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Abrasive and erosive wear resistance of GMA metal cored wire cermetal deposits

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ABSTRACT

Purpose: Purpose of these researches was to determine influence of GMA metal cored wire surfacing parameters on the abrasive and erosive wear resistance of the one layer and three layer weave bead cermetal deposits.
Design/methodology/approach: One layer and three layer weave bead deposits were GMA surfaced using metal cored wire (nickel based + 54%WC) 1.6 [mm] dia. To determine quality of deposits Visual Inspection, MT examinations, hardness HRC and HV10 measurements on the ground surface of deposits, macrostructure and microstructure observations, abrasive and erosion wear resistance tests were done.
Findings: Hardness of deposits tested is in the range from 453–517 HV10 (44.5-47.9 HRC) and is a function of the value of heat input of surfacing. WC carbides population density, size and distribution in nickel alloy matrix of deposits tested is a function of GMA heat input of surfacing. Low heat input of surfacing insures uniform distribution of WC carbides on the cross section of deposits. The low heat input GMA surfaced weave bead deposits provide 10 times higher abrasion wear resistance and 4.2 times higher erosion wear resistance than HARDOX 400 steel plate.
Research limitations/implications: Results of this paper is to increase quality of GMA cermetal deposits.
Originality/value: Hardness of deposits can not be treated as the abrasion and erosion wear resistance indicator.
Keywords: Welding; Surfacing; GMA

1. Introduction

Semi- and automatic GMA flux and metal cored wire surfacing is one of most popular method of surfacing of new or worn machine parts [1-4]. It is possible to deposit layers in all surfacing positions with efficiency from a few up a dozen or so kilograms of weld metal deposit per hour.

Modern metal cored wires allow to deposit layers providing a broad spectrum of almost optional chemical compositions e.g. iron based alloys including ferritic/bainitic alloys, martensitic alloys, mixed martensitic/austenitic alloys, austenitic alloys, austenitic manganese alloys, primary austenite with austenite-carbide eutectic, primary carbides with austenite-carbide eutectic, nickel and cobalt based alloys and metal-ceramic materials, e.g. iron, nickel or cobalt alloys with primary WC or W_2C carbides and iron based alloys with liquid metal-like structures called nano wires [3, 4, 5]. All these materials are GMA surfaced on new or worn working surfaces of machine parts or elements to provide specific properties as abrasive and adhesive wear resistance, erosion resistance, corrosion resistance, heat resistance and many of theirs combinations [1-20].

It is reported that 50-60% of machine elements are worn due to erosive and abrasive wear which has many forms including low stress, high stress, dry or wet abrasion [1, 2, 6-20]. Erosion and abrasion wear resistance of GMA surfaced layers is a function of many factors but basic are chemical composition and microstructure which on other hand depend on GMA surfacing parameters. The solidification morphology and as the result the microstructure of weld metal deposits depends on speed of surfacing, surfacing arc current and arc voltage (heat input of GMA surfacing). Additionally the heat input allows controlling the shape of fusion line, penetration depth and dilution, thus chemical composition of the deposit.

Cermetal deposits contain very hard tungsten carbides, usually in proportion 40-60% carbide anchored in matrix alloy.

The structure of the cermetal deposits is very sensitive to heat input of welding process, mainly the size and dissolution of tungsten carbides in the alloy matrix. The main functions of the alloy matrix are to anchor and support the WC granules and on the other hand to increase wear resistance of the deposit by hardening alloy matrix by chromium and nickel borides and chromium carbides.

The present study was focused on the abrasive and erosive wear resistance of the one layer and three layer weave bead deposits GMA nickel based + 54%WC cermetallic wire, Fig. 1, Table 1. The preliminary study of a weld metal of GMA DO*611 wire 1,6 [mm] dia. surfaced indicates that the weld metal microstructure presents partially dissolved tungsten carbides in a matrix of nickel alloy with participated chromium and nickel borides and chromium carbides. The wear performance of one and three layer deposits GMA surfaced at three levels of heat input was compared to their microstructure and hardness.

a)

b)

