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DRY SLIDING WEAR INVESTIGATION OF HARD CHROME AND NICKEL COATING ON EN19 FOR ROLLING APPLICATION

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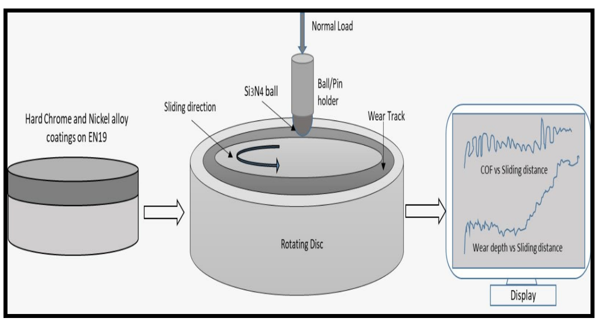
Graphical abstract



Abstract

In the heavy sheet metal industry, in cold rolling process rolls are typically made of EN19 steel. Due to the severe loading and pressure conditions experienced during cold rolling of steel sheet causes wear and failure of the rolls. Enhancing the life of these rolls under such demanding operating conditions necessitates the application of coatings on EN19. This paper focuses on investigating the effectiveness of Hard Chrome and Nickel alloy coatings on Engineering Steel (EN19) through a comparative sliding wear experimental study. The research examines the impact of Hard Chrome and Nickel coatings on the properties of EN19. Various characterization techniques, including X-ray diffraction (XRD), surface roughness analysis, hardness testing, scanning electron microscopy (SEM), and energy-dispersive X-ray spectroscopy (EDS), are employed to evaluate the coatings. The wear tests are conducted under standard operating conditions to determine the improvement in roll life achieved through the coatings. The results reveal that the Hardchrome coating exhibits greater hardness and wear resistance compared to the Nickel coating and the EN19 base material. Nickel gives 9.49 times more life than substrate EN19 whereas Hardchrome gives 15.19 times more life than substrate EN19 and 1.6 times more life than Nickel coating. The findings suggest that applying Hard Chrome to EN19 rolls can effectively enhance their durability and prevent failure. The experimental investigation presented in this study provides valuable insights into the selection and performance of coatings for improving the longevity of rolls in heavy sheet metal rolling processes.

Keywords: Sliding wear, Cold Rolls, Coating, EN19, Hard Chrome.

1.0 INTRODUCTION

In rolling steel industries, the line of production is usually automatic where the rolls are widely employed for cold rolling steel sheets. The simple rolls are frequently replaced due to its wear and short life span. This affects the production line, maintenance and increases the cost of production. Coating is usually work as a protective layer to enhance the capability of material against wear resistance, erosion, abrasion etc. and prevent the failure resulting due to severe operating conditions.

Various alloys of coatings such as Nickel, Chromium, Cobalt, super alloy etc. are widely used in different industrial applications for such purposes to obtain optimum surface conditions. For aesthetics, functional and industrial applications, different types of coatings/electroplating results in protection against wear and corrosion, high temperature oxidation, chemical resistance, and good lubricity. The selection of coating material on the substrate and coating process significantly affects the performance of the coating along with the operating conditions.

