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Study of the Effect of Electro-co-deposition on Transmission Gears

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Abstract: ***The word Electro-co-deposition means deposition of Anodic material on to the cathode along with additives which are mixed in to the electrolyte solution. In the present work nickel is used as the anode, Mild Steel Substrate as cathode and Tungsten carbide(WC) is used as additive material. Intially the coating was done on MS plates, later the coating was done on Spur gears. The Coated gears were tested for coating thickness and Hardness. The coated plates were used for characterisation using XRD, as it is not feasible to carry out XRD on the gears after coating. The coating thickness was found to be more uniform throughout the gears but high quality coating was found at the edges. Also Hardness of the coated gears was higher compared to uncoated gears. The XRD Analysis was done for 2θ range of 20^0 to 80^0 at four degrees per minute. The analysis was used as a confirmation test for Ni-WC crystal growth. With all these increases trends in properties after coating the MS substrate there is wide scope of this technology in Automobile as well as aerospace domains.***

Keywords: Electro-co-deposition, Nickel, Tungsten Carbide (WC), Mild steel, Coating Thickness, XRD

1. Introduction

Gears are the main elements which are used for power transmission. The Indian gear market is poised to grow at a compound annual growth rate of 17.3% over 2010 to 2018 [1]. At the same time, US gear and gear assembly is predicted to be of $25 billion industry growing at 3.9% from 2013 to 2018[2]. Hence, there is a lot of research regarding improvement of life of gears by coating a thin film of material imparting resistance to wear, corrosion and crack propagation. Carburizing, Nitriding, Physical Vapor Deposition, Chemical Vapor Deposition and Electro-deposition are a few techniques used to improve fatigue life of gears. The physical conditions required and the economic feasibility required for electro-plating are simpler. Hence, global electroplating market is estimated to have a compound growth rate of 3.7% per year to reach $15.3 billion at 2020[3].

Electroplating is regularly used to alter surface properties of an object such as wear and abrasion resistance, hardness, corrosion resistance etc.[5] It is known to be the most economical and easy method of metal coating. Many attempts have been made to find methods for enhancing the surface properties of metal components to protect against corrosion, wear and pitting and reducing their costs since all of them are the effective factors in the degradation of industrial parts. Electrodeposition is considered as one of the most important and cost effective industrial techniques for producing protective coatings [6].

Nickel is one of the most widely used metals for electrodeposition. Ni coatings offer corrosion resistance, wear resistance along with aesthetic quality to the component. However, the scopes of such coatings are limited by the life span, mechanical strength, and wear and corrosion resistance to the aggressive environment. Many studies have proven that Ni composite coatings enhance the properties by increasing the nucleation sites causing reduction in crystallite size leading to modified mechanical properties of the deposit. Therefore these WC composite coatings attract attention and a wide range in applications [7].

2. Literature Survey

Electrodeposition

Temperature:
The amount of material deposited on the cathode part depends on the electrolyte temperature. Coating thickness increases as the temperature of the bath increases. However, the temperature range for the Ni-WC composite coating is set to be 30^oC to 70^oC. However, the content of the WC in the deposition will not change with the temperature [8]. But it is observed that the mechanical properties of the coating such as micro-hardness, tensile strength are maximum at 50^oC bath temperature. [9]

Current Density:
For proper coating, the current density plays a vital role. However, neither low nor higher values of current produce quality coatings. Therefore, an optimum range of current is necessary to obtain proper coatings. As the current density increases solution in the vicinity of cathode tends to become depleted of metallic ions and polarization as well as co-deposition rate are increased. So, the content of WC adsorbed on the cathode surface increases . Hardness of the coating was found to be maximum at the current density of 3 A/dm^2. [9] .

Composite Coatings
Various studies have shown that composite coatings obtained from electrodeposition are more economical and effective. Ni composite coatings combine strength and hardness with good

corrosion resistance. Tungsten Carbide (WC) is preferred for composite coatings due to its high melting point, extreme hardness and chemical inertness and finds a wide range of applications in industries. Nickel based WC composites, in particular, finds their main uses as hard faces for anti-wear, anticorrosive [10]. It is observed that Ni-WC composite coatings have more stable friction factor values and they have a tendency to increase under high applied load [11].

