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# Erosion and abrasion wear resistance of GMA wire surfaced nanostructural deposits

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## ABSTRACT

**Purpose:** Purpose of this study was to find influence of chemical composition, structure and hardness of modern metal cored wire deposits on their hardness and erosion and abrasion wear resistance of three different wires which gives the nanostructural deposits.

**Design/methodology/approach:** Methodology surfaced deposits were investigated by macro- and microscope observations, hardness tests, erosion wear resistance test and abrasive wear resistance test.

**Findings:** wire which gives highest hardness, erosion wear resistance and abrasive wear resistance deposits was indicated.

**Research limitations/implications:** Information aobut an influence of chemical composition of nanostructural deposit filler materials on hardness, erosion wear resistance and abrasive wear resistance of these deposits.

**Practical implications:** Results of this paper are the informations for industrial partners how we can change properties of modern deposits and possibilities of surfacing process steering.

**Originality/value:** the researches were provided using newest filler material for GMA surfacing of high quality nanostructural deposits.

**Keywords: Welding; GMA surfacing; Nanostructure; Abrasive wear resistance**

MATERIALS MANUFACTURING AND PROCESSING

## 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 nanostructure [2,3,4]. 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 [1,2,5-20].

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 [2,4]. 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. The purpose of study was to compare properties of two layer stringer bead deposits GMA surfaced by three different metal cored wires produced by Castolin Electric Co.: nano wire EnDOtec DO*390N, high alloyed steel wire EnDOtec DO*33 and cermetallic wire EnDOtec DO*48.

## 2. Main researches

To study influence of chemical composition, structure and hardness of modern metal cored wire deposits on their hardness and erosion and abrasion wear resistance, following wires were chosen: EnDOtec DO*390N of nano structured iron alloy base complex borocarbides structure, EnDOtec DO*33 of iron alloy based complex metal borides and carbides structure and EnDOtec DO*48 of ferrous alloy matrix reinforced with cast tungsten carbide particles structure, Table 1 and Fig.1. Specimens for erosion and abrasion wear resistance tests of metal cored wire two layer deposits were robotized GMA surfaced on 6,0 [mm] thick low carbon steel plate S355NL, Table 2.

Table 1.
Classification, chemical composition, typical hardness and GMA surfacing parameters of deposits of metal cored wires of test coupons for the erosion and abrasion wear resistance tests, Fig. 1

| Coupons Classifica-tion | Chemical composition, wt%, and typical hardness of deposit (by CASTOLIN) | Surfacing parameters | | |
|---|---|---|---|---|
| | | Current [A] | Voltage [V] | Welding speed [mm/s] |
| EnDOTec DO*390N | Fe + <5%C, <2,0%Si, <5,0%Mn, <20,0%Cr, <10,0%Mo, <10,0%Nb, <10,0%W, <5,0%B 71 HRC | 170-180 | 20,0-22,0 | 5,0 |
| EnDOTec DO*33 | Fe + 2,5%C, 0,8%Si, 2,0%Mn, 13,0%Cr, 5,0%Nb, 2,2%B, 0,02%P, 0,01%S 68 HRC | 150-160 | 20,0-22,0 | 5,0 |
| EnDoTec DO*48 | Fe + 0,1%Si, 0,2%Mn + 50%WC 65 HRC | 140-150 | 19,0-19,5 | 5,0 |

Remarks: all tested metal cored wires diameter 1,6 [mm]. Shielding gas 97%Ar+2,5%$CO_2$, flow rate 18,0 [l/min]. Cored wire pull angle 70-80º.