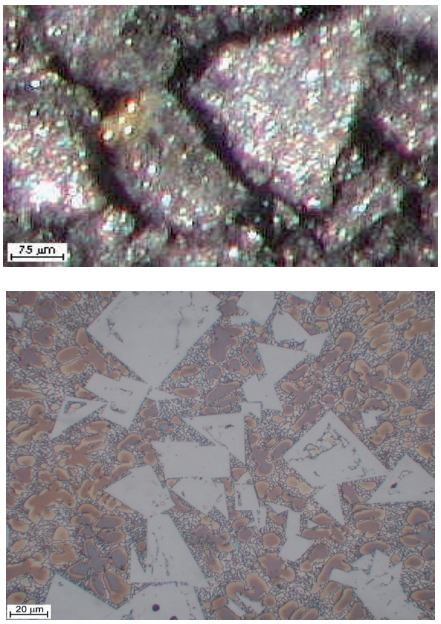


Fig. 1. a, b) A view of tungsten carbide granules and microstructure of the weld metal of GMA EnDOtec DO*611 metal cored wire surfaced

2. Researches

Robotized GMA pulsed-arc surfacing was conducted on the welding stand equipped with TotalArc^2 5000 CASTOLIN synergetic programmable power source and SRV6 REIS ROBOTICS welding robot, Fig. 2. TotalArc^2 5000 synergetic program no 39 was set during course of experiments. Robotized GMA EnDOtec DO*611 1,6 [mm] dia., metal cored wire surfacing of one and three layers weave bead deposits at different arc current, arc voltage and speed of surfacing was executed. The heat input levels were chosen on the bases of wire weldability criterion (arc stability and quality of the weave bead) and to preserve tungsten carbides against dissolution in the nickel alloy matrix. All specimens of deposits fulfilling quality criteria: uniform penetration, smooth face, no undercuts and no porosity were machined to proper dimensions of specimens for G65 and G76 tests, metallographic examinations and hardness tests, Tables 2 to 5, Figs. 3 to 7.

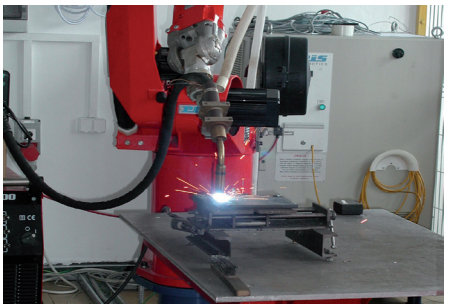


Fig. 2. A view of robotized GMA metal cored wire arc surfacing stand equipped with TotalArc^2 5000 CASTOLIN synergic programmable power source and SRV6 REIS ROBOTICS welding robot

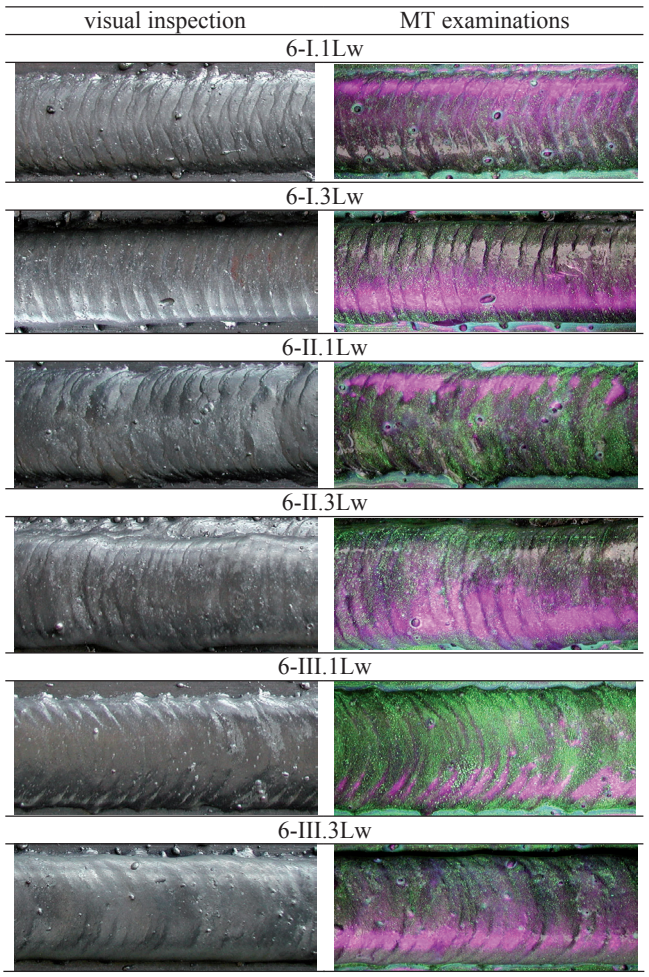


Fig. 3. A view of the surface of one and three layer GMA EnDoTec DO*611 wire surfaced weave bead deposits, Table 2. No cracks observed

