A. CZUPRYŃSKI, J. GORKA, M. ADAMIAK

ISSN 0543-5846
METABK 55(2) 173-176 (2016)
UDC – UDK 621.793:72:621.778:621:365.2:620.178.1=111

EXAMINING PROPERTIES OF ARC SPRAYED NANOSTRUCTURED COATINGS

Received – Primljeno: 2015-04-08
Accepted – Prihvaćeno: 2015-10-20
Original Scientific Paper – Izvorni znanstveni rad

The article presents the results of examining properties of arc sprayed coating obtained with nano-alloy on the iron matrix with a high amount of fine carbide precipitates sprayed on non-alloyed steel plates intended for high temperature operation. Powder metal cored wire EnDOtec DO*390N 1,6 mm diameter, was used to produce, dense, very high abrasion and erosion resistant coatings approx. 1,0 mm thick. Nano-material coatings characterization was done to determine abrasion resistance, erosion resistance, adhesion strength, hardness as well as metallographic examinations. Results have proved high properties of arc sprayed nano-material coatings and have shown promising industrial applications.

Key words: coating, wire arc spraying, nano-alloys, abrasive and erosion wear, adhesion strength

INTRODUCTION

Dynamic expansion of nanotechnologies, which are one of the most intensely growing technologies, has been observed for the last few year's [1, 2]. Nanotechnology also has an impact on the significant development of surface engineering and welding technologies. For the present, it is possible to obtain high quality nanostructure layers e.g. aluminium alloys for car engine parts, or copper alloys for ships screw propellers.

Continuous development of welding engineering in scope of equipment construction and filler materials metallurgy gives possibilities to obtaining surface layers providing special extreme properties, e.g.: thermal barrier coatings, gradient layers, high-hardness layers, wear-, erosion- and corrosion-resistant layers or biocompatible coatings [1, 3-8]. One of the modern surface engineering technologies assuring high quality surface layers is wire arc spraying process, where spraying of metallic layer is made without melting the base material, layer is mechanically or adhesively bonded with the base material, a pair of solid or cored metal wires is feed with constant speed and is melted by electric arc heat with precisely controlled current and voltage, Figure 1 [9].

Melted filler material is atomized by compressed air and then thrown onto the surface of base metal. Melted particles of wires hit the base metal, and solidify after quick cooling. Wire arc spraying process ensures high quality coatings characterized by low porosity and very strong adhesion or mechanical bond to the base metal and is successfully applied in modern industry in the production of new parts or as the repair process of worn parts [1, 9].

A. Czrupynski, J. Gorka, M. Adamiak, Silesian University of Technology, Gliwice, Poland

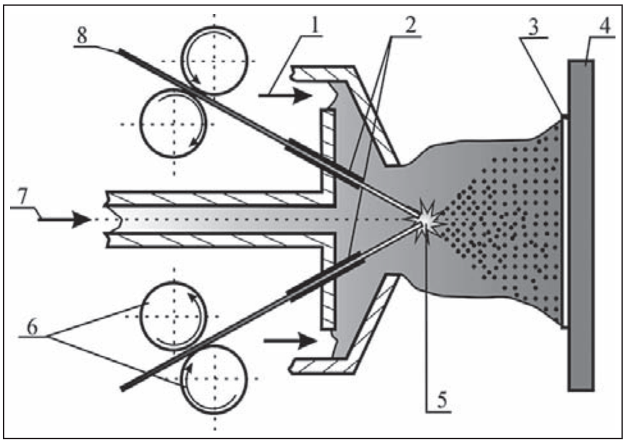

Figure 1 A scheme of wire arc spraying apparatus: 1 – compressed air; 2 – wire electric contact; 3 – sprayed layer; 4 – base metal; 5 – electric arc; 6 – wire feeder; 7 – compressed air [9].

The examination results of the welding procedure (Table 1) of nano-material EnDOtec DO*390N wire arc spraying on a base metal, Grade 55 steel sheet allowed to establish optimum welding conditions of spraying high quality surface layers 1,0 mm thick. Study of structure, grain size, hardness, wear and erosion resistance and adhesion strength to base metal of DO*390N wire arc sprayed coatings proved their high quality.

