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INFLUENCE OF FILLER MATERIAL TYPE AND GMAW PAD WELDING PROCESS PARAMETERS ON THE GEOMETRY AND WEAR RESISTANCE OF SURFACED COMPONENTS

UTICAJ TIPA DODATNOG MATERIJALA I PARAMETARA GMAW POSTUPKA NAVARIVANJA NA GEOMETRIJU I OTPORNOST NA HABANJE NAVARENIH KOMPONENTI

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Abstract: Pad welding is one of the techniques used to extend the service life of components. Although this method has been applied for many years, there is still much to explore, as increasingly advanced filler materials are being developed. These materials require thorough investigation to find the best technological parameters process parameters that enable full utilization of their material properties. One of the most efficient and versatile hardfacing methods is gas metal arc welding (GMAW). In this study, the influence of GMAW process parameters on the geometry and quality of single beads deposited onto a base material was analyzed for three selected wear-resistant materials. Based on the conducted experiments, process parameters ensuring the highest bead quality were identified. The selected parameters were subsequently used to manufacture specimens for wear resistance testing. The paper highlights all factors affecting the service life of wear-resistant surfaces. The results indicate that not only the selection of appropriate wear-resistant materials is critical, but also the proper choice of technological process parameters and the hardfacing technique.

Keywords: hardfacing, GMAW, wear resistant, abrasive wear

Rezime: Navarivanje je jedna od tehnika koja se koristi za produženje radnog veka komponenti. Iako se ova metoda primenjuje već dugi niz godina, još uvek ima mnogo prostora za istraživanje, budući da se razvijaju sve napredniji dodatni materijali. Ovi materijali zahtevaju detaljna ispitivanja kako bi se pronašli optimalni tehnološki parametri procesa koji omogućavaju potpunu iskorišćenost njihovih svojstava. Jedna od najefikasnijih i najuniverzalnijih metoda navarivanja je elektro-lučno zavarivanje topljivom elektrodom u zaštiti gasa (GMAW). U ovom radu analiziran je uticaj parametara GMAW postupka na geometriju i kvalitet pojedinačnih navara nanetih na osnovni materijal, i to za tri odabrana dodatna materijala otporna na habanje. Na osnovu sprovedenih eksperimenata, definisani su parametri procesa koji obezbeđuju najviši kvalitet navarenih slojeva. Odabrani parametri su potom iskorišćeni za izradu uzoraka za ispitivanje otpornosti na habanje. Rad ističe sve faktore koji utiču na radni vek navarenih površina otpornih na habanje. Rezultati ukazuju na to da je kritičan faktor ne samo izbor odgovarajućih materijala otpornih na habanje, već i pravilan odabir tehnoloških parametara procesa, kao i same tehnike navarivanja.

Ključne reči: navarivanje, GMAW, otpornost na habanje, abrazivno habanje

1. INTRODUCTION

Hardfacing technology is a well-established method for protecting components exposed to wear, particularly abrasive wear. It is applied both to newly manufactured components, such as large-scale parts used in the metallurgical industry (e.g., blast furnace closure systems), and to worn components for which replacement with new parts is not economically justified, such as working elements of agricultural machinery.

The tribological performance of hardfaced layers is primarily determined by the type and composition of the deposited material. However, the technological parameters of the MIG/MAG hardfacing process can also significantly affect the abrasive wear resistance of the deposited layer [1,2].

To evaluate the wear resistance of the deposited layers, abrasive wear tests were conducted. For research purposes, a specially designed abrasion-testing rig was used, in which the mass loss of the tested specimens was measured. The substrate material onto which the hardfacing layers were deposited was S235 steel, commonly used as a structural material in the manufacture of machinery and agricultural equipment. This material also served as the reference material for the results obtained during the abrasive wear tests.

2. EXPERIMENT

The study was conducted using a mechanized hardfacing workstation (Fig. 1) and an X8 MIG Welder welding power source manufactured by Kemppi (Fig. 2), employing the MAG welding process.



