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Abrasive wear resistance of robotized GMA surfaced cermetal deposits

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ABSTRACT

Purpose: of this paper: Study of abrasive wear resistance of robotized GMA surfaced cermetal deposits. The one-, two- and three layers stringer bead and weave bead deposits were surfaced by a metal-cored wire.

Design/methodology/approach: The study were based on the analysis of deposits dilution, structure, measurements of hardness and microhardness, determination of WC carbide morphology and abrasive wear resistance type metal-ceramic according to ASTM G65.

Findings: It was found that robotized GMA surfacing process with EnDOtec DO*11 wire of diameter 1,6 [mm], with oscillation of the welding torch, can be applied for producing high quality of deposits in a wide range of surfacing parameters especially heat input. The abrasive wear resistance of stringer bead deposits is significantly higher compared with weave bead deposits. The weave bead deposits are free of transverse cracks, contrary to stringer beads. This phenomenon can be explained by different thermal stresses in the deposits.

Research limitations/implications: It was found that further investigations and detailed studies are required to identify the mechanism of deposit shaping, especially the control of dilution, shape of fusion zone and penetration depth, depending on parameters of surfacing and the trajectory and parameters of oscillation of the surfacing GMA torch.

Practical implications: The technology can be applied for wear plates manufacturing .

Originality/value: Improve of the wear resistance of wear plates.

Keywords: Welding; GMA; Surfacing; Cermetal deposit

MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

Processes of automated and semi automated GMA surfacing with flux cored wires and metal cored wires are widely used for surfacing at stage of manufacturing and for regeneration of working surfaces of used parts, Fig. 1 [1-10]. Thanks to the high flexibility and small size of the welding torch the GMA surfacing process can be carried out at any welding position. Efficiency of surfacing can be precisely controlled from several to dozen kg of deposit per hour. The modern metal cored wires provide any chemical composition of the deposit, from mild steel, high alloyed austenitic, ferritic and martensitic steel, chromium cast iron, nickel and cobalt based alloys, to cermetal layers, eg. nickel based layers including primary carbides of WC or W_2C [3, 4, 5]. The manufacturers of cored wires give all detailed properties and chemical composition the of deposit and also necessary surfacing procedure specification and recommended techniques of surfacing [14, 15]. One of the basic criterions for choosing of surfacing procedure and parameters, especially in a case deposit of chemical composition distinctly different from base material, is a minimum dilution in the first layer of the multi-layer deposit, Fig. 2:

$$U = \frac{F_w}{F_w + F_n} \cdot 100\% \quad (1)$$

where: Fw – area of fusion zone [mm^2], Fn – area of reinforcement [mm^2].

The dilution of the first layer of a deposit during GMA surfacing with cored wire can be controlled in a rang from about 10[%] to over 40[%], depending on the parameters and the surfacing technique [1, 4, 5, 15]. The easiest way to achieve a minimum dilution of the deposit is a multi-layer surfacing, but unfortunately it is the most expensive way. The dilution in a second layer during GMA surfacing can be even lower in a range 5-15[%] in, depending on heat input and technique of surfacing [4, 5, 11-15]. The other solution to achieve a lower dilution of deposits is decreasing the heat input of surfacing process, but also the efficiency and economics of the surfacing is decreased. Other solution is applying a so called "push technique", with the GMA torch inclined towards the welding direction. Most of recommendations of welding handbook's and catalogue's ignore the weaving technique of surfacing with oscillation of the welding torch. There are no information and directions concerning the recommended direction and the angle of GMA torch during surfacing when weaving technique is applied. The results of study of GMA and SSA surfacing using cored wires, carried out in the Welding Department of Silesian University of Technology [15], have shown that the weaving technique during surfacing, Fig. 3, can significantly lower the dilution and also, in a case of properly selected additional materials - consumables, can avoid cracks of the deposit as a result of thermal stresses, especially in a case of straight beads surfacing [5, 15]. The effect of the heat input of surfacing, the direction and the torch angle on the dilution of deposit surfaced applying weaving technique is investigated.

