Cathodic Arc Vapor Deposition Technique Using Zn Coating For Stainless Steel Thin Wires

Maftah H. Alkathafi[1] and Alhammali A.Younis[2]

Abstract— Cathodic arc vapor deposition technique is employed to coat stainless steel wires that are used as a wire-reinforced composites to enhance the bonding strength of the fiber-matrix system . In this technique, there are three basic experimental activities. Firstly the coating parameter optimization, followed by wire coating and finally the fiber coats properties characterization. The properties of the coated wires have been analyzed through metallographic analysis. The scratch test has been applied on the samples coated by cathodic arc vapor deposition process to determine the optimal coating parameters. The results showed that the optimal parameters to coat Zn-layer on the stainless steel wires are as following: Current: 50 A ,Bias voltage: 30 V ,Gas pressure: 0.05 Pa, Etching temperature: 450 °C. These optimized parameters were used to deposit Zn on the thin stainless steel wires. Furthermore, the average coating thickness was varied between 8µm and 12µm.

Index Terms: Cathodic Arc Vapor Deposition, Zn Coating, Stainless Steel wire.

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1 INTRODUCTION

Light weight composite materials are considered to be one of the important fields of production technologies due to the combination of light weight with high stiffness and strength. In addition, a low density, combined with high specific strength, good corrosion resistance and high specific thermal conductivity. To enhance the adhesion between the reinforce elements and matrix, coating of the reinforced fibers or wires has been employed. It is one of the successful techniques adopted to allow the interfacial reaction and enhance the wetting of the reinforcement[1].Coating is frequently applied to the surface of materials to protect the surface from the environment (corrosion protection), and to improve the surfaces appearance. There are many coating techniques available and choosing the appropriate process depends on the functional requirements (size, shape and metallurgy of the substrate), adaptability of the coating material to the technique intended, and level of adhesion required, availability and cost of the equipment. Some of the important coating techniques are chemical vapor deposition (CVD), physical vapor deposition (PVD), thermal spraying, electrolytic, electroless and cementation technologies[2].

1.1 Physical Vapor Deposition (PVD)

Physical Vapor Deposition (PVD) processes are atomistic deposition processes, in which material is vaporized from a solid source in the form of atoms or molecules, transported in the form of vapor through a vacuum or low pressure gaseous (or plasma) environment to the substrate, where it condenses. PVD processes are used to deposit films with thicknesses in the range of few nanometers up to some micrometers. However, they can also used to form multilayer and graded coatings. The substrates can be range in size from very small to large (depend on the PVD chamber) and can range in shape from flat to complex geometries. Typical PVD deposition rates are 1-10 nm/s. The PVD processes are divided into: vacuum evaporation, sputter deposition and ion plating [3]. Cathodic arc vapor deposition is a kind of ion plating process, which has been employed in this research work.

1.2 Modification Of Substrate Surface

The surface morphology of the substrate surface is important for the deposited film. Smooth surface will typically yield more dense PVD coatings than rough surfaces, due to the lack of "macro-columnar morphology" resulting from geometrical shadowing of features on the substrate surface. Very smooth metal surfaces can be prepared by diamond-point machining. Mechanical polishing is commonly used to smooth surfaces[3].

1.3 Cleaning

Cleaning is the reduction of surface contamination to an acceptable level so that desirable processing and film/coating properties can be obtained. Cleaning can be divided into external cleaning (ex situ cleaning), that is performed exterior to the deposition system (e.g. ultrasonic cleaning) and in situ cleaning, that is performed in the deposition system by several means. In situ cleaning is intended to remove the strong bounded contaminations and to activate the substrate surface (e.g. ion etching)[3].

1.4 Cathodic Arc Vapor Deposition

The cathodic arc is a low-voltage, high-current plasma discharge, which takes place between two metallic electrodes in vacuum. The cathodic arc is also called a vacuum arc, but cathodic arc also occur at elevated gas pressure when the gas participates significantly in the discharge processes. Nevertheless, the terms cathodic arc and vacuum arc often correctly used interchangeably[4]. The solid cathode with water cooling is the most common cathodic arc source for film deposition. In order to form a stable arc, there must be a minimum current passing through the arc. The arc current can be about 10-100A, depending on the melting point of the target material. Most of the arc voltage will occur near the cathode surface. The arc voltage can be about 15-100V,

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depending on the ease of electron motion from the cathode to the anode. Problems with the cathodic arc deposition technique include stabilization and movement of the arc on the solid surface and the formation of molten micron-sized "droplets" of the ejected material from the solid surface. Droplets are formed by ablation of molten or solid particles by thermal shock and hydrodynamic effects in the molten spot on a solid surface. The number and size of droplets produced from the solid arc cathode surface depends on the melting point, vapor pressure of the cathode material and the arc movement. If the arc is allowed to move randomly over the surface, the arc source is called a random arc. If it is confined and caused to move over the surface in the particular path is called a "steered arc" source. The high-density electron current on the solid arc-cathode forms a cathode spot, which generally moves over the surface until it is extinguished. If the current density is very high, the arc will break up into two or more spots (arcs). Arc movement on the cathode is affected by the gas composition and pressure, cathode material and impurities and the presence of magnetic field. When there is no magnetic field, the arc tends to move in a completely random manner. It is exists a number of cathodic arc sources designs. Each source has different way of initiating the arc and a configuration that re-ignites the arc, when it is extinguished. The arc can be initiated by touching and separating the electrodes, using a high voltage "trigger arc," laser ionization or some other technique. Typically a trigger arc is obtained from a high voltage on an auxiliary electrode near the cathode surface causing the arc to form. When an arc is extinguished, the inductance in the arc power supply gives a voltage spike, which re-ignites the arc [5]. Random arc sources are generally round and either surrounded by a shield separated from the target or an insulator in contact with the target. The anode can be either the chamber walls or a separate surface in the vacuum system. A weak magnetic field can be used to keep the arc on the surface without really controlling the arc motion. In the steered arc source the arc is confined to the surface by a magnetic field and caused to move in a specific path and with a greater velocity than with the random arc. The magnetic field can be established using electromagnets or permanent magnets. Permanent magnets can be physically moved to steer the arc. Pulsed arcs can be made by breaking the arc circuit by repetitively touching the arcing surfaces or by using a pulsed DC power supply. Cathodes for cathodic arcing should be made from fully dense electrically conductive material. Pressed powder targets should be avoided, since they do not give stable arcing and particles are ejected from the arcing surface [6].

