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Robotized PTA surfacing of nanomaterial layers

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ABSTRACT

Purpose: of this research was to investigate the influence of heat input in robotized surfacing on quality and properties of nanomaterial layers.
Design/methodology/approach: quality of single and multilayer, stringer and weave beads was assessed by abrasion resistance tests according to ASTMG65 standard, erosion resistance tests according to G76 standard, metallographic examinations and hardness tests.
Findings: due to the fact that the robotized surfacing stand was used, the analysis of properties of the deposits was performed for single and multilayer, stringer and weave beads.
Research limitations/implications: for complete information about tested deposits it is needed to compare deposits properties PTA surfaced with other technologies of nanomaterial layers manufacturing products.
Practical implications: Results of this paper is an optimal range of parameters of surfacing of single and multilayer, stringer and weave beads of nanomaterial layers.
Originality: tests, abrasion and erosion resistance tests) were provided for surfacing of single and multilayer, stringer and weave beads, and the results were compared. The influence of heat input on layers properties and theirs structure was defined.
Keywords: welding, robotized surfacing, nanomaterial, abrasion and erosion resistance

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1. Introduction

In designing process of modern machines, designers must remember about ensuring the highest possible economical and technical effects. Unfortunately, not all machines work in optimal service conditions, very often in dusty and moist rooms with maximal 3 working ships duty. Operational wear of parts of these machines, defined as decrease of working surface operational use properties, occurred during their using [1, 4, 6, 7, 9].

Worn out parts of machines should be replaced to ensure correct machines' operation and workers safety. Necessity of worn parts replacement results in growing operational costs. Because of this frequent replacement is economically ineffective, welding regeneration processes are competitive and provide with significant decrease of operating costs. Usually costs of regeneration using thermal spraying or surfacing is not higher than 60% of new part price [2, 4, 5, 7, 8].

Most effective solutions is a machine part manufactured with modified surface layer of higher corrosion, erosion or cavitation resistance or if needed, heat resistance properties with possibility to repair regeneration [2, 3, 19, 20, 21].

Particular application to regenerate surfacing is plasma surfacing process. PTA surfacing leads to obtain high quality deposits with strictly limited dilution in comparison with other arc surfacing methods. PTA surfacing can be used for regeneration of plain and also rotatable parts made of carbon, alloy and stainless steel and some sorts of cast iron. This method is used for producing surface layers on engine parts, cutting tools, valves, valve-seats, roll necks and metallurgical fittings parts [7, 8, 10].

Technological progress in science and industry results in continuous, intensive growth of many sectors of modern technological processes including nanotechnologies.

Nanotechnology term encloses science and engineering concerns materials manufacturing in nanometres scale [11]. First information about nanotechnologies we can find in R. Feynman (1918-1988) publications where he shows world picture where arbitrary structures are built from single atoms. Also K. E. Drexler (born in 1955) has shown theoretical possibility to create mechanical structures in nano-macro scale – building machines from single atoms [12, 13, 14].

Typical nanostructure materials are quantum dots and bars, grains, particles, nanopipes, nanorods, nanofibres, nanocrystalines, intermetallic phases, semiconductors, minerals, biomaterials, polymers and organic materials. Nanomaterials are defined as regular structures with grain size not bigger than 100 nanometres or thickness of layers manufactured on substrate [17].

It is probable that in next 15 years period, biggest market participation will have nanomaterials in technological means (for tough materials and coatings) [16,18].

As in nanostructure particles about 40% atoms are placed at the surface and are a phase boundary, it has significant influence on mechanical properties (ex. hardness, strength in higher temperatures, brittle cracking, creep, wear and corrosion resistance) [16, 18].

2. Researches

Programme of study of technology of automatic PTA X161 metal cored wire surfacing and properties of the stringer and weave bead deposits was as follows:

- design and set up of automatic PTA metal cored wire surfacing stand equipped with REIS welding robot SRV6, Casto TIG 2202 AC/DC and MultiPlasmaModul ToolTec GAP-Multibox E12N power source and KD3 wire feeder produced by Castolin, Fig. 1,
- study of influence of parameters of PTA X161 metal cored wire 1.2 [mm] dia. surfacing of stringer and weave bead deposits on 2.0 and 4.0 [mm] thick carbon steel S355J2G3 on the quality and geometry of the deposits and dilution and efficiency of surfacing, Table 3 to 7,
- visual and penetrant testing (PT) inspections, Figs. 2 and 3,
- metallographic examinations – macrostructure of stringer bead deposits, multi stringer bead deposits and weave bead deposits surfaced,
- HRC hardness tests on the ground surface of all deposits tested, Table 8.
- ASTM G65 abrasive wear resistance tests and ASTM G76 erosion wear resistance tests of selected one layer multi stringer bead deposits and weave bead deposits PTA X161 1.2 [mm] dia. wire surfaced in comparison with HARDOX 400 steel plate, Tables 9 and 10 and Figs. 4 and 5.