2. Experimental

The studies of GMA surfacing process were carried out using a REIS SVR6 robot and TotalArc2 5000 welder. The EnDOtec DO*11 metal cored wire of diameter 1,6 [mm] was chosen for the study of robotized GMA surfacing with weave technique, Fig. 1, Table 1. The EnDOtec DO*11 wire was designed and manufactured for surfacing of high wear resistant deposits, especially ceramic material – metal wear resistant and also high erosion resistant, even at elevated temperatures. The deposit contains approximately 50 [%] of tungsten carbides WC, evenly spread in the nickel alloy matrix, enforced additionally by hard phases which are produced at a stage of recristalization, Table 1. The main criterion for choosing of the surfacing procedure specification in a case of surfacing of cermetal deposits is a minimum dilution of the deposit, but not the efficiency of surfacing process. To ensure very high stability of surfacing process and parameters, especially the trajectory of the welding torch during weaving technique surfacing, surfacing speed, direction and the angle of welding torch inclination, the robotized GMA surfacing was applied. The trials of GMA surfacing were conducted at a down-hand position of surfacing. The samples of base material S355J2G3 steel were prepared for surfacing as plates of dimension 120x150x12 [mm], Table 2. The current of surfacing was set as DC(+) pulse at 125 [A], 155 [A] and 185 [A]. The welding power source used for the experiments had a flat static characteristic (CV). The parameters of surfacing such as current, arc voltage, stick-out of electrode and surfacing speed were kept in a range of optimal parameters for GMA surfacing of straight beads with the cored wire EnDOtec DO*11 of diameter 1,6 [mm], Table 3 [16]. On the base of preliminary tests of GMA surfacing, a weaving technique trajectory ZIG-ZAG of the surfacing torch was applied at amplitude of 10 [mm], frequency 0,2 [Hz], and constant linear speed of surfacing 0,83 [mm/s]. The shielding gas was a mixture of 97,5[%] Ar and 2,5[%] CO_2 (M13 according to standard EN 439), at gas flow 16 [l/min]. For every set of welding current: 125 [A], 155 [A] and 185 [A], the process of robotized GMA surfacing was carried out with push technique, in a range of angles of the welding torch inclination 65[^{o}], 75[^{o}], 80[^{o}], 85[^{o}] then the surfacing torch was set at an angle 90o. A further study was carried out applying pull technique, in a range of angles of the welding torch inclination 95[^{o}], 100[^{o}], 105[^{o}], 110[^{o}] and 115[^{o}]. Results of investigations on heat input and the technique of surfacing on the shape and the dilution of the deposit produced during GMA surfacing with the weaving technique are given in Table 4 and Fig. 4 to 8 and the microhardness distribution on the cross section of deposits are given in Table 5. No cracks were observed on the surface of deposits produced by weaving bead technique, contrary to the stringer bead deposits. Cracks of the stringer bead deposits were the result of thermal stresses in the deposits, Fig. 4. All deposits are very regularly shaped and the face of deposits is flat and smooth and the fusion zone is very regular. Additionally, tests of wear resistance type ceramic material – metal were carried out for three selected layers of deposits surfaced with weaving technique and also three layers of stringer bead deposits produced at overlap 25-30[%] and at minimum and also maximum heat input of surfacing, Table 6, Fig. 9 and 10.

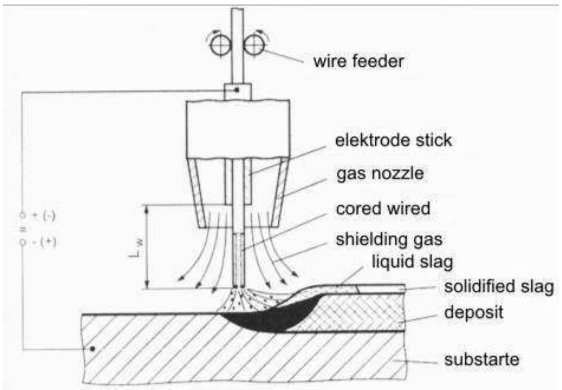


Fig 1. Schematic view of GMA surfacing process

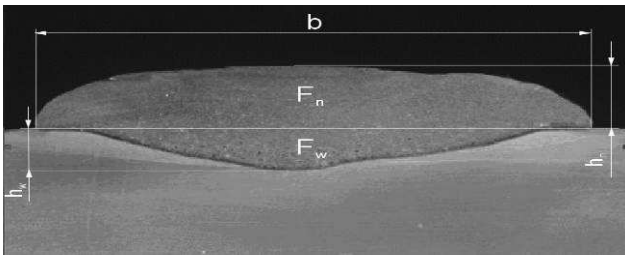
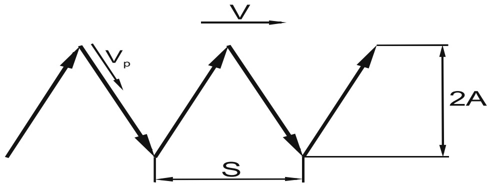


Fig. 2. The values measured for dilution calculation: b – width of the bead, hn – high of the deposit, hw – depth of the penetration, Fn – area of the deposit, Fw – area of the fused zone



