welding of the third layer of the three-layer hard-facing.

The result can also be applied to real repair technology. A three-layer coating is best used for repair, while the third-layer of hard-facing will be an addition for chipping the surface. With this procedure, we achieve the highest wear resistance of the repaired part [4, 22-24].

4 Conclusions

The contribution aimed to determine the effect of mixing additive material in multi-layer hard-facings on the properties of the hard-facing, namely hardness and tribological properties. These multi-layer welds were made by welding technology with a non-melting tungsten electrode in an argon inert atmosphere (TIG). The chemical analysis of the weld metal, mechanical properties, and resistance to wear using the "ball on flat" tribological test was carried out in the experimental part of the work. The result of the work is the assessment of the individual weld layer's properties of the weld. The structural steel S355 JR was used as the base material. UTP-A 696 was chosen as additional material. The weld metal properties are equivalent to high-speed steel (HSS) for high performance. The hard-facings were made as one, two, or three-layers. The following conclusions can be drawn from the results of experiments and analyses:

- A chemical composition close to the additive material was only achieved with the third layer of the three-layer coating.
- The third layer of the three-layer hard-facing reached the highest surface hardness with an average value of 64 HRC. The influence of the annealing temperature on the hardness of the deposit was confirmed here. The theoretical and practical assumptions were confirmed here, that the influence of the mixing of the base material and the weld metal is lost only in the third-layer hard-facing. (Jankura, 2013) This value is the highest measured value that we measured on individual samples.
- The second layer of the three-layer hard-facing achieved the best tribological properties. The friction coefficient measured

by the tribological test with a load of 10 N was the lowest in the second layer of the three-layer hard-facing, namely 0.205 at the end of the test at a time of 5000 s.

- The results obtained with the help of the experiment confirmed that with each layer of the weld, the effect of mixing the additional material in multi-layer welds is reduced, which has a good effect on the mechanical properties of the weld.

Acknowledgement

This article was funded by the University of Žilina project 313011ASY4 „Strategic implementation of additive technologies to strengthen the intervention capacities of emergencies caused by the COVID -19 pandemic".

References

[1] BRADLEY, R. K. (2022). Education in Plastics Manufacturing: Aluminum Mold Making and Injection Molding. In: *International Journal of Mechanical Engineering Education*, Vol. 50, No. 3, pp. 726-738. SAGE Publications Inc. ISSN 0306-4190, doi: 10.1177/03064190211051105.

[2] MORITZER, E., MARTIN, Y. (2017). Experimental Investigations on the Fibre Length Degradation in Injection Moulds. In: *AIP Conference Proceedings*, Vol. 1914, Article No. 140004, American Institute of Physics Inc. France. ISBN 978-073541606-2, doi: 10.1063/1.5016769.

[3] BREZINOVA, J. at. al (2020). Progressive CMT Cladding for Renovation of casting Mold. In: *Acta Metallurgica Slovaca*, Vol. 26, No. 3, pp. 104-110. Technical University of Kosice. Slovakia. ISSN 1335-1532, doi: 10.36547/ams.26.3.565.

[4] SUTKA, J. et. al. (2021). Arc welding renovation of permanent steel molds. In: *Archives of metallurgy and materials*, Vol. 21, No. 2, pp. 35-40. Polska Akademia Nauk. Poland. ISSN 1897-3310, doi: 10.24425/afe.2021.136095.

[5] JANKURA, D. (2013). Influence of the Number of layers on the Tribological Hard-facing Properties. In: *Transfer of Innovations*, No. 26, pp. 126 – 129. Technical University of Kosice. Slovakia. ISSN 1337-7094.

[6] BREZINOVA, J. et. al (2021). Selected Properties of Hardfacing Layers Created by PTA Technology. In: *Metals*, Vol. 11, No. 1, pp. 1-20. MDPI AG. ISSN 2075-4701, doi: 10.3390/met11010134

[7] KHAN, P. L., BHIVSENE, S. V. (2018). Experimental Analysis and Investigation of Machining Parameters in Finish Hard Turning of AISI4340 Steel. In: *Procedia Manufacturing*, Vol. 20, pp. 265-270. Elsevier. ISSN: 2351-9789, doi: 10.1016/j.measurement.2020.107712.

[8] CHAUSE, A. (2010). *Cast Metal-Cutting Tools Made of High-Speed Steels*, p. 116. Forschungszentrum Dresden—Rossendorf, Dresden, Germany. ISBN 978-3-941405-09-7.