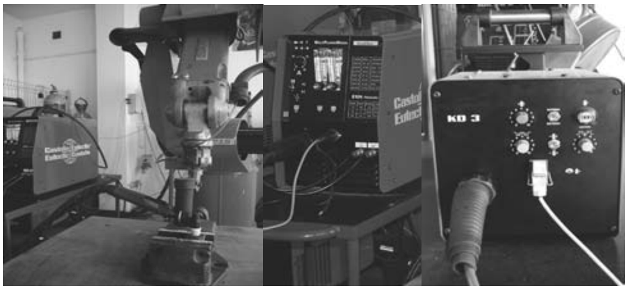

Fig.1. PTA surfacing robotized stand, power source, wire feeder

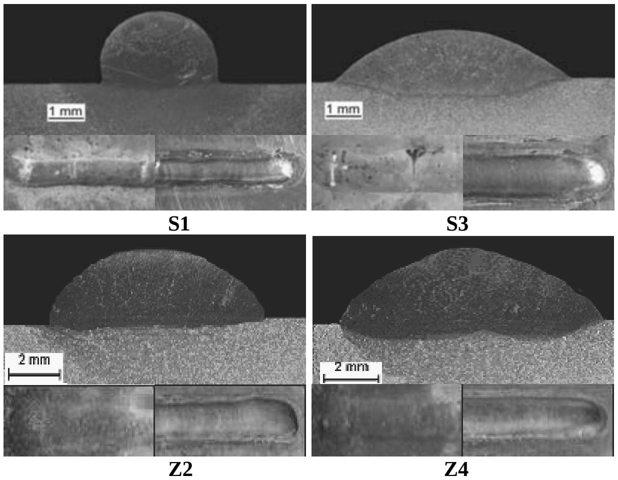

Fig. 2. Macrographs of single stringer bead deposits PTA X161 metal cored wire 1.2 [mm] dia. Surfaced and view of deposits face after PT examinations and visual inspection, Tables 3 and 4

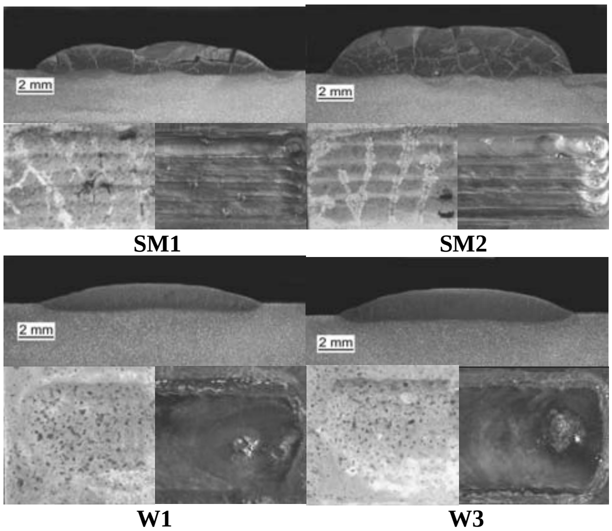

Fig. 3. Macrographs of single weave bead deposits PTA X161 metal cored wire 1,2 [mm] dia. surfaced, Surfaced and view of deposits face after PT examinations and visual inspection Tables 5 to 7. Visible transverse and longitudinal cracks in multi stringer beads deposits

Table 1.
Chemical composition of materials used as the base plates for PTA surfacing of X161 wire dia. 1.2 [mm] deposits (PN-EN 10025:2007)