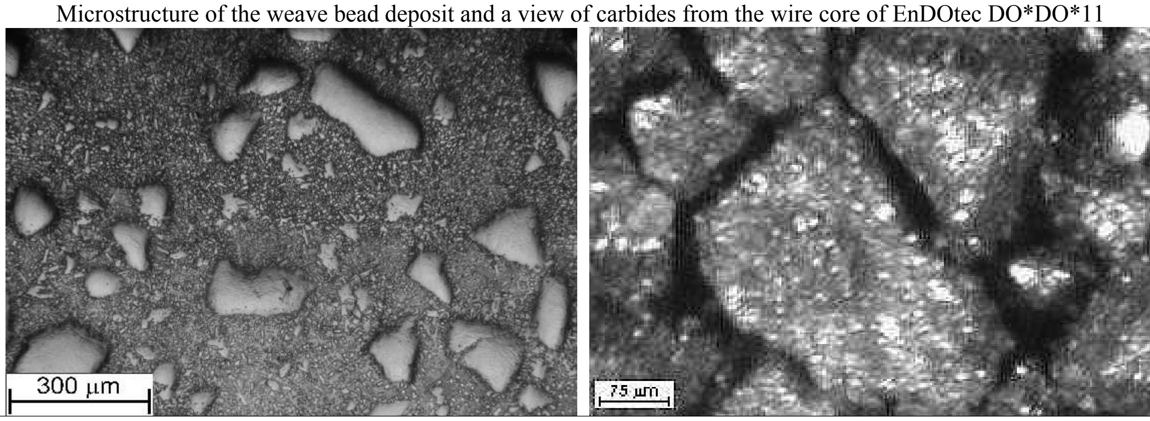
Rys. 3. The trajectory of GMA torch during robotized surfacing with EnDOtec DO*11 wire of diameter 1,6 [mm], Table 4

Table 1
Chemical composition % and hardness of the deposit of EnDoTec DO*11 wire and its physical properties [4]

Ni	C	Si	Cr	B	WC	Hardness	
						Deposit	Carbides WC
Rest	0,4	2,5	3,0	1,5	50	55 HRC	2400 HV0,3

Grain size f the carbide WC [µm]	Mass of the wire per length [kg/m]	Density of the wire [g/cm^3]	Density of the deposit [g/cm^3]
1,0-400	0,0197	9,78	11,36

Microstructure of the weave bead deposit and a view of carbides from the wire core of EnDOtec DO*DO*11



