David Novak [1,a], Tomaž Vuherer [1]

WEAR RESISTANCE OF MAG CLADDED 27MnCrB5-2 BASE MATERIAL WITH THE SG3 SOLID WIRE

OTPORNOST NA HABANJE MAG OBLOŽENOG 27MnCrB5-2 OSNOVNOG MATERIJALA SA SG3 ČVRSTOM ŽICOM

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Author's address / Adresa autora:

[1] *University of Maribor, Faculty of Mechanical Engineering Maribor, Smetanova ulica 17, Maribor, Slovenia*

Email / ORCID ID:

[a] *david.novak4@student.um.si*

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Abstract

Cladding is one of the most commonly used technologies for extending the lifespan of wear-exposed products and surface hardening. This work presents cladding using the MAG process, where, during the experimental part of the research, the filler material BÖHLER SG 3 in the form of wire was clad onto the base material (27MnCrB5-2). We applied one, two, and three layers of cladding. It is known that cladding creates a dilution zone between the base and filler material, which is most visible in single-layer cladding. Our primary interest of research was how the number of cladding layers affects the hardness and wear resistance of the top layer of the cladding. The cladding was performed using a robot in a robotic cell, where we produced nine samples. We then conducted a wear test to ASTM G65 standard on a custom-made SLO-ASTM G65 testing machine. The samples were later halved, and the specimens were prepared for laboratory work, where we examined them and measured hardness and the dilution zone. None of the measurements showed significant differences in wear resistance and hardness. A slight deviation was observed only in the sample with three layers, which proved slightly more resistant than the samples with one and two layers.

Rezime

Oblaganje je jedna od najčešće korišćenih tehnologija za produženje životnog veka proizvoda izloženih habanju i površinskom očvršćavanju. U ovom radu je prikazano oblaganje postupkom MAG, pri čemu je u eksperimentalnom delu istraživanja na osnovni materijal (27MnCrB5-2) nanet materijal za punjenje BOHLER SG 3 u vidu žice. Naneli smo jedan, dva i tri sloja obloge. Poznato je da oblaganje stvara zonu razblaženja između podloge i materijala za punjenje, što je najvidljivije kod jednoslojnih obloga. Naš primarni interes istraživanja bio je kako broj slojeva obloge utiče na tvrdoću i otpornost na habanje gornjeg sloja obloge. Oblaganje je izvedeno pomoću robota u robotskoj ćeliji, gde je proizvedeno devet uzoraka. Zatim je sproveden test habanja prema standardu ASTM G65 na mašini za testiranje SLO-ASTM G65 po meri. Uzorci su kasnije prepolovljeni i pripremljeni za ispitivanja u laboratoriji, gde su pregledali i izmerene tvrdoću i zonu razblaženja. Nijedno od merenja nije pokazalo značajne razlike u otpornosti na habanje i tvrdoću. Neznatno odstupanje uočeno je samo kod uzorka sa tri sloja, koji se pokazao nešto otpornijim od uzoraka sa jednim i dva sloja

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1. Introduction

Wear and corrosion are among the major challenges faced by the mining and steel industries [1], and these issues are also common in agricultural machinery [2] and the military industry [3]. Cladding, a process in which a new layer of material is applied to an existing base material that is typically of lower quality, is a widely used solution to mitigate these problems [4]. Various cladding methods are available, and the choice of method depends on several factors, including production costs, process flexibility, the amount of heat input, and overall economic efficiency [5]. The primary objective of cladding is to extend the lifespan of products, as applying a cladding layer not only increases the strength and hardness of the material but also enhances its resistance to wear and impact [5].

However, it is important to note that an increase in the hardness of the cladding does not necessarily lead to improved wear resistance. This phenomenon is largely influenced by the chemical composition of the alloy and its resulting microstructure [6]. The materials used for cladding are typically alloyed with elements such as iron, nickel, and cobalt, and the selection of these materials is based on the characteristics of the base material and the specific type of wear they are intended to withstand [7]. There are several well-known cladding methods, including MAG cladding with flux-cored wire (FCAW) [8], MIG/MAG with solid wire (GMAW) [9], submerged arc welding (SAW), and TIG cladding (GTAW) [9]. The focus of this work is on the GMAW method, where the arc is established between the wire fed through the nozzle and the base material, all within a gas shield that prevents air from infiltrating the arc. In this process, it is crucial to select the appropriate parameters that will maximize both the process's efficiency and the cladding's quality. This is particularly important because the thermal conditions play a significant role in determining the quality, as faster solidification and crystallization can lead to higher-quality cladding [10].