<table>
<tr><th>Grade of steel</th><th colspan="5">Chemical composition, % by weight</th></tr>
<tr><td rowspan="4">S355NL</td><td>C</td><td>Mn</td><td>Si</td><td>P</td><td>S</td></tr>
<tr><td>0.18</td><td>1.36</td><td>0.45</td><td>0.02</td><td>0.02</td></tr>
<tr><td>Cr</td><td>Ni</td><td>B</td><td>Mo</td><td>C_e</td></tr>
<tr><td>0.09</td><td>0.10</td><td>-</td><td>-</td><td>0.424</td></tr>
</table>

An influence of PTA X161 metal cored wire 1.2 [mm] dia. surfacing parameters on the quality of single and multilayer stringer bead deposits was tested on 2.0 and 4.0 [mm] thick S355J2G3 steel plates in wide range of surfacing parameters changes. Deposits quality was assessed based on visual and PT examinations results, Table 3 and 4, Fig. 2. Analogical to stringer beads surfacing, the influence of PTA X161 metal cored wire 1.2 [mm] dia. surfacing parameters on the quality of weave bead deposits was tested on 2.0 and 4.0 [mm] thick S355J2G3 steel plates in wide range of surfacing parameters changes.

Table 2.
Chemical composition and typical hardness of X161 metal cored wire of the whole weld metal

<table>
<tr><th colspan="5">Chemical composition, wt%</th></tr>
<tr><td>Fe</td><td>C</td><td>Si</td><td>Cr</td><td>Mn</td></tr>
<tr><td>Bal.</td><td><5</td><td><2.0</td><td><20.0</td><td><5.0</td></tr>
<tr><td>W</td><td>Mo</td><td>Nb</td><td>B</td><td>Hardness HRC</td></tr>
<tr><td><10.0</td><td><10.0</td><td><10.0</td><td><5.0</td><td>68-72</td></tr>
</table>

Deposits quality was also assessed based on visual and PT examinations results, Tables 5 to 7, Fig. 3.

Hardness was measured on surface and cross section of deposits, Table 8. Measurements were provided to determine an influence of heat input on surface hardness and matrix microhardness.

Table 3.
The influence of PTA X161 metal cored wire 1.2 [mm] dia. surfacing parameters of S355J2G3 steel plates 2.0 and 4.0 [mm] thick on the quality of single stringer bead deposits, Fig. 2

<table>
<tr><th rowspan="2">Specimen designation</th><th rowspan="2">Arc current [A]</th><th rowspan="2">Arc voltage [V]</th><th rowspan="2">Surfacing speed [mm/s]</th><th rowspan="2">Wire feed speed [cm/min]</th><th rowspan="2">Heat input [kJ/mm]</th><th colspan="2">Transverse cracks</th></tr>
<tr><th>number of cracks</th><th>average distance between cracks [mm]</th></tr>
<tr><td colspan="8">Surfaced plate thickness: 4.0 mm</td></tr>
<tr><td>S1</td><td>50.0</td><td>18.1</td><td rowspan="4">3.0</td><td rowspan="4">80.0</td><td>0.300</td><td>5</td><td>6.94</td></tr>
<tr><td>S2</td><td>60.0</td><td>18.3</td><td>0.366</td><td>3</td><td>9.57</td></tr>
<tr><td>S3</td><td>70.0</td><td>18.2</td><td>0.425</td><td>3</td><td>12.85</td></tr>
<tr><td>S4</td><td rowspan="8">80.0</td><td>18.6</td><td>0.496</td><td>2</td><td>14.93</td></tr>
<tr><td>S5</td><td>18.1</td><td>2.0</td><td rowspan="4">100.0</td><td>0.724</td><td>3</td><td>15.26</td></tr>
<tr><td>S6</td><td>18.0</td><td>3.0</td><td>0.480</td><td>3</td><td>9.00</td></tr>
<tr><td>S7</td><td>17.8</td><td>4.0</td><td>0.356</td><td>3</td><td>8.80</td></tr>
<tr><td>S8</td><td>17.6</td><td>6.0</td><td>0.235</td><td>5</td><td>5.34</td></tr>
<tr><td>S9</td><td>18.2</td><td rowspan="3">3.0</td><td>60.0</td><td>0.485</td><td>5</td><td>7.53</td></tr>
<tr><td>S10</td><td>17.9</td><td>70.0</td><td>0.477</td><td>3</td><td>10.65</td></tr>
<tr><td>S11</td><td>18.2</td><td>120.0</td><td>0.485</td><td>8</td><td>5.92</td></tr>
<tr><td colspan="8">Surfaced plate thickness: 2.0 mm</td></tr>
<tr><td>Z1</td><td>70.0</td><td>18.3</td><td rowspan="4">3.0</td><td rowspan="4">80.0</td><td>0.427</td><td>0</td><td>0</td></tr>
<tr><td>Z2</td><td rowspan="5">80.0</td><td>18.2</td><td>0.485</td><td>0</td><td>0</td></tr>
<tr><td>Z3</td><td>18.2</td><td>0.485</td><td>0</td><td>0</td></tr>
<tr><td>Z4</td><td>18.6</td><td>0.496</td><td>0</td><td>0</td></tr>
<tr><td>Z5</td><td>18.1</td><td>2.0</td><td rowspan="3">100.0</td><td>0.724</td><td>0</td><td>0</td></tr>
<tr><td>Z6</td><td>18.0</td><td>3.0</td><td>0.480</td><td>0</td><td>0</td></tr>
<tr><td>Z7</td><td rowspan="2">70.0</td><td>17.8</td><td>4.0</td><td>0.311</td><td>0</td><td>0</td></tr>
<tr><td>Z8</td><td>18.2</td><td>3.0</td><td>120.0</td><td>0.425</td><td>0</td><td>0</td></tr>
</table>