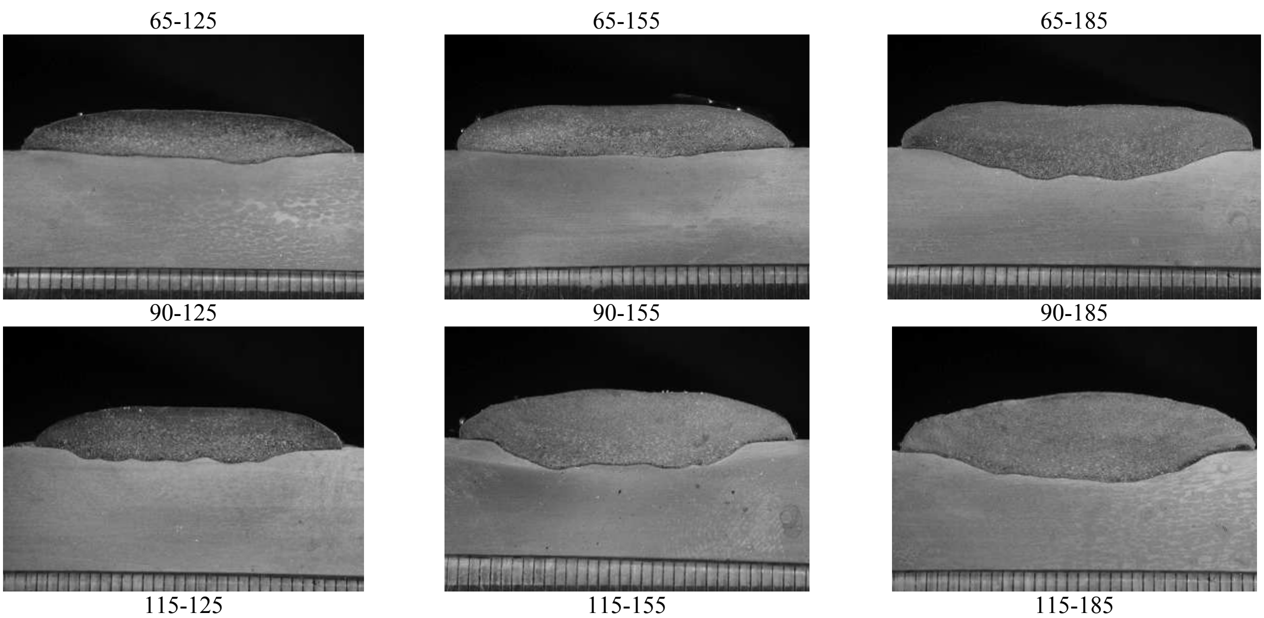


Fig. 4. Macrostructure of a single layer weave bead deposits produced with EnDOtec DO*11 wire of diameter 1,6 [mm]. Samples are marked - 65-125: 65 – torch inclination contrary to surfacing direction at an angle - 65^o (push technique), 125 – arc current - 125 [A], Table 4 [4]

Table 2
Chemical composition % of the substrate material - steel S355J2G3 [4]

C	Mn	Si	P	S	Cr	Ni	Hardness
0,18	1,36	0,45	0,02	0,02	0,09	0,10	155-195 HV 30

Table 3
Optimal parameters of robotized GMA surfacing of stringer bead deposit, with EnDOtec DO*11 cored wire of diameter 1,6 [mm] [16]

Wire feeding rate [m/min]	Arc current [A]	Arc voltage [V]	Surfacing speed [m/min]	Heat input [kJ/mm]	Wire stick-out [mm]
1,2-5,3	85-247	12,5-22,5	0,2-0,4	0,16-0,1,86	20

Remarks: Surfacing current pulsed DC(+), horizontal position of welding, vertical position of wire. Shielding gas - 97,5[%]Ar+2,5[%]O_2, flow rate 16,0 [l/min].

Table 4
The effect of heat input of robotized GMA surfacing of weave bead deposit, with EnDOtec DO*11 cored wire of diameter 1,6 [mm] and the GMA torch angle on shape and dilution of the deposit, Fig. 2

Bead no.	Wire feed speed [m/min]	Arc current [A]	Arc voltage [V]	Heat input [kJ/mm]	b [mm]	Hw [mm]	Fw $[mm^2]$	Hn [mm]	Fn $[mm^2]$	Dilution [%]
65-125	2,6	117-132	19,9-22,4	0,33	28,2	0,58	11,4	3,32	79,8	12,5
65-185	3,9	155-178	25,2-27,2	0,55	27,1	2,78	38,7	4,53	101,4	27,6
70-125	2,6	117-130	20,5-22,7	0,34	27,5	1,06	11,7	2,92	68,7	14,5
70-185	3,9	155-181	24,8-26,9	0,55	28,3	2,11	38,0	5,0	103,7	26,8
75-125	2,6	116-129	20,8-22,9	0,34	25,6	1,23	14,2	3,04	65,8	17,7
75-185	3,9	157-181	24,0-27,2	0,54	27,5	2,31	38,8	4,40	94,45	29,1
80-125	2,6	109-140	20,9-22,3	0,34	25,4	1,38	14,5	3,91	81,4	15,1
80-185	3,9	165-189	24,1-26,2	0,56	29,4	2,5	35,0	4,1	91,2	27,7
85-125	2,6	121-142	20,9-22,1	0,35	26,0	1,0	11,3	3,51	75,5	13,0
85-185	3,9	161-188	23,8-25,3	0,54	28,3	3,32	45,6	4,1	102,9	30,7
90-125	2,6	116-133	20,7-22,4	0,34	27,9	1,89	11,3	3,46	76,5	12,9
90-185	3,9	159-177	23,8-26,1	0,52	29,3	2,77	41,5	3,75	94,12	30,6
95-125	2,6	108-122	20,5-23,1	0,32	25,3	1,2	17,3	2,99	63,5	21,4
95-185	3,9	158-179	24,1-26,2	0,53	28,5	2,23	37,3	4,44	93,0	28,6
100-155	3,3	134-159	22,9-25,0	0,44	26,9	1,73	31,5	4,08	91,5	25,6
100-185	3,9	162-184	23,4-25,7	0,53	27,6	2,79	48,1	3,9	89,2	34,5
105-125	2,6	119-135	20,6-21,9	0,34	28,1	2,2	32,4	3,36	82,4	28,2
105-155	3,3	132-155	22,7-24,4	0,42	27,5	2,02	36,1	3,62	77,0	31,9
105-185	3,9	166-182	23,7-25,8	0,54	29,9	3,15	54,2	3,45	104,6	34,1
110-125	2,6	119-139	20,4-22,1	0,34	25,6	1,48	17,3	3,91	80,1	17,7
110-155	3,3	147-166	22,7-24,2	0,46	27,7	2,4	36,8	3,97	87,86	29,5
110-185	3,9	160-185	22,9-25,1	0,52	29,8	2,54	44,6	4,81	113,5	28,2
115-125	2,6	117-136	20,7-22,5	0,35	26,2	1,25	19,2	3,46	78,7	19,6
115-155	3,3	148-161	23,6-24,1	0,46	28,8	2,86	45,2	4,21	96,4	31,9
115-185	3,9	164-193	23,8-25,0	0,55	29,8	2,72	44,0	4,99	110,6	28,4