The company uses different filler materials for cladding. The cladding material is selected based on the exposure of the machine part to wear, as well as the customer's needs and requirements. Materials with high hardness are more prone to flaking, while materials with lower hardness tend to be tougher. Since softer materials are also less complex to weld and repair, we explored the possibility of cladding with such material. In this study, we analyzed BÖHLER SG 3 material with different numbers of cladding layers, aiming to demonstrate the differences between samples with one, two, and three layers. Using a robotic cell, we prepared the samples and subsequently performed wear tests, hardness measurements, and an analysis of weld metal and base material dilution. The overarching goal for manufacturers of clad parts is to ensure the longest possible service life for machine components under their specific operating conditions while also maintaining economic viability. Cladding is not only applied to new products but is also used in the repair of worn components, where both the economic justification and the quality of the repair are of even greater importance.

2. Experimental

2.1 Material

We examined the filler material BÖHLER SG 3, which we applied in different layers onto a test piece that is a forging made of 27MnCrB5-2 base material with dimensions of 115 x 89 mm and a thickness of 30 mm. Due to the varying number of layers applied, the test pieces were appropriately labelled. Test pieces with a single-layer weld are labelled B1, those with a two-layer weld are labelled B2, and those with a three-layer weld are labelled B3. We produced three identical test pieces for each option, resulting in a total of 9 test pieces. The mechanical and chemical properties of the filler and base materials are presented in Table 1 and Table 2. We do not have data on the mechanical properties of the base material in its forged form, but the mechanical properties of this material before forging are provided.

Table 1. *Chemical composition and mechanical properties of the filler material BÖHLER SG 3*

Tabela 2. *Hemijski sastav i mehaničke karakteristike dodatnog materijala BÖHLER SG 3*

Filler material			BÖHLER SG 3
Chemical composition (wt. %)			
C	Si	Mn	
0.5	1.3	1.3	
Mechanical properties			
R_e (MPa)	R_m (MPa)	*A* (%)	ISO-V KV (J)
485	602	26	50 (-40 °C)

Table 3. *Chemical composition and mechanical properties of 27MnCrB5-2 (BM)*

Tabela 2. *Hemijski sastav i mehaničke karakteristike BÖHLER SG 3 (OM)*

Base material				27MnCrB5-2			
Chemical composition of (wt. %)							
C	Mn	Si	Cr	Mo	P	S	Ni
0,29	1.240	0.160	0.340	1.300	0.015	0.003	0.120
Cu	V	Al	Ti	N	Nb	Sn	B
0,22	0.003	0.028	0.038	0.007	0.001	0.011	0.022
Mechanical properties							
R_e (MPa)	R_m (MPa)	*A* (%)	ISO-V KV (J)				
695	922	15	65				

2.2 Welding

Before starting the experimental work, we decided first to conduct a wear test, after which we would cut the test pieces in half using a water jet and create cross-sections for microstructure imaging and hardness measurements in the cross-section. We were primarily constrained by the shape and dimensions of the test pieces due to the clamping fixture integrated into the testing device. Fortunately, we found a suitable forging, which is also a machine part typically clad in the production of mixing, crushing, and shredding equipment. While welding the test pieces, we used the parameters shown in Table 3.