Remarks: Surfacing current DC(-), W+ThO_2 electrode diameter – 2.4 [mm], electrode sharpening angle – 30˚, Plasma pilot arc current – 5.0-7.0 [A]. Arc length – 4.0 [mm], wire stick out – 15.0 [mm], wire feeding angle – 15°, shielding gas: argon - flow rate – 10.0 [dm^3/min], plasma gas: argon - flow rate – 0.7 [dm^3/min], temp. of surfacing – no preheat – 25-30˚C. All deposits are high quality -examination of the quality of stringer bead deposits on the length of 40 [mm]

Table 4.
The influence of PTA X161 metal cored wire 1.2 [mm] dia. surfacing parameters of S355J2G3 steel plate 2.0 and 4.0 [mm] thick on the shape, dilution and deposition rate of single stringer bead deposits, Table 3, Fig. 2

Specimen designation	b [mm]	hR [mm]	hBM [mm]	FR [mm2]	FBM [mm2]	Dilution * [%]	W** [kg/h]
Surfaced plate thickness: 2,0 mm							
S1	3.29	2.16	0.14	6.00	0.30	4.71	3.78
S2	4.69	1.77	0.22	5.94	0.61	9.30	3.74
S3	6.25	1.40	0.46	5.79	1.81	23.77	3.64
S4	6.24	1.39	0.57	5.83	2.31	28.36	3.67
S5	7.59	1.42	0.39	7.26	2.02	21.75	3.04
S6	6.09	1.23	0.32	5.15	1.18	18.69	3.24
S7	5.14	1.13	0.32	3.90	1.00	20.45	3.27
S8	3.92	1.16	0.22	3.10	0.37	10.71	3.90
S9	5.55	1.02	0.34	3.75	1.43	27.62	2.36
S10	5.68	1.09	0.31	4.15	1.42	25.53	2.61
S11	5.80	1.47	0.25	5.81	1.11	16.10	3.65
Surfaced plate thickness: 4,0 mm							
Z1	3.00	1.2	0.12	2.6	0.24	8.45	1.64
Z2	3.97	1.42	0.15	4.43	0.61	12.1	2.80
Z3	6.42	1.5	0.79	7.06	0.88	11.13	4.45
Z4	5.65	1.62	0.57	7.15	2.31	24.41	4.50
Z5	5.81	1.41	0.68	5.8	2.02	25.8	2.44
Z6	3.93	1.42	0.19	4.08	1.18	27.68	2.57
Z7	6.24	1.32	0.32	6.11	1.02	16.67	5.13
Z8	6.19	1.61	0.19	7.62	0.18	12,3	4.80

Remarks: * - dilution = FBM/(FR+FBM) x 100%, ** - deposition rate - W [kg/h] = FR [mm^2] x speed of surfacing [mm/s] x density of the deposit - [g/cm^3] x 0.0277. Geometrical parameters of stringer bead deposits: b – deposit bead width, hR – reinforcement height, hBM – penetration depth, FR – reinforcement area, FBM –penetration area