At room temperature wear properties were almost same for coating of hard chromium and electroless nickel-phosphorus. The experimental results indicate that on rough surfaces, hard chromium coating demonstrated superior performance in terms of wear resistance and durability. Conversely, on smooth surfaces, electroless nickel-phosphorus coating exhibited better results in terms of wear prevention and protection against surface degradation. [1]. Both for military and industrial applications, hard chromium coating is widely used as it imparts better erosion and wear resistance to workpiece. This coating provides low coefficient of friction and high hardness, better thermal and corrosion properties etc. [2]. By employing an electroplating process to coat the piston rod, significant reductions in maintenance rework costs and improvements in process efficiency have been observed. The implementation of optimized tools has played a pivotal role in achieving these outcomes. [3]. The application of a chromium layer with high hardness can effectively overcome corrosion, high temperature effects, and wear, which contribute to the decreased lifespan of steel rods. [4]. In the cold rolling process, reciprocating and scratch sliding tests were conducted to assess the impact of hard chrome plating on rolls, revealing that the use of hard chrome plated pins resulted in reduced material transfer, lower friction values, and minimized iron fines generation, attributed to the tribo-chemistry of the chromium layer [5]. The fatigue strength of standard steel AISI 4340 substrate exhibited a greater reduction in chrome electroplating compared to the WC specimen, while the wear weight loss tests revealed better results for the WC coating than chrome electroplating [6]. The hardness of (CrFeCoNi)1-x(WC)x High Entropy Alloys (HEAs) exhibited a consistent enhancement as the WC content increased, ranging from 336.41 HV for (CrFeCoNi)1.0(WC)0.0 to 632.48 HV for (CrFeCoNi) 0.80 (WC) 0.20, with the strengthening mechanism attributed to the presence of hard WC particles and the precipitation of Cr-rich carbides [7]. The widespread application of hard chrome plating includes providing abrasion resistance, extending the lifespan of dies and tools, and refurbishing worn-out workpieces, among various other uses [8]. Nitrocarburizing and plasma nitriding improve wear resistance better than hard chrome plating [9]. The application of nickel-based electroless coatings (Ni-P, Ni-B) on metallic work pieces resulted in enhanced wear resistance, hardness, and corrosion resistance, with nano-sized particles demonstrating superior surface finish, high hardness, and a lower coefficient of friction compared to micron-sized particles [10]. A process was invented to produce high-quality, strongly adherent nickel deposits by chemically reducing nickel salt with hypophosphites in a hot ammoniacal solution, eliminating the need for electric current [11]. The study investigated the influence of nickel coating thickness on the tensile strength and surface condition of carbon fibers, with SEM images revealing that a nickel coating approximately 0.5 µm thick exhibited the highest continuity on the carbon fibers [12]. It has been observed that substrates coated with a Cr-Ni alloy exhibit greater corrosion resistance compared to individual Ni and Cr coated substrates. [13]. The inner layer of electroless nickel-boron coatings on mild steel exhibited properties like vacuum nitride coatings, indicating potential for improved corrosion resistance and mechanical properties [14]. It is found that the developed model for AA5052 Aluminium alloy can accurately predict the rolling force in hot rolling with a maximum error of 5%, taking into account the influence of model parameters such as deformation resistance, elastic flattened roll, and stress state coefficient. [15]. The dry sliding wear rate of Ni-based coatings is predominantly influenced by the properties of the counter material, deposition process, normal load, and exhibits an increase with rising temperatures [16], [17]. The Ni based coating sprayed with HVOF gives enhanced oxidation resistance [18]. The investigation of tribological properties plays a crucial role in enhancing component lifespan, optimizing operating parameters, and preventing system failures for any given pair of materials [19]–[21].

1.1 Novelty of this Research

From the various literature [1]-[23] it is found that different coating options are available and may be used for enhancing the cold rolls life used in heavy steel sheet industry. As per literature survey [24]-[27] it is found earlier the work has been done on FEA analysis, heat analysis, microstructure analysis, vibration analysis of the roll and that there has not been enough study found or done on the aforementioned title based on roller base material EN19, hence this work is being done to increase the life of the roll used in heavy steel industry. However, the wear investigation and characterization of the coating is very important for the selected material before its practical implementation.

In this work, EN 19 is coated with hard chrome using electro plating and nickel using electroless plating method. The properties of the coatings were obtained, and coatings were tested for the unidirectional sliding wear using tribometer at room temperature condition. The results are systematically presented and discussed.

2.0 MATERIALS AND METHODS

Hardchrome and nickel coating materials is being selected based on their physical, chemical properties and based on the literature review. Hard chrome is coated by the Electro deposition coating method at Hydrochrome industries as shown in Figure 1. It is also known as the E-coating method. It is similar to electroplating method. Initially the surface has to be cleaned (ultrasonic washing/ degreasing/de-rusting/ manual cleaning etc.). After this water rinsing needs to be done to remove any type of chemical used during the cleaning process. Then surface activation of substrate is done by chrome salt so that nature of substrate gets adapted to chrome plating. After the surface is activated, the substrate is now ready to get chrome plated. The substrate is attached to cathode, which is negatively charged, and Chromium is attached to anode which is positively charged. When the current is supplied, the solution gets converted into ions, i.e., chromium ions become positive, and substrate becomes negative. The positively charged chromium ions get attracted towards negatively charged substrate. Chromium gets deposited on substrate and layer of chromium is formed on substrate. The solution used is Chromic acid or chrome sulphate. After completion of Hard chrome plating, it is again rinsed with water nicely. Then the final inspection is done.