Fig. 1. Mechanized hardfacing workstation used for the deposition of weld overlays



Fig. 2. Kemppi X8 welding system [3]

For the study, metal-cored wires belonging to the wear-resistant filler material group were used. Wear-resistant wires manufactured by Castolin Eutectic from the EnDOtec product line,

designed for the refurbishment and protection of components requiring high wear resistance, were selected. All wires had a diameter of 1.6 mm.

In the first stage of the investigation, eight test specimens were produced using Wire A and eight specimens using Wire B. The samples were hardfaced with a single-layer deposit in the PA (flat) welding position. Several process parameters were maintained constant throughout the trials. A shielding gas mixture consisting of 82% Ar and 18% CO_2 was used, with a shielding gas flow rate of 10 l/min. The hardfacing travel speed was set at $v_n = 6$ mm/s.

The wire feed speed was investigated at four settings: 3, 6, 8, and 10 m/min. Each wire feed speed was tested in both standard transfer mode and pulsed mode. The welding current was automatically adjusted by the welding machine as a resultant parameter of the voltage setting, wire feed speed, and wire diameter. The contact tip-to-workpiece distance (CTWD) was maintained at 15 mm.

Specimens A1–A8 were produced using EnDOtec DO*351 wire supplied by Castolin Eutectic. For clarity, this consumable will hereafter be referred to as WIRE A. Specimens B1-B8 were produced using EnDOtec DO*332 wire, also supplied by Castolin Eutectic; throughout the paper, this consumable will be designated as WIRE B. The process parameters used in the experiments are summarized in Table 1. Owing to cost limitations, WIRE C (EnDOtec DO*611X) was not included in the first stage of the study. Fig. 3 shows the results of the first experimental stage, consisting of 16 different hardfacing beads, each approximately 100 mm in length. The samples were deposited on C45 steel plates. The dimensions of the plates used in the study were 450 × 150 × 25 mm. No preheating of the base material was applied prior to hardfacing.



Fig. 3. Hardfacing beads obtained during the experimental study.

Abrasive wear test

Abrasive wear test is performed using a comparative method. The mass loss of a steel reference specimen is compared with the mass loss of a specimen coated with a hardfacing layer.

The method of determining the abrasivity index has forced the design and construction of a laboratory test stand (Fig. 4). The test stand has a drive unit that carries out rotational movement of the steel pin at a constant speed. On the shaft of the gearmotor, there is a holder in which a steel pin is fixed. Together with the rock sample, they form an abrasive pair (Fig. 5). The steel pin is continuously pressed against the face of the rock sample by a gravity-loaded hold-down system using weights.[4]

The tests were conducted under the following basic input parameters: a normal load of 300 N applied between the specimen holder and the face of the rock sample, a rotational speed of 50 rpm, and a test duration of 8 minutes. The rock specimen used in the study was sandstone.

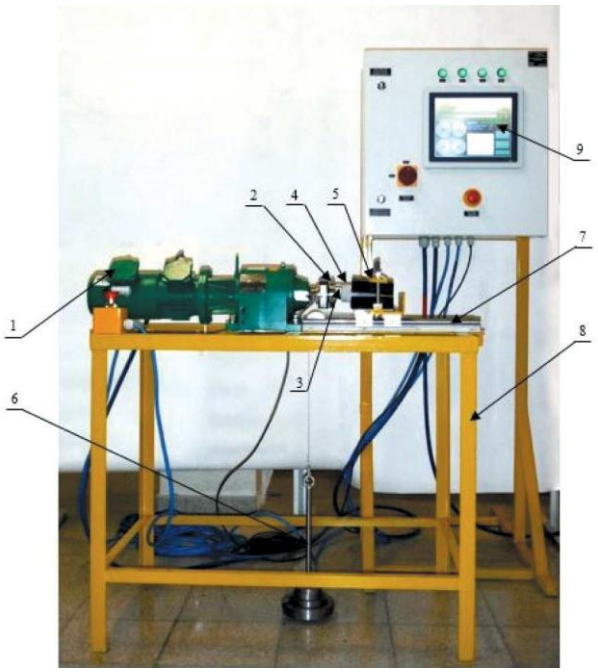


Fig. 4. Test stand for determining rock abrasivity: 1 – drive unit, 2 – steel pin, 3 – holder of steel pin, 4 – rock sample, 5 – holder of rock sample, 6 – gravity-loaded hold-down system, 7 – sliding system, 8 – supporting frame, 9 – control panel [4]