3. Scope and Objective

After going through various research papers, it has been observed that very few studies are concentrated on nickel composite coating on gears. Though found economical and effective, electro-deposition is rarely used to coat the gears, therefore this research work is proposed to have following main objectives.

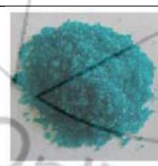
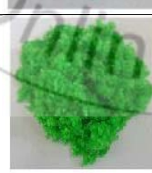
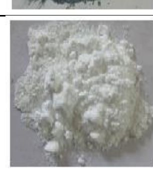
- Coating of MS Substrates, and on Gears
- Coating Thickness Measurement
- Hardness Measurement
- Characterization using XRD

4. Experimental Set-Up

4.1 Composition of Electrolytic bath

Based on the literature survey, composition of Watts solution illustrated in Table 4.1, is found to be suitable for nickel composite coating and therefore it is adopted for coating process.

Table 4.1: Chemicals used for electrodeposition of Ni-WC

Chemical Name	*Quantity taken to prepare 1 litre bath solution*	*Picture of Chemicals*
Nickel Sulphate ($NiSO_4.6H_2O$)	**250 g/l**	
Nickel chloride ($NiCl_2.6H_2O$)	**35 g/l**	
Tungsten Carbide (WC)	**3 g/l**	
Boric acid (H_3BO_3)	**40 g/l**	

4.2 Preparation of bath solution

The chemical reagents mentioned in Table 4.1 along with distilled water were used to prepare electrolytic bath solution as shown in Fig 4.1. Once the solution is prepared, 400 ml of it is transferred to a small beaker and WC powder was added in the concentration of 3g/l. The mixture is then subjected to ultra-sonication (Fig 4.2) for proper wetting of WC particles added, for a period of one hour. After ultra-sonication, the suspension is added to the main electrolytic solution and diluted to the required concentration. The pH is adjusted to 3.7 using sodium-hydroxide (NaOH) solution.

Figure 4.1: Electrolytic solution

Figure 4.2: Ultra-Sonicator

4.3 Coating Methodology

The electrodeposition is carried out in three stages so that it is helpful for characterization and understanding coating thickness distribution on curved edges. Physical conditions, which are found optimum from literature, are used for each experiment to obtain good quality coating. Those are as given below,

- Temperature of bath – 50^0 C
- Distance between the electrodes – 9 cm
- pH of the electrolyte – 3.7
- Time Duration – 2 Hours

Figure 4.3: Electroplating equipment used for Coating

Electrodeposition is carried out in following stages

Electrodeposition on sample plate

Main purpose of carrying out deposition on flat mild steel plate is to characterize the coating sample. It is not feasible to carry out XRD on the gears after coating. Fig 4.4 shows the sample plates after deposition. The amount of current supplied was varied from 0.6A to 1A for the second plate.

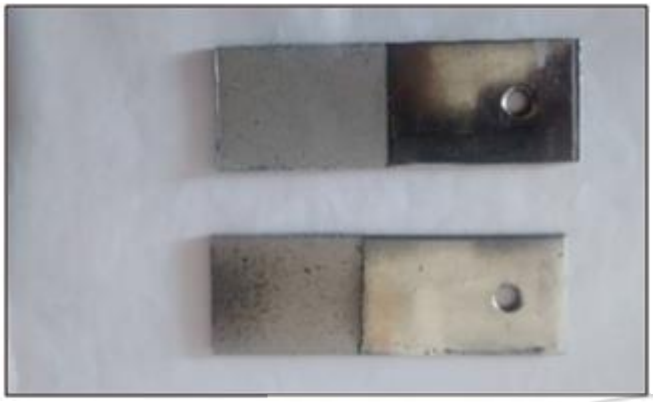


Figure 4.4: Electrodeposited sample plates (a) Current=1 A (b) Current=0.6 A

After Electrodeposition on plate, a sample gear is used for composite coating. It helps to understand the growth of coating material on gear parts such as top land, root fillet etc. where there are edges present. Also, the parts which have to be masked are determined from this experiment. Fig 4.5 & Fig 4.6 show the sample gear used for coating before and after applying masking tape respectively.