2. EXPERIMENTAL WORK

2.1 Equipment

The PVD coatings have been carried out in an arc-PVD-system (20 Interatom/ 1987,USA, Figure 1). The main components of this system are the vacuum/coating chamber(1),the vacuum pumps(3), the control system(4), the arc evaporators (cathodes) including power supplies(5), the DC bias source and the pulsed bias source, the rotational

drive for the substrate holders, the substrate holders and the process control system.
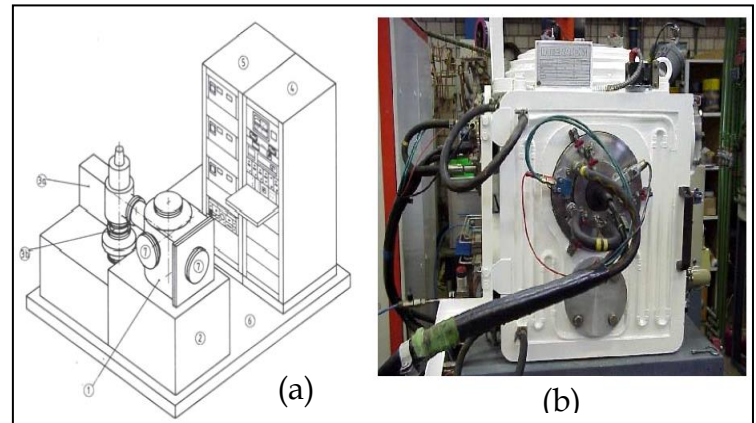

Fig.1- (a) Arc-PVD System Schema, (b) Vacuum Chamber.

Technical Specification Of Arc-PVD System, 20 Interatom:
- Coating chamber dimensions: Volume, 130 dm³
- Utilizable coating space/room: Diameter 190 mm and Height 410 mm
- Evaporators: 3 Pieces, 4 Installation Sites
- Power supply: 27 – 40 V; 35 – 100 A adjustable
- Rotary drive : Centric at chamber base, 0 – 10.5 rpm

The vacuum chamber (Figure1-b) is water cooled. The machine is equipped with front door for loading. When the chamber is closed, an automatic sequence with all related interlocks will start the pump stand successively and pump down the vacuum chamber to a pressure of 1x10-3 mbar. The systems are equipped with four cylindrical evaporators (Figure 2), which are placed in the chamber door and at the sides of the vacuum chamber. Each evaporator is equipped with its own DC power supply to avoid any electrical interference between each other. The cathodes are switched on by a mechanical trigger between cathode and anode. The material evaporated from this short circuit will ignite the arc running.

Fig.2- Cylindrical Evaporator/Cathode

The temperature is measured by a non-contact infrared sensor and appears on temperature gauge in control unit. To

avoid an oxidation and to reduce the thermal stresses of the coated substrates, they should not be removed from the vacuum chamber until cooling down up to 100 °C. The necessary time depends mainly on the size and shape of the substrates. Before a new loading, the chamber is shortly cleaned by a vacuum cleaner, to remove the generated dust.

2.2 Coating Parameters Optimization

Two kinds of stainless steel alloys are used:

• Austenitic chromium-nickel stainless steel 1.4310 (AISI 301), signed with "Y".

• Duplex stainless steel 1.4410 (AISI F53), signed with "A".

Table 1 and Table 2 show the chemical composition, mechanical and physical properties for these kinds of steels

Table 1: Chemical composition, mechanical and physical properties of 1.4310[7]

Chemical Composition							
Element	C_{max}	Si_{max}	Mn_{max}	P_{max}	S_{max}	Ni	Cr
Wt%	0.15	1.00	2.00	0.045	0.03	6-8	16-18
Mechanical Properties							
Yield Strength (Annealed)		205 MPa					
Tensile Strength (Annealed)		515 MPa					
Elongation (2%)		40 %					
Physical Properties							
Density		8.03 g/cm3					
Young's Modulus		193 GPa					
Specific Heat (0-100°C)		500 j/kg.°K					

Table 2: Chemical composition, mechanical and physical properties of 1.4410[8].

Chemical Composition					
Element	C	Cr	Mo	Ni	N
Wt%	0.03	25	4.0	7.0	0.27
Mechanical Properties					
Yield Strength (Annealed)		550 MPa			
Tensile Strength (Annealed)		795 MPa			
Elongation (2%)		15 %			
Physical Properties					
Density		7.8 g/cm3			
Young's Modulus		200 GPa			
Specific Heat (0-100°C)		485 j/kg.°K			

2.3 Samples Preparation And Coating
Substrate surface preparation and cleaning

Substrate surface morphology has an important effect on the film properties. By using of a hacksaw small samples in dimension 30x20x5 mm have been prepared. Before coating the samples surface have been grinded and polished. Grinding is done by using a rotary disc (Bühler LTD, 1974) with silicon carbide papers and water as cooling media. Different kind of grinding papers have been used (320, 600 and 1000 mesh). It has been always applied light pressure at the centre of the sample during grinding. Each grinding step has been proceeding until all the blemishes have been removed and all the scratches have been aligned in the same direction. Before starting the next grinding step, the samples have been washed in water and aligned in this way, which

the scratches from the previous step were perpendicular to the rotation direction. This makes easy to see, when the all rough scratches have been removed. After the final grinding step with 1000 mesh grain paper, the samples have been washed and dried before moving to the polishers. The polishing process has been carried out in a hand polishing machine (WIRTZ, 1974) with diamond particles impregnated soft cloth in three steps : 6, 3 and 1µm size, using a blue lubricant (DP-Lubricant Blue). After each polishing step, the samples have been cleaned in an ethanol ultrasonic bath.

