

Agnieszka Kiszka, Jacek Górka, Piotr Kiszka

Plasma Powder Surfacing of Toughened Steel S690Q Performed Using the NiBSi Powder with a Tungsten Carbide Addition

Abstract: The article presents results obtained during the plasma powder surfacing of steel s690Q. The tests involved the use of the NiBSi-based EuTroLoy PG 6503 powder with a tungsten carbide addition as well as the making of overlay welds on 30 mm thick plates. The tests involved the making of both simple and overlap runs with an overlap of 30÷70%. The overlay welds were subjected to hardness tests, abrasive wear tests as well as macro and microscopic tests. The tests made it possible to obtain high-quality overlay welds within a wide range of process parameters.

Keywords: Plasma Powder Surfacing, s690Q Steel, EuTroLoy PG 6503

DOI: [10.17729/ebis.2018.1/5](https://doi.org/10.17729/ebis.2018.1/5)

Introduction

The past 80 years have seen the nearly five-fold increase in the strength of structural steels, ranging from low-carbon steel S235J2G3 having a tensile strength of approximately 200 MPa, through normalised high-strength low-alloy steels (R_e – ca. 350 MPa) or TMCP (thermomechanical control processed and fast cooled) steels (R_e – 450-700 MPa) to toughened steels of the yield points reaching 1300 MPa [1, 2].

Properties of steels can be improved through the process of toughening, i.e. hardening and tempering. Toughened steels, characterised by a tensile strength of 690 MPa, are often used as structural materials in civil engineering or in load-bearing elements of industrial machines. However, mechanical properties are not the only criterion adopted when selecting materials.

Another important factor is appropriate resistance to abrasion and other wear-related phenomena. Exemplary applications of toughened steels include critical elements of mining equipment operated in the chemically aggressive environment and subjected to significant abrasion. Other applications of toughened steels include working elements of construction equipment such as excavator scoops, transport worms, drop forging dice, crusher hammers, rolls used in steelworks etc. [1, 6, 7, 8, 9, 10].

Operating conditions of machinery elements made of toughened steels often require the additional protection of surface (because of insufficient hardness). The selection of a protective measure should be preceded by the determination of wear-related phenomena and material weldability. One of the more precise methods

mgr inż. Agnieszka Kiszka (MSc Eng.) – Instytut Spawalnictwa, Welding Technologies Department;
dr hab inż. Jacek Górka (PhD (DSc) Habilitated Eng.), Professor at Silesian University of Technology, Department of Welding; mgr inż. Piotr Kiszka (MSc Eng.) – Fronius Poland Ltd.

enabling the protection of surface is PTA (plasma transferred arc) powder surfacing making it possible to surface layers with the minimum stirring of the material and the significantly reduced effect of heat on the base material [2, 3, 4, 5].

Objective and Scope

The research work aimed to develop the technology of the plasma powder welding of 30 mm thick toughened steel s690Q. The research-related tests involved the use of specimens having dimensions of 150 mm × 300 mm. The abrasion resistant surfaced material was powder NiBSi with an addition of tungsten carbides [3]. The material was selected to protect steel s690Q against intense abrasion. The significant content of tungsten carbides (approximately 60%) and the high hardness of the matrix itself (approximately 49 HRC) make the weld deposit of the above-named powder resistant to abrasive wear. Table 1 presents the chemical composition of the PG 6503 powder used in the tests.

Table 1. Chemical composition of powder EuTroLoy PG 6503 [3]

Chemical composition, %				
Ni	Si	Fe	B	C
Rest	3.5	3.0	2.3	0.2

Note: tungsten carbide constitutes 60% of the powder mass.

The EuTroLoy PG 6503 powder is made through atomisation in gas. The powder granularity is restricted within the range of 63 to 180 µm. The powder matrix hardness was restricted within the range of 45 to 49 HRC. The hardness of carbides amounted to 2000 HV10.










All of the overlay welds on steel s690Q plates were made using a robotic station equipped with a SRV6 welding robot (Reis Robotics) and an EuTronic GAP 2000 DC plasma device (Castolin Eutectic) combined with a GAP E52 plasma torch mounted on the robot arm. The station enabled the swinging motion of the torch. The process of surfacing was performed using plasma gas, powder carrier gas and shielding gas (pure argon).