Figure 4.5: Sample gear

Figure 4.6: Sample gear applied with masking tape

Electrodeposition on testing gears

Figure 4.7: Testing gear

Figure 4.8: Testing gear applied with masking tape

4.4 Coating thickness measurement

After completing the coating of Ni-WC on sample plate as well as gears, thickness of the coating is measured using Electro Physik thickness gauge (Fig 4.9). These electronic instruments measure the change in magnetic flux density at the surface of a magnetic probe as it nears a steel surface. The magnitude of the flux density at the probe surface is directly related to the distance from the steel substrate. By measuring flux density the coating thickness can be determined. Initially, the gauge is calibrated with reference to the non-coated part of the sample/gear. Then, coating thickness is measured at various key locations on the surface of the sample by pressing the pointer. The thickness displayed on digital indicator is noted down. Same procedure is followed for measuring coating thickness on gears.

(a) (b)

Figure 4.9: Coating thickness measurement using Electro Physik gauge (a) On sample plate (b) On gears

4.5 Characterization

Characterization is the technique used in material science to identify the constituents and microstructure and macrostructure of the sample. This has gained prevalence as the material science has grown and as new materials are being discovered. Many techniques such as Scanning Electron Microscopy (SEM), Scanning tunneling microscope (STM), Atomic force microscope (AFM), X-Ray Diffraction (XRD) technique etc. are used for characterization of materials. For our analysis, XRD is chosen because it is found to be widely used method for composite coatings. X-ray diffraction technique on the sample plate is carried out using the standard experimental procedures. As referred in the literature survey for Ni-WC coatings the 2θ values for the XRD are taken from 20^0 to 80^0. It is varied in the steps of 4 degrees/minute. The data obtained is analyzed to observe peaks in the pattern. Sample plates which are coated for characterization purpose were analyzed using XRD machine. Fig 4.10 shows the plate subjected to XRD.

Figure 4.10: Coated plated characterization using XRD

4.6 Hardness Measurement

As found in literature, surface parameters such as hardness is responsible for pitting, spalling of the tooth surface. Hence, improving hardness in turn improves fatigue life of gears.

Hardness measurement was carried out using cone indenter in Rockwell Testing machine as shown in Fig 4.11. Each of the coated and non-coated samples was tested at four different positions and readings were tabulated.

Figure 4.11: Hardness testing of gear using Rockwell hardness tester

5. Results and Discussion

5.1 Characterization of the coated sample using XRD

Sample plate was coated with Ni-WC composite. The plate was characterized using X-Ray diffraction technique to identify the crystal structure and Electro-Physic meter to evaluate the coating thickness throughout the plate.

X-Ray Diffraction Analysis

The XRD Analysis was done for 2θ range of 20° to 80° at four degrees per minute. The analysis was used as a confirmation test for Ni-WC crystal growth.

X-Ray Diffraction Pattern

The XRD Plot for the Ni-WC coated sample plate has been described in Fig 5.1

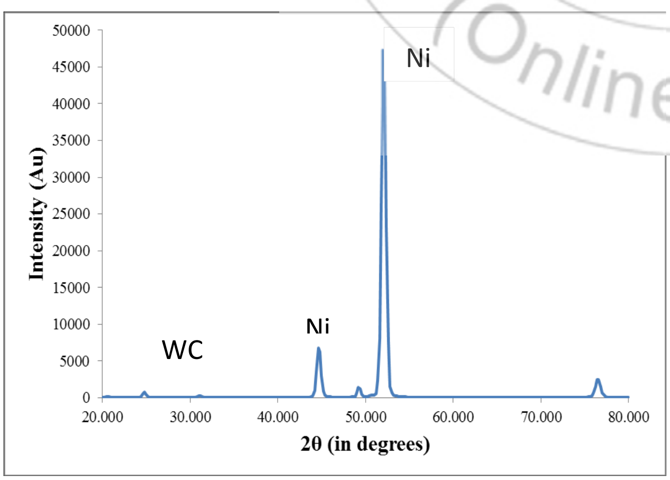


Figure 5.1: X-Ray Diffraction plot for Ni-WC coating

Peaks at 2θ values of 44.65^0, 52.04^0 and 76.43^0 confirm the presence of Ni in the crystal growth. The smaller peak at 2θ value of 49.23^0 confirms WC presence.

X-Ray Diffraction peak data

Table 5.1 gives all the data regarding prominent peaks to confirm Ni-WC crystal growth.