[9] PTACEK, L. et. al. (2002). *Materials science (Nauka o materialů II)*, p. 392. CERM, Brno, Czech. ISBN: 80-7204-248-3

[10] JHVAR, S., PAUL, C. P., JAIN, N. K. (2013). Causes of failure and repairing options for dies and molds: A review. In: *Engineering Failure Analysis*, Vol. 34, pp. 519-535. ISSN 1350-6307, doi: 10.1016/j.engfailanal.2013.09.006.

[11] CHANDER, S., CHAWLA, V. (2017). Failure of forging design update perspective. In: *Materials Today*, Vol. 4, pp. 1147-1157. ISSN 2214-7853.

[12] CHEN, C. et al. (2014). A review on remanufacture of dies and molds. In: *Journal of Cleaner Production*, Vol. 64, pp. 13-23. Elsevier. ISSN 0959-6526.

[13] BRONCEK, J. et al. (2020). Investigation of the tribological properties of the nitride layer on heat-treated steel 100Cr6. In: *Lecture Notes in Mechanical Engineering*, pp. 463-471. ICMD 2018. ISSN 2195-4356, doi: 10.1007/978-3-030-33146-7_53.

[14] MICIAN, M. et al. (2018). The Repair of Foundry Defects in Steel Castings Using Welding Technology. In: *Archives of foundry engineering*, Vol. 18, No. 2, pp. 177-180. De Gruyter Open Ltd. Poland. ISSN 1897-3310, doi: 10.24425/122524

[15] WINCZEK, J. et al. (2019). The Evaluation of the Wear mechanism of High-Carbon Hardfacing Layers. In: *Archives of metallurgy and materials*, Vol. 64, no. 3, pp. 1111-1115. Polish Academy of Sciences. Poland. ISSN 1733-3490, doi: 10.24425/amm.2019.129502.

[16] PLISZKA, I. et al. (2018). Surface Improvement by WC-Cu Electro-Spark Coatings with Laser Modification. In: *Materials Research*, Vol. 4, pp. 237-242. Kielce University

of Technology. Kielce. Poland. ISSN 2474-3941, doi: 10.21741/9781945291814-42.

[17] PASTIRCAK, R., SCURY, J. (2017). Effect of Technological Parameters on Microstructure in Alloy AlCu4Ti Using Squeeze Casting Technology. In: *AIP Conference Proceedings*, Vol. 1745, No. 020044, American Institute of Physics. USA. ISSN 0094-243X, doi: 10.1063/1.4953738.

[18] GUCWA, M. et al. (2017). The effect of type of welding sequence during hardfacing chromium cast iron for erosion resistance. In: *Archives of foundry engineering*, Vol. 17, No. 3, pp. 51-54. De Gruyter Open Ltd. Poland. ISSN 1897-3310, doi: 10.1515/afe-2017-0089

[19] ZURAWSKI, P. (2022). Perspectives of the Low Force Friction Welding Process. In: *Manufacturing Technology*, Vol. 22, No. 5, pp. 633-643. FME JEPU. Czech Republic. ISSN 1213-2489, doi: 10.21062/mft.2022.067.

[20] MICIAN, M. et al. (2020). Effect of the $t_{8/5}$ cooling time on the properties of S960MC steel in the HAZ of welded joints evaluated by thermal physical simulation. In: *Metals*, Vol. 10, No. 2, Article No. 229. MDPI AG. ISSN 2075-4701, doi: 10.3390/met10020229

[21] KISHORE, R., SAMPATHKUMARAN, P., SEETHARAMU, S. (2005). Erosion and abrasion characteristics of high manganese chromium irons. In: *Wear*, Vol. 259, No. 1-6, pp. 70-77. Indian Inst Sc, India. ISSN 0043-1648, doi: 10.1016/j.wear.2005.03.001.

[22] TAVODOVA, M., HNILICA, R. (2020). Assessment of selected properties of treated tool surfaces examined to increase tool life time. In: *Manufacturing Technology*, Vol. 20, No. 2, pp. 257-264. FME JEPU. Czech Republic. ISSN 1213-2489, doi: 10.21062/mft.2020.023.

[23] TAVODOVA, M. et al. (2022). Analysis of Damaged Delimber Knives and the Possibility of Increasing their Service Life. In: *Manufacturing Technology*, Vol. 22, No. 1, pp. 80-88. FME JEPU. Czech Republic. ISSN 1213-2489, doi: 10.21062/mft.2022.011.

[24] JAGIELSKA-WIADEREK, K. (2021). Effect of boronizing process of AISI 321 stainless steel surface on its corrosion resistance in acid environment (pH = 1). In: *Manufacturing Technology*, Vol. 21, No. 5, pp. 714-719. FME JEPU. Czech Republic. ISSN 1213-2489, doi: 10.21062/mft.2021.075.