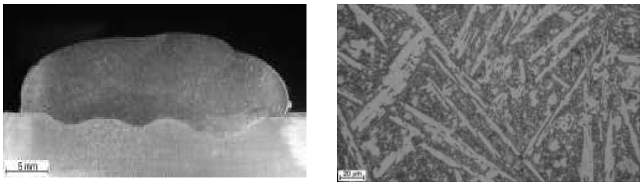
Table 2.
Chemical composition, wt. %, of the materials used as the base plates for GMA surfacing of metal cored wire deposits for abrasion resistance tests and the reference base plate HARDOX 400

| Plate material | C | Mn | Si | P | S | Cr | Ni | B | Mo |
|---|---|---|---|---|---|---|---|---|---|
| S355NL | 0,18 | 1,36 | 0,45 | 0,02 | 0,02 | 0,09 | 0,10 | - | - |
| HARDOX 400 | 0,14 | 1,6 | 0,7 | 0,025 | 0,010 | 0,50 | 0,25 | 0,004 | 0,25 |

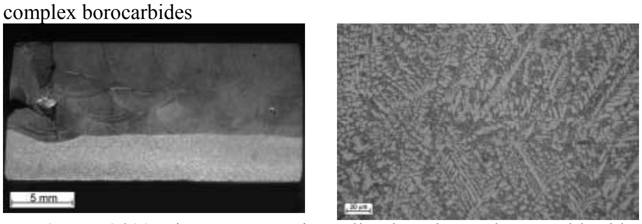
Results of erosion and abrasion wear resistance tests and HRC hardness tests were compared to HARDOX 400 steel erosion and abrasion wear resistance and HRC hardness, Table 2. HRC hardness tests on the ground surface of deposits were conducted, and results are collected in Table 3.

Table 3.
Results of hardness HRC tests on the ground surface of two layer deposits of DO*390N, DO*33 and DO*48 wire GMA surfaced specimens and HARDOX 400 steel plate

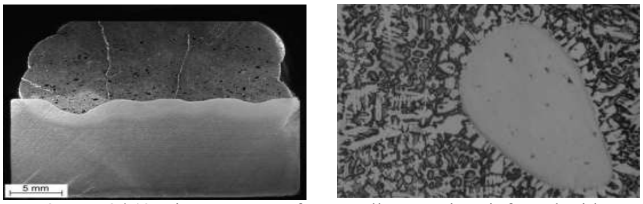
| Specimen designation | HRC hardness measurement points 1 | 2 | 3 | 4 | 5 | 6 | HRC average |
|---|---|---|---|---|---|---|---|
| HARDOX 400 | 44,0 | 43,8 | 43,8 | 43,8 | 43,4 | 43,9 | 43,8 |
| DO*390N | 68,9 | 71,4 | 72,4 | 70 | 70,9 | 71,2 | 70,8 |
| DO*33 | 64,2 | 65,8 | 65,4 | 61 | 64,4 | 62,4 | 63,8 |
| DO*48 | 63,9 | 62,3 | 65,5 | 66,6 | 67,5 | 66,8 | 65,4 |



EnDOtec DO*390N microstructure: nano structured iron alloy base complex borocarbides



EnDOtec DO*33 microstructure: iron alloy based complex metal borides and carbides



EnDOtec DO*48 microstructure: ferrous alloy matrix reinforced with cast tungsten carbide particles

Fig. 1. Macro and microstructure of two layer GMA surfaced deposits tested, Table 1

### 2.1. Erosion wear resistance tests

To determine quantitatively the erosion wear resitance of two layer GMA DO*390N, DO*33, DO*48 wires surfaced deposits and HARDOX 400 steel, the tests of erosion wear resistance were conducted in accordance to standard ASTM G 76-95 - Standard Test Method for Conducting Erosion Tests by Solid Particle Impingement, Fig. 3. Samples 70x25x10 [mm] cut from DO*390N, DO*33, DO*48 wires two layer GMA surfaced deposits and HARDOX 400 steel plate and the surface of deposits were ground by abrasive papers to 400 grit and prepared by alcohol cleaning.

Before erosion wear resistance tests of specimens have been started the calibration of erosion test apparatus was conducted as per standard ASM G76-95. Results of calibration of erosion test apparatus at standard test condition B, proved that erosion mass loss of AISI 1020 steel is the same as indicated in Table 1 of standard ASTM G76-95. It proves that following results of erosion wear resistance tests are valid as the inter laboratory tests.

