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# THE PROPERTIES AND STRUCTURE OF ARC SPRAYED COATINGS ALLOY OF Fe-Cr-Ti-Si-Mn

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***Abstract:*** Comprehensive study of EuTronic Arc 502 wire arc spraying technology were conducted to establish optimum properties of very high wear resistance coatings alloy of Fe-Cr-Ti-Si-Mn sprayed on ASTM A516, Grade 55 base metal sheets. Alloy of Fe-Cr-Ti-Si-Mn coatings characterization was done in accordance to ASTM G 65-00 Procedure A abrasion resistance test, ASTM G 76-95 erosion resistance tests, ASTM C 633-01 adhesion strength, HV 0.1 hardness tests and metallographic examinations. The research the influence of the basic parameters of the wire arc spraying EuTronic arc 502 shown possible to fabricate a high quality coating of Cr-Fe-Si-Ti, Mn having a thickness of approx. 1.0 [mm], which is characterized by a low porosity in the range of 10-15%, and average grain size less then 50 [nm]. Bonding between base material and sprayed coating is adhesive with bonding strength above 10 [N/mm$^2$]. Alloy of Fe-Cr-Ti-Si-Mn sprayed coating show very high hardness (above 58 HRC), and provide high wear resistance, comparable to HARDOX 400 steel. Erosion resistance at particle impingement angles from 15$^o$ to 30$^o$ is high but 40% lower than HARDOX 400 steel plate.
***Key words:*** wire arc spraying, coating, abrasive wear resistance, erosion wear resistance, adhesion strength.

## 1. INTRODUCTION

Dynamic expansion of nanotechnologies, which are on of the most intensive growth technologies, is observed from a few last year's, [1-3]. Nanotechnology has also influence on significant development of surface engineering and welding technologies. For the present, it is possible to obtain a high quality nanostructure working layers e.g. aluminum car engine parts, copper alloys cast ships screw propellers and modern heat-resisting alloys engine parts. Welding engineering development in equipment and filler materials metallurgy gives possibilities to obtain surface working layers providing special properties, for example: coatings resistant to high temperature gradient layer, the layer resistant to wear and erosion, the layer of high hardness, [1-3]. Among the methods used for surface engineering is performed such layers arc spraying process, which uses as an additive material powder or solid wire, which is fed at a constant speed, and is melted by the heat of the arc precisely controlled current and voltage, [3].

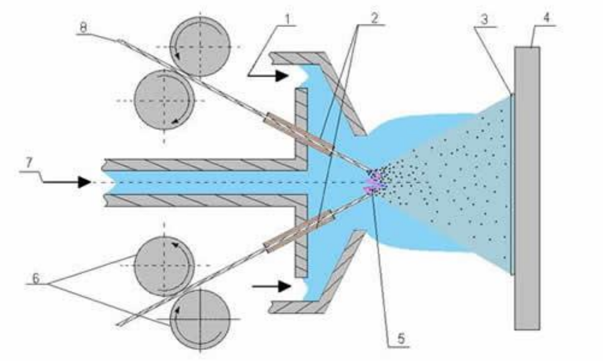



Fig. 1. A scheme of wire arc spraying apparatus: 1 – compressed air; 2 – wire electric contact; 3 – sprayed layer; 4 – base metal; 5 – electric arc; 6 – wire feeder; 7 – compressed air [3]

The molten material of the electrode wire is sprayed with pressurized air and is sprayed onto a substrate base material. The molten particles of the additive material and against the surface and undergo rapid solidification on a cold substrate. Arc spraying process provides high quality coatings which are characterized by low porosity and a very strong adheres to the substrate surface. This manufacturing process has been successfully used used in modern industry, the manufacture of new machine parts or in the process of repair parts exploited [4-11].