Remarks: Surfacing current pulsed DC(+). Wire stick-out – 20 [mm]. Shielding gas- 97,5[%]Ar+2,5[%]O_2, flow rate 16,0 [l/min]. Surfacing of weave bead deposits at constant velocity zig-zag oscillation technique at frequency 0,2 [Hz]. Amplitude of oscillation 10 [mm]. Speed of surfacing 0,83 [mm/s], linear speed of surfacing 8,04 [mm/s]. Deposits are marked : - 65-125: 65 – GMA torch angle of GMA contrary to welding direction – 65[^{o}] 125 – arc current - 125 [A].

Table 5
The effect of arc current and GMA torch angle during robotized GMA surfacing of weave bead deposit with EnDOtec DO*11 wire, on hardness of the deposits

Deposit no.*	Area and points of hardness measurement HV30					Mean value HV 30
	area near the face of deposit	middle area of the deposit			fusion zone	
	1	2	3	4	5	
65-125	444	467	527	557	550	509
65-155	451	478	467	514	517	485
65-185	432	418	467	520	521	471
90-125	449	486	511	533	554	506
90-155	457	451	454	550	543	491
90-185	481	473	444	505	523	485
115-125	459	481	497	536	540	502
115-155	465	478	484	508	514	492
115-185	441	432	454	478	496	460

Remarks: Deposits are marked: 65-125: 65 – GMA torch angle contrary to the surfacing direction – 65[^{o}], 125 – arc current - 125 [A].

Table 6
Results of ceramic material – metal wear tests of three layer weave bead deposits surfaced with cored wire EnDOtec DO*11 of diameter 1,6 [mm], set at vertical position Table 4, Fig. 9 and 10

Deposit no.	Mass before test [g]	Mass after test [g]	Mass lose [g]	Mean mass lose [g]	Mean volume lose [cm^3]	Relative wear resistance*
HARDOX 400-1	62,2260	60,7526	1,4734	1,4617	185,7306	1,00
HARDOX 400-2	63,1222	61,6721	1,4501			
95-3w-036	195,2934	194,9311	0,3623	0,3722	32,7641	5,67
	188,0271	187,6450	0,3821			
220-3w-089	199,8889	199,4368	0,4521	0,4314	37,9753	4,89
	193,2661	192,8553	0,4108			
125-3ww-034	198,3502	197,8243	0,5259	0,5139	45,2377	4,11
	199,7505	199,2486	0,5019			
185-3ww-052	199,9296	199,2592	0,6704	0,6561	57,7553	3,22
	198,4975	197,8556	0,6419			

Remarks: Density of the deposit of wire EnDoTec DO*11 = 11,36 [g/cm^3], density of steel HARDOX 400 = 7,87 [g/cm^3]. * - wear resistance compared to steel HARDOX 400. Deposits are marked : 95-3w-036, where: 95 – arc current 95 [A], 3w – three layer stringer bead deposit, 3ww – three layer weave bead deposit, 0,36 – mean heat input 0,36 [kJ/mm].

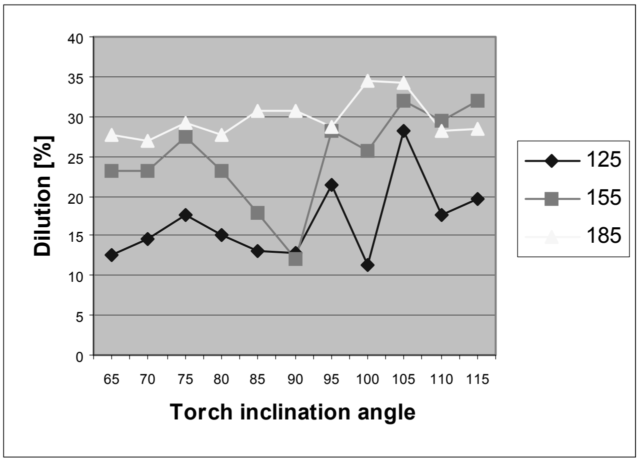


Fig. 5. Influence of arc current and the GMA torch inclination angle during robotized GMA surfacing with EnDOtec DO*11 wire of diameter 1,6 [mm], when weave technique applied, on dilution of the deposit - U, Table 4 [4]