EXPERIMENTAL PROCEDURE

Test were conducted to determine the structure, size of grain, hardness, abrasion wear resistance and adhesion strength to the base of arc sprayed layer on non-alloyed ASTM A516, Grade 55 steel plates intended for high-temperature operation, obtained with EnDOtec DO*390N powder wire.

The influence of wire arc spraying parameters on the quality of sprayed coatings on the clean surface of Grade 55 steel sheets was tested at wide range of arc current, arc voltage, wire feed speed, atomizing air pressure and distance between torch and surface of the base metal. Arc spraying tests of 1,0 mm thick layers were conducted in vertical position on a manufacturing stand equipped in the EuTronic Arc Spray 4 arc wire spraying equipment and hand spraying gun, Gun 4.

200 χ 200 χ 9 mm steel sheets were sand blasted and preheated with a gas burner to the temperature of about 40 ^{o}C just before wire arc spraying process. The range of optimum wire arc spraying parameters was defined on the basis of following quality criteria of sprayed coatings: uniform thickness of coating, low porosity and high adhesion strength of coating to the base metal, Table 1.

RESULTS AND DISCUSSION

Porosity of DO*390N wire arc sprayed coatings was evaluated in accordance to ASTM B - 276 standard. Porosity was defined using Materials-Pro Analyser. The software used calculated the overall number of pixels on scanned surface of the sample and determined the percentage amount of black pixels (empty spaces). Tests of grinded surface of external layer on 1,0 cm^2 area in Materials-Pro Analyser software have shown that porosity is at the range 5 - 10 %. Metallographic macro and micro structure examinations proved very high quality of DO*390N wire arc sprayed coatings, with uniform bonding with base metal and limited porosity, Figure 2a, b. Results of the X-ray phase analysis show peaks from Cr_7C_3 and Fe_3C as well as from Fe α. Grain size measurements of DO*390N wire arc sprayed layer microstructure were conducted on PANalytical Xpert PRO roentgen diffractometer. Based on crystallite size calculations using Scherrer's equation (1) it was found that the average grain size of arc sprayed coating, measured in perpendicular direction to the base, is around 28,6 nm.

$$D = \frac{K \cdot \lambda}{B_{\text{struct}} \cdot \cos\theta}$$

where:

D – average crystallite size in perpendicular direction to the deflection plane, K – Scherrer's factor (nearly 1) λ – wave length used, B_{struct}. – the structural broadening which is the difference in integral profile width between a standard and the sample to be analysed, θ – describes the angle of incidence.

HV 0,1 hardness tests were conducted on ground surface of arc sprayed coating in six measurement points, in accordance to ISO 6507-1:2007 standard. The average hardness of the coating was 873 HV0,1 (63 HRC). Abrasion wear resistance tests were conducted in accordance to ASTM G65-00 standard, Procedure A [10]. 75 χ 25χ 10 mm samples were cut out in the middle of arc sprayed plate and HARDOX 400 steel and

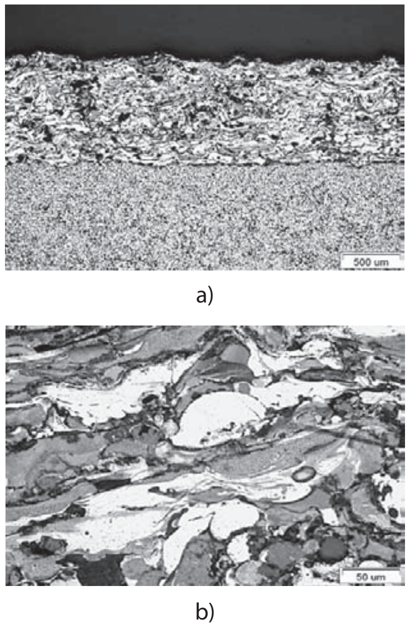

Figure 2 Macro (a) and microstructure (b) of DO*390N wire arc sprayed coating, etching: HCl+ HNO_3

minimally grinded. All of samples, acc. to demands of standard, before and after the tests were weighed on lab scale with 0.0001 g accuracy. Weight loss of DO*390N wire arc sprayed coatings was compared directly to HARDOX 400 steel plate volume loss. Using measured density of sprayed layer and weight loss of the sample also volume weight loss was calculated, Table 2. Quantitative assessment of erosion wear resistance of DO*390N wire arc sprayed coatings and HARDOX 400 steel plate was conducted in accordance to ASTM G76-95 [11]. Erosion resistance was tested on the same specimens used for abrasion wear resistance tests. Before the tests, ASTM G76-95 apparatus was calibrated on AISI 1020 steel plate specimen to set the stable flow of erosion particles and define reference erosion value. Erosion resistance of DO*390N wire arc sprayed coatings and HARDOX 400 steel plate were tested at erosion particles impingement angle: 90^{o}, 60^{o}, 30^{o} and 15^{o}, Table 3.