Table 4. *Welding parameters*

Tabela 5. *Parametri zavarivanja*

Layer	Process	Diameter of FM (mm)	Current (A)	Voltage (V)	Type / polarity	Wire speed (m/min)	Welding speed (cm/min)	Heat input (kJ/cm)
1	135	1,2	222	25.2	DC+	8.8	9	37.3
2	135	1,2	201	25.5	DC+	8.4	10	30.7
3	135	1,2	200	25.6	DC+	8.3	10	30.7

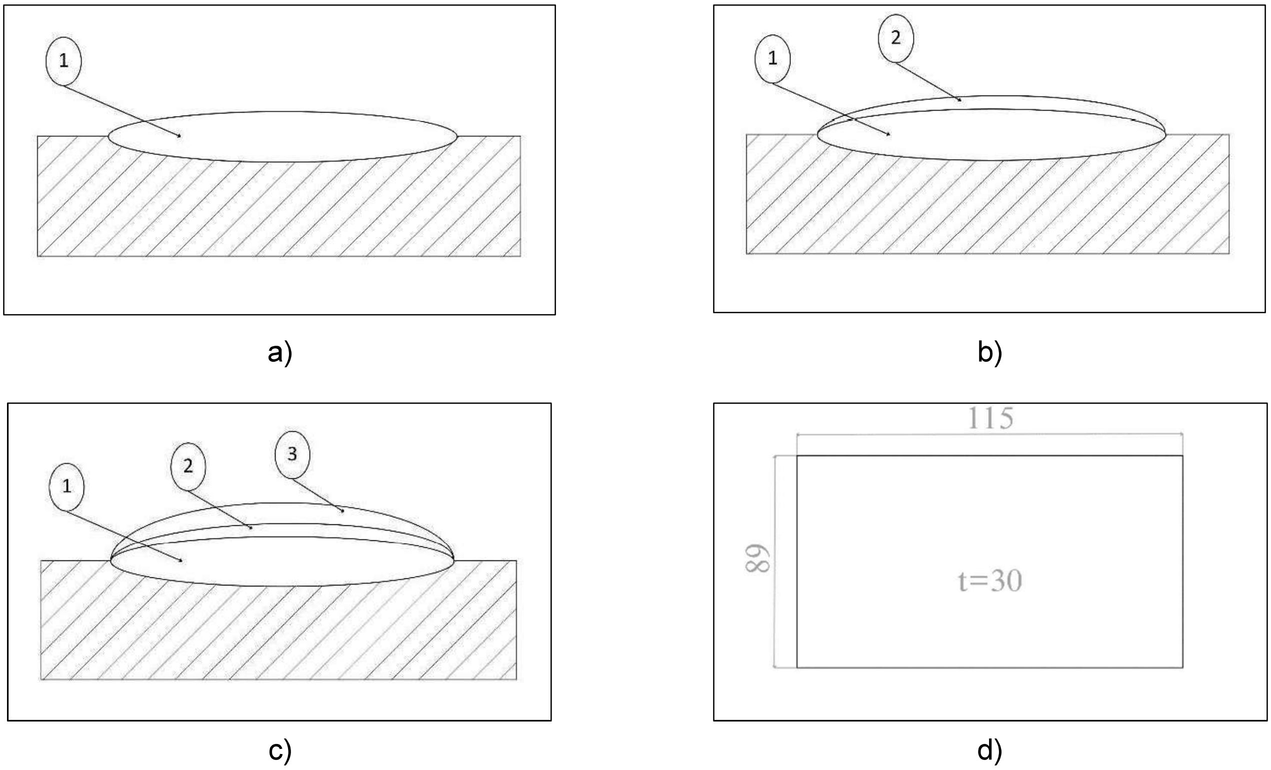


Figure 1. *Sample with: a) one layer b) two layers c) three layers and d) dimensions of test sample*

Slika 1. *Uzorak sa: a) jednim slojem b) dva sloja c) tri sloja i d) dimezije ispitnog uzorka*

The MAG cladding process was carried out using a CLOOS welding robot equipped with a CLOOS QINEO PULSE 600 welding power source. We chose automated cladding for the test pieces to ensure the homogeneity of the cladding shape, the consistency of the torch movements during the welding process. This way, we closely replicate the actual production technology used for such parts. The forging was clamped in a specialized fixture typically used for this purpose. A sketch of the cladded part and the sequence of the cladding layers is shown in Figure 1. Using the robot's control unit, shown in Figure 2, we determined the path and position of the welding torch and the welding parameters commonly used for cladding forgings. The cladding was performed without preheating, and we monitored the temperature between the cladding layers. We used a mixture of argon and carbon dioxide for shielding gas, specifically M21 with 18% CO_2.