Ultrasonic Cleaning

Principle of the ultrasonic cleaning is realizing high energetic sonic waves in a liquid cleaning medium, from which the sample complete will be surrounded. Agitating or sonicating that medium with high-frequency (18 to 120 kHz) sound for a brief interval of time (usually a few minutes). The mechanism underlying this process is based on the imploding or collapsing of microscopic bubbles in the liquid medium under the pressure of agitation to produce shock waves, which impinge on the surface of the part and, through a scrubbing action, displace or loosen particulate matter from that surface. The process by which these bubbles collapse or implode is known as cavitations (Figure 3).
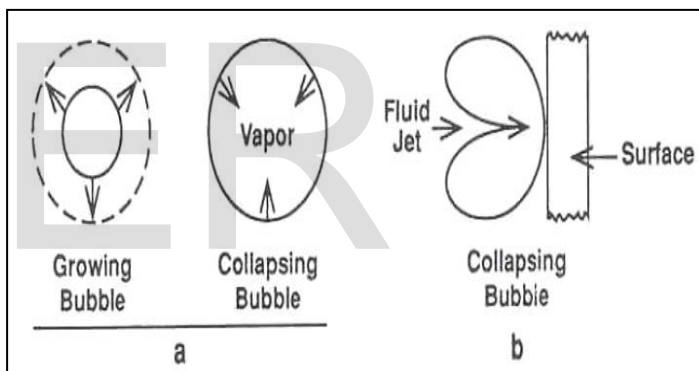

Fig.3-Ultrasonic cavitations: (a) bubble free in fluid, (b) bubble in contact with a surface.

Advantages of the ultrasonic cleaning including: cleaning of the areas difficult to access, (cavities, rough surfaces, etc.), environment compatibility and protection of the cleaning solution.

Coating Set-Up

After preparing and cleaning of the samples surface, the coating process has been carried out to optimize the parameters, which will be used later to coat thin wires. Zn is used as coating material. The cathode has been fixed on the top of the coating chamber. Figure 4 shows the adjustment of the samples and the cathode in the vacuum chamber during optimization steps. Current, bias voltage, pressure and etching temperature have been varied to find the optimized coating parameters.

Fig.4- (a) Samples set-up inside the coating chamber,(b) the cathode position on the top of the coating chamber.

Zn-Coating

Table 3 present experimental set-up of zinc coating. At the end of each coating group, the scratch test is applied to find out the optimal coating parameter. It gives the information about the adhesion strength.

Table 3: Experimental set-up of Zn coating

Current optimization(without etching)								
Samples number	A1	Y8	A11	Y11	A27	Y20	A14	Y4
Current [A]	25		50		75		100	
Bias voltage[V]	30		30		30		30	
Coating time [Ah]	20		20		20		20	
Argon pressure [Pa]	0.5		0.5		0.5		0.5	
Temp [°C]	< 180		< 180		<180		<180	
Current optimization(with etching)								
Samples number	A12	Y13	A10	Y10	A13	Y14	A16	Y16
Current [A]	25		50		75		100	
Bias voltage[V]	30		30		30		30	
Coating time [Ah]	20		20		20		20	
Argon pressure [Pa]	0.5		0.5		0.5		0.5	
Temp.[°C]	< 180		< 180		<180		<180	
Bias voltage optimization								
Samples number	A10	Y10	A9	Y9	A2	Y1	A6	Y12
Current [A]	50		50		50		50	
Bias voltage [V]	30		40		50		60	
Etching temp. [°C]	300		300		300		300	
Coating time [Ah]	20		20		20		20	
Argon pressure [Pa]	0.5		0.5		0.5		0.5	
Temp [°C]	< 180		< 180		<180		<180	
Gas pressure optimization								
Samples number	A17	Y17	A15	Y15	A18	Y18	A10	Y10
Current [A]	50		50		50		50	
Bias voltage[V]	30		30		30		30	
Etching temp. [°C]	300		300		300		300	
Coating time [Ah]	20		20		20		20	
Argon pressure [Pa]	1		0.1		0.05		0.5	
Temp [°C]	< 180		< 180		<180		<180	
Etching temperature optimization								
Samples number	A18	Y18	A21	Y21	A22	Y22	A23	Y23
Current [A]	50		50		50		50	
Bias voltage[V]	30		30		30		30	
Etching temp. [°C]	300		350		400		450	
Coating time [Ah]	20		20		20		20	
Argon pressure [Pa]	0.05		0.05		0.05		0.05	
Temp [°C]	< 180		< 180		<180		<180	

2.4 Thin Wire Coating

Stainless steel 1.4310 thin wires (Ø 0.2mm) have been coated with the optimal parameters. Wire handling system and the cathodes position as well as their number play an essential role to get a uniform coating. The handling system, in which a thin steel sheet (1 cm in width) has been employed, as illustrated in Figure 5.

Fig.5- Thin sheet handling system

To enhance the uniformity of the wire coating, the mechanism

was modified using instead of thin sheet hard wires (3 mm in diameter), Figure 6-a. Figure 6-b illustrates the adjustment of the handling system in the coating chamber.

Fig.6-a. Hard wire handling system

Fig.6-b.Set-up of thin wire inside the coating chamber by using the hard wire.

Two cathodes have been used to coat the thin wire. They are positioned in the right, left side or in the front (the door) of the coating chamber walls. To improve the coating uniformity the thin wire samples have been rotated throughout the coating process.