Table 5.
The influence of PTA X161 metal cored wire 1.2 [mm] dia. surfacing parameters of S355J2G3 steel plates 2.0 and 4.0 [mm] thick on the quality of single and multi layer stringer bead deposits, Fig. 3

Specimen designation	Arc voltage [V]	Speed of surfacing [mm/s]	Wire feed speed [cm/min]	Heat Input [kJ/mm]	Transverse cracks: number of cracks	Transverse cracks: distance between cracks [mm]	Longitudinal cracks in between transverse cracks
Surfaced plate thickness: 4.0 mm							
SM1*	18.5	3.0	120.0	1.479	8	5.07	4
SM2*	18.2			2.910	9	4.81	7
SL	18.4	4.0	100.0	0.368	12	7.64	20
SH	18.3	2.5	85.0	0.586	10	5.59	3
Surfaced plate thickness: 2,0 mm							
2Z1	18.4	3.0	100.0	0.490	11	5.8	7
2Z2					7	7.32	11

Remarks: W+ThO_2 electrode diameter – 2.4 [mm], electrode sharpening angle – 30˚, Arc current – 80.0 [A], Plasma pilot arc current – 5.0-7.0 [A]. Arc length – 4.0 [mm], wire stick out – 15.0 [mm], wire feeding angle – 15˚, shielding gas Ar - flow rate – 10.0 [dm^3/min], plasma gas Ar - flow rate – 0.7 [dm^3/min], temp. of surfacing – no preheat – 25-30 [˚C]. All deposits are of high quality, smooth face, no undercuts, but cracked - examination of the quality of stringer bead deposits on the length of 50 [mm]. * – SM1, 2Z1 – one layer multi stringer bead deposit, SM2, 2Z2 – two layer multi stringer bead deposit. Overlap width: SM1, SM2, SL, SH and 2Z2 – 4.0 [mm], 2Z1 – 3.0 [mm]

Table 6.
The influence of PTA X161 metal cored wire 1.2 [mm] dia. surfacing parameters of S355J2G3 steel plates 2.0 and 4.0 [mm] thick on the quality of single layer weave bead deposits, Fig. 3

Specimen designation	Arc voltage [V]	Speed of surfacing [mm/s]	Wire feed speed [cm/min]	frequency of triangle weaving motion [Hz]	Heat input [kJ/mm]	Transverse cracks: number of cracks	Transverse cracks: average distance between cracks [mm]	Longitudinal cracks in between transverse cracks
Surfaced plate thickness: 4.0 mm								
W1	18.3	0.8	70.0	0.3	1.830	0	-	-
W2	18.2	1.0	70.0	0.4	1.456	0	-	-
W3	18.5	1.2	70.0	0.5	1.233	0	-	-
WL*	18.4	1.2	70.0	0.5	1.226	10	7.24	9
WH*	18.2	0.8	60.0	0.25	1.820	1	-	2
Surfaced plate thickness: 2.0 mm								
2W1	18.4	1.0	70.0	0.4	0.368	6	4.63	-
2W2	18.3	1.2	70.0	0.5	0.488	4	8.32	-

Remarks: W+ThO$_2$ electrode diameter – 2.4 [mm], electrode sharpening angle – 30˚, Arc current – 80.0 [A], Plasma pilot arc current – 5.0-7.0 [A]. Arc length – 4.0 [mm], wire stick out – 15.0 [mm], wire feeding angle – 15˚, shielding gas Ar - flow rate – 10.0 [dm^3/min], plasma gas Ar - flow rate – 0.7 [dm^3/min], temp. of surfacing – no preheat – 25-30 [˚C]. Amplitude of triangle weaving motion – 6.0 [mm]. All deposits are of high quality, smooth face, no undercuts, but cracked - examination of the quality of weave bead deposits on the length of 50 [mm]. * - amplitude of triangle weaving motion – 12.0 [mm]

Table 7.
The influence of PTA X161 metal cored wire 1.2 [mm] dia. surfacing parameters of S355J2G3 steel plate 4.0 [mm] thick on the shape, dilution and deposition rate of multi stringer and weave bead deposits, Tables 5 and 6, Figs. 3