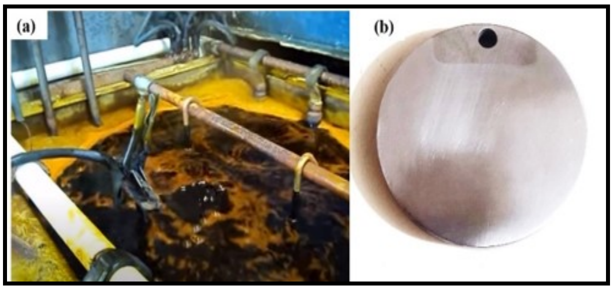


Figure 1 (a) EDM Method, (b) Hard Chrome coating on substrate

Coating of nickel has been done by electroless nickel plating method on the substrate EN19. The coated specimen is shown in Figure 2.

Figure 2 Electroless Nickel coating done on substrate EN19.

For the wear test, samples were made of substrate EN19 which was cylindrical in shape of diameter 40 mm and thickness 6 mm. Substrate were grinded. On one was coated with Hardchrome of thickness 100 microns by Electro Deposition Coating Method as explained above. On other substrate electroless Nickel coating was done of thickness 100 microns with electroless nickel plating method wherein no electricity is used. The characterization of the coating is done for Surface Roughness, X-Ray diffraction, Hardness, EDS, and Scanning electron microscopy. Tribological properties are obtained using the sliding wear tester.

Surface roughness was checked of substrate and coatings by surface roughness tester TR200 by ASTM D3359-09 standard as shown in Figure 3 (a). The hardness of all substrates were checked with Rockwell hardness tester by Hardness testing by ASTM E 18-07 standard, as shown in Figure 3 (b).

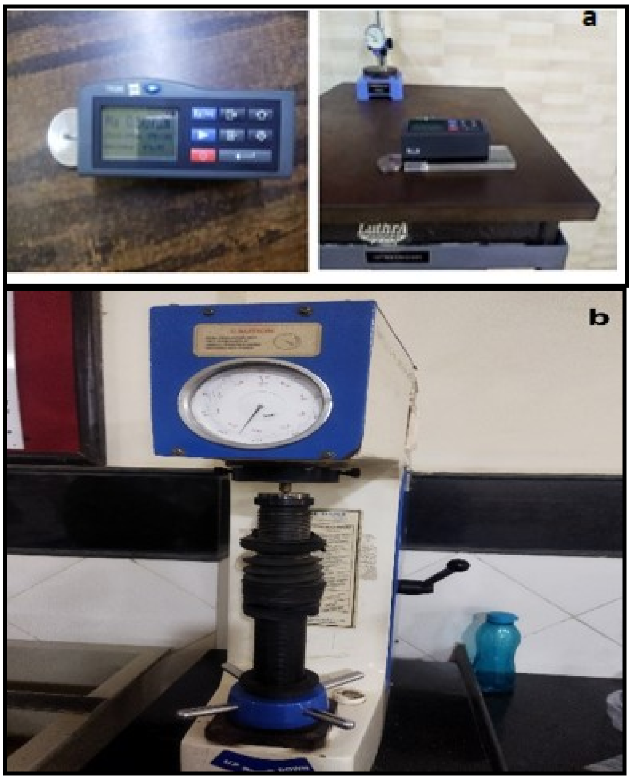


Figure 3 (a)Surface roughness checking for substrate and coatings (b) Hardness checking on Rockwell Hardness Tester