Table 1.
Chemical composition % wt of EnDOtec DO*611 metal cored wire weld metal

C	Cr	Si	B	Ni	WC
0.38	2,1	1,5	1,2	reszta	54

Table 2.
The effect of one and three layer GMA EnDoTec DO*611 1,6 [mm] dia., metal cored wire surfacing parameters of weave bead deposits on the deposits quality, Figs. 3, 4 and 5

Deposit no.	Wire feed speed [m/min]	Arc current [A]	Arc voltage [V]	Heat input** [kJ/mm]	Quality of deposits assessed by visual inspection and PT examinations
6-I.1Lw	2,6	94 - 110 (125)*	22,8 – 24,5	0,26 – 0,33	High quality, smooth surface, no undercuts
6-I.3Lw					High quality, smooth surface, no undercuts
6-II.1Lw	4,0	115 - 125 (155)*	24,5 – 26,2	0,35 – 0,41	High quality, smooth surface, no undercuts
6-II.3Lw					High quality, smooth surface, no undercuts
6-III.1Lw	4,7	130 –160 (185)*	24,0 – 27,5	0,39 – 0,55	High quality, smooth surface, no undercuts
6-III.3Lw					High quality, smooth surface, no undercuts

Remarks: GMA surfacing of weave bead deposits using constant velocity zigzag oscillation technique at frequency 0,2 [s^{-1}]. Speed of surfacing 0,05 [m/min], linear speed of surfacing 0,48 [m/min]. Amplitude of oscillation 10,0 [mm]. Surfacing current pulsed DCEP, welding program of TOTAL ARC no 39. Shielding gas 97,5%Ar+2,5%CO_2, flow rate 16,0 [l/min]. Vertical position of wire. Wire stick out 20,0 [mm]. Interpass temperature 100-150 [^oC]. * - set current of surfacing. ** - heat input of GMA surfacing of one layer weave bead deposit.

Table 3.
Results of HRC and HV10 hardness tests on the ground surface of one and three layer GMA DO*611 wire surfaced weave bead deposits and HARDOX 400 steel plate

Specimen designation	HRC measurement points						HRC average
	1	2	3	4	5	6	
HARDOX 400	44,0	43,8	43,8	43,8	43,4	43,9	43,8
6-I.1Lw	47	47,9	47,8	46	47,7	48,4	47,4
6-I.3Lw	48	49,5	48,5	46,9	47,2	47,7	47,9
6-II.1Lw	47,8	46,9	46,6	45,9	49	47,1	47,2
6-II.3Lw	45,6	46,2	46,3	44,6	47,6	43,4	45,6
6-III.1Lw	44,4	45,5	46,9	42,2	43,4	44,9	44,5
6-III.3Lw	46,6	46,3	48,1	43,6	45,3	46,5	46
	HV 10 measurement points						HV 10 average
HARDOX 400	439	441	449	438	445	437	441,5
6-I.1Lw	454	444	484	484	444	467	462
6-I.3Lw	524	499	526	529	527	502	517
6-II.1Lw	465	537	514	481	493	499	498
6-II.3Lw	465	446	441	459	439	470	453
6-III.1Lw	460	444	444	434	457	487	454
6-III.3Lw	430	467	490	481	461	434	460