The identification of the field of the plasma powder surfacing of plates made of steel s690Q performed using the EuTroLoy PG 6503 powder required the performance of surfacing tests involving the making of simple runs and enabling the determination of the following:

- surfacing current range, A,
- powder feeding rate, g/min (Table 2).

To determine the field of the parameters of the plasma powder surfacing of 30 mm thick toughened steel s690Q it was necessary to make a number of overlap overlay welds. The adopted variable parameters were the following:

Table 2. Overlay welds made using simple runs

Specimen no. 1 55 A, 25 g/min	Specimen no. 2 55 A, 30 g/min	Specimen no. 3 55 A, 35 g/min	Specimen no. 4 65 A, 25 g/min	Specimen no. 5 65 A, 30 g/min	Specimen no. 6 65 A, 35 g/min	Specimen no. 7 75 A, 25 g/min	Specimen no. 8 75 A, 30 g/min	Specimen no. 9 75 A, 35 g/min
								

- surfacing current, A,
- surfacing rate, mm/s,
- powder feeding rate, g/min,
- overlay weld overlap, %.

All of the tests involved the use of a plasma gas (Ar) flow rate of 3.5 l/min, a shielding gas (Ar) flow rate of 9 l/min, a powder carrier gas (Ar) flow rate of 2.5 l/min and the distance between the torch nozzle and the material amounting to 8 mm.

All of the overlay welds were subjected to visual and macroscopic tests as well as hardness measurements performed in the base material, HAZ and in the overlay weld. Table 3 presents the macroscopic metallographic photographs and photographs of exemplary overlay weld faces.

The subsequent stage of the research involved the performance of hardness measurements. The measurements were performed on the cross-section of the specimens, in one measurement line in the base material, HAZ and in the overlay weld, maintaining appropriate distances between successive measurement points (Fig.1). Microhardness measurements were performed using a Micro Vickers 401 MVD hardness tester. The results of the visual, metallographic and hardness tests of the overlay welds were used to select 2 groups of parameters related to the surfacing of toughened steel S690Q performed using the PTA method and the EuTroLoy PG 6503 powder and applied in abrasive wear resistance tests (Table 5).

Table 3. Photographs of the overlay weld face and the cross-sectional macroscopic metallographic photographs of the overlay welds with the overlap run; etchant: Adler's reagent.

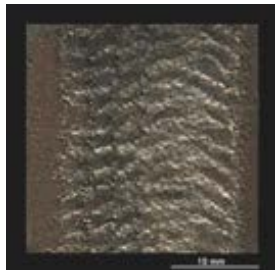
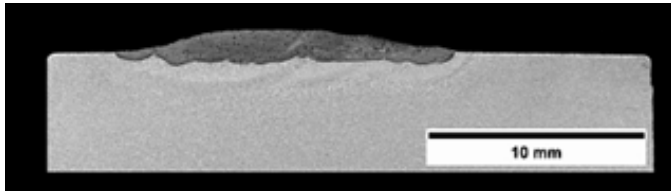
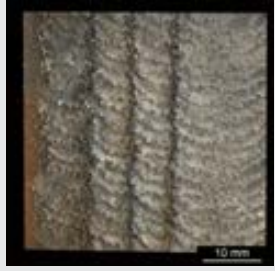
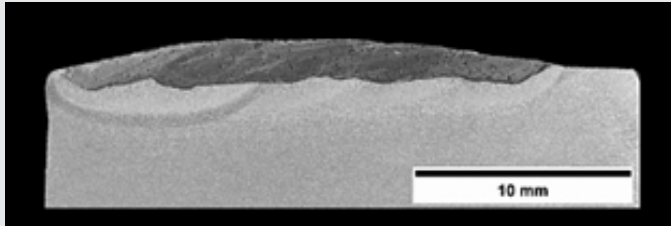

