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Robotized GMA surfacing of cermetal deposits

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ABSTRACT

Purpose: Purpose of this paper: Study of robotized GMA metal-cored wire surfacing of one-, two- and three layers stringer bead and weave bead deposits has been carried out.
Design/methodology/approach: The dilution of deposits, structure, hardness, WC carbide morphology and abrasive wear resistance type metal-ceramic as per ASTM G65, was determined.
Findings: It was shown that the abrasive wear resistance of stringer bead deposits is higher than weave bead deposits. Study of robotized GMA surfacing process with EnDOtec DO*11 wire of diameter 1.6 [mm], applying weaving (oscillation) technique of surfacing, showed that it is possible to produce high quality of deposits in a wide range of surfacing parameters (heat input). Contrary to stringer bead deposits, weave bead deposits are transverse cracks free which can be caused by thermal stresses in the deposits.
Research limitations/implications: The mechanism of deposit formation (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 demands further investigations and detailed studies.
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

1. Introduction

Automated and semi automated GMA surfacing with flux cored wires and metal cored wires is one of the welding processes widely used for surfacing at manufacturing stage and also for regeneration of working surfaces of parts [1-10]. The GMA surfacing process can be carried out at any welding position, and the efficiency of surfacing is from several to dozen kg of deposit per hour. The modern metal cored wires enable surfacing (producing) of top layers of any chemical composition, 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]. Manufacturers of cored wires characterize service properties of top layers and chemical composition of the deposit and also give detailed surfacing procedure specification and recommended techniques of surfacing [17-19].

One of the basic criterions for selection of welding procedure, especially in a case of surfacing the top layers of chemical composition distinctly different from base material, is a minimum dilution in the first layer of the multi-layer deposit

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

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

The dilution of the first layer of deposit surfaced with GMA using cored wire process can be controlled in a rang from approximately 10% to over 40%, depending on the parameters and technique of surfacing [1, 4, 5, 15, 16]. The simplest way to achieve the minimum dilution of the deposit is the multi-layer surfacing process, but it is simultaneously the most expensive way. It is recognized that the dilution of deposit during GMA surfacing can be lower below 5-15% in second layer, depending on heat input and technique of surfacing [4, 5, 14, 15, 16]. The other solution is decreasing the heat input of surfacing process, but in this case the efficiency (economics) of surfacing is also decreased, or applying a technique of surfacing with the GMA torch inclined towards the welding direction - push technique.

Most of handbook's and catalogue's recommendations ignore (omit) the weaving (oscillation) technique of surfacing.

There is no any information concerning the recommended direction and the GMA torch angle during GMA surfacing process when weaving technique is applied.

Results of study of GMA and SSA surfacing processes with cored wires, carried out in the Welding Department of Silesian University of Technology [16], have shown that the weaving technique applied during surfacing can significantly lower the dilution and also, in a case of some additional materials, can avoid cracks of deposit which are the result of thermal stresses, especially when straight beads of deposit are produced [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. Results

Investigations of GMA surfacing process were carried out using a REIS SVR6 robot and TotalArc2 5000 power source. Metal cored wire EnDOtec DO*11 of diameter 1,6 [mm] was chosen for the study of robotized GMA surfacing applying weave technique, Table 1. The wire is designed for surfacing deposits which are high wear resistant especially ceramic material – metal wear resistant and also high erosion resistant, even at elevated temperatures.

The structure of the deposit contains approximately 50% of tungsten carbides WC, evenly spread in the nickel alloy matrix, enforced additionally with hard phases which are produced during a recristalization process, Table 1. The basic criterion for selection of the surfacing procedure specification in a case of cermetal layers surfacing is the minimum dilution of the deposit , not the efficiency f surfacing process. The robotized surfacing process was applied to ensure maximum stability of surfacing parameters, especially the trajectory of the surfacing torch during weaving technique surfacing, speed of surfacing, direction and the torch angle. The surfacing trials were carried out in a down hand position of surfacing on samples of dimension 120x150x12 [mm] of S355J2G3 steel. The surfacing current was DC(+) pulse set at 125 [A], 155 [A] i 185 [A], and the power source static characteristic was flat (CV). The surfacing current, arc voltage, stick-out of electrode, and surfacing speed are in the 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 basis of initial trials of surfacing process, 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 each set of welding current: 125 [A], 155 [A] and 185 [A], the process of GMA surfacing was carried out applying push technique, in a range of angles 65 ^{o}, 75 ^{o}, 80 ^{o}, 85^o, then the surfacing torch was set at an angle 90^o, further study was carried out applying pull technique, in a range of angles 95 ^{o}, 100 ^{o}, 105 ^{o}, 110^o and 115^o. Study results of the effect of heat input and the technique of surfacing on shape and dilution of the deposit produced with weaving technique surfacing, Fig. 1 to 4. Contrary to the stringer bead deposits, no cracks were observed in the weaving bead deposits. Cracks of the stringer bead deposits were a result of thermal stresses in the deposits, Fig. 1. Deposits are very regularly shaped, the face of deposits is flat an smooth, and deposits are regularly fused into the substrate.