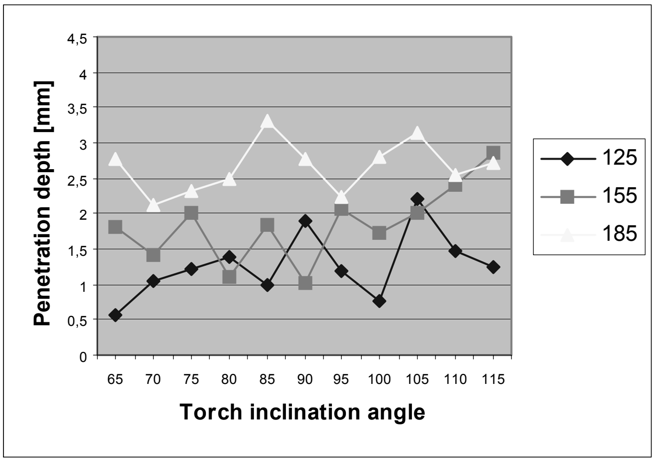


Fig. 6. Influence of arc current and the GMA torch inclination angle during robotized GMA surfacing with EnDOtec DO*11 wire of diameter 1,6 [mm], when weave technique applied, on penetration depth – hw, Table 4 [4]

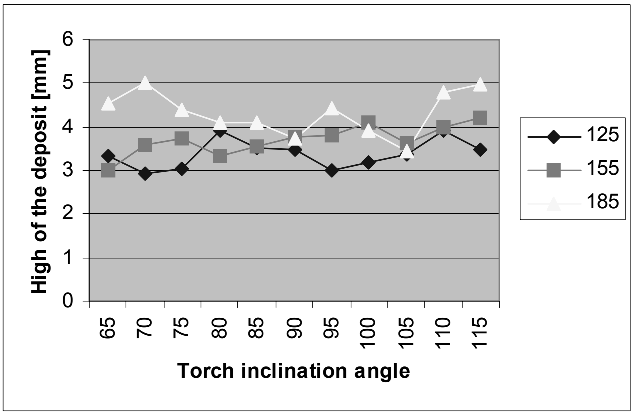


Fig. 7. Influence of arc current and the GMA torch inclination angle during robotized GMA surfacing with EnDOtec DO*11 wire of diameter 1,6 [mm], when weave technique applied, on high of the deposit – hn, Table 4

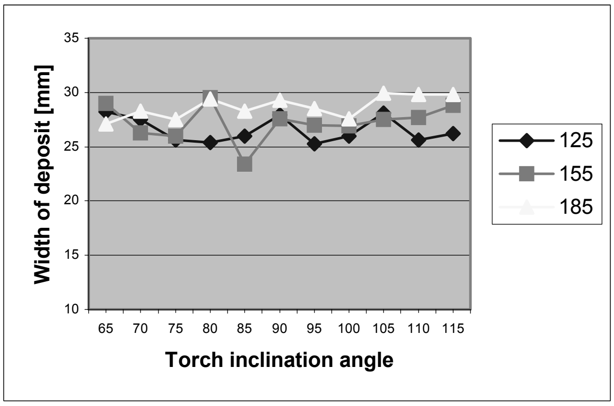
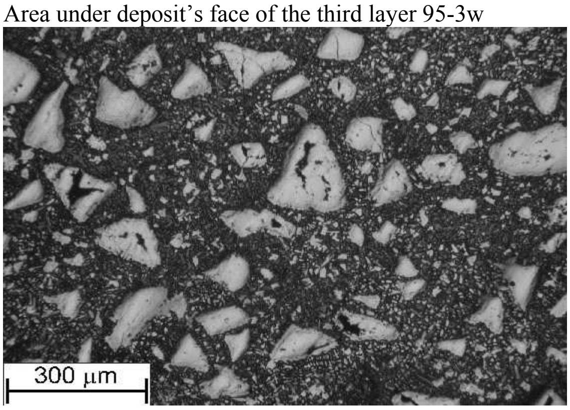


Fig. 8. Influence of arc current and the GMA torch inclination angle during robotized GMA surfacing with EnDOtec DO*11 wire of diameter 1,6 [mm], when weave technique applied, on width of the deposit - b, Table 4