## 2. EXPERIMENTAL DETAILS

The article presents the results of the process of arc spraying alloy Fe-Cr-Si-Ti, Mn on the base material of steel ASTM A516, Grade 55, tables 1, 2. Developed the optimum process parameters arc spraying allows to obtain surface layers with a thickness of 1.0mm. In order to assess the quality of the spraying, the obtained coating was subjected to metallographic examination, defined grain size, hardness tests, resistance to wear and erosion determining the adhesion force of the coating alloy of Fe-Cr-Ti-Si-Mn to the base metal. In order to assess the quality of the spraying process are subject to change in the following parameters: arc voltage, arc current, atomizing air pressure, distance between torch and surface of the base metal and wire feed speed, using industrial stand equipped in EuTronic Arc Spray 4 apparatus with manual gun in down hand 1G position, Fig. 2, 3.

Fig. 2. View of equipment for arc spraying EuTronic Arc Spray 4


Fig. 3. Tthe process of spraying test plates

ASTM A516, Grade 55 steel sheets 200x200x9 [mm], they were blasted before spraying the surface and heated to a temperature of about 40°C using an oxy-acetylene torch. They were selected range of parameters spraying based on the criteria: a uniform coating thickness, the low porosity and high strength of adhesion of the coating to the base metal, Table 1.

Table 1. The chemical composition and hardness of deposit alloy of Fe-Cr-Ti-Si-Mn wire weld metal and arc spraying parameters

| Type wire | The chemical composition of the weld metal, wt%, and hardness of deposit | Arc spraying parameters | | |
|---|---|---|---|---|
| | | Current [A] | Current [A] | Current [A] |
| EuTronic Arc 502 | Fe:15.0÷20.0% Cr: 2.5÷3.5% Ti: 1.0÷1.5% Si: 5÷1.5%Mn ~66 HRC | 200 | 35.0 | 180 |

Remarks: EuTronic Arc 502 wire dia. 1.6mm. Preheating temperature of base metal sheet 40$^{o}$C. Air pressure (5.5-5.8) bar.

Table 2. Chemical composition, wt. %, of the base metal and reference plate - HARDOX 400

| ASTM A516 Grade 55 | | | | |
|---|---|---|---|---|
| C | Mn | Si | P | S |
| 0.18 | 0.9 | 0.4 | 0.035 | 0.035 |

| HARDOX 400 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| C | Mn | Si | P | S | Cr | Ni | B | Mo |
| 0.14 | 1.6 | 0.7 | 0.025 | 0.010 | 0.50 | 0.25 | 0.004 | 0.25 |

Remarks: Thickness of ASTM A516 steel plate, Grade 55 – 9.0 mm, HARDOX 400 steel plate – 10.0mm.

## 3. RESULTS & DISCUSSION

Porosity of EuTronic Arc 502 wire arc sprayed coatings was evaluated in accordance to ASTM B-276 standard, [12]. Pictures analyses of sprayed coating area on 1.0cm$^2$ area it showed a porosity of (10-15)%, Fig. 4.