Additionally, tests of wear resistance type ceramic material – metal were carried out for three layers deposits surfaced with weaving technique, and three layers stringer bead deposits produced at overlap 25-30%, and at minimum and also maximum heat input of surfacing, Fig. 1.

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

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	

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

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
	65-125			65-185			90-185

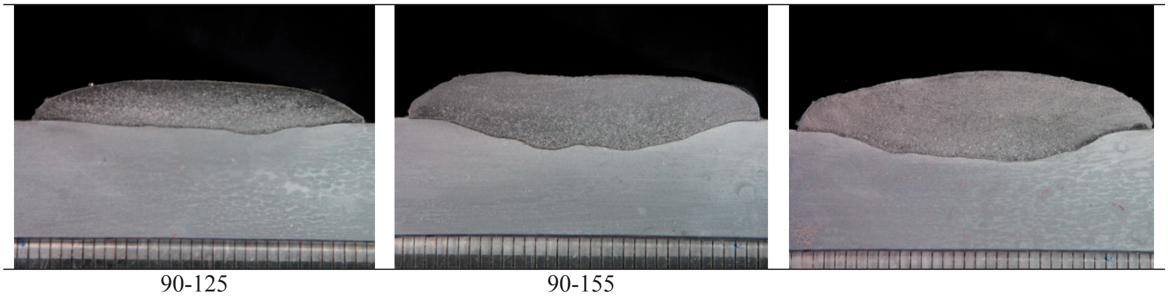


Fig. 1. Macrostructure of a single layer weave bead deposits produced with EnDOtec DO*11 wire of diameter 1,6 [mm]. Samples are marked - 65-125: 65 – torch inclination contrary to surfacing direction at an angle - 65^{o} (push technique), 125 – arc current - 125 [A]

Table 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].

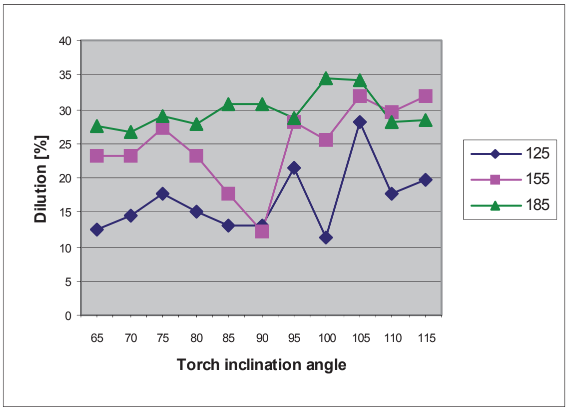


Fig. 2. Influence of arc current and the GMA torch inclination angle during robotized GMA surfacing with EnDOtec DO*11 wire of diameter 1,6 [mm], when weave technique applied, on dilution of the deposit - U

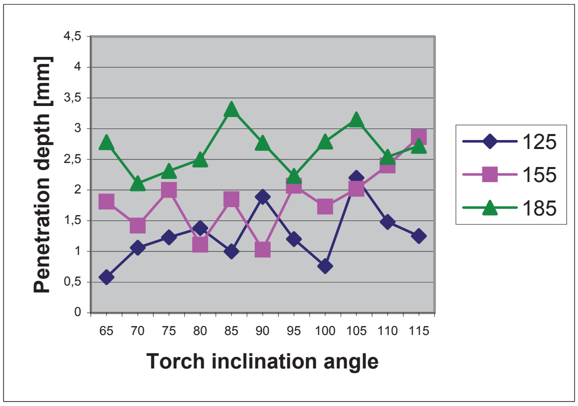
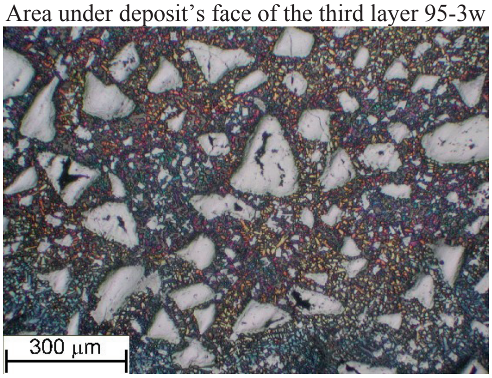