Area under deposit's face of the third layer 95-3w



Area under deposit's face of the third layer 185-3ww

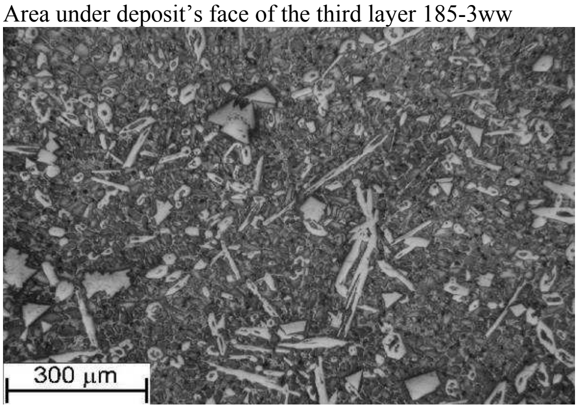


Fig. 9. Microstructure of the area under deposit's face of the third layer after GMA surfacing with EnDOtec DO*11 wire of diameter 1,6 [mm], stringer bead deposit– 95-3 and weave bead deposit – 185-3ww, Table 6 [4]

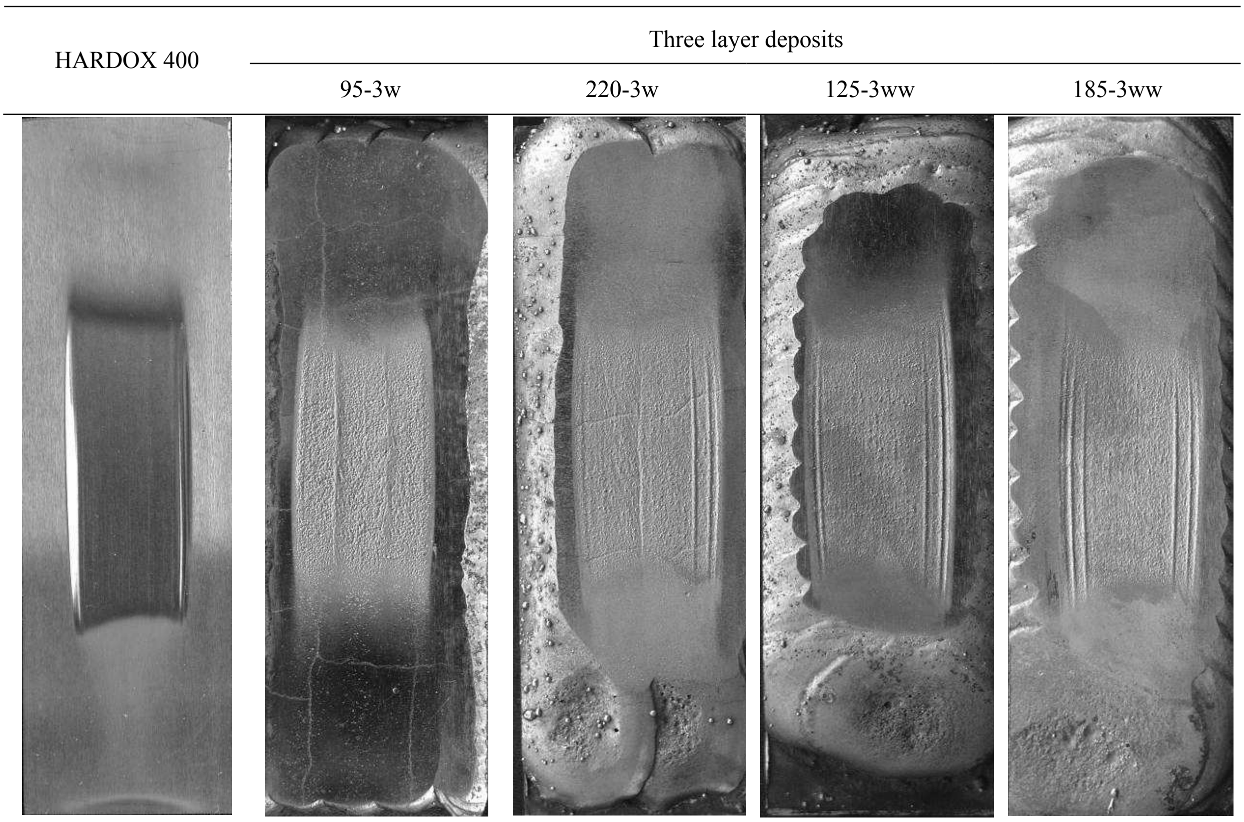


Fig. 10. A view of samples after wear resistance tests according to ASTM G65, Table 6