Dry Wear test was performed on Pin on disk wear test machine by ASTM G99-17 standard at VJTI institute Mumbai. This machine was DUCOM, Bangalore, India Make as shown in Figure 4. In this machine a specific load is attached. Track diameter is set which is generated and visible on specimen by removal of material. Velocity rpm is set at which disc will rotate on which substrate is mounted. Specifications set in the wear test machine are given in Table 1. Machine is put ON. The disk rotates at the set velocity rpm on which specimen is mounted, i.e., specimen is set into circular motion. Now a hard ball (indenter) of Silicon Nitride Si_3N_4 of 8 mm diameter which is very hard is mounted on the lever, the ball rubs and scratches the specimen and tries to remove the coating material at the set diameter track. So, a circular track is formed and gets visible on the specimen as shown in Figure 5. Weight of the specimen is measured before and after the wear test with High Precision Laboratory Balance by Contech Instruments Ltd. Change (Difference) in weight is found by subtracting the final weight after wear test from initial weight of specimen before wear test. Then Mass wear rate is found by the following expression:

Mass wear rate (gm/Nm) = Change in weight (gm) / [Load (N) $\times$ Sliding distance (m)]

This mass wear rate indicates which material or coating will wear out faster compared to others. It will indicate which material can last for a longer period of time.

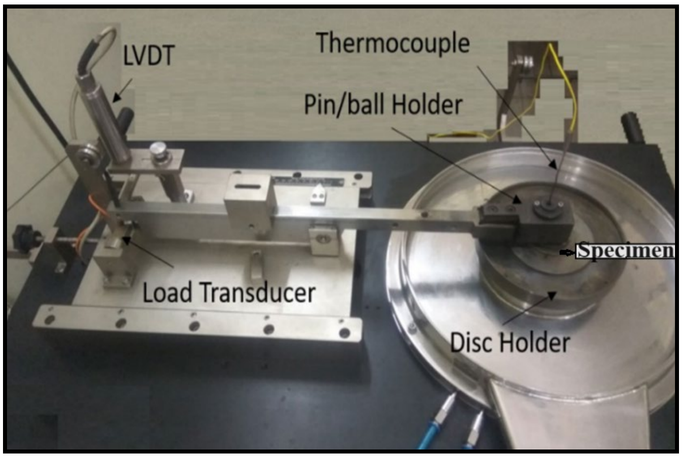


Figure 4 Pin on disc wear test machine on which wear test has been performed.

Table 1 Wear test parameters.

Substrate Material	EN19
Coating Material	Hardchrome, Nickel
Dimension of test piece	Dia.=40mm, Thickness= 6 mm
Surface finish	0.5 to 0.7 µm
Hardness	Hard Chrome-55 HRC Nickel – 45 HRC EN19 – 23 HRC
Sliding Velocity (V)	1 m/s
Normal Load (P)	30 N
Sliding distance	500 m
Track dia.	30 mm
RPM	637

Figure 5 Track formed on specimens (Hard chrome, Nickel & EN19) after wear test.

The wear machine is connected to a PC (ACER VERITON M200-H81 DESKTOP, PCI-E -6321 NI Card, DUCOM, Bangalore, India) which shows all the readings in the graphical form.

3.0 RESULT AND DISCUSSION

The surface roughness tested by Surface roughness Tester TR200 of substrate, Hardchrome and nickel was found to be 0.722, 0.576 and 0.507 Ra microns respectively. The hardness of substrates checked with Rockwell Hardness tester were found to be 55 HRC, 45 HRC & 23 HRC for hardchrome, Nickel and EN19 respectively.

The COF is received in the form of an excel sheet from the WINDUCOM 2010 machine software. The COF (coefficient of friction) of hardchrome, Nickel, EN19 was found to be 0.554, 0.323 & 0.66 respectively as shown in Figure 6. The difference in COF is due to the difference in roughness value. EN19 has maximum roughness followed by hardchrome and nickel due to which the substrate EN19 has maximum COF followed by hardchrome and nickel.

In the case of wear test five readings were taken for each material at load of 30N and velocity 1m/s and average value is mentioned in Table 2. Wear test experimental result is shown in Table 2. Mass wear rate of hardchrome, Nickel, EN19 was found to be 1.66667×10^{-07}, 2.66667×10^{-07} & 2.53333×10^{-06} (gm/Nm) respectively as shown in Figure 7. It means substrate EN19 worn out at a faster rate followed by Nickel and hardchrome was found out to be the best coating with least wear amongst these.