Fig. 3. Influence of arc current and the GMA torch inclination angle during robotized GMA surfacing with EnDOtec DO*11 wire of diameter 1,6 [mm], when weave technique applied, on penetration depth – hw

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



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

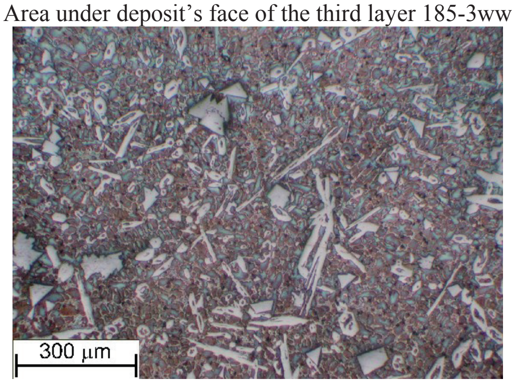


Fig. 4. Microstructure of the area under deposit's face of the third layer after GMA surfacing with EnDOtec DO*11 wire of diameter 1,6 [mm], stringer bead deposit– 95-3 and weave bead deposit – 185-3ww

3. Summary

Study of robotized GMA surfacing process with EnDOtec DO*11 wire of diameter 1,6 [mm], applying weaving (oscillation) technique of surfacing, showed that it is possible to produce high quality of deposits in a wide range of surfacing parameters (heat input). Contrary to stringer bead deposits [16], weave bead deposits are transverse cracks free which can be caused by thermal stresses in the deposits, Fig 1. Probably this phenomenon is a result of totally different, compared to the process of stringer bead deposit surfacing, mechanism of formation (shaping) of the deposit bead produced applying weaving technique of surfacing. The size of a weld pool during weaving technique surfacing is large and thus the crystallization of liquid metal is very low, and also in every half-cycle of the torch oscillation the metal is again partially molted. Large volume of the weld pool suppresses the dynamic force of the arc is, thus the dilution can be minimized to approximately 10%. This phenomenon makes that the change of direction and the torch angle doesn't affect significantly to the shape and dilution of the surfaced deposit, Fig. 2 and 3. Slightly lower dilution and penetration depth can be observed in the case of deposits surfaced applying push technique, especially at current set 125 [A], Fig. 2 and 3. Width of the deposits and high of the reinforcement are at the same level, depending just on the current set (heat input).

The mechanism of deposit formation (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 demands further investigations and detailed studies.

Increase of the heat input during GMA surfacing with EnDOtec DO*11 wire of diameter 1,6 [mm], when weaving technique is applied, 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 surfaced deposit is higher in the middle area and by the fusion line, because the density of carbides is almost twice higher than the liquid metal, thus the carbides fall (sink) in the molten metal toward the fusion line (WC = 15,72 [g/cm^3], Ni = 8,9 [g/cm^3]). Thus the hardness, measured on the cross section of the deposit from the top surface of the deposit to the fusion line, increases significantly, Fig 1. Surfacing with weaving technique, at heat input 0,33-0,35 [kJ/mm] (current set 125 [A]), resulted in efficiency of surfacing in a range 2,5-2,8 [kg/h], but also the dilution of deposit is very low, approximately 11-12%, and hardness of the deposit 530-550 HV 30. Increase of the heat input to 0,52-0,55 [kJ/mm] (current set 185 [A]), resulted in increase of efficiency to approximately 3,5-3,9 [kg/h], but simultaneously the dilution increases significantly up to 27-34 [%], and the hardness is lower in a range 470-520 HV 30.

Three layer weave bead deposits are free of transverse cracks free, but the wear resistance is approximately 30-35 [%] lower then the wear resistance of three layer stringer bead deposits produced at 25-30% overlap.

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, Fig 4. Thus 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, Fig. 4.

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