Adhesion strength tests of DO*390N wire arc sprayed coatings to the surface of ASTM A516, Grade 55 steel sheets were conducted in accordance to ASTM C 633-01 standard [12]. 25 mm diameter samples were cut from sprayed test plate and glued together using Henkel Loctite®Hysol® 348 A&B Superior Metal glue. Properly prepared samples were exposed to the static tensile test lasting till their damage. Failure of all tested specimens took place in the centre part of arc sprayed coatings, with adhesion strength above 10 N/mm^2, Table 4.

CONCLUSIONS

Based on the results of arc spraying using 1,6 mm diameter, DO*390N grade powder wire of non-alloyed ASTM A516, Grade 55 steel, one can conclude that it is

Table 1 **Properties of EnDOtec DO*390N wire weld metal and optimum wire arc spraying parameters**

Wire designation	Chemical composition / mas.% and typical hardness of deposit (by CASTOLIN)	Arc spraying parameters		
		Current /A	Voltage /V	Gun distance from base metal sheet /mm
EnDOTec DO*390N	Fe + < 5,0 C,< 2,0 Si, < 5,0 Mn, < 20,0 Cr, < 10,0 Mo,< 10,0 Nb, < 10,0 W, < 5,0 B 71 HRC	160 - 170	30,0 - 31,0	180 - 190

Remarks: EnDOtec DO*390N wire dia. 1,6 mm. Preheating temperature of base metal sheet 40 °C. Air pressure 5,5 - 5,8 bar

Table 2 **Results of low-stress abrasion wear resistance to metal-ceramic scratching**

Specimen designation	Number of specimen	Weight before test / g	Weight after test / g	Mass loss / g	Average mass loss / g	Average volume loss / mm³	Relative* abrasion resistance
DO390N	N1	127,3654	126,1191	1,2463	1,2335	191,5373	0,99
	N2	128,3998	127,1791	1,2207			
HARDOX 400	H1	62,2260	60,7526	1,4734	1,4617	185,7306	1,00
	H2	63,1222	61,6721	1,4501			

Remarks: density of DO*390N wire arc sprayed coating: – 6,44 g/cm³, the force applied against the test specimen TL = 130 N. Volume loss, mm³ = (mass loss g : density g/cm³) x 1000. * - relative to HARDOX 400 steel plate.

Table 3 **Results of erosion wear resistance tests**

Specimen designation	Erodent impact angle / °	No of speci-men	Erosion weight loss / mg	Erosion rate / mg/min	Erosion value /0,001mm³/g	Average erosion value / 0,001 mm³/g	Relative erosion resistance*
DO390N	90	390N-90-1	14,8	1,48	113,4882	113,1048	0,36
		390N-90-2	14,7	1,47	112,7214		
HARDOX 400		400-90-1	6,5	0,65	40,7862	40,7862	1.,0
		400-90-2	6,5	0,65	40,7862		
DO390N	60	390N-60-1	22,9	2,29	175,6000	176,3668	0,27
		390N-60-2	23,1	2,31	177,1337		
HARDOX 400		400-60-1	7,4	0,74	46,4336	46,7473	1,0
		400-60-2	7,5	0,75	47,0610		
DO390N	30	390N-30-1	14,7	1,47	112,7214	111,9546	0,42
		390N-30-2	14,5	1,45	111,1878		
HARDOX 400		400-30-1	7,6	0,76	47,6885	47,3748	1,0
		400-30-2	7,5	0,75	47,0610		
DO390N	15	390N-15-1	14,8	1,48	113,4882	113,1048	0,43
		390N-15-2	14,7	1,47	112,7214		
HARDOX 400		400-15-1	7,6	0,76	47,6885	48,3160	1,0
		400-15-2	7,8	0,78	48,9435		

Remarks: Erosion rate, mg/min = (mass loss mg : time plot min), Erosion value, mm³/g = (volume loss of specimen mm³ : total mass of abrasive particles g). Erosion conditions: velocity – 70 ± 2 m/s, temperature 20 °C, erodent – Al_2O_3 of nominal dimension – 50 µm, feed rate – 2,0 ± 0,5 g/min., erosion time – 10 min, distance between nozzle and specimen – 10 mm, test temperature 20 °C, * – relative to HARDOX 400 steel plate.