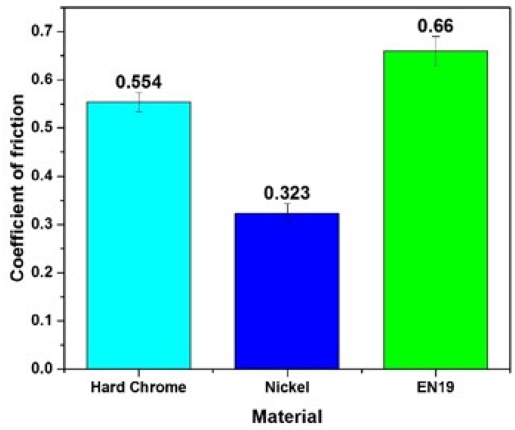


Figure 6 COF for different material

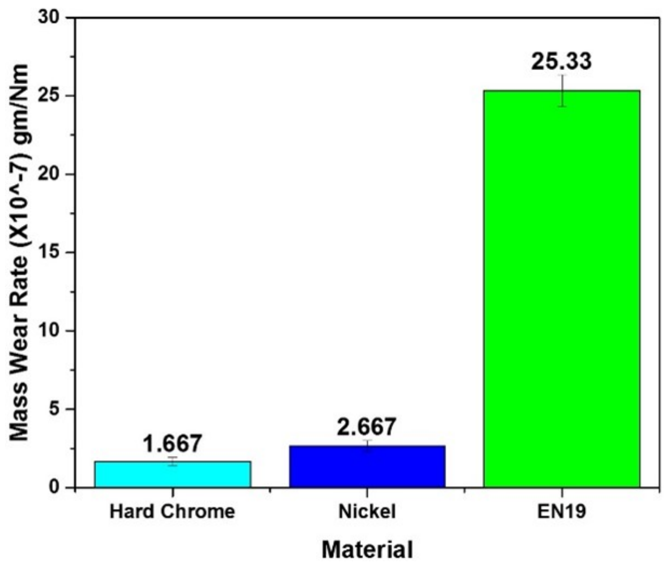


Figure 7 Mass Wear rate (gm/Nm) for different material

Hardchrome has high COF compared to nickel, but low wear rate compared to nickel and EN19 due to its high hardness and chemical & physical compositions.

Table 2 Wear test experimental result

Material	**Load (N)**	**V (m/s)**	**Sliding distance (m)**	**time (min)**	**RPM**	**track diameter (mm)**	**Weight before (gm)**	**Weight After (gm)**	**Change in weight (gm)**	**Mass Wear rate (gm/Nm)**	**COF**
Hard Chrome	30	1	500	8.3333	637	30	64.349	64.3465	0.0025	1.66667×10^{-07}	0.554
Ni	30	1	500	8.3333	637	30	64.812	64.808	0.004	2.66667×10^{-07}	0.323
EN19	30	1	500	8.3333	637	30	65.502	65.464	0.038	2.53333×10^{-06}	0.66

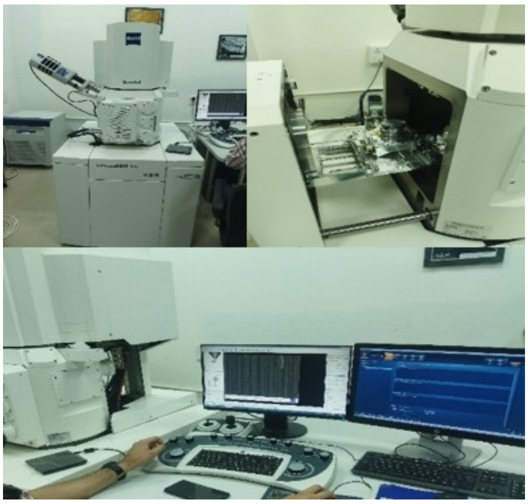


Figure 8 FE SEM and EDS performed for different specimens on ZEISS Gemini SEM 300 machine.