Table 5.1: Prominent Peaks for Ni-WC from XRD

Sl. No.	Peak No.	2 Theta (deg)	d^* (A°)	I/I_o	FWHM (deg)	Intensity (Au)
1	3	52.0399	1.75593	100	0.57130	35131
2	1	44.6542	2.02767	14	0.54740	4939
3	4	76.4302	1.24520	5	0.63480	1870

5.2 Coating Thickness

Sample Plate

The coating thickness on the sample plate was measured using an electro-physic gauge. A set of fixed reference co-ordinates was used along X and Y axes to obtain the thickness along Z-axis. X refers to the plate breadth, Y refers to the plate length and Z refers to the coating thickness. The results are as tabulated in Table 5.2. Thickness distribution is as shown in Fig 5.2.

Table 5.2: Thickness of coating at corresponding coordinates

X(cm)	Y(cm)	Z(mills)	Thickness in µm
0	0	1.47	37.34
0	1	1.65	41.91
0	2	1.9	48.26
0	3	1.93	49.02
0	4	2.11	53.59
1.5	0	0.83	21.08
1.5	1	1.2	30.48
1.5	2	1.16	29.46
1.5	3	1.22	30.99
1.5	4	1.28	32.51
3	0	1.17	29.72
3	1	1.24	31.49
3	2	1.38	35.02
3	3	1.54	39.12
3	4	1.72	43.16

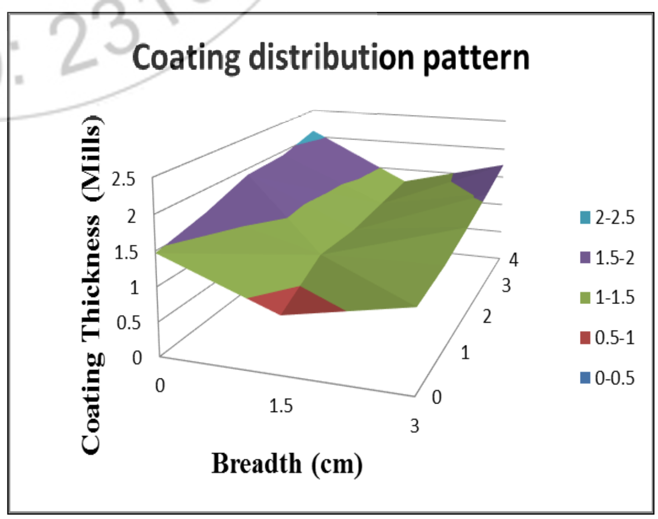


Figure 5.2: Coating Thickness distribution on sample plate

Testing Gears
Coating thickness variation on the driver and driven gears as measured by the electro-physik gauge has been provided in Table 5.3

Table 5.3: Coating thickness on testing gears

Position	Coating Thickness in µm	
	Driver Gear	Driven Gear
1	56.39	67.82
2	61.47	66.80
3	72.39	65.28
4	64.26	62.48
5	58.67	57.66
6	59.69	61.47
AVG	62.15	63.59

5.3 Hardness of the Gear surface

The surface hardness of gears was measured before and after coating to validate the assumption that increase in hardness would be seen upon coating.

Table 5.4 gives the comparison for the hardness values before and after coating.

Table 5.4: Hardness value comparison

Position	Hardness Value (HRC)	
	Non Coated	Coated
1	110	112
2	103	115
3	98	113
4	111	115
Average	105.5	113.75

6. Conclusion

The prominent peaks obtained from X-Ray Diffraction plot at 2θ values of 44.6 ^{0}, 52 ^{0} and 76.4 ^{0} were close to the expected values as obtained from literature review. Hence the characterization confirmed the presence of Ni-WC crystal growth.

For the sample plate Ni-WC coating, thickness was found to be more at the edges and lesser at the center. It was concluded that sharp change in contour created a more favorable deposition region. The Ni-WC coating on the test gears resulted in an average coating thickness of 63 µm.

The coated gears had higher hardness value of 113.75 compared to uncoated gears which showed hardness of 105.5.Due to coating, the gears exhibited higher hardness. This is a potential benefit for usage of coated components in automobile and aerospace domains.

7. Future Scope

- In the present work Ni-WC is used, different combinations of ceramic and non ceramic particulates can be used.
- Coating can be done by varying the parameters like Temperature, PH, Concentration of bath and Time duration
- Coating was done on gears other components can be coated and tested.

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