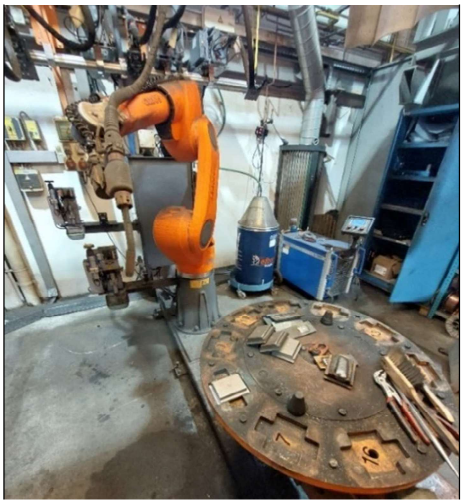


Figure 2. *CLOOS welding robot*

Slika 2. *CLOOS robot za zavarivanje*

2.3 Preparation of cross-sections

Before laboratory work, it was necessary to prepare the test pieces to ensure they were suitable for hardness measurements and cross-sectional imaging. The test pieces were cut using a water jet cutting method with an abrasive additive. The cross-sections required further processing through milling and grinding to achieve a flat and smooth surface. After polishing, the cross-sections were etched with an etchant (1% Nital) to distinguish the filler material from the base material in the cross-section and to identify the heat-affected zone.

2.4 Hardness measurements

Hardness was measured across the cross-section of the sample, starting from the weld's top downward, as we were interested in observing the change in hardness relative to the depth and number of layers. The hardness measurements were carried out using the Vickers hardness testing method by mass of load of 10 kg (HV10) for 15 sec. We also captured images of each cross-section and later used AutoCAD software to measure the areas. This allowed us to calculate the dilution area of the base and filler materials.

2.5 Wear testing - procedure description

The test area of the testing machine is shown in figure 3. The device consists of a housing, an electric motor, a control unit for parameter regulation, a clamping fixture, a feeding mechanism, and a reservoir for the abrasive medium. We used aluminium oxide ($Al2O_3$) sand with a grain size between 300 and 425 μm, sold under the trade name WSK 46 by IMERYS.

We decided to test the samples up to 3000-wheel revolutions, measuring the mass of the test piece after every 1000 revolutions, representing one cycle. The sand flow rate was set to approximately 350 g/min. During the test, we randomly checked the flow rate multiple times and paid close attention to the moisture content of the abrasive. Special care was needed when positioning and clamping the sample between cycles to ensure it was clamped in the same position, allowing for consistent material removal, as shown in Figure 3.

Weighing at the end of each cycle was performed using a calibrated scale with a resolution of 0.01 g. Before weighing, the test piece was cleaned with compressed air to remove any sand and other contaminants that could lead to inaccurate mass measurements.

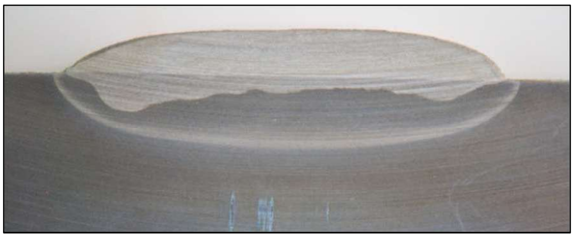
Figure 3. *Position of the sample during abrasion test a), and weighting of the worn test sample b)*

Slika 3. *Položaj uzorka tokom testa na habanje a), i merenje istrošenog uzorka za ispitivanje b)*

3. Results and discussion

3.1 Results of macro-section examination

Results of macro-section examinations are presented in Figure 4



a)

b)

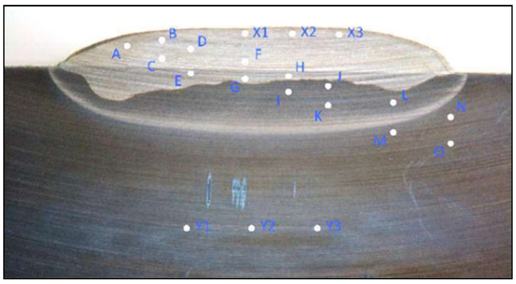
c)