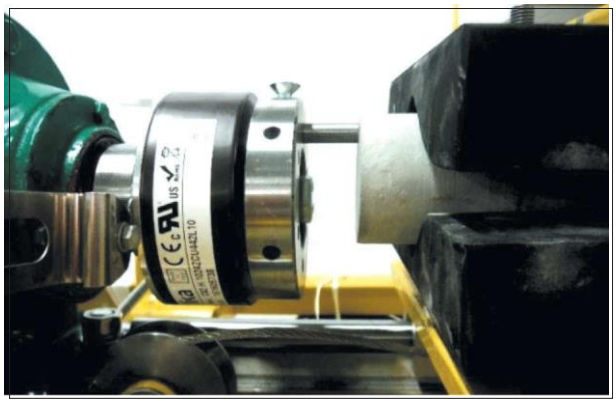


Fig. 5. View of abrasive pair [4]

3. RESULTS AND DISCUSSION

Specimens A1–A8 were hardfaced using Castolin Eutectic EnDOtec DO*351 wire. For the sake of clarity and brevity throughout the remainder of this paper, this consumable will be referred to as Wire A.

During the production of specimens A2–A5, the standard welding mode was employed, whereas specimens A1 and A6–A8 were deposited using the pulsed welding mode. For each welding mode, the wire feed speed was varied successively at 3, 6, 8, and 10 m/min.

Table 5.2 summarizes the hardfacing process parameters for Wire A, together with the basic geometrical characteristics of the deposited beads, including bead width (b), reinforcement height (h), and penetration depth (g), as well as the cross-sectional areas of the melted filler metal (A_n) and the melted base material (A_v). These parameters were determined using optical microscopy.

All specimens were properly prepared and subsequently examined using a Keyence VHX-7000 Series digital microscope. During the geometrical analysis, three parameters were

measured: (1) bead width, b; (2) overlay height, h; and (3) penetration depth, g, as shown in Figure 6. These parameters were identified in this order on all measurements.

For the cross-sectional area analysis of the hardfacing layers, the following designations were used: (1) cross-sectional area of the melted filler metal (overlay reinforcement area), A_n; and (2) cross-sectional area of the melted base material (penetration area), A_v, as illustrated in Fig. 7.