Zn-Coating For Thin Wire

Using the optimal parameters, two samples of thin wire have been coated with Zn layer.
• PVD-Wire 1: the sample has been fixed and two cathodes have been used.
The cathodes have been installed in the front (the door) and left side of the coating chamber.
• PVD-Wire 2: the sample has been rotated. The cathodes position and number have been the same with the first experiment (PVD-Wire 1).

2.5 Sample Characterization
Scratch Test

The adhesion between layer and substrate has been characterized by employing the scratch test. It involves drawing a Rockwell-C diamond over the sample surface under a stepwise or continuously increasing normal force

until the coating detaches as Figure 7 shows. Metallographic investigation has been applied by using the light microscope to investigate the coating layer morphology and thickness.
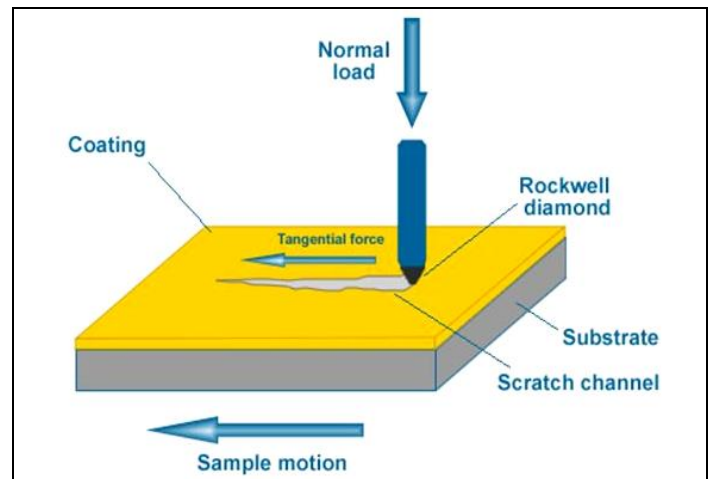
Fig.7- the scratch test set up

The scratch test has been applied on the samples coated by Arc-PVD to determine the optimal coating parameter.

Metallographic Characterization
Sample Preparation
Mounting

The cold mounting process is used according this study. The cold-mount material consists of polymeric resin and hardener. The mounts are typically cured and ready to sectioning, grind and polish within 30 min.

Cutting

Following proper mounting metallographic samples have been cutting. Cutting operation obtained by using abrasive cutting machine (Accutom-5, Struers). The abrasive wheel from silicon carbide is used to perform the cutting. Water was used as a coolant during the cutting process.

Grinding And Polishing

After cutting process the samples have been grinding by using grinding/polishing machine RotoPol-22 from Struers. The machine parameters including: grinding/polishing pressure (30N), relative velocity distribution (300rpm) and the time (3min.). Silicon carbide (SiC) abrasive paper was used. An abrasive grinding procedure would consist of 320 grit SiC paper followed by decreasing the size of the SiC paper (600,1200, 2400 and 4000 grit). According grinding process, water was the coolant. After each grinding step, sample has been washed by water and dried by compressed air.

Polishing is the most important step in preparing a specimen for microstructural analysis. It is the step which is required to completely eliminate previous damage. Diamond spray from Struers has been used as an abrasive material in the polishing process. Polishing subdivided into rough and fine polishing. One rough polishing step was applied with diamond abrasives 3 micron and low nap cloths. Two fine polishing

steps were applied by using higher napped polishing cloths, first with diamond abrasives 3 micron followed by 1 micron. DP-lubricant Blue from Struers was used as a cooling and lubricant throughout polishing process. Between the polishing steps and after the last step of grinding process the sample was cleaned through an ultrasonic.

Metallographic Investigation

Metallographic investigation of coating layer was done by using a light microscope ZEISS (Axiophot, 1987) equipped with digital video camera ZEISS (AxioCam HRC) and software Axiovision 3.1. With this system the coating thickness and porosity can be also measured. The coating morphology and the adhesion between the coating and substrate can be analyzed.

3. RESULTS AND DISCUSSION

3.1 Optimization Of Parameters For Zn-Coating.

Scratch test has been carried out on the coated samples to determine the optimal coating parameters. The set of parameters for which the adhesion exhibits the highest value (highest critical load) has been defined as the optimal parameters. Two kind of steels have been used as substrate materials, duplex stainless steel 1.4410, "A" and austenitic stainless steel 1.4310,"Y". Figure 8 represents the variation of the critical load of the coated samples, in which the current during deposition (without etching) has been varied.
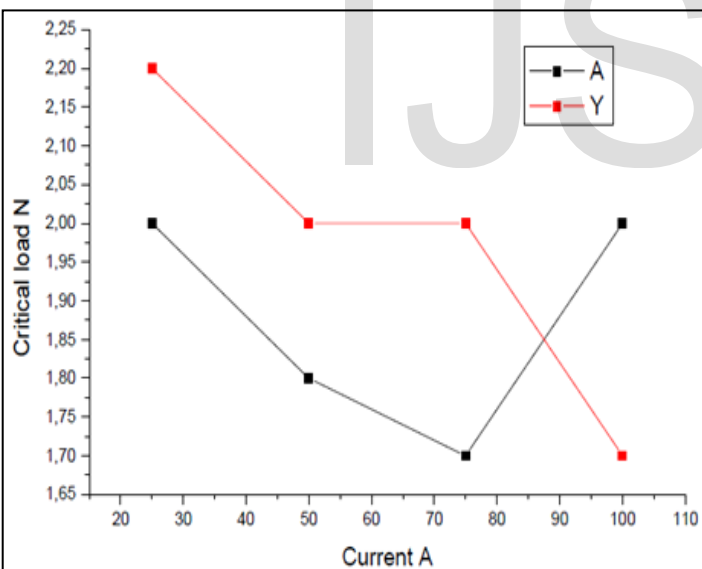
Fig.8- Current optimization (without etching)