Figure 4. *Macro-section; a) one layer, b) two layers, c) three layers*

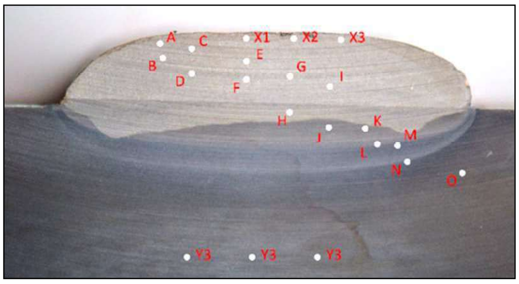
Slika 4. *Makro-presek; a) jedan sloj, b) dva sloja, c) tri sloja*

3.2 Results of hardness measurements

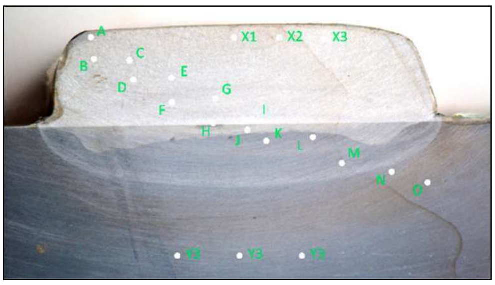
The cross-sectional images of the samples are shown in Figure 5, with the HV10 hardness measurement locations indicated.



a)



b)



c)

Location of measurements

WM: Top surface X1, X2 X3

WM: Measures A-H

HAZ: J-N

BM: Y1, Y2, Y3, O

blue – one layer (a)

red – two layers (b)

green – three layers (c)

Figure 5. *Cross-section of: a) one layer, b) two layer and c) three-layer sample*

Slika 5. *Poprečni presek; a) jedan sloj, b) dva sloja c) tri sloja*

The results of the hardness measurements are shown in the Table 4 below.

Table 4. *HV10 hardness measurements*

Tabela 4. *Ispitivanje tvrdoće po Vikersu*

Measurement point	Hardness HV10			Measurement point	Hardness HV10		
	B1	B2	B3		B1	B2	B3
A	268	268	257	L	372	268	263
B	293	293	252	M	312	249	275
C	273	273	247	N	341	309	297
D	209	209	244	O	464	294	329
E	198	198	242	X1 (surface layer WM)	202	203	234
F	211	199	231	X2 (surface layer WM)	235	204	240
G	355	210	236	X3 (surface layer WM)	242	204	223
H	354	220	257	Y1 (BM)	490	488	423
I	382	237	247	Y2 (BM)	514	466	475
J	365	290	272	Y3 (BM)	515	463	476
K	340	314	290	B1 – one leyer, B2 – 2 layers, B3 –3 leyers			
Dilution (%)	31%	21%,	15%				

3.2 Results of wear tests

The following graphs (Figure 6 to Figure 8) show the wear curves of the individual layers. The wear of sample B1 is shown in Figure 6, the wear of sample B2 is shown in Figure 7, and the wear of sample B3 is shown in Figure 8. The differences in mass were converted into volume changes, so the results are presented in volumetric units (mm³) relative to the number of spins.