Table 4 **Results of adhesion strength tests**

Designation of test specimens	Number of test specimen	Max. load at rapture / kN	Specimen cross-sectional area / mm²	Adhesion strength / N/mm²	Average adhesion strength / N/mm²
DO390N	DO1	5,9	490,6	11,9	10,9
	DO2	5,2		10,5	
	DO3	5,1		10,4	

possible to obtain high-quality, nano-structural layer with medium sized crystallites below 30 nm. Results of study of influence of basic parameters of EnDOtec DO*390N wire arc spraying process on the quality of nano-structural coatings proved that it is possible to produce high quality, approx. 1,0 mm thick coatings, characterized by low porosity in the range 5 – 10 %. Sprayed layer is characterized by high hardness over 63 HRC and abrasion wear resistance comparable to parameters of HARDOX 400. Erosion resistance at particle impingement angles from 15° to 30° is high however 40 % lower than HARDOX 400 steel plate. Adhesion strength tests of arc sprayed layer with EnDOtec DO*390N nanoalloy on ASTM A516, Grade 55 steel were conducted acc. to ASTM C 633 - 01 standard and have shown adhesive-mechanical character of layer/base material bonding above 10 MPa. Binder material EnDOtec DO*390N is a modern material for arc spraying of high hardness, abrasion and erosion wear resistant layer.

REFERENCES

[1] Ch. P. Jr Poole, F. J. Ownes, Introduction to Nanotechnology, Wiley, New Jersey, 2003, 1-8.

[2] S. Boncel, J. Gorka, M. Shaffer, K. Koziol, "Binary Salt" of Hexane-1,6-Diaminium Adipate and "Carbon Nanotubate" as a Synthetic Precursor of Carbon Nanotube/Nylon-6,6 Hybrid Materials Polimer Composites 35 (2014) 5, 523-529.

[3] A. Lisiecki, Titanium Matrix Composite Ti/TiN Produced by Diode Laser Gas Nitriding Metals 5 (2015) 1, 54-69.

[4] D. Janicki, Power Diode Laser Cladding of Wear Resistant Metal Matrix Composite Coatings, Solid State Phenomena, Mechatronic Systems and Materials V, 199 (2013) 587-592.

[5] D. Jevremovic, T. Puskar, B. Kosec, D. Vukelic, I. Budak, S. Aleksandrovic, D. Eggbeer, R. Williams, The analysis of the mechanical properties of F75 Co-Cr alloy for use in selective laser melting (SLM) manufacturing of removable partial dentures (RPD), Metalurgija 51 (2012) 2, 171-174.

[6] J. Kusiński, S. Kac, A. Lisiecki, : Laser modification of the materials surface layer – a review paper, Bulletin of the Polish Academy of Sciences, Technical Sciences 60 (2012) 4, 711-728.

[7] L. A. Dobrzański, M. Adamiak, G. D'Errico, Relationship between erosion resistance and the phase and chemical composition of PVD coatings deposited onto high-speed steel, Journal of Materials Processing Technology 92/93 (1999) 184-189.

[8] K. Raic, R. Rudolf, B. Kosec, I. Anzel, V. Lazic, A. Todorovic, Nanofoils for soldering and brazing in dental joining practice and jewellery manufacturing Materiali in tehnologije 43 (2009) 1, 3-9.

[9] T. Degitz, K. Dobler, Thermal spray basics, Welding Journal 11(2002) 50-52.

[10] ASTM G 65-00: Standard Test Method for Measuring Abrasion Using the Dry Sand/Rubber Wheel Apparatus, 2000.

[11] ASTM G 76-95: Standard Test Method for Conducting Erosion Test by Solid Particle Impingement Using Gas Jets, 1995.

[12] ASTM C 633-01: Standard Test Method for Adhesion or Cohesion Strength of Thermal Spray Coatings, 2001.

Note: The responsible translator for English language is Translation Bureau "TRANSLATIUM", Wroclaw, Poland