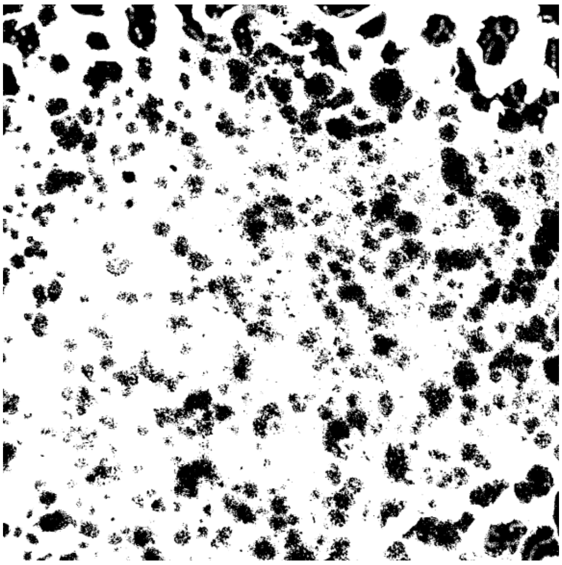
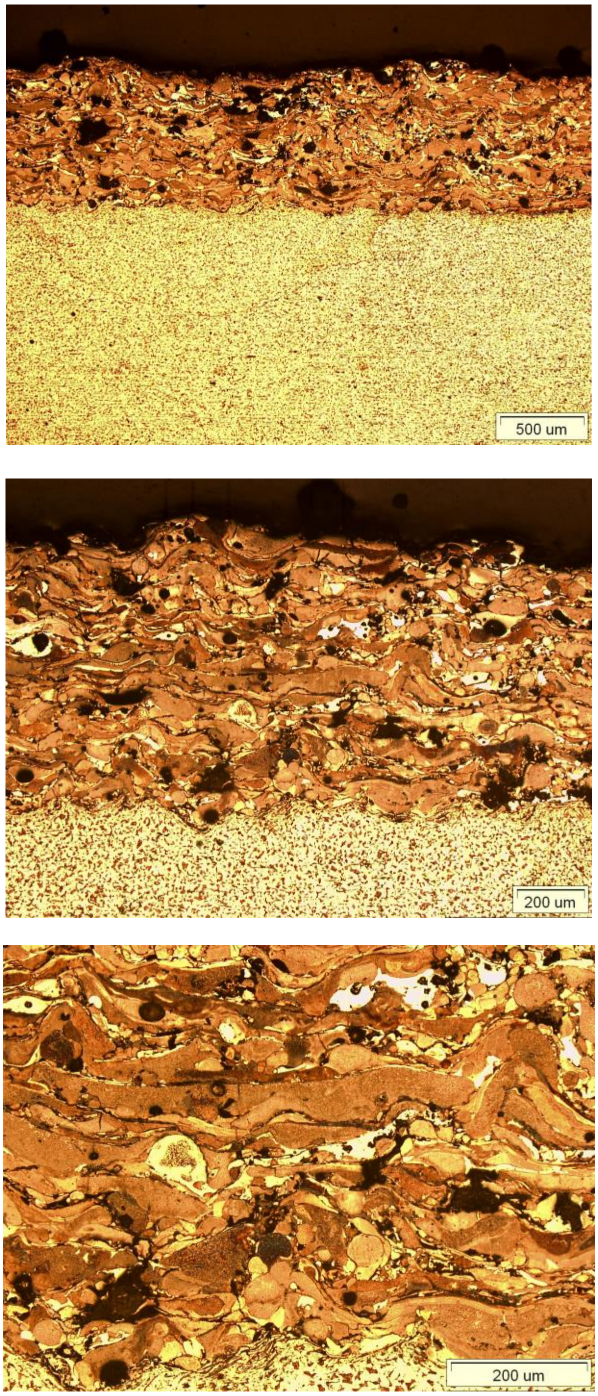


Fig. 4. The area of the sprayed coating evaluated porosity in Materials-Pro Analyzer software

Metallographic studies showed a very high quality alloy of Fe-Cr-Ti-Si-Mn sprayed on ASTM A516, with uniform bonding with base metal and low porosity, Fig. 5. Grain size measurements alloy of Fe-Cr-Ti-Si-Mn were performed using a Xpert PRO PANalytical roentgen diffractometer. To calculate the crystallite size Scherrer formula was used (1).

$$D = \frac{K \cdot \lambda}{B_{struct} \cdot cos\theta} \qquad (1)$$

where:
D – average crystallite size in perpendicular direction to the deflection plane, K – Scherrer's factor - nearly 1, λ – wave length, $B_{structural}$ – 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.
The calculations showed that the average grain size of sprayed coatings, measured in the perpendicular direction is approximately 90[nm.