FE SEM and EDS performed for different specimens on machine of ZEISS make Gemini SEM 300 model at IIT Bombay as shown in Figure 8. EDS ie., Energy Dispersive Spectroscopy was done for various samples.

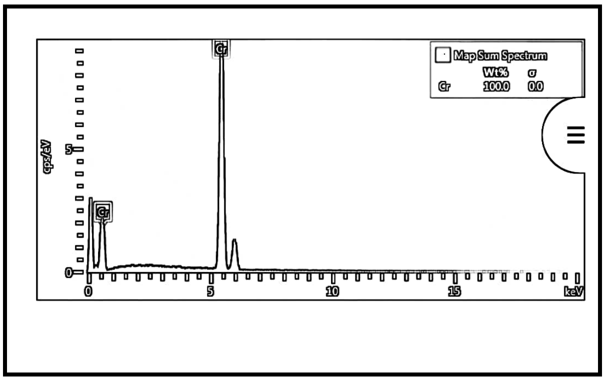


Figure 9 EDS for Hardchrome coating

EDS Graph as shown in Figure 9 confirms the presence of Hardchrome coating by 100% by weight.

EDS Graph as shown in Figure 10 confirms the presence of Nickel coating. This coating has Nickel 86.6% and Phosphorus 13.4% by weight.

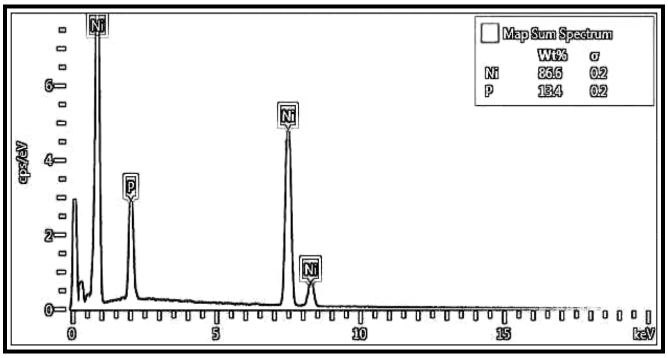
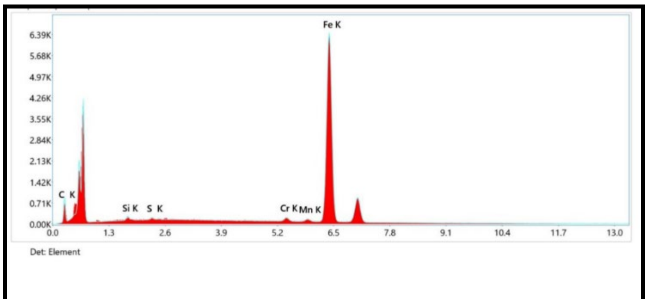


Figure 10 EDS for Nickel coating



eZAF Quant Result

Element	Weight %	MDL	Atomic %	Net Int.	Error %	R	A	F
C K	25.3	0.76	61.0	132.1	12.5	0.8303	0.0684	1.0000
Si K	0.4	0.09	0.4	37.3	17.6	0.8776	0.4338	1.0099
S K	0.2	0.10	0.2	20.7	27.8	0.8870	0.6531	1.0248
Cr K	0.6	0.15	0.3	49.3	17.1	0.9204	0.9600	1.5342
Mn K	0.6	0.27	0.3	27.6	23.4	0.9245	0.9688	1.1489
Fe K	72.9	0.29	37.8	3023.9	2.1	0.9286	0.9744	1.0259

Figure 11 EDS for EN19 coating

FESEM and EDS for substrate EN19 was performed on Quanta 200F Netherlands make machine.

EDS Graph as shown in Figure 11 confirms the presence of Iron – 72.9%, Carbon- 25.3%, and Silicon, Sulphur, Chromium, Manganese in small amount – 0.2 to 0.6 by weight for EN19 of which Roll is made up of in heavy steel industry.