Table 4.
Results of erosion wear resistance tests of specimens of two layer GMA DO*390N, DO*33, DO*48 wires surfaced deposits and HARDOX 400 steel plate in accordance to ASTM G76-95

| Specimen designation | No of specimen | Erosion weight loss [mg] | Erosion rate [mg/min] | Erosion value [0,001 mm$^3$/g] | Average erosion value [0,001 mm$^3$/g] | Relative erosion resistance* |
|---|---|---|---|---|---|---|
| DO390N | 390N-1 | 4,3 | 0,43 | 27,9221 | 34,7402 | 1,40 |
| | 390N-2 | 6,4 | 0,64 | 41,5584 | | |
| DO33 | 33-1 | 6,9 | 0,69 | 46,6847 | 40,5954 | 1,20 |
| | 33-2 | 5,1 | 0,51 | 34,5061 | | |
| DO48 | 48-1 | 4,7 | 0,47 | 19,4698 | 23,6123 | 2,07 |
| | 48-2 | 6,9 | 0,69 | 28,5833 | | |
| | 48-3 | 5,5 | 0,55 | 22,7838 | | |
| HARDOX 400 | 400-1 | 7,6 | 0,76 | 48,2846 | 48,9199 | 1,0 |
| | 400-2 | 7,8 | 0,78 | 49,5553 | | |

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

Table 5.
Results of low-stress abrasion wear resistance to metal-ceramic scratching by means dry quartz sand as the abrasion material of HARDOX 400 wear plate and GMA surfaced two layer deposits of CASTOLIN metal cored wires tested

| Specimen designation | 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 |
|---|---|---|---|---|---|---|---|
| DO390N | N1 | 155,4632 | 155,3631 | 0,1001 | 0,0996 | 12,90 | 14,40 |
| | N2 | 155,8611 | 155,7620 | 0,0991 | | | |
| DO33 | 33/1 | 132,9067 | 132,7268 | 0,1799 | 0,1800 | 23,46 | 7,92 |
| | 33/2 | 132,8690 | 132,6889 | 0,1801 | | | |
| DO48 | 48/1 | 188,8091 | 188,6945 | 0,1146 | 0,1152 | 10,96 | 16,94 |
| | 48/2 | 188,8364 | 188,7206 | 0,1158 | | | |
| 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 two layer deposits: DO*390N – 7,72 [g/cm$^3$], DO*33 – 7,39 [g/cm$^3$], DO*48 10,51 [g/cm$^3$]. * - relative to HARDOX 400 steel plate.

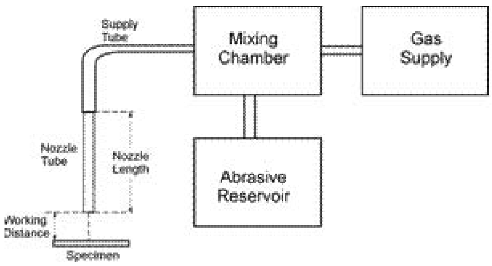



Fig. 2. Schematic diagram and of standard ASTM G76-95 erosion wear resistance tests apparatus. Specimen eroded at impact angle 90$^o$

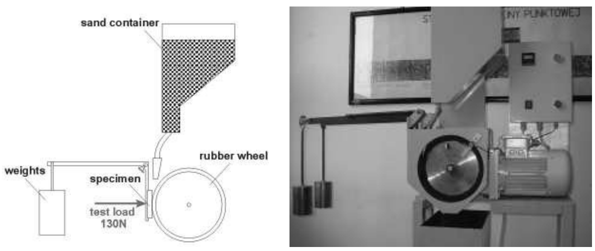



Fig. 3. Schematic diagram of ASTM G65 Procedure A abrasive wear resistance test and apparatus overview

Next the erosion wear resistance tests of specimens of two layer GMA DO*390N, DO*33, DO*48 wires surfaced deposits and HARDOX 400 steel plate were done during 10 [min], at erodent impact angle 30$^o$, and results are collected in Table 4. Erodent impact angle 30$^0$ was chosen as the typical impact angle advised for erosion wear resistance tests of very hard materials [6-12].