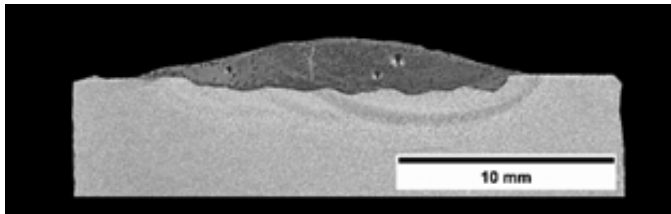

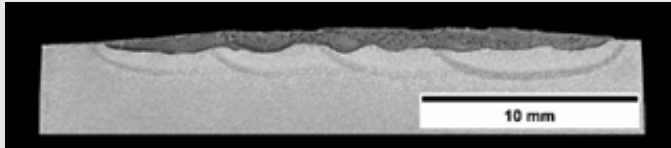
Specimen no.	Photograph of overlay weld face	Overlap size, %	Overlay weld cross-sectional macroscopic photograph
1		30	
2		50	
3		70	
4		30	

Table 4. Hardness measurements test results related to the specimens cut out of the overlay welds

Specimen no.	Microhardness (HV1) measurement								
	Overlay weld			HAZ			Base material		
	1	2	3	4	5	6	7	8	9
1	544	597	607	301	295	299	285	286	283
2	572	606	620	297	299	232	287	289	285
3	590	623	644	312	304	281	286	283	284
4	544	566	582	299	295	292	285	285	287

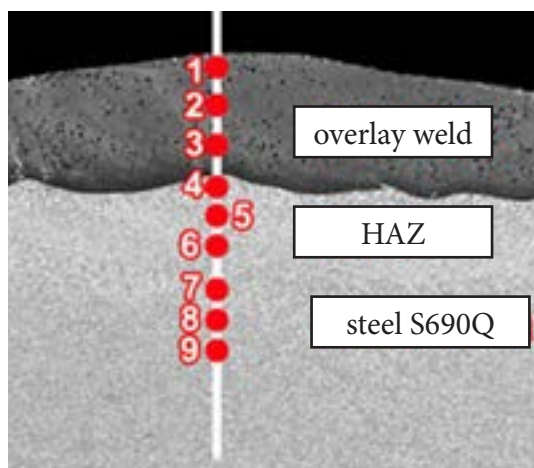


Fig. 1. Measurement line and points used in the microhardness HV1 tests of overlay welds

The subsequent stage of the research work involved Rockwell hardness tests performed on the ground faces of overlay weld specimen nos. 8 and 15 as well as steel HARDOX 400 (as a reference standard). The hardness measurements were performed using a Wilson Wolpert Rockwell Hardness 600MRD hardness tester. Hardness was measured at 5 points on each test specimen. The HRC hardness tests were performed on 6 specimens described below. The hardness measurement results are presented in Table 6.

- specimen 8-1: overlay weld no. 8 (surfacing parameters in Table 4),
- specimen 8-2: overlay weld no. 8 (surfacing parameters in Table 4),
- specimen 15-1: overlay weld no. 15 (surfacing parameters in Table 4),
- specimen 15-2: overlay weld no. 15 (surfacing parameters in Table 4),
- specimen H-1: steel Hardox 400,
- specimen H-2: steel Hardox 400.

Table 5. Parameters of the PTA surfacing of steel S90Q using the EuTroLoy PG 6503 powder

Specimen no.	Current, A	Voltage, V	Surfacing rate, mm/s	Overlap, %	Powder feeding rate, g/min
8	65	27.7	0.8	30	30
15	75	29.5	0.8	70	35

Table 6. Results of the HRC hardness tests performed on the ground face of the overlay welds subjected to abrasive wear resistance tests

Specimen designation	HRC hardness, successive measurement points				
	1	2	3	4	5
8-1	40.4	41.5	46.5	48.4	50.2
8-2	46.0	41.2	41.7	46.7	46.3
15-1	47.8	47.0	45.6	49.2	45.0
15-2	39.6	44.0	41.0	47.6	45.9
H-1	44.3	43.4	43.0	44.6	44.7
H-2	44.0	43.5	42.2	43.7	43.6

The subsequent stage of research involved the performance of microscopic metallographic tests. The tests included the taking of photographs of the base material, the interface with the HAZ and of the overlay weld (Fig. 2÷9). The images were magnified 200 and 500 times.