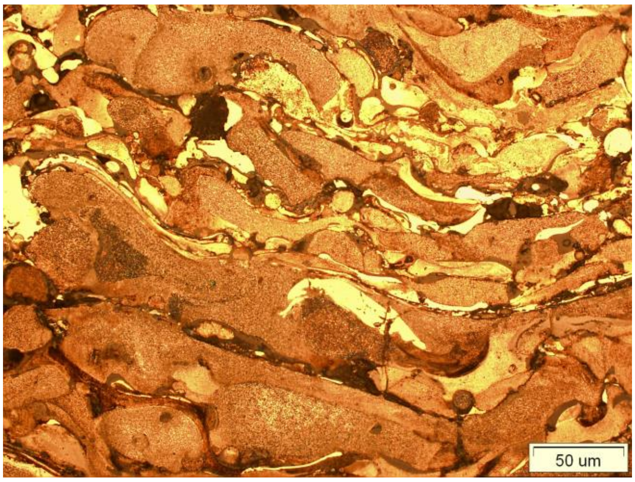




Fig. 5. View macro and microstructure of Fe-Cr-Ti-Si-Mn coating, etching: HCl+ $HNO_3$

The hardnees HV 0.1 were conducted on ground surface of arc sprayed coating in six measurement points in accordance to ISO 6507-1:2007, Fig. 6, Table 3.

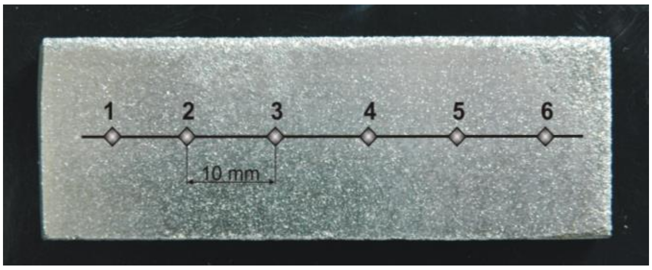



Fig. 6. Distribution of hardness measurement points on the surface of the outer layer

Table 3. Results of hardness HV 0.1 tests on the ground surface alloy of Fe-Cr-Ti-Si-Mn coating and HARDOX 400 steel plate

| Hardness | Hardness measurement points | | | | | Average |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | |
| ASTM A516 Grade 55 | | | | | | |
| HV 0.1[1)] | 652.5 | 589.0 | 740.0 | 491.7 | 536.7 | 785.4 |
| HRC | 58.0 | 54.7 | 61.8 | 48.6 | 51.5 | 63.5 |
| HARDOX 400 | | | | | | |
| HRC[2)] | 44.0 | 43.8 | 43.8 | 43.8 | 43.4 | 43.8 |

Remarks: [1)] Hardness was measure in Vickers scale and converted into HRC scale. [2)] Measurements in Rockwell scale. Distance between following points – 10.0mm.

Abrasion wear resistance tests were conducted in accordance to ASTM G65-00 standard, Procedure A. Volume loss of EuTronic Arc 502 wire arc sprayed coatings was compared directly to HARDOX 400 steel plate volume loss, Fig. 7, 8, Table 4. Density of EuTronic Arc 502 wire arc sprayed coating was 6.37g/cm$^3$, and the force applied against the test specimen TL=130N.