Specimen designation	b [mm]	hR [mm]	hBM [mm]	FR [mm2]	FBM [mm2]	Dilution* [%]	W** [kg/h]
SM1	13.26	1.87	0.33	17.57	208	10.61	1.84
SM2	13.75	2.93	0.33	33.31	2.23	6.27	3.49
W1	12.97	1.54	0.48	14.04	4.48	24.19	3.53
W2	11.89	1.40	0.47	11.51	3.37	22.66	2.41
W3	12.23	1.15	0.48	9.52	475	33.28	1.60
2Z1	18.22	1.51	0.89	25.23	14.09	35.83	3.18
2Z2	16.81	1.91	0.81	30.70	12.24	28.51	4.83
2W1	13.07	1.89	1.4	20.65	15.73	43.23	4.3
2W2	13.13	1.61	1.32	19.24	14.23	42.5	4.9

Remarks: * - dilution = FBM/(FR+FBM) x 100%, ** - deposition rate - W [kg/h] = FR [mm^2] x speed of surfacing [mm/s] x density of the deposit - [g/cm^3] x 0.0277. Geometrical parameters of stringer bead deposits: b – width of deposit bead, hR – reinforcement height, hBM – depth of penetration, FR – reinforcement area, FBM – depth of penetration area

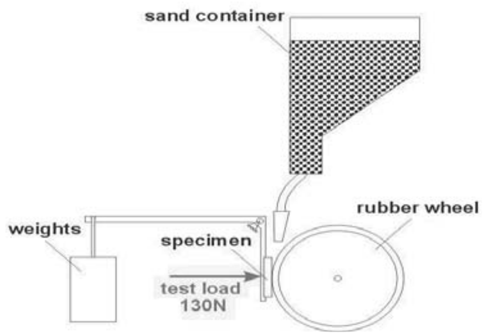

Fig. 4. Schematic diagram of ASTM G65 Procedure A abrasive wear resistance test apparatus

To determine quantitatively the abrasive wear resistance of PTA X161 wire single layer stringer and weave bead deposits and HARDOX 400 steel plate, the tests of abrasive wear of metal-ceramic type were conducted in accordance with standard ASTM G 65-00 - Standard Test Method for Measuring Abrasion Using the Dry Sand/Rubber Wheel Apparatus, Fig. 4.

Procedure A of the ASTM G65 standard was chosen. Quartz Ottawa sand was used for the tests. Sand had tightly limited particle size in U.S. sieve size - 50 to +70 (-300 to + 212 [μm]) and moisture content under 0.5% weight. The rate of sand flow through the special nozzle, in the shape of thin layer between the test piece and a hard rubber wheel 229 [mm] in diameter, was adjusted at the rate 300-400 [g/min]. The 25 [mm] wide and 75 [mm] in length abrasive wear resistance test specimens were cut from the middle area of surfaced deposits and HARDOX 400 steel plate. All specimens were weighed to the nearest 0.0001 [g] as required by ASTM G65-00. Next abrasive wear resistance test was conducted. The force applied pressing the test coupon against the wheel was TL = 130 [N] (test load - TL). After the abrasive wear resistance test, the test specimen was weighed at weight sensitivity 0.0001 [g]. Mass loss of specimens was reported directly and relatively in comparison with the mass loss of the reference HARDOX 400 steel plate. Next the density of the weld metal of PTA X161 metal cored wire was measured and abrasive tests results were reported as volume loss in cubic millimetres, Table 9, by converting mass loss to volume loss as follows:

Volume loss, [mm^3] = mass loss [g] : density [g/cm^3] x 1000

To determine quantitatively the erosion behaviour of PTA X161 metal cored wire surfaced single layer stringer and weave bead deposits and HARDOX 400 steel plate, the tests of erosion wear were conducted in accordance with standard ASTM G 76-95 - Standard Test Method for Conducting Erosion Tests by Solid Particle Impingement , Fig. 5. Nozzle tube is manufactured from tungsten carbide and is 50 [mm] long and 1, 5 [mm] of the inner diameter. Abrasive particles of angular Al_2O_3 of nominal dimension – 50 [µm] are fed with the rate 2.0±0.5 [g/min] during the tests. The abrasive particles velocity was kept in the range 70±2 [m/s] and stream of dry air is supplied at the flow rate 8.0 [l/min]. Samples 70x25x10 [mm] were cut from surfaced deposits and HARDOX 400 steel plate and the surface of deposits and HARDOX 400 steel plate were ground by abrasive papers to 400 grit size and prepared by alcohol cleaning.