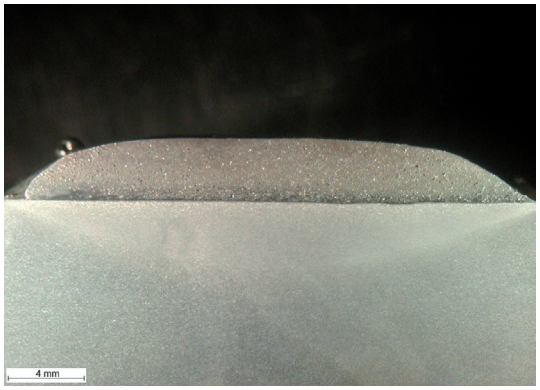
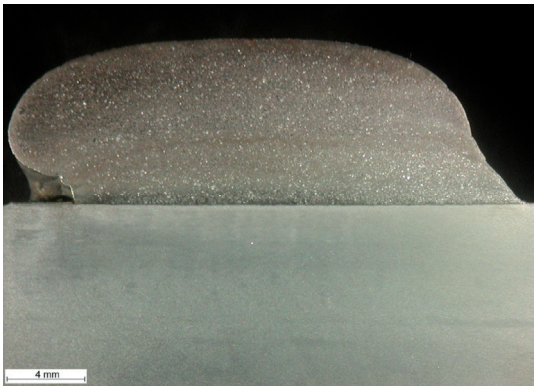
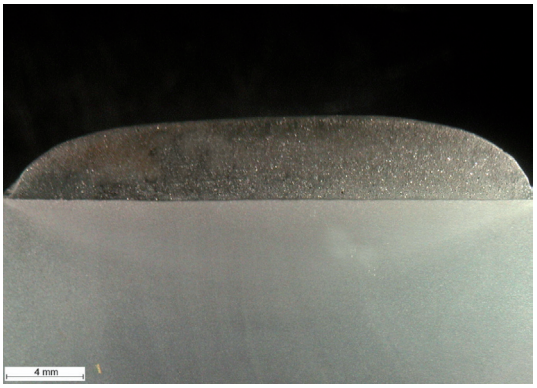
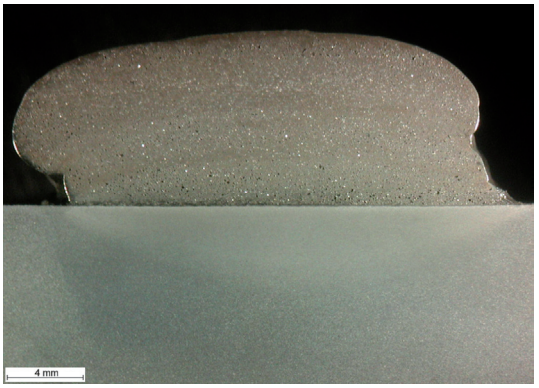
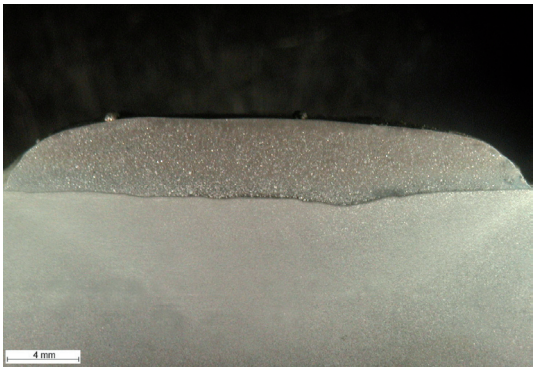
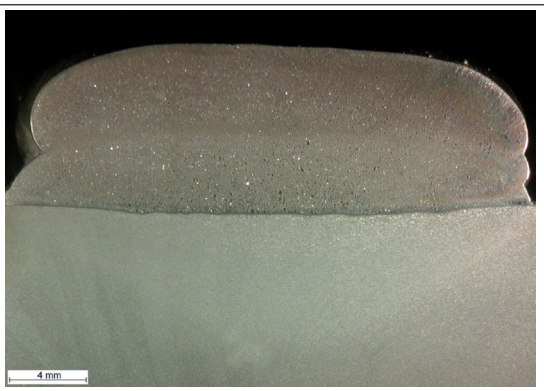
6-I.1Lw	6-I.3Lw
	
6-II.1Lw	6-II.3Lw
	
6-III.1Lw	6-III.3Lw
	

Fig. 4. Macrographs of one and three layer GMA EnDoTec DO*611 wire surfaced weave bead deposits, Table 2. Uniform fusion of deposits to the base metal, no internal defects observed