Abrasive Wear Resistance Tests

Tests aimed to identify the abrasive wear resistance of the layers applied using plasma surfacing and the EuTroLoy PG 6503 powder and of steel HARDOX 400 (used as a reference standard) were performed in accordance with ASTM G 65-00, Procedure A. The test specimens (75×25×10 mm) were cut out of plates subjected to plasma powder surfacing performed using the EuTroLoy PG 6503 powder and steel



Fig. 2. Base material – microstructure of steel S690Q, mag. 200x, etchant: Nital, specimen no. 8, welding parameters presented in Table 5



Fig. 3. Microstructure of the interface between the overlay weld and the base material, mag. 200x; specimen no. 8; etchant: FeCl₃; surfacing parameters presented in Table 5

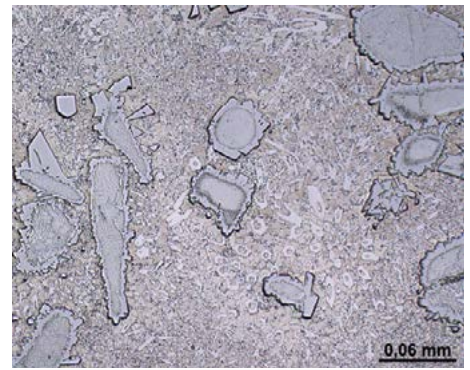


Fig. 4. Overlay weld microstructure; mag. 200x; specimen no. 8; etchant: FeCl₃; surfacing parameters presented in Table 5

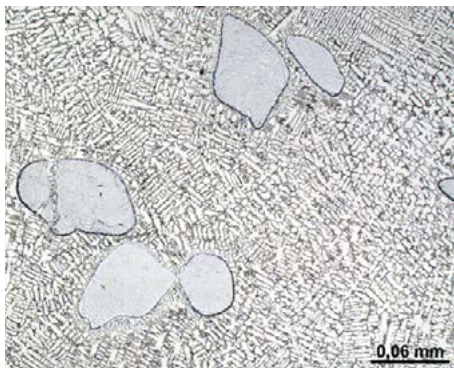


Fig. 5. Overlay weld microstructure; mag. 200x; specimen no. 8; etchant: FeCl₃; surfacing parameters presented in Table 5

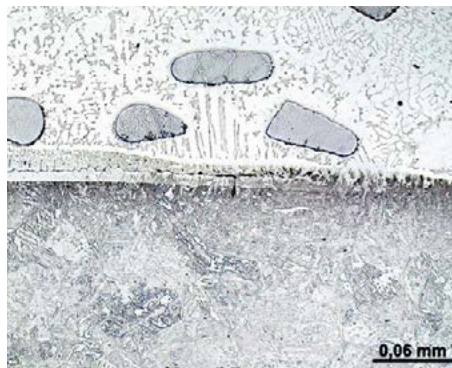


Fig. 6. Interface microstructure; mag. 200x; specimen no. 15; etchant: FeCl₃; surfacing parameters presented in Table 5

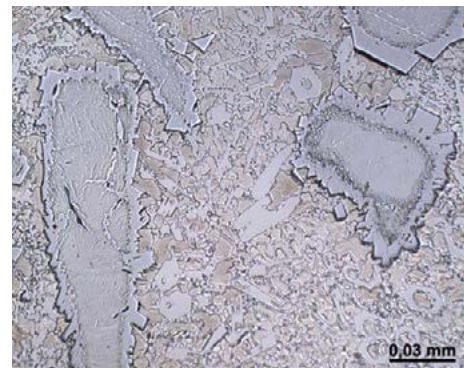


Fig. 7. Overlay weld microstructure; mag. 500x; specimen no. 15; etchant: FeCl₃; surfacing parameters presented in Table 5