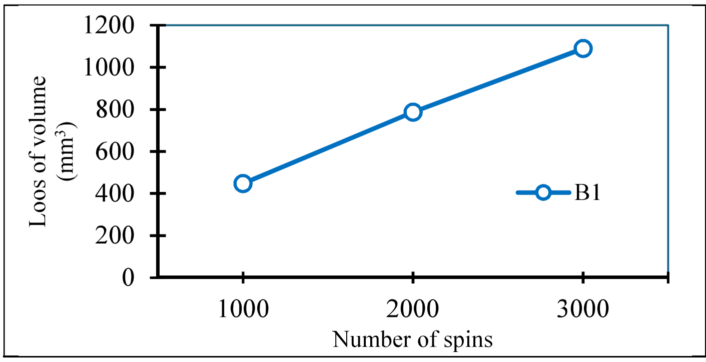


Figure 6. *Wear of sample B1*

Slika 6. *Habanje uzorka B1*

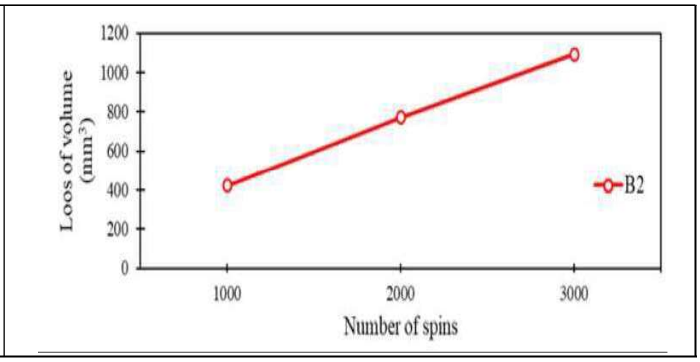


Figure 7. *Wear of sample B2*

Slika 7. *Habanje uzorka B2*

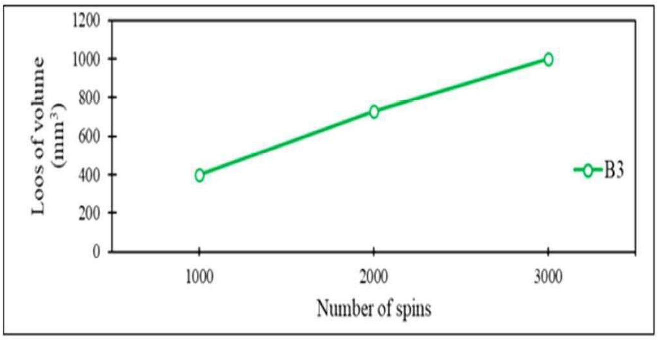


Figure 8. *Wear of sample B3*

Slika 8. *Habanje uzorka B3*

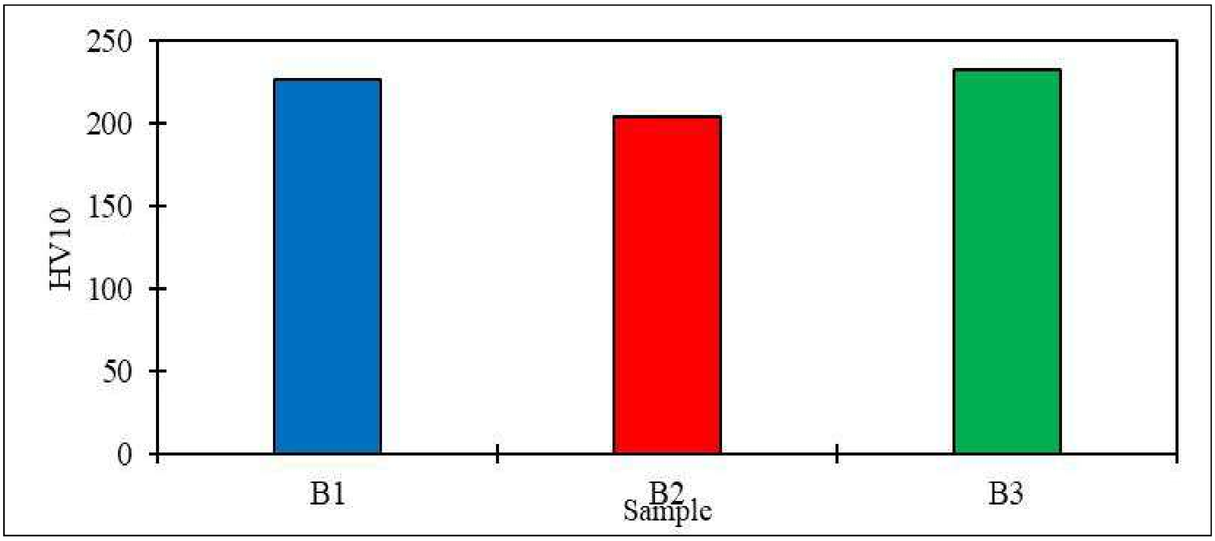


Figure 9. *Averaged hardness measurements on the top surface layer*

Slika 9. *Prosečne vrednosti rezultata prilikom merenja tvrdoće na gornjem površinskom sloju*

Figure 10 shows the wear test results for samples with different numbers of cladding layers. The dependence of wear on the number of wheel revolutions during the test is presented for each sample. As can be seen, the number of cladding layers does not significantly affect the volume loss. A slight deviation was observed only in the sample with three layers (B3), which proved to be the most resistant.