Before erosion tests of specimens, it was started to calibrate the erosion test apparatus, which was conducted as per standard ASTM G76-95. Next the erosion tests of surfaced specimens and HARDOX 400 steel plate were made during 10 [min], at erodent impact angle 30°, and results are collected in Table 10. Erodent impact angle 30° was chosen as the typical impact angle advised for erosion tests for very hard materials.

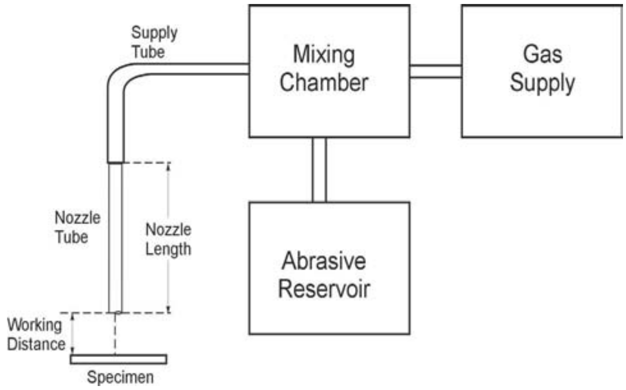

Fig. 5. Schematic diagram of standard ASTM G76-95 erosion tests apparatus

Table 8.
Results of hardness HRC tests on the ground surface of PTA X161 metal cored wire surfaced single stringer and weave bead deposits, Tabs. 3 to 7

Specimen designation	HRC hardness measurement points						HRC average
	1	2	3	4	5	6	
S1	65.6	64.1	65.6	64.9	66.0	65.9	65,4
S2	63.4	67.6	66.0	65.3	65.4	66.7	65.7
S3	60.0	68.4	68.9	69.3	68.0	68.2	67.1
S4	66.7	58.5	67.0	67.4	67.2	66.5	65.6
S5	66.1	62.6	68.1	68.1	66.9	68.3	66.7
S6	61.8	67.0	67.7	67.5	68.7	67.9	66.8
S7	69.0	68.2	60.2	69.3	67.9	68.1	67.1
S8	63.7	68.8	68.7	69.2	67.1	68.2	67.6
S9	66.5	69.9	68.7	68.9	68.5	68.9	68.6
S10	67.9	61.5	69.1	70.0	69.9	70.3	68.1
S11	63.2	66.7	61.2	71.0	65.4	67.8	65.9
SM1	66.9	65.6	62.6	58.8	68.8	62.3	64.2
SM2	61.0	59.3	69.6	69.3	61.9	67.8	64.8
SL	65.1	64.0	64.7	70.5	70.3	70.9	67.6
SH	56.0	62.3	66.0	62.5	65.5	63.6	62.7
W1	67.4	67.1	68.3	67.0	66.9	67.0	67.3
W2	64.5	67.8	66.8	66.6	68.1	66.0	66.6
W3	65.2	68.3	68.0	68.9	68.1	67.9	67.7
WL	67.3	68.1	67.4	68.1	67.5	68.0	67.7
WH	60.5	64.5	66.5	66.1	64.9	66.5	64.8

Table 9.
Results of low-stress abrasive wear resistance to metal-ceramic scratching by Ottawa quartz sand of PTA X161 metal cored wire 1.2 [mm] dia. surfaced stringer bead and weave bead deposits in accordance to ASTM G65-00, Tables 5 to 7

Specimen designation	Number of specimen	Weight before test [g]	Weight after test [g]	Mass loss [g]	Average mass loss [g]	Average volume loss [mm^3]	Relative* abrasive wear resistance
HARDOX 400 steel plate	H-1	62.2260	60.7526	1.4734	1.4617	185.730	1.00
	H-2	63.1222	61.6721	1.4501			
SL**	SL1	64.3443	64.3068	0.0977	0.1077	14.2272	13.05
	SL2	59.8615	59.7435	0.1177			
SH	SH1	67.7796	67.6733	0.1065	0.0977	12.9128	14.38
	SH2	65.8580	65.8290	0.0890			
WL	WL1	55.9765	55.8104	0.1661	0.1638	21.6314	8.59
	WL2	58.5282	58.3668	0.1614			
WH	WH1	59.9548	59.7876	0.1672	0.1506	19.8943	9.34
	WH2	59.9800	59.8860	0.1340			