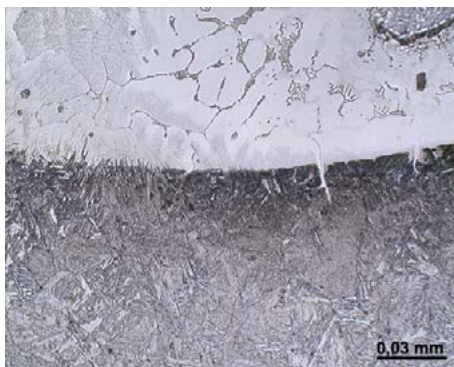


Fig. 8. Interface microstructure; mag. 500x; specimen no. 15; etchant: FeCl₃; surfacing parameters presented in Table 5

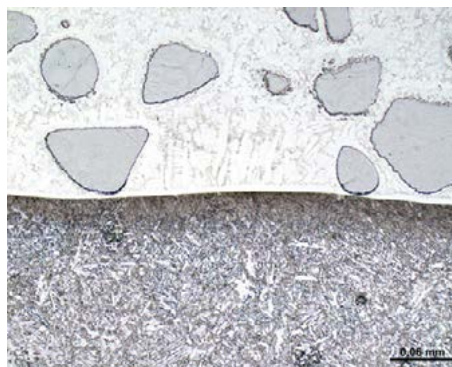


Fig. 9. Interface microstructure; mag. 200x; specimen no. 15; etchant: FeCl₃; surfacing parameters presented in Table 5

HARDOX 400, and, subsequently, subjected to grinding. Following the recommendations of ASTM G 65-00, before and after the abrasion tests, all of the specimens were weighed on a laboratory scale using an accuracy of up to 0.0001 g (Table 7). The mass decrement of the specimens subjected to plasma surfacing performed using the EuTroLoy PG 6503 powder were compared directly with that of the

specimens made of steel HARDOX 400. The volume mass decrement was calculated using the measured density of the sprayed (surfaced) layer and the specimen mass decrement (Table 8).

Analysis of Test Results

The surfacing tests performed using variable parameters revealed their effect on the geometry and the content of the base material in the overlay weld. In terms of the parameters subjected to the tests, the maximum penetration depth was restricted within the range of 0.85 to 1.67 mm, whereas the penetration area was restricted within the range of 10.20 to 38.79 mm². The shallowest penetration depth of 0.85 mm was obtained using a welding current of 55 A, a filler metal powder filling rate of