The highest critical load (highest adhesion) is obtained at a current value of 25 A, in which the critical load of sample type "A" is 2 N and for sample type "Y" is 2.2 N. The coating morphology of sample "A" and "Y" corresponding to the optimal current are illustrated in Figures 9 and 10, respectively. To study the influence of the etching process on the film adhesion, the coating parameters remained the same as before, while the surface before coating has been etched. The variation of the critical load with the coating currents for pre-etched samples is presented in the Figure 11.
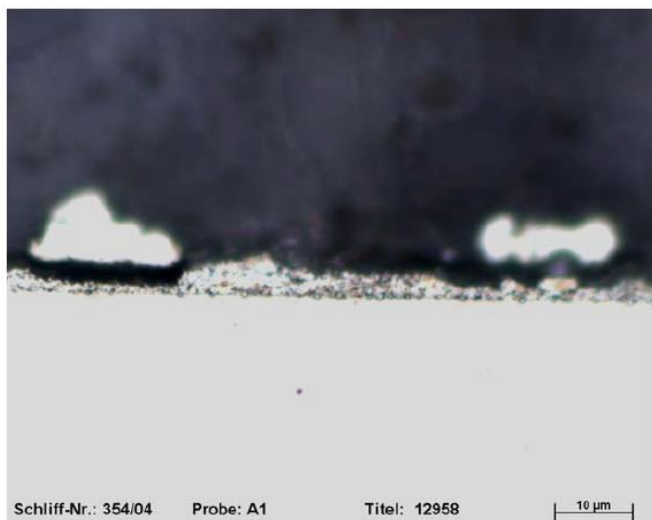

Fig.9-Coating morphology of sample"A",Current optimization (without etching).Optimal current value: 25 A, Average coating thickness:7.42 µm.
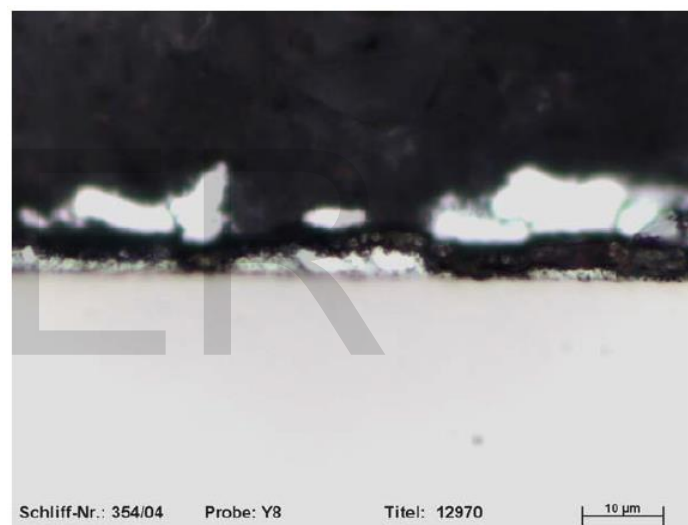

Fig.10- Coating morphology of sample "Y", Current optimization (without etching). Optimal current is 25 A, Average coating thickness:11.66 µm
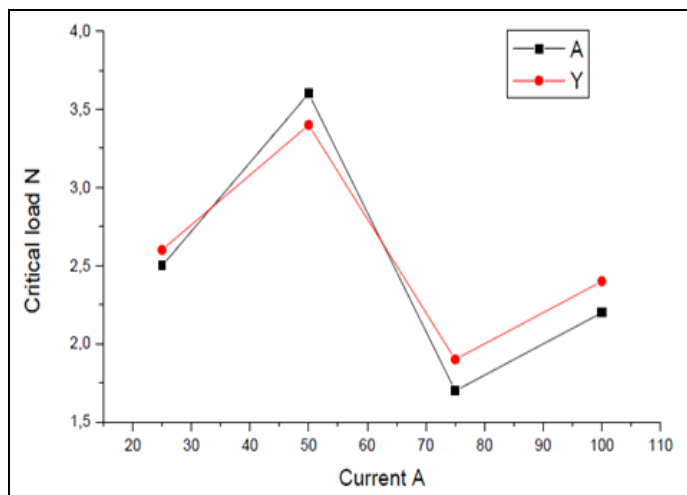

Fig.11- Current optimization (with etching)

The highest critical load has been achieved at a current value of 50 A, where the critical load of sample type "A" was 3.6 N and for sample type "Y" was 3.4 N. The coating morphology of sample "A" and "Y" corresponding to the optimal current are illustrated in Figures 12 and 13 respectively. Comparing the Figures 12 and 13 with Figures 10 and 11, it was established, that the etching improves the coating morphology. The film deposited on etched samples was denser compared to the film deposited on sample without etching. Droplets (molten particles of coating material) on the film were found in both cases i.e. with and without etching. Comparison of Figures 8 and 11 indicate that etching improves adhesion. Therefore, further optimizations of parameters for arc vapors deposition process have been carried out with etched samples.

Fig.12- Coating morphology of sample "A", Optimal current value: 50 A, optimal bias voltage: 30 V, Average coating thickness:13.94 μm.
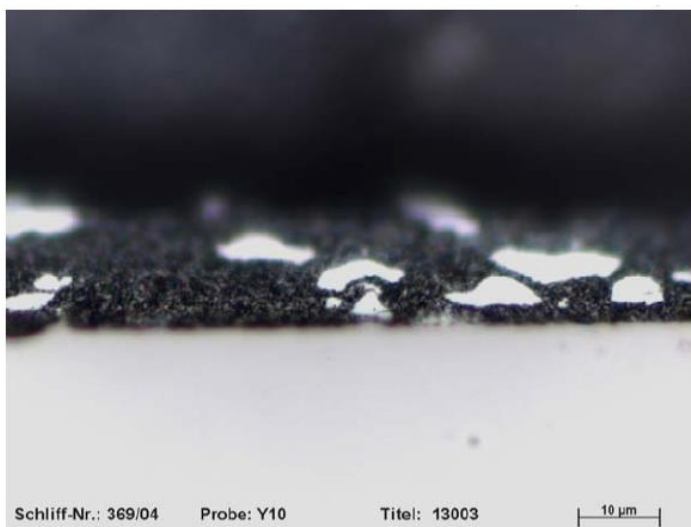
Fig.13- Coating morphology of sample "Y", Optimal current: 50A, optimal bias voltage: 30V, Average coating thickness: 15.32 μm.