3. Results

The study of robotized GMA surfacing process with EnDOtec DO*11 wire of diameter 1,6 [mm], with oscillation of the welding torch - weaving technique of surfacing, showed that it is possible to produce high quality of deposits in a wide range of surfacing parameters, especially heat input of surfacing, Table 4. The weave bead deposits are free of transverse cracks, contrary to stringer bead deposits, which can be caused by thermal stresses in the deposits, Fig 4. This phenomenon probably is a result of totally different mechanism of shaping of the deposit produced during the weaving technique of surfacing, compared to the surfacing of stringer bead deposit. The size and volume of the weld pool during weaving technique surfacing is larger than during stringer bead surfacing thus the crystallization of liquid metal is different. Additionally in every half-cycle of the torch oscillation the metal is again partially molted. Large volume of the weld pool during weave bead surfacing can suppress the dynamic force of the arc so the dilution can be minimized to approximately 10%. Thanks to this phenomenon, a change of direction and the angle of the torch inclination doesn't affect significantly to the shape and dilution of the surfaced deposit, Fig. 5 to 8. It was found that the push technique ensures slightly lower dilution and penetration depth, especially at current set 125 [A], Fig. 5 and 6. Width and height of the deposits are at the same level, depending just on the surfacing current set and the heat input, Fig. 7 and 8.

Further investigations and detailed studies of the mechanism of deposit shaping, especially the control of dilution, shape of fusion zone and penetration depth, depending on parameters of surfacing and the trajectory and parameters of oscillation of the surfacing torch, are required.

Increase of the heat input of GMA surfacing with EnDOtec DO*11 wire of diameter 1,6 [mm], with weaving technique, resulted in increase of the efficiency of surfacing, increase of dilution of the deposit and slightly decrease of deposit hardness, Table 5.

Population and distribution of tungsten carbides WC in the volume of the deposit is higher in the middle and near the fusion line. The density of carbides is almost twice higher than the density of the molten metal of the weld pool so the carbides sink in the weld pool toward the fusion line (WC = 15,72 [g/cm^3], Ni = 8,9 [g/cm^3]). The microhardness on the cross-section of the deposit measured from the top surface of the deposit increases significantly until to the fusion line, Table 5 and Fig 4. Robotized GMA surfacing with weaving technique, at heat input 0,33-0,35 [kJ/mm] (current set 125 [A]), ensures the efficiency in a range 2,5-2,8 [kg/h] and also the dilution of deposit is very low, approximately 11-12[%] and hardness of the deposit is in a range 530-550 HV 30. Increase of the heat input of GMA surfacing to 0,52-0,55 [kJ/mm] (current set 185 [A]) resulted in increase of efficiency to about 3,5-3,9 [kg/h], but the dilution increases significantly up to 27-34 [%] and the hardness is lower about 470-520 HV 30.

The three layer weave bead deposits are free of transverse cracks, but the wear resistance is approximately 30-35 [%] lower compared with wear resistance of three layer stringer bead deposits surfaced at 25-30[%] overlap, Table 6 and Fig 10.

The wear resistance of cermet deposits Ni+WC depends mainly on the population, size and distribution of the primary tungsten carbides WC spread in the nickel alloy matrix of the deposit, Fig 10. The highest concentration of primary tungsten carbides WC in nickel alloy matrix is near the top surface in the third bead of the stringer bead deposits produced at minimal heat input, that is why the deposits have the highest wear resistance, Table 6 and Fig. 10.

4. Conclusions

Robotized GMA surfacing with EnDOtec DO*11 wire of diameter 1,6 [mm] and oscillation of the welding torch ensures high quality of deposits in a wide range of surfacing parameters, especially heat input.

Weave bead deposits are free of transverse cracks, contrary to stringer bead deposits, thanks to different mechanism of crystallization of the weld pool. In a case of weave bead deposits dilution is significantly lower compared with the stringer bead deposits.

Increase of the heat input during GMA surfacing with EnDOtec DO*11 wire of diameter 1,6 [mm] with weaving technique resulted in increase of the efficiency of surfacing, increase of dilution of the deposit and slightly decrease of deposit hardness.

Population of tungsten carbides WC on the cross section of deposit is higher in the middle and near the fusion line, because of high density of carbides which fall the molten metal of weld pool. Microhardness measured on the cross section of the deposit from the top surface increases significantly toward to the fusion line.

The wear resistance of cermet deposits Ni+WC depends mainly on the population and size of primary tungsten carbides WC in the nickel alloy matrix of the deposit. The stringer bead deposits produced at minimal heat input have the highest wear resistance, because the population of primary tungsten carbides WC in nickel alloy matrix is the highest near the top surface in the third bead.

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