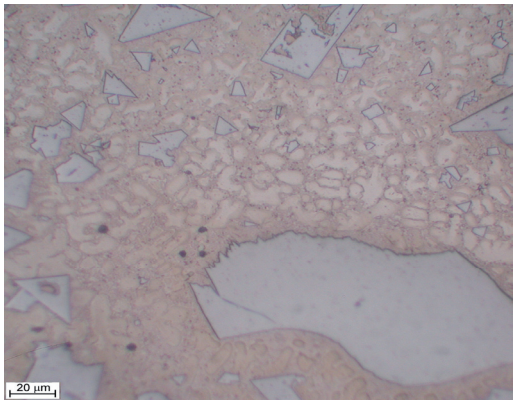
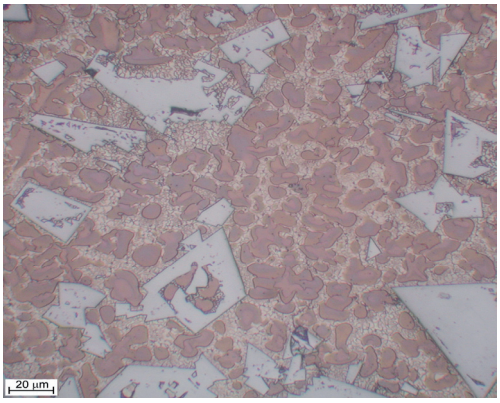
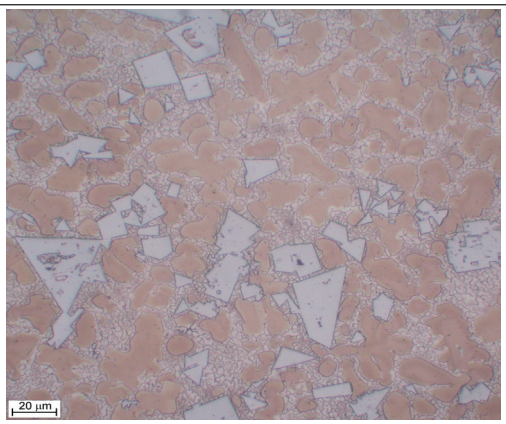
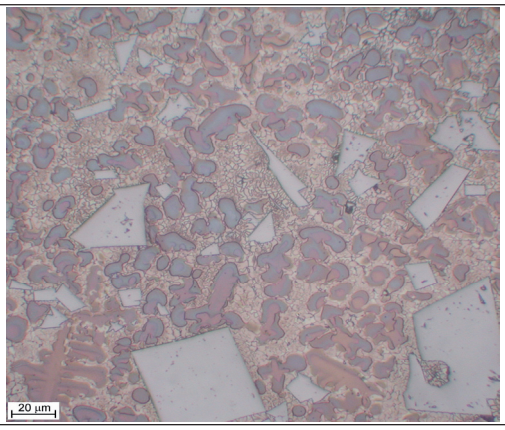
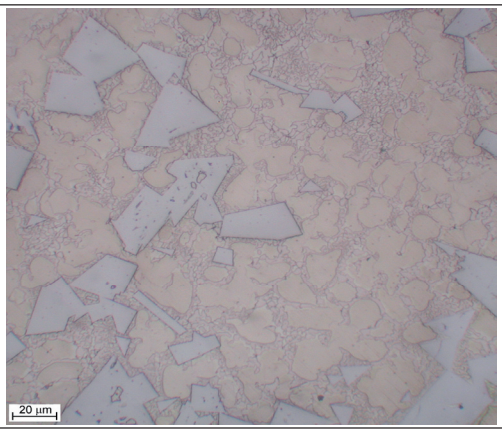
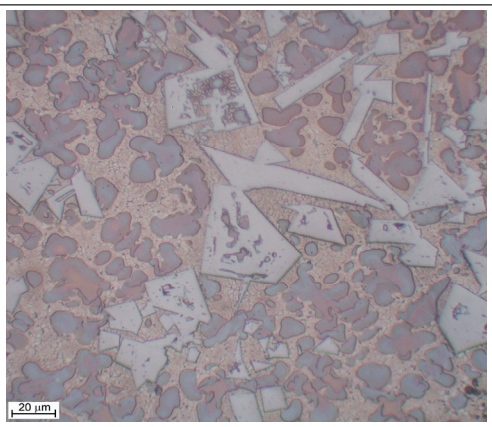
6-I.1Lw	6-I.3Lw
	
6-II.1Lw	6-II.3Lw
	
6-III.1Lw	6-III.2Lw
	

Fig. 5. Micrographs of undersurface area of one, two and three layer GMA EnDoTec DO*611 wire surfaced weave bead deposits, Table 2

2.1. Abrasive wear resistance tests

To determine quantitatively the abrasive wear resistance of one and three layer GMA EnDoTec DO*611 wire surfaced weave bead deposits and HARDOX 400 steel plate, the tests of abrasive wear type metal-ceramic were conducted in accordance to standard ASTM G 65-00 - Standard Test Method for Measuring Abrasion Using the Dry Sand/Rubber Wheel Apparatus, Fig. 6. 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 one and three layer GMA EnDoTec DO*611 wire surfaced weave bead 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 specimens were weighed at weight sensitivity 0,0001 [g]. Mass loss of specimens of one and three layer GMA EnDoTec DO*611 metal cored wire surfaced weave bead deposits was reported directly and relatively in comparison to the mass loss of the reference HARDOX 400 steel plate. Next the density of weld metal of EnDoTec DO*611 wire was measured and abrasive tests results were reported as volume loss in cubic millimeters, Table 4, by converting mass loss to volume loss as follows:

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

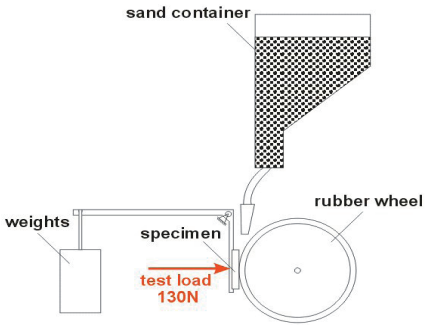


Fig. 6. Schematic diagram of ASTM G65 Procedure A abrasive wear resistance test apparatus

Table 4.
Results of low-stress abrasive wear resistance to metal-ceramic scratching by Ottawa quartz sand of one and three layer GMA EnDoTec DO*611 wire surfaced weave bead deposits

Specimen designation	Average mass loss [g]	Average volume loss [mm^3]	Relative* abrasion resistance
HARDOX 400	1,4617	185,7306	1,00
6-I-1Lw	0,1877	18,26	10,17
6-I-3Lw	0,1926	18,74	9,91
6-II-1Lw	0,2402	23,36	7,95
6-II-3Lw	0,2215	21,55	8,62
6-III-1Lw	0,3184	30,97	6,00
6-III-3Lw	0,3097	30,13	6,16

Remarks: * - relative to the abrasive wear resistance of reference HARDOX 400 steel plate. Density of weld metal of EnDoTec DO*611 wire measured by picnometer: 10,28 [g/cm^3].

2.2. Erosion wear resistance tests

To determine quantitatively the erosion wear resistance of one and three layer GMA EnDoTec DO*611 wire surfaced weave bead deposits and HARDOX 400 steel plate, the tests of erosion were conducted in accordance to standard ASTM G 76-95 - Standard Test Method for Conducting Erosion Tests by Solid Particle Impingement [11], Fig. 7. Nozzle tube is manufactured from tungsten carbide and is 50 [mm] long and 1,5 [mm] inner diameter. Abrasive particles of angular Al_2O_3 of nominal dimension – 50 [μm] are feed 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 with flow rate 8,0 [l/min]. Samples 70x25x10 [mm] were cut from one and three layer weave bead deposits and HARDOX 400 steel plate and the surface of deposits and HARDOX 400 steel plate were ground by abrasive papers to 400 grit and prepared by alcohol cleaning.

Before erosion tests of specimens have been started the calibration of erosion test apparatus was conducted as per standard ASM G76-95. Next the erosion tests of specimens of one and three layer GMA EnDoTec DO*611 wire surfaced weave bead deposits and HARDOX 400 steel plate were done during 10 [min], at erodent impact angle 30°, and results are collected in Table 5. Erodent impact angle 30^0 was chosen as the typical impact angle advised for erosion tests of very hard materials [12-20].

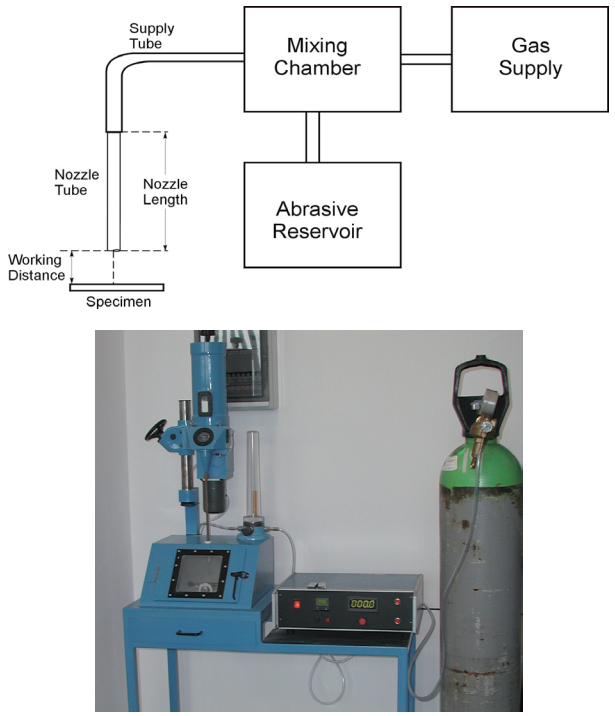


Fig. 7. Schematic diagram and overview of standard ASTM G76-95 erosion tests apparatus

Table 5.
Results of erosion wear resistance tests of one and three layer GMA metal cored wire EnDoTec DO*611 dia. 1,6 [mm] surfaced weave bead deposits