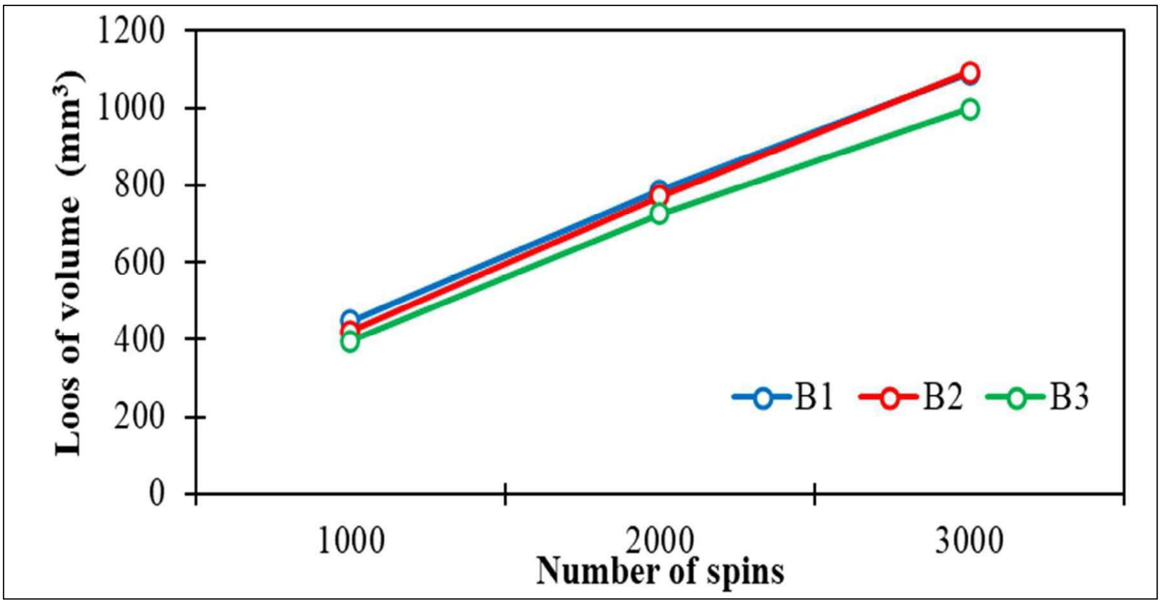


Figure 10. *Wear resistance between samples B1, B2, B3*

Slika 10. *Otpornost na habanje između uzoraka B1, B2, B3*

Additionally, we can confirm that there is no linear relationship between hardness and wear resistance in this material choice, as the differences in hardness are too small, and measurement uncertainty must be considered.

5. Conclusions

The research revealed important findings regarding single-pass and multi-pass cladding. The results will serve the company as a guide in selecting filler materials for cladding, ensuring that the process delivers the highest quality products. It was found that, for this material combination, hardness does not significantly change with different numbers of layers. Additionally, we could not confirm a linear relationship between hardness and wear resistance for this material combination. However, to deepen this hypothesis, it would be worthwhile to conduct further research with other material combinations that might result in significantly greater differences in surface hardness, which is a plan for future investigations.

5. Zaključci

Istraživanje je otkrilo važne nalaze u vezi sa jednoprolaznim i višeprolaznim oblaganjem. Rezultati će poslužiti kompaniji kao vodič u odabiru materijala za punjenje za oblaganje, osiguravajući da proces daje proizvode najvišeg kvaliteta. Utvrđeno je da se za ovu kombinaciju materijala tvrdoća ne menja značajno sa različitim brojem slojeva. Pored toga, nije potvrđena linearna veza između tvrdoće i otpornosti na habanje za ovaj odabir materijala. Međutim, da bi se ova hipoteza produbila, bilo bi potrebno sprovesti dalja istraživanja sa drugim kombinacijama materijala koje bi mogle rezultovati znatno većim razlikama u površinskoj tvrdoći, što je plan za buduća istraživanja.

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Zahvalnica

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