The bias voltage optimization was done using the optimized current value. The variation of the critical load with bias voltage is indicated in the Figure 14.
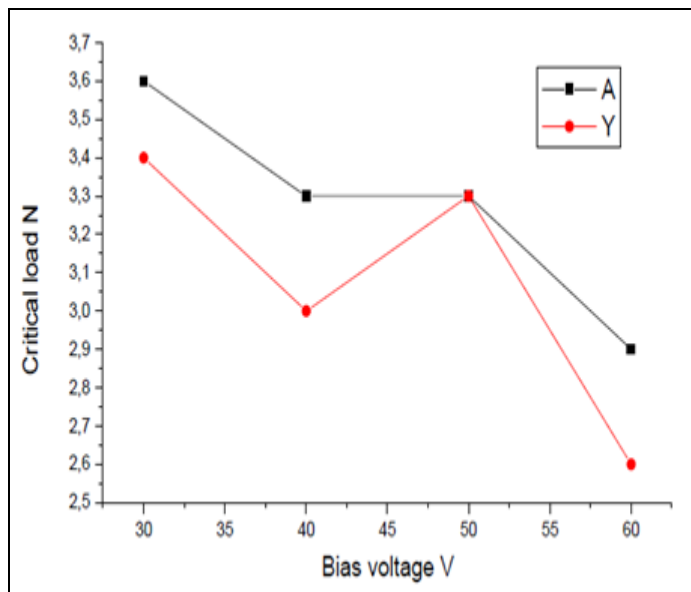
Fig.14- Bias voltage optimization

The Figure 14 shows, that the critical load decreases with increasing bias voltage for both A and Y samples. The highest critical load was obtained at the lowest value of bias voltage, i.e. 30 V. The critical loads corresponding to this bias voltage are 3.6 N for sample type "A" and 3.4 N for type "Y". The argon pressure optimization was done using the optimized current and bias voltage values. The variation of the critical load with argon pressure is displayed in the Figure 15.
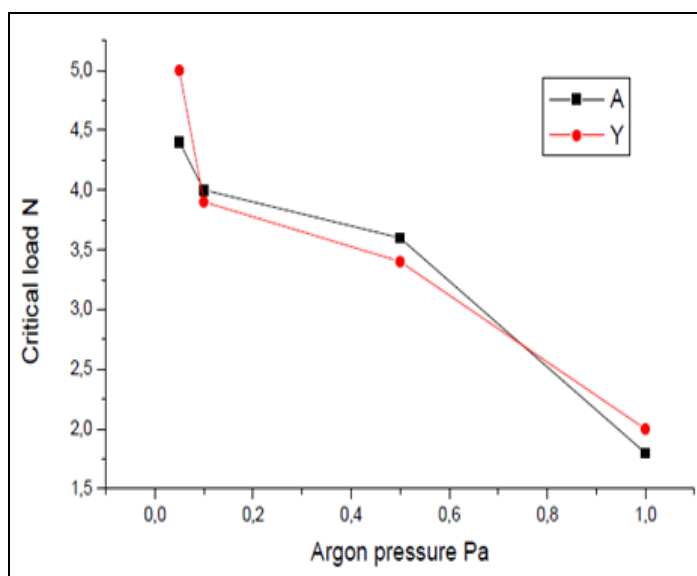

Fig.15- Gas pressure optimization

The Figure 15 shows, that the critical load decreases with increasing argon pressure for both A and Y samples. The highest critical load was obtained at the lowest value of argon pressure, i.e. 0.05 Pa. The critical loads corresponding to this

argon pressure are 4.4 N for sample type "A" and 5.0 N for type "Y". The coating morphology of sample "A" and "Y" corresponding to the optimal argon pressure are illustrated in Figures 16 and 17, respectively.

Fig.16- Coating morphology of sample "A", Optimal argon pressure:0.05 Pa   average coating thickness: 6.28 μm.
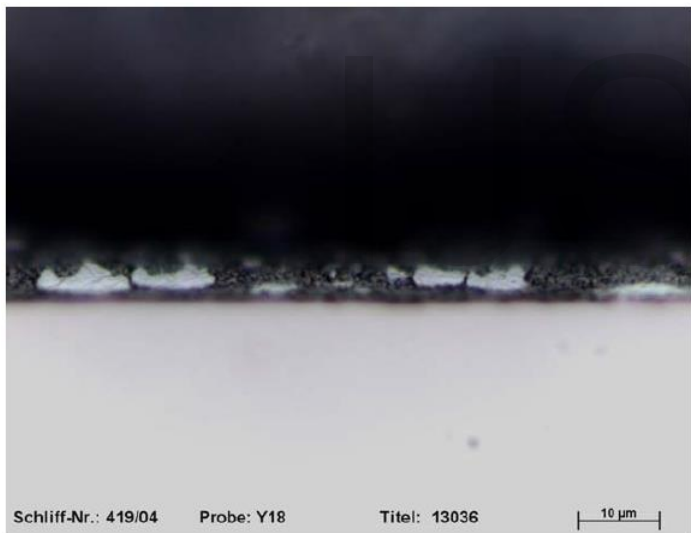