Specimen designatin	Average erosion weight loss [mg]	Erosion rate [mg/min]	Erosion value [0,001 mm^3/g]	Relative erosion resistanc*
HARDOX 400	7,7	0,77	48,9199	1,0
6-I.1Lw	2,8	0,28	13,6187	3,59
6-I.3Lw	2,4	0,24	11,6732	**4,19**
6-II.1Lw	3,1	0,31	15,0778	3,26
6-II.3Lw	2,9	0,29	14,1051	3,47
6-III.1Lw	3,4	0,34	16,5370	2,96
6-III.3Lw	3,3	0,33	16,0506	3,06

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: erodent - Al_2O_3 of nominal dimension – 50 [μm], erodent impact angle 30°, velocity - 70 ± 2 [m/s], temperature 20°C, feed rate - 2,0 ± 0,5 [g/min]. * - relative to HARDOX 400 steel plate.

3. Conclusions

One and three layer GMA EnDOtec DO*611 metal cored wire 1,6 [mm] dia., surfacing provides high quality weave bead deposits in the wide range of surfacing parameters (heat input 0,26 – 0,55 [kJ/mm), Table 2 and Figs. 3, 4 and 5. All deposits are free of any external or internal defects and all are free of transverse cracks, in contrary to single and multi layer overlapped stringer bead deposits [5].

Hardness of deposits tested is in the range from 453 – 517 HV10 (44,5-47,9 HRC) and is a function of the value of heat input of surfacing, Table 3. The highest and uniform hardness approx. 520 HV10 has shown three layers weave bead deposit no. 6-I.3Lw, GMA surfaced at the lowest heat input. Increase of heat input of surfacing decreases hardness of three layers deposits to the level of approx. 450 HV10, due to strong dissolution of tungsten carbides in nickel alloy matrix, Fig. 5.

WC carbides population density, size and distribution in nickel alloy matrix of deposits tested is a function of GMA heat input of surfacing, Fig. 5. Low heat input of GMA surfacing of weave bead deposits provides that max. size of WC carbides in the undersurface area of deposit is 40-65 [μm] and average distance between WC carbides is in the range 50-60 [μm]. Low heat input of surfacing insures uniform distribution of WC carbides on the cross section of deposits additionally, Fig. 5. Increase of heat input of GMA surfacing is the cause of expected increased dissolution of WC carbides in nickel alloy matrix and in the same time overheated weld pool stimulates more intensive sinking of heavy and small WC carbides toward fusion zone of a deposit and decrease of size and population density of WC carbides in the undersurface area of the deposit. Heat input of GMA surfacing of weave bead deposits in the range 0,39-0,55 [kJ/mm] (deposit no 6.III.3Lw) provides that max. size of WC carbides in the undersurface area of deposit is 15-30 [μm] and average distance between WC carbides is in the range 70-75 [μm]. It means that small changes of GMA surfacing parameters have strong influence on WC carbides population density, size and distribution in the deposit and have to be very precisely selected for specific production applications.

Low-stress abrasive wear resistance to metal-ceramic scratching by means dry quartz Ottawa sand tests of one and three layer GMA EnDoTec DO*611 wire surfaced weave bead deposits conducted as per ASTM G65 Procedure A standard [6], have proved that abrasive wear resistance of deposits is approx. 6,0 to 10,0 times higher then abrasive wear resistance of HARDOX 400 steel, Table 4. The highest abrasive wear resistance has been shown by low heat input GMA surfaced three layer weave bead deposit no 6-I-3Lw, what proves results of hardness tests of deposits and metallographic examinations, Table 3 and Figs. 4 and 5. On the other hand lowest heat input GMA surfaced deposit no 6-I.3Lw provides 65% higher abrasion resistance than highest heat input GMA surfaced deposit 6-III.3Lw, which shows just 12% lower hardness. Additionally hardness of HARDOX 400 steel plate is just 10% lower than all deposits tested but abrasion wear resistance of HARDOX 400 steel plate is much lower, Tables 4 and 5.

Results of erosion wear resistance testes conducted as per G76-00 standard have proved very high properties of one and three layer GMA EnDoTec DO*611 wire surfaced weave bead deposits and very similar influence of heat input of GMA surfacing on erosion wear resistance as have shown abrasion wear resistance tests, Table 5. Again highest erosion wear resistance shows three layer lowest heat input GMA surfaced deposit 6-I-3Lw, which is approx. 4,2 times higher than HARDOX 400 steel plate and 1,4 times higher than highest heat input GMA surfaced deposit 6-III.Lw. Results of study clearly proves than hardness can not be treated as the abrasion and erosion wear resistance indicator.