Fig. 7. The view of stand for the testing of abrasion resistance as ASTM G 65

EuTronic Arc 502 HARDOX 400

Fig. 8. View of the samples after the test surface abrasion

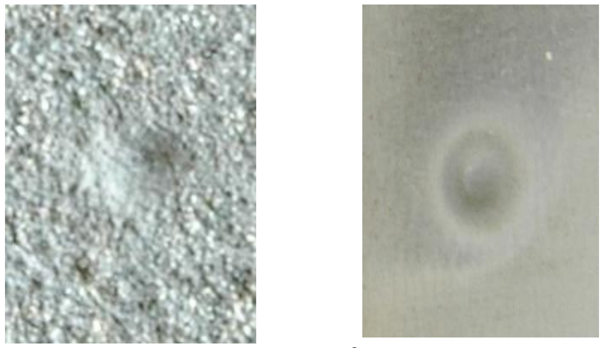
Before the erosion tests in accordance to ASTM G76-95, apparatus was calibrated on AISI 1020 steel plate specimen to set the stable flow of erosion particles and define reference erosion value. Erosion resistance of Fe-Cr-Ti-Si-Mn sprayed coatings and HARDOX 400 steel plate were tested at erosion particles impingement angle: $90^o$, $60^o$, $30^o$ and $15^o$, Fig. 9, 10, Table 5. Erosion resistance was tested on the same specimens used for abrasion wear resistance tests. Erosion conditions were: velocity $(70 \pm 2)$m/s, temperature $20^oC$, erodent - $Al_2O_3$ of nominal dimension – $50\,\mu$m, feed rate $(2.0 \pm 0.5)$g/min, erosion time - 10min, distance between nozzle and specimen - 10mm, test temperature $20^oC$. In accordance to ASTM C 633-01 standard were conducted adhesion strength tests of Fe-Cr-Ti-Si-Mn sprayed coatings to the surface of ASTM A516, Grade 55 steel sheets. Failure of all tested specimens took place in the center part of arc sprayed coatings, with adhesion strength above $10N/mm^2$, Fig. 11, Table 6.

a)

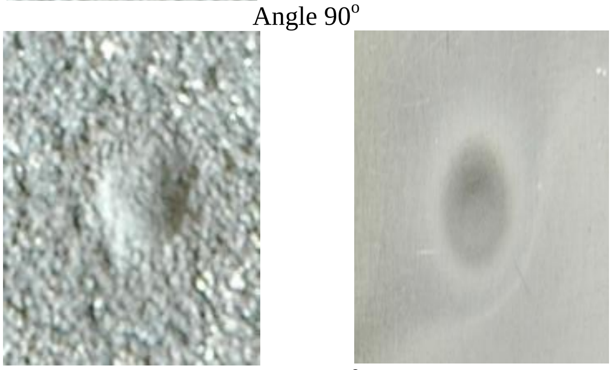
b)

Fig. 9. The position of the test of resistance to erosive wear in accordance with ASTM G 76-95: a) general view, b) back into the chamber erosive

EuTronic Arc 502 HARDOX 400

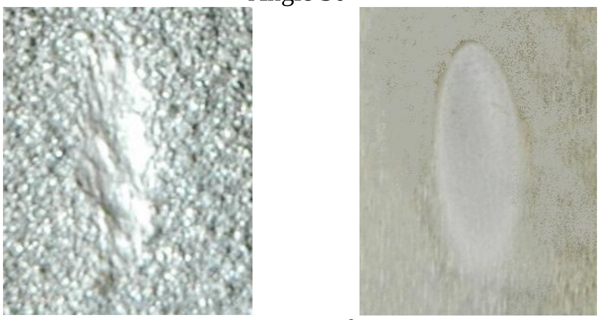


Angle $90^o$



Angle $60^o$

Angle 30$^o$



Angle 15$^o$

Fig. 10. View samples after testing the corrosion resistance

Fig. 11. View samples after testing adhesion

Table 4. Results of of abrasion resistance tests in accordance to ASTM G 65-00, procedure A, alloy of Fe-Cr-Ti-Si-Mn coating and HARDOX 400 steel plate

| Designation of test specimens | Number of specimen | Weight before test [g] | Weight after test [g] | Mass loss [g] | Average mass loss [g] | Average volume loss [mm$^3$] | Relative* abrasion resistance |
|---|---|---|---|---|---|---|---|
| EuTronic Arc 502 | A1 | 120.0641 | 118.6974 | 1.3667 | 1.2435 | 1.2672 | 198.7755 |
| | A2 | 120.3947 | 119.2291 | 1.1656 | | | |
| HARDOX 400 | Hardox1 | 62.2160 | 60.7536 | 1.4734 | 1.4627 | 185.7406 | 1.00 |
| | Hardox2 | 63.1232 | 61.6721 | 1.4501 | | | |

Remarks: * - relative to HARDOX 400 steel plate, volume loss, [mm$^3$] = mass loss [g]: density [g/cm$^3$] x 1000.