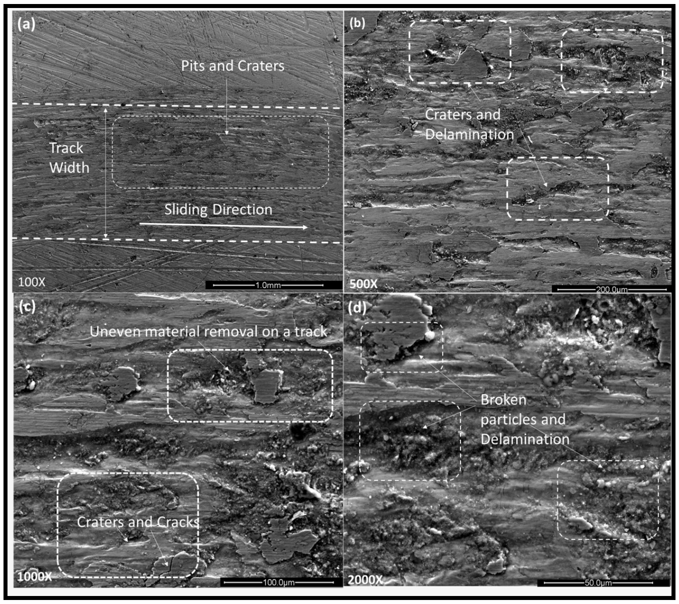


Figure 12 FESEM of EN19 inside the wear track at different magnification [a) 100X, b) 500X, c)1000X, d) 2000X.

The Figure 12 FE SEM at 100X shows the wear track formed in substrate EN19 after wear test has been performed. The images at different magnification (100X, 500X, 1000X, 2000X) show that pits and craters are formed due to wear. The images show that wear has occurred due to abrasive and adhesive wear. SEM images show that maximum wear (pits and craters) is formed in EN19 compared to Hardchrome and nickel.

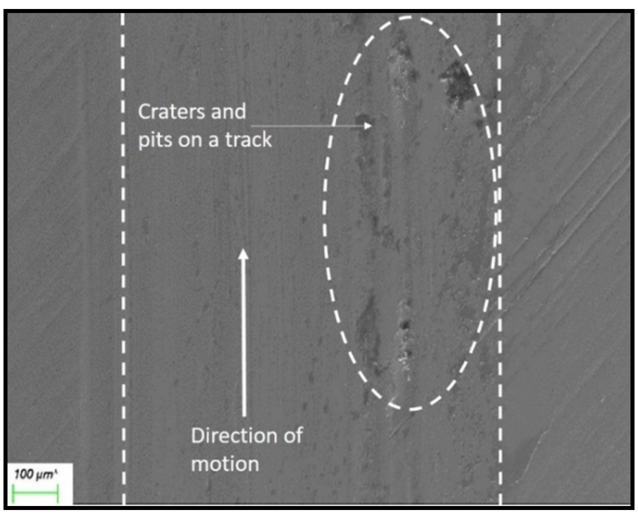


Figure 13 FESEM of Hardchrome inside the wear track at 200X.

Figure 13 shows FESEM of Hardchrome inside the wear track formed after wear test at magnification 200X. Pits and Craters are formed due to wear which depicts that wear has occurred due to abrasive and adhesive wear. Also, this SEM image shows that less wear has occurred in Hardchrome compared to images of substrate EN19.

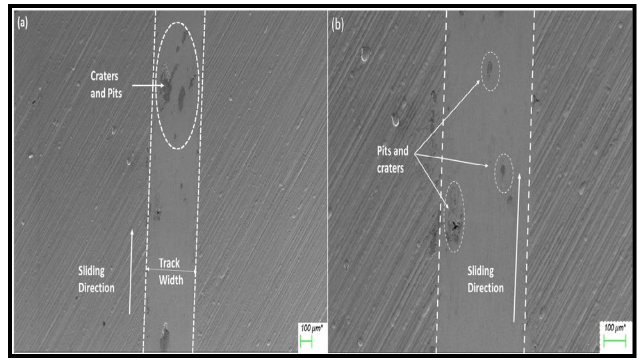


Figure 14 FESEM of Nickel inside the wear track formed after wear test at different magnification (100X, 200X).