References

[1] G.E. Linnert, Welding Metallurgy Carbon and Alloy Steels. AWS. Miami, Florida, 1994. Ed. 4. Vol.1. Fundamentals. Chapter 6, 628-633. Ed.4. Vol. 2. Technology. Chapter 10. 100-107.

[2] Welding Handbook. AWS, Miami, Florida, 1996. Ed. 8. Vol. 4. Materials and Applications. Pt.2. Chapter 7- Surfacing, 391-436.

[3] G. Heath, Nanotechnology and welding – actual and possible future applications. CASTOLIN-EUTECTIC SEMINAR, Brussels, Belgium, 25-25.10.2006.

[4] A. Klimpel, at al., Robotized GMA surfacing of cermetal deposits. Journal of Achievements in Mechanical and Materials Engineering, 18 (2006) 395-398.

[5] Y.I. Oka, K. Okamura, T. Yoshida, Practical estimation of erosion damage caused by solid particle impact. Part 1: Effects of impact parameters on a predictive equation. Wear. 2005, no. 259, 95 – 101.

[6] Y.I. Oka, T. Yoshida, Practical estimation of erosion damage caused by solid particle impact. Part 2: Mechanical properties of materials directly associated with erosion damage. Wear. 2005, no. 259, 102 – 109.

[7] J.C. Cassina, I.G. Machado, Low-Stress Sliding Abrasion Resistance of Cobalt-Based Surfacing Deposits Welded with Different Processes, Welding Journal, April, 1992, 133.
[8] D.J. Kotecki, J.S. Ogborn, Abrasion resistance of iron-based hardfacing alloys. Welding Journal. 1995, vol.74, no.8, 269-288.
[9] I. Sevim, I.B. Eryurek, Effect of abrasive particle size on wear resistance in steels. Materials & Design 2006, 173–181.
[10] H. Klaasen, J. Kubarsepp, Abrasive wear performance of carbide composites. Wear. 2006, 520 – 526.
[11] M. Divakar, V.K. Agarwal, S.N. Singh, Effect of the material surface hardness on the erosion of AISI 316. Wear. 2005, no. 259, 110 – 117.
[12] G. Sundararajan, R. Manish, Solid particle erosion behaviour of metallic materials at room and elevated temperatures, Tribology International Volume: 30, Issue: 5, 1997, 339-359.
[13] Y.I. Oka, H. Ohnogi, T. Hosokawa, M. Matsumura, The impact angle dependence of erosion damage caused by solid particle impact, Wear. Volume: 203-204, March, 1997, 573-579.
[14] L.A. Dobrzański, M. Bonek, E. Hajduczek, A. Klimpel, Application of high power diode laser (HPDL) for alloying of X40CrMoV5-1 steel surface layer by tungsten carbides, Journal of Material Processing Technology (2004) 155-156.
[15] L.A. Dobrzański, M. Bonek, A. Klimpel, A. Lisiecki, Surface layer's structure of X40CrMoV5-1 steel remelted and/or WC alloyed with HPDL laser, Materials Science Forum, 3(140), (2003) 69-72.
[16] M. Bonek, L.A. Dobrzański, Functional properties of laser modified surface of tool steel, Worldwide Journal of Achievements in Materials and Manufacturing Engineering, 17 (2006) 313-316.
[17] L.A. Dobrzański, M. Bonek, M. Piec, E. Jonda, Diode laser modification of surface gradient layer properties of a hot-work tool steel, Materials Science Forum, Vols. 532-533, Switzerland (2006) 657-660.
[18] L.A. Dobrzański, M. Piec, K. Labisz, M. Bonek, A. Lisiecki, Klimpel A.: Laser treatment of surface layer over choosen hot work tool steels, 13th Scientific International Conference „Achievements in Mechanical and Materials Engineering" AMME'2005, Gliwice – Wisła, (2005) 183-186.
[19] M. Bonek, L.A. Dobrzański, Functional properties of laser modified surface of tool steel, Worldwide Journal of Achievements in Materials and Manufacturing Engineering, 17 (2006) 313-316.
[20] M. Bonek, L.A. Dobrzański, E. Hajduczek, A. Klimpel, Laser modification of surface layer properties of a hot-work tool steel, Worldwide Journal of Achievements in Materials and Manufacturing Engineering, 14, (2006) 152-155.