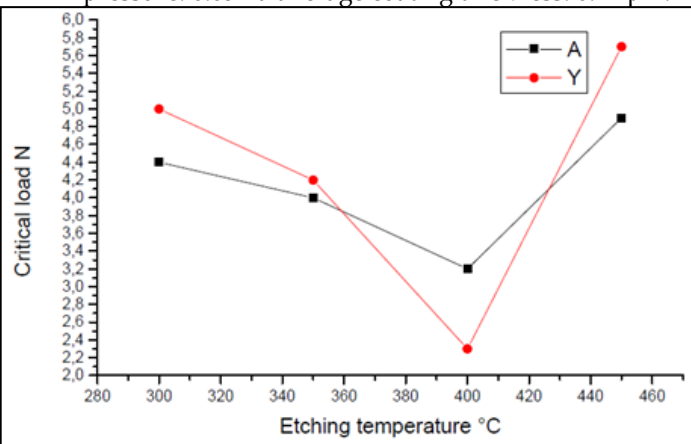Fig.17- Coating morphology of sample "Y", Optimal argon pressure: 0.05 Pa average coating thickness: 6.44 μm.

Fig.18- Etching temperature optimization

The highest critical load has been obtained at the highest value of etching temperature, i.e. 450 °C. The critical loads corresponding to this etching temperature are 4.9 N for sample type "A" and 5.7 N for type "Y". The coating morphology of sample "A" and "Y" corresponding to the optimal etching temperature are illustrated in Figures 19 and 20, respectively.
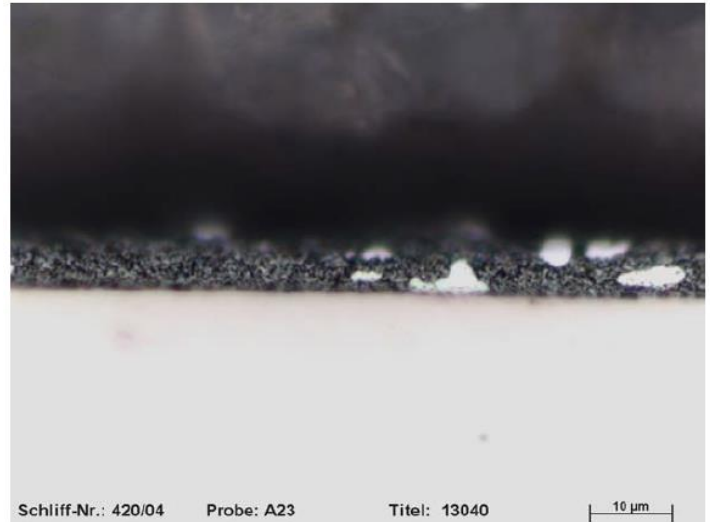

Fig.19- Coating morphology of sample "A", Optimal etching temperature 450 °C, Average coating thickness: 6.94 μm
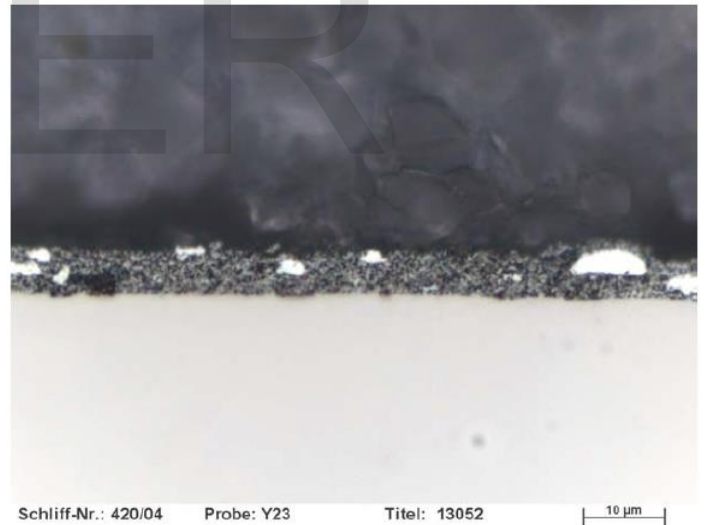

Fig.20- Coating morphology of sample "Y", parameters optimization of Zn coating, optimal etching emperature, 450 °C, Average coating thickness: 6.31 μm

Based on these results the optimal parameters to coat Zn-layer on the steel through Arc-PVD-Process are as following:
Current : 50 A
Bias voltage : 30 V
Gas pressure : 0.05 Pa
Etching temperature : 450 °C
These optimized parameters were used to deposit Zn on the thin steel wires.

3.2 Results Of Thin Wires Coating

Thin stainless steel (1.4310) wires of diameter 0.2 mm have been coated with Zn using the respective optimal parameters obtained in this study. These optimal parameters were kept constant during the deposition process, whereas the position and the number of cathodes have been changed to obtain a uniform coating. Two samples of thin wires have coated with Zn using optimized parameters: In the first experiment (PVD-1), thin wire sample (30 cm long) was coated by using two cathodes, one fixed on the door and the other on left side of the coating chamber. In this case the sample was not rotated. To investigate the coating uniformity, the sample was cut into three equal parts (bottom, middle and top). These three parts were separately investigated by metallographic examination. These results are shown in Figure 21-a, b, and c.
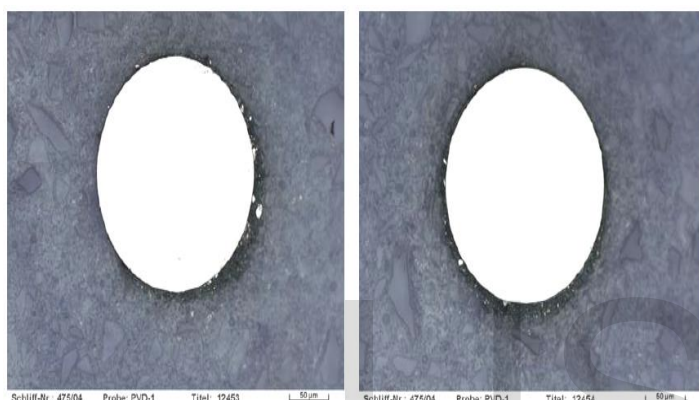