### 2.2. Abrasive wear resistance tests

To determine quantitatively the abrasive wear resistance of two layer GMA DO*390N, DO*33, DO*48 wires surfaced deposits, 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. 3. Procedure A of the ASTM G65 standard was chosen.

The 25 [mm] wide and 75 [mm] in length abrasive wear resistance test specimens were cut from the middle area of DO*390N, DO*33, DO*48 wires two layer GMA surfaced deposits. 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]

Table 6.
Results of hardness HRC tests on the ground surface of two layer deposits of DO*390N, DO*33 and DO*48 wear plates and HARDOX 400 steel plate

| Specimen designation | Relative erosion resistance* | Relative abrasion resistance* | HRC average |
|---|---|---|---|
| HARDOX 400 | 1,00 | 1,00 | 43,8 |
| DO*390N | 1,40 | 14,40 | 70,8 |
| DO*33 | 1,20 | 7,92 | 63,8 |
| DO*48 | 2,07 | 16,94 | 65,4 |

(test load - TL). After the abrasive wear resistance test, the test specimen was weighed at weight sensitivity 0,0001 [g]. Mass loss of specimens of two layer GMA DO*390N, DO*33, DO*48 wires surfaced deposits was reported directly and relatively in comparison to the mass loss of the reference HARDOX 400 steel. Next the density of two layer GMA DO*390N, DO*33, DO*48 wires surfaced deposits was measured and abrasive tests results were reported as volume loss in cubic millimeters, Table 5, by converting mass loss to volume loss as follows:

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

## 3. Conclusions

1. The highest erosion wear resistance for most severe erodent impact angle 30$^o$ provides two layer GMA DO*48 wire surfaced cermetallic deposit which is approx. 2 times higher than HARDOX 400 steel plate and 32% higher than two layer GMA DO*390N wire of nano structured deposit and over 42% higher than two layer GMA DO*33 wire deposit of iron alloy based complex metal and boride carbides structure. So large difference of erosion wear resistance is due to cermetallic structure of GMA surfaced DO*48 wire deposit, where very hard tungsten carbides (2000-2400HV) fused to iron matrix strongly protect the surface of cermetallic deposit against ceramic particles erosion.
2. The highest abrasion wear resistance shows two layer GMA surfaced DO*48 wire deposit which is over 17 times higher than HARDOX 400 steel plate and approx. 32% higher then two layer GMA DO*390N wire deposit and approx. 52% higher then two layer GMA DO*33 wire deposit. Similar difference of abrasion wear resistance of DO*390N wire and DO*48 wire deposits (32%) as for erosion wear resistance test, results from dissimilar mechanism of wear during abrasion process, where particles of abrasive sand are pressed to the deposit surface under low stress and as the result very hard tungsten carbides particles are protecting the iron alloy matrix in similar way as during erosion wear process. On the other hand very hard and glass like structure with secondary complex borocarbides of DO*390N deposit provides very high abrasion wear resistance, 14 times higher then HARDOX 400 steel plate, comparable to abrasion wear resistance of cermetallic iron alloy matrix+WC deposit.
3. Results of study clearly indicate that hardness can not be valuable indicator of erosion and abrasion wear resistance of metallic and cermetallic deposits as there is no correlation between hardness and erosion and abrasion wear resistance of deposits tested. The highest hardness approx. 71 HRC, shows two layer GMA DO*390N wire surfaced deposit, which is 10% higher then two layer GMA DO*48 wire surfaced deposit of 32% higher erosion and abrasion wear resistance.

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