Remarks: Density of weld metal of PTA X161 metal cored wire 1.2 [mm] dia. surfaced deposit – 7.57 [g/cm^3] and HARDOX 400 steel density – 7.86 [g/cm^3]. * - abrasive wear resistance relative to HARDOX 400 steel plate. ** - SL – low heat input stringer bead deposit, WH – high heat input weave bead deposit

Table 10.
Results of erosion wear resistance tests of specimens of PTA X161 metal cored wire 1.2 [mm] dia. surfaced stringer bead and weave bead deposits in accordance to ASTM G76-95, Tables 5 to 7

Specimen designation	No of specimen	Erosion weight loss [mg]	Erosion rate [mg/min]	Erosion value [0.001 mm^3/g]	Average erosion value [0.001 mm^3/g]
HARDOX 400 steel plate	400-1	7.6	0.76	48.2846	48.9199
	400-2	7.8	0.78	49.5553	
SL**	SL1	4.8	0.48	31.7041	33.0251
	SL2	5.2	0.52	31.3461	
SH	SH1	5.4	0.54	35.6671	33.0251
	SH2	4.6	0.46	30.3831	
WL	WL1	4.3	0.43	28.4016	27.4108
	WL2	4.0	0.40	26.4201	
WH	WH1	4.8	0.48	31.7041	29.0621
	WH2	4.0	0.40	26.4201	

Remarks: Erosion rate, [mg/min] = mass loss [mg] : time plot [min], Erosion value, [mm^3/g] = volume loss of specimen [mm^3] : Total mass of abrasive particles [g]. Erosion conditions: velocity – 70±2 [m/s], erodent impact angle – 30˚, temperature – 20 [˚C], erodent: Al_2O_3 of nominal dimension – 50 [μm], feed rate – 2.0±0.5 [g/min]. ** – SL - low heat input stringer bead deposit, WH - high heat input weave bead deposit

3. Conclusions

Based on results of investigations of PTA X161 metal cored wire 1.2 [mm] dia. surfacing it was found that:

- using proper welding procedure of PTA X161 1.2 [mm] dia. metal cored wire surfacing it is possible to achieve high quality stringer bead with maximum width up to 7.6 [mm] and height up to 2.2 [mm] and also weave bead deposits with maximum height up to 2.9 [mm] for single layer deposit and width dependent on weave path dimensions, Tables 3 to 7.
- Quality of all deposits was high but most of them were transverse and longitudinal cracked but only on plates 4.0 mm in thickness. All 2.0 mm plates have no cracks and other defects.
- Dilution of single stringer deposits is in the range of 4.71 up to 28.36 %. Dilution of one layer multi stringer bead deposits is about 10.61 % and two layers – 6.27 %. For weave bead deposits it is change from 22.66 up to 33.28 %.
- Efficiency of PTA X161 wire surfacing is high and is in the range of 1.6 [kg/h] at minimum heat input up to 5.0 [kg/h] for maximum heat input, Tables 3 to 7.
- Cracking of all tested stringer bead and weave bead deposits starts at high temperatures and number of cracks decreases with increase of heat input of PTA surfacing, as depicted in Tables 3 to 7. Longitudinal cracks of weave bead deposits

disappear at higher heat inputs of surfacing, over 0.36 [kJ/mm]. Preheating should provide deposits free of any cracks.

- HRC hardness measured on the ground surface of single stringer bead and weave bead deposits PTA X 161 1.2 [mm] dia. wire surfaced is very high and is in the range of 62.7-68.6 HRC, Table 8. Weave bead deposits show higher hardness then stringer bead deposits and hardness of stringer bead and weave bead deposits drops with increase of heat input.
- Abrasive wear resistance of multi stringer bead deposits and single weave bead deposits surfaced at min and max heat input is in the range 8.5 to 14 times higher than HARDOX 400 steel, Table 9. Weave bead deposits show 34.0-35.0% smaller G65 wear resistance, then stringer bead deposits. Results analyses indicate mass loss growth with decreasing heat input in both techniques of surfacing.
- Erosion wear resistance was 1.48 times higher than HARDOX 400 steel for multi stringer bead deposits and 1.7 times higher for weave beads deposits, Table 10.

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