Fig.21.a.Optical micrograph of thin steel wire coated with Zn(Bottom)

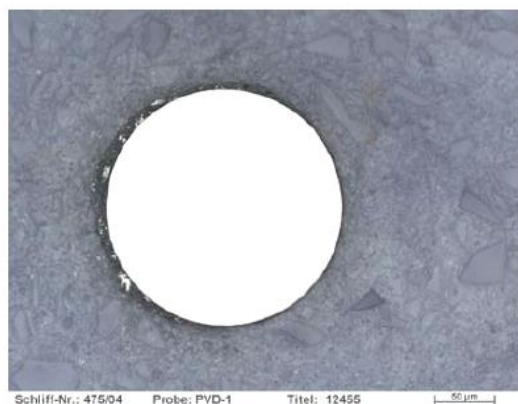Fig.21-b. Optical micrograph of thin steel wire coated with Zn (Middle)

Fig.21-c. Optical micrograph of thin steel wire coated with Zn (Top)

From the Figures 21, it can be established that the coating was not uniform over the surface of the thin wire. Droplets of target material were also observed in the coating. In the second experiment (PVD-2) the same procedure as that of (PVD-1) has been followed with the only exception that the sample has been rotated around a fixed axis in order to enhance the coating uniformity along the surface. The results are shown in Figure 22-a, b, and c.
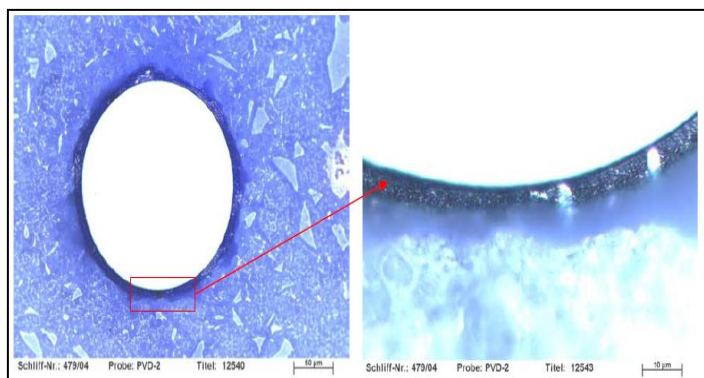

Fig.22-a. Optical micrograph of thin steel wire coated with Zn (Bottom)
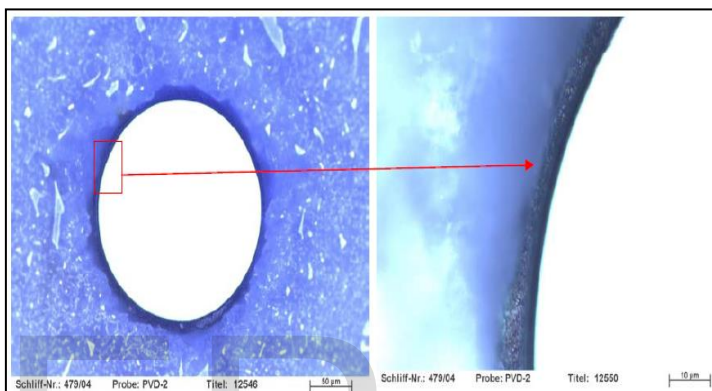

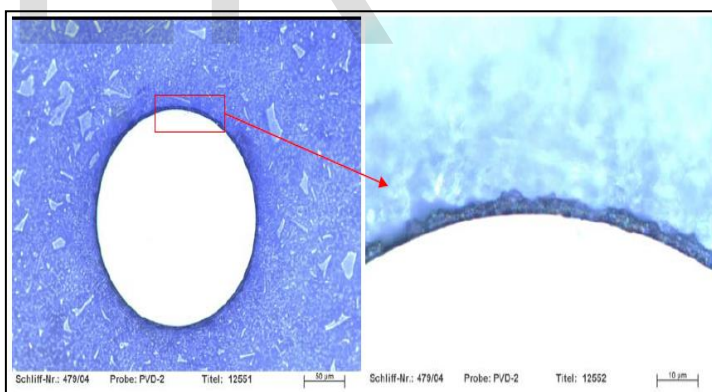Fig.22-b. Optical micrograph of thin steel wire coated with Zn (Middle)

Fig.22-c. Optical micrograph of thin steel wire coated with Zn (Top)

From the Figure 22, it was observed that the obtained coating has been uniform. It was established that the coating thickness increases from top to bottom. The average coating thickness was found to be 12 μm at the bottom and 8 μm at the top. Therefore, the first reason for non-uniform coating may be referred to the higher temperature at the top compared to the bottom. Heat was constantly conducted through the base fixture keeping the bottom part at a lower temperature compared to the top. The two cathodes were positioned more towards the top part in this case. This contributes towards the higher temperature of the top part.

The high temperature increases the adatom mobility by decreasing the coating thickness. The second factor which may be contribute to that is the gravity. The adatoms may migrate from top to bottom during deposition due to its weight. This also leads to a lower thickness at the top part.

4. CONCLUSIONS

In the cathodic arc vapor deposition it was observed:
• Due to the bombardment energy the temperature was increased during the
  coating process. The film adhesion decreased with increasing the temperature.
• Film adhesion was increased as the bias voltage and gas pressure decreased.
• Etching process leads to improve the film adhesion by activate the substrate
  surface.
• Droplets cannot be avoided; it was presented on the coating films.

The coating parameters with which the uniform Zn coating was obtained are:
• Current 50A
• Bias voltage 30V
• Argon gas pressure 0.05Pa
• Etching temperature 450°C
Two cathodes were used which fixed on front (the door) and left side of the coating chamber. Sample was rotated. Average coating thickness was varied between 8µm and 12µm.

5. REFERENCES

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