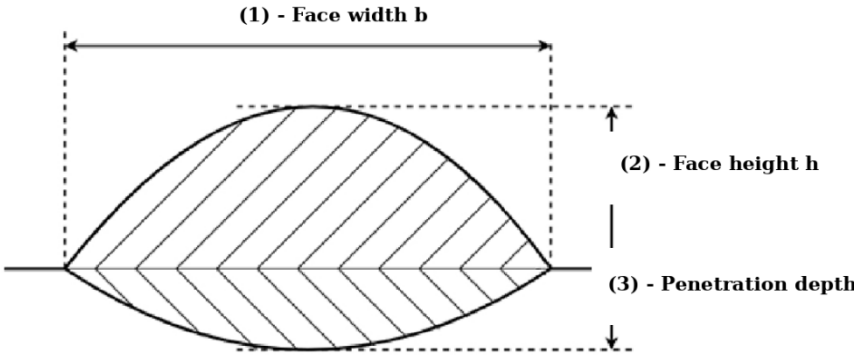


Fig. 6. Measurement scheme for the geometric dimensions of the hardfacing bead

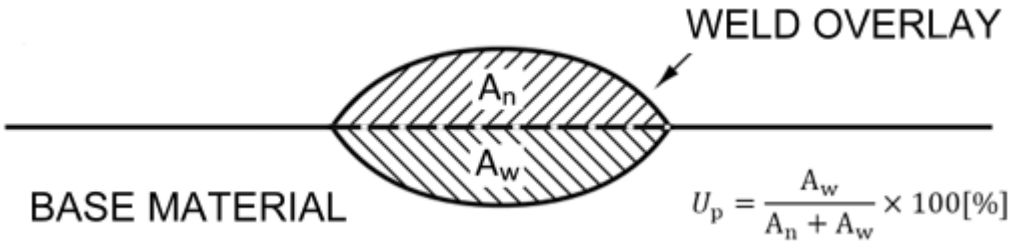


Fig. 7. Designation of the overlay reinforcement area (A_n) and penetration area (A_v) of the hardfacing bead [5]

Tab. 1. Summary of hardfacing process parameters and the corresponding measurement and calculation results for Wires A and B

Specimen No.	Wire	Welding Mode	v_{el} [m/min]	U_n [V]	U [V]	I [A]	b [mm]	h [mm]	g [mm]	A_n [mm²]	A_w [mm²]	U_p [%]
A2	DO*351	Standard	3	22	22.4	221	9.56	2.66	2.46	16.05	13.67	46%
A3	DO*351	Standard	6	22.1	21.9	341	16.43	3.66	3.57	39.79	25.21	39%
A4	DO*351	Standard	8	22.1	21	398	13.60	4.56	4.94	47.52	32.73	41%
A5	DO*351	Standard	10	22.1	16.1	453	10.55	5.59	3.02	53.68	15.8	23%
A1	DO*351	Puls	3	21.7	15.3	191	6.29	3.29	1.48	15.45	4.38	22%
A6	DO*351	Puls	6	25.2	15.3	328	8.66	4.18	1.05	28.49	4.04	12%
A7	DO*351	Puls	8	27.2	16.9	382	11.51	5.23	0.71	43.87	2.93	6%
A8	DO*351	Puls	10	29.2	16.3	436	10.96	5.30	1.43	47.95	5.63	11%
B1	DO*332	Puls	3	21.7	21.7	129	7.90	2.71	1.76	16.35	7	30%
B2	DO*332	Puls	6	25.2	23.9	224	11.16	3.84	2.19	32.17	14.87	32%
B3	DO*332	Puls	8	27.2	20.7	273	11	4.45	2.37	39.38	13.66	26%
B4	DO*332	Puls	10	29.2	23.6	304	11.22	5.35	2.61	52.67	15.31	23%
B8	DO*332	Standard	3	22.1	22.4	160	7.66	2.82	2.35	15.51	10.96	41%
B7	DO*332	Standard	6	22.1	22	242	9.31	4.03	2.24	29.16	11.05	27%
B6	DO*332	Standard	8	22.1	22.4	267	9.12	4.79	2.30	36.96	12.05	25%
B5	DO*332	Standard	10	22.1	22.5	302	10.41	5.63	2.11	54.43	10.51	16%

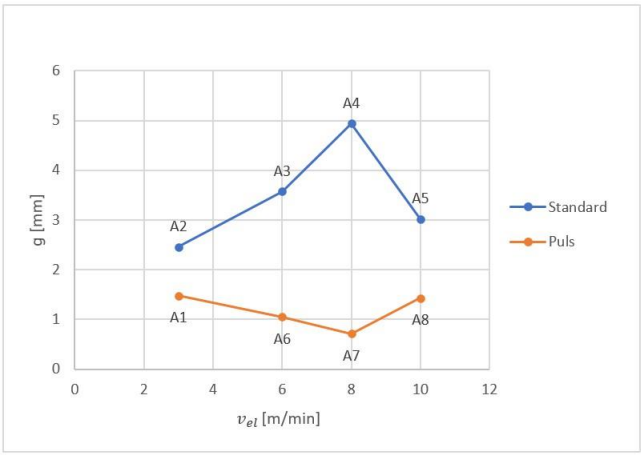


Fig. 8. Effect of electrode wire feed speed (v_{el}) on the penetration depth (g) of hardfacing beads produced with Wire A (EnDOtec DO*351)