The above Figure 14 shows the wear track formed for Nickel at magnification 100X and 200X after performing wear test. The images show that wear has occurred due to adhesive and abrasive nature but less then substrate EN19.

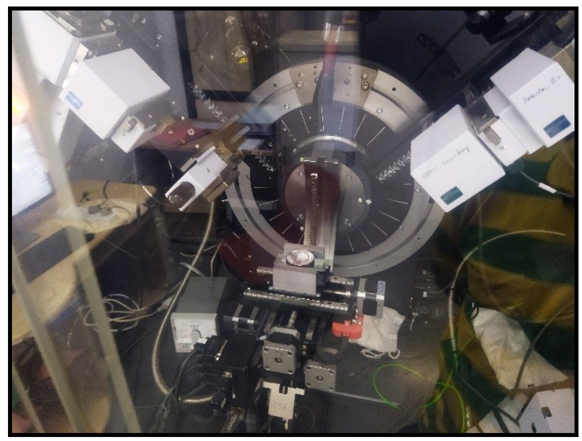


Figure 15 XRD performed for various experiments.

XRD i.e., X-ray diffraction was performed on different specimens on D8 DISCOVER BRUKER make machine as shown in Figure 15. XRD was performed at voltage of 40kV, current 40mA, power of 1600W on copper tube with 1.5418 A.

The XRD graph was plotted using Origin software as per data obtained from XRD machine for different specimen coatings.

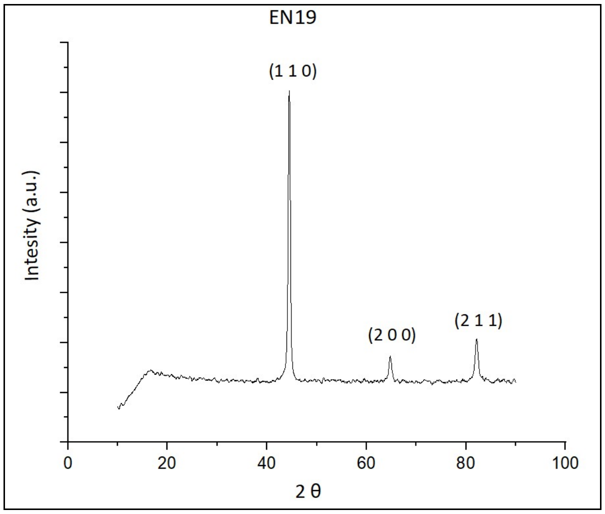


Figure 16 XRD graph for EN19

Peaks for EN19 as shown in Figure 16 are observed at 2θ=44.48 (intensity 6582) corresponds to Fe (110) plane, 2θ=64.73(2908.41) corresponds to Fe (200) plane and 2θ=82.14 (3099.87) corresponds to Fe (211) plane and it matches with the standard diffraction peak as per the literature survey [28]. This graph has narrow sharp peaks and no broad peak which represents that EN19 is crystalline in nature.

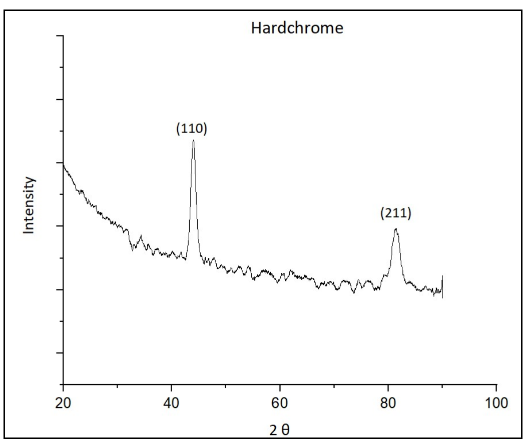


Figure 17 XRD graph for Hardchrome

As per the literature survey and comparing to standard diffraction peak for chrome [22] the peak for Hardchrome (HC) coating done on substrate as shown in Figure 17 is observed at 2θ = 43.956 (intensity 1180.18) corresponds to HC (110) plane, 2θ = 81.07 (1019.28) corresponds to HC (211) plane. This graph has narrow sharp peaks which represent that hardchrome coating is crystalline in nature.