Table 7. Specimens after abrasive wear resistance tests

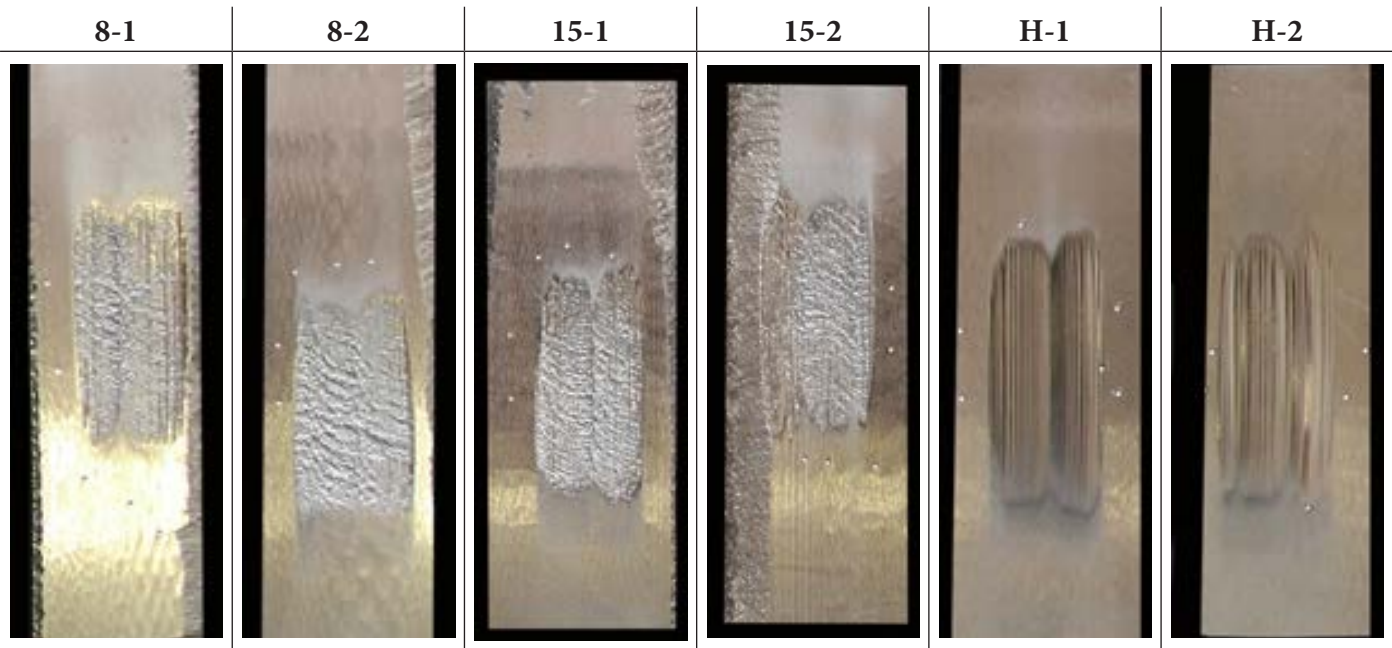


Table 8. Test results concerning the metal-mineral type abrasive wear resistance of layers applied plasma surfacing performed using the EuTroLoy PG 6503 powder and referred to the abrasive wear resistance of steel HARDOX 400; test were performed in accordance with ASTM G 65-00

Specimen symbol	Weight before test, g	Weight after test, g	Mass decrement, g	Mean mass decrement, g	Volume decrement, mm ³	Relative abrasive wear resistance
8-1	130.8829	129.8003	1.0826	0.9936	109.6689	1.68
8-2	130.6147	129.7101	0.9046			
15-1	159.4813	158.1007	1.3806	1.4071	148.8995	1.24
15-2	164.0396	162.6060	1.4336			
H-1	58.0006	56.4997	1.5009	1.4464	184.4898	1.00
H-2	56.5966	55.2048	1.3918			

Note: thickness of layers: EuTroLoy PG 6503: specimen 8 – 9.06 g/cm³, specimen 15 – 9.45 g/cm³, Hardox 400 (specimens H) – 7.84 g/cm³; force exerted on the specimens during the test amounted to 130 N; volume decrement, mm³ = mass decrement g/density g/cm³ x 1000.

25 g/min, an overlap of 30 % and a welding rate of 1.2 mm/s. In turn, the deepest penetration depth of 1.67 mm was obtained using a welding current of 65 A, a filler metal powder filling rate of 30 g/min, an overlap of 50 % and a welding rate of 1.2 mm/s.

The Vickers (HV₁) hardness tests revealed that the base material was characterised by a hardness of 280 HV₁. The cross-sectional hardness measurements of the overlap overlay welds made of steel s690Q subjected to plasma powder surfacing performed using the EuTroLoy PG 6503 powder revealed that the hardness in the HAZ was restricted within the range of 264

to 389 HV₁, whereas the hardness of the overlay weld was restricted within the range of 680 to 400 HV₁.

The Rockwell hardness tests involving the ground face of the overlay welds revealed hardness values restricted within the range of 39.6 to 50.2 HRC. It can be assumed that the above-named range was consistent with the matrix hardness-related data provided by the producer.

The microscopic tests revealed that the base material structure was composed of tempered martensite and that the HAZ contain martensitic structures having a hardness of 400 HV₁. The structure of the overlay welds consisted of

solution γ with boride silicate eutectics with visible tungsten carbides. It was observed that the effect of the surfacing thermal cycle led to the dissolution of carbides located in the matrix, which, in turn, triggered changes in the functional properties of the coatings. The size of overlay weld grains was not significantly affected by the welding linear energy.