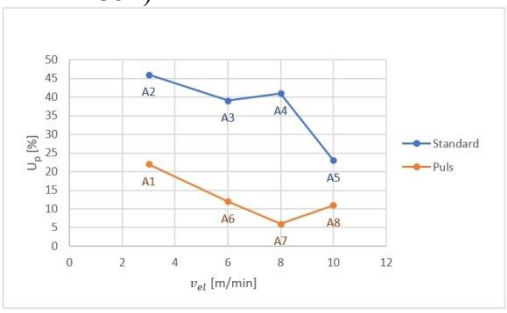


Fig. 9. Effect of electrode wire feed speed (v_{el}) on the dilution ratio (U_p) of hardfacing beads deposited using Wire A (EnDOtec DO*351)

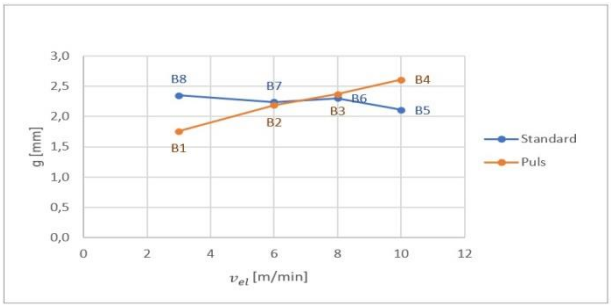


Fig 10. Effect of electrode wire feed speed (v_{el}) on the penetration depth (g) of hardfacing beads deposited using Wire B (EnDOtec DO*332)

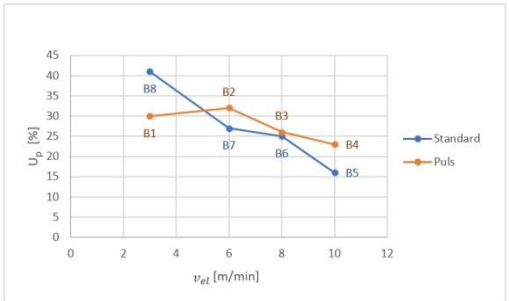


Fig. 11. Effect of electrode wire feed speed (v_{el}) on the dilution ratio (U_p) of hardfacing beads deposited using Wire B (EnDOtec DO*332)

By analyzing the results presented in Table 1, it can be observed that, as expected, an increase in the electrode wire feed speed (v_{el}) leads to a pronounced increase in the welding current, as well as in the width and reinforcement height of the deposited beads.

Analysis of the plots shown in Figures 8 and 10 indicates that, for Wire A deposited in the standard welding mode, the penetration depth initially increases significantly with increasing wire feed speed and then decreases sharply at the highest wire feed setting. In contrast, for Wire A deposited in the pulsed mode and for Wire B deposited in both welding modes, only minor changes in penetration depth were observed.

The plots presented in Figures 9 and 11 show that, for both filler materials, an increase in the electrode wire feed speed (v_{el}) results in a reduction of the dilution ratio, i.e., the proportion of base material incorporated into the deposited layer decreases. The lowest dilution values were recorded for Wire A deposited in the pulsed mode.

The conducted experiments clearly demonstrate the influence of individual process parameters on the geometry of the hardfacing bead. Such investigations are essential because the obtained results do not always follow trends reported in the literature. The observed discrepancies are most likely associated with the use of metal-cored wires rather than solid wires.

As mentioned previously, no geometrical investigations were performed for Wire C. Instead, the analysis was based on the results reported in [6]. The process parameters selected for both specimens are summarized in Tab. 2, while all remaining parameters were kept identical to those used in the earlier experiments.

Tab. 2. Summary of hardfacing process parameters and the corresponding measurement and calculation results for Wire C.

Specimen No.	Wire	Welding Mode	v_{el} [m/min]	Un [V]	U [V]	I [A]	b [mm]	h [mm]	g [mm]	A_n [mm²]	A_w [mm²]	U_p [%]
C1	DO*611X	Standard	6	19	19	220	11.41	1.44	0.47	10.93	1.5	12.1
C2	DO*611X	Standard	8	24	23.8	261	12.37	1.73	1.78	13.87	6.99	33.5

Each specimen was evaluated with respect to the uniformity of tungsten carbide distribution within the cross-section of the hardfacing layer. To achieve the most uniform wear resistance throughout the deposit, these high-hardness carbide particles should be distributed as evenly as possible across the entire hardfacing cross-section. Fig. 12 shows an example of Specimen C1, in which the distribution of tungsten carbides can be considered uniform.



Fig. 12. Cross-section of Specimen C1

Fig. 13 shows a photograph of Specimen C2. In this specimen, the hardfacing process parameters selected during deposition, particularly the excessively high welding current, caused the tungsten carbide particles to settle at the bottom of the hardfacing layer. This non-uniform carbide distribution reduces the wear resistance of the upper region of the deposited layer, where protection against abrasive wear is most critical.

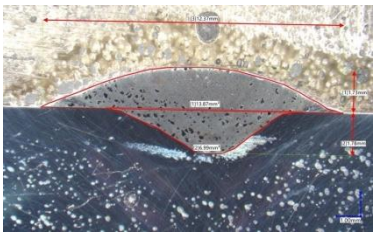


Fig. 13. Cross-section of Specimen C2

The results of the wear abrasive tests are presented in Tab. 3

Tab. 3. Results of the abrasive wear tests for the three filler wire types

Test Pin	Test Pin Mass		Test Pin Mass Loss [g]
	Before Testing [g]	After Testing [g]	
Test Pin without Hardfacing Layer	9.8001	9.7004	0.0997
Hardfaced Test Pin (Wire A)	11.5423	11.5379	0.0044
Hardfaced Test Pin (Wire B)	9.4240	9.4081	0.0159
Hardfaced Test Pin (Wire C)	12.4296	12.4237	0.0059

All test pins with hardfacing layers exhibited significantly lower mass loss compared with the unhardfaced test pin. However, the best performance was achieved by the hardfacing layer deposited using Wire A. In this case, the wear-related mass loss was less than 5% of that recorded for the unhardfaced specimen. For Wire B, the corresponding wear was less than 16%, while for Wire C it was less than 6% of the mass loss measured for the reference specimen without a hardfacing layer.

4. CONCLUSION

Based on the hardness measurements, tribological tests, and microscopic observations, the following conclusions can be drawn:

• All deposited hardfacing layers were free from welding defects such as cracks and porosity.

• For Wire A (EnDOtec DO*351), despite the increase in penetration depth, the proportion of base material incorporated into the hardfacing layer decreased.

• For Wire A (EnDOtec DO*351) deposited in the pulsed mode, the lowest dilution ratio between the deposited material and the substrate was achieved, reaching 6%.

• For Wire B (EnDOtec DO*332), despite the increase in welding current, only minor variations in penetration depth were observed. However, the dilution ratio, particularly in the standard welding mode, decreased significantly.

• The application of hardfacing layers produced with appropriate filler materials made it possible to substantially improve wear resistance. Compared with the unhardfaced reference specimen, wear was reduced by approximately 6 times for Wire B (EnDOtec DO*332), 17 times for Wire C (DO*611X), and nearly 23 times for Wire A (EnDOtec DO*351). Therefore, the selection of the hardfacing material plays a critical role in achieving the required wear resistance.

• The wear rate of the hardfacing layers, as determined by the abrasive wear tests, depends primarily on their chemical composition. However, the hardfacing process parameters also have a significant influence on bead geometry, penetration depth, overlay cross-sectional area, and the dilution ratio with the base material. These factors directly affect the performance and service properties of the deposited layer.

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