Table 5. Results of erosion wear resistance tests alloy of Fe-Cr-Ti-Si-Mn coating and HARDOX 400 steel plate in accordance to ASTM G 76-95

| Designation of test specimens | Erodent impact angle [$^o$] | Number of specimen | Erosion weight loss [mg] | Erosion value [0,001mm$^3$/g] | Average erosion value [0,001 mm$^3$/g] | Relative erosion resistance* |
|---|---|---|---|---|---|---|
| EuTronic Arc 502 | 90 | 502-90-1 | 12.3 | 95.3086 | 96.1067 | 0.42 |
| | | 502-90-2 | 12.5 | 96.9048 | | |
| HARDOX 400 | | 400-90-1 | 6.5 | 40.7862 | 40.7862 | 1.0 |
| | | 400-90-2 | 6.5 | 40.7862 | | |
| EuTronic Arc 502 | 60 | 502-60-1 | 10.4 | 80.6248 | 80.2372 | 0.58 |
| | | 502-60-2 | 10.3 | 79.8496 | | |
| HARDOX 400 | | 400-60-1 | 7.4 | 46.4336 | 46.7473 | 1.0 |
| | | 400-60-2 | 7.5 | 47.0610 | | |
| EuTronic Arc 502 | 30 | 502-30-1 | 13.1 | 101.5562 | 101.1686 | 0.47 |
| | | 502-30-2 | 13.0 | 100.7810 | | |
| HARDOX 400 | | 400-30-1 | 7.5 | 47.7885 | 47.3748 | 1.0 |
| | | 400-30-2 | 7.5 | 47.0610 | | |
| EuTronic Arc 502 | 15 | 502-15-1 | 14.2 | 109.3086 | 110.0839 | 0.44 |
| | | 502-15-2 | 14.3 | 110.8591 | | |
| HARDOX 400 | | 400-15-1 | 7.7 | 47.7885 | 48.3160 | 1.0 |
| | | 400-15-2 | 7.6 | 48.8435 | | |

Remarks: * - relative to HARDOX 400 steel plate, 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].

Table 6. Results of adhesion strength tests alloy of Fe-Cr-Ti-Si-Mn coating to ASTM A516, Grade 55 steel sheets in accordance to ASTM C 633-01

| Specimen designation | No. of test specimen | Maximum load at rapture [kN] | Cross-sectional area [$mm^2$] | Adhesion strength [$N/mm^2$] | Average adhesion strength [$N/mm^2$] |
|---|---|---|---|---|---|
| EuTronic Arc 502 | A1 | 5.9 | 490.6 | 12.0 | 10.8 |
| | A2 | 4.7 | | 9.5 | |
| | A3 | 5.4 | | 11.0 | |

## 4. CONCLUSIONS

The research the influence of the basic parameters of spraying the alloy of Fe-Cr-Ti-Si-Mn base steel ASTM A516, Grade 55 demonstrated the possibility to obtain layers with high quality. The resulting thickness of approximately 1mm, characterized by improved shape and the microstructure and low porosity in the range of (10-15)% and average grain size less then 90nm. Bonding between base material and sprayed coating is adhesive with bonding strength above $10N/mm^2$. Alloy of Fe-Cr-Ti-Si-Mn sprayed coating show very high hardness (above 58 HRC) and provide high wear resistance, comparable to HARDOX 400 steel. Erosion resistance at particle impingement angles from $15^o$ to $30^o$ is high but 40% lower than HARDOX 400 steel plate.

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