The test results concerning the metal-mineral type abrasive wear resistance of the layers subjected to plasma surfacing performed using the EuTroLoy PG 6503 powder and the specimens made of steel Hardox 400 revealed the mass decrement restricted within the range of 0.9046 g to 1.5009 g. The measured volume decrement was restricted within the range of 109.6689 mm³ to 184.4898 mm³. The above-presented data were used to calculate relative abrasive wear, referring to the test results concerning the abrasive wear resistance of steel Hardox 400. The best result was obtained in terms of specimen no. 8, where the abrasive wear resistance amounted to 1.64 in relation to steel Hardox 400. In turn, as regards specimen no. 15, the abrasive wear resistance amounted to 1.24 in relation to steel 400.

It was possible to observe the effect of welding linear energy on the abrasion resistance of overlay welds nos. 8 and 15. The specimens cut out of overlay weld no. 8, where linear energy amounted to 2.251 kJ/mm, were characterised by higher abrasion resistance. In turn, specimens cut out of overlay weld no. 15, where linear energy amounted to 2.766 kJ/mm, were characterised by slightly lower abrasion resistance. Higher welding linear energy increases the content of the base material in the overlay weld, which significantly affects abrasive wear resistance.

Conclusions

The test results concerning the plasma powder surfacing of 30 mm thick toughened steel S690Q using the NiBSi-based EuTroLoy PB 6503 containing a tungsten carbide addition revealed the following.

1. It is possible to make high-quality welding imperfection-free overlap overlay welds within a wide range of surfacing parameters (surfacing current restricted within the range of 55A to 75A, filler metal wire feeding rate restricted within the range of 25 g/min to 35 g/min and an overlap restricted within the range of 30 % to 50 %).
2. The overlay welds were characterised by the nickel matrix containing tungsten carbides and a hardness of 600 HV1. The HAZ structure was martensitic and characterised by a hardness of approximately 400 HV1. The base material structure was composed of tempered martensite.
3. The hardness of the ground overlay weld face amounted to 45 HRC, which was consistent with the data provided by the filler metal manufacturer.
4. Resistance to metal-mineral abrasion of the overlay welds was higher by approximately 30 to 70% in comparison with that of steel Hardox 400.
5. The abrasive wear was affected by welding linear energy. An increase in welding linear energy was accompanied by an increase in the content of the base material in the overlay weld, which, in turn, led to a decrease in abrasive wear resistance.

References

- [1] Beake B.D., Goodes S.R., Smith J.F.: *Micro-impact testing: a new technique for investigating thin film toughness, adhesion, erosive wear resistance and dynamic hardness*. Surface Engineering, 2001, no. 3, pp. 187-192.
<http://dx.doi.org/10.1179/026708401101517755>
- [2] O'Brien M., Lumb R.F.: *Effect of repeated post-weld heat treatment cycles on properties of a QT pressure vessel plate: some preliminary observations*. Australian Welding Journal, 2001.
- [3] Cards of material specifications by Messer Eutectic Castolin

- [4] Nefedov B.B., Lyalyakin V.P.: *Development of plasma welding and surfacing abroad*. Welding International, 1998, no. 12. <http://dx.doi.org/10.1080/09507119809452045>
- [5] Marconi B.: *Powder plasma arc welding of thick walled pipes*. Welding World, 2005, special edition, pp. 249-264.
- [6] Kuba P., Kubenka M.: *Corrosion-and wear-resistant 17% Cr strip weld overlays*. Svetsaren, 2001, no. 1, pp. 8-10.
- [7] Sun Y., Li X., Bell T.: *Low temperature plasma carburising of austenitic stainless steels for improved wear and corrosion resistance*. Surface Engineering, 1999, no. 1, pp. 49-54. <http://dx.doi.org/10.1179/026708499322911647>
- [8] Jiang W.H., Kovacevic R.: *Slurry erosion resistance of laser clad Fe-Cr-B-Si coatings*. Surface Engineering, 2004, no. 6, pp. 464-468. <http://dx.doi.org/10.1179/174329404x7135>
- [9] Silva R.H., Dutra J.C.: *Thermal-pulsed MIG/MAG welding applied to the repair of cavitation erosion on large-scale hydraulic turbines*. Welding and Cutting, 2009, no. 1, pp. 27-30.
- [10] Matthes K.J., Alalus K.: *Welding deformation and internal welding stress in PTA deposition shaped components*. Welding & Metal Fabrication, 2001, no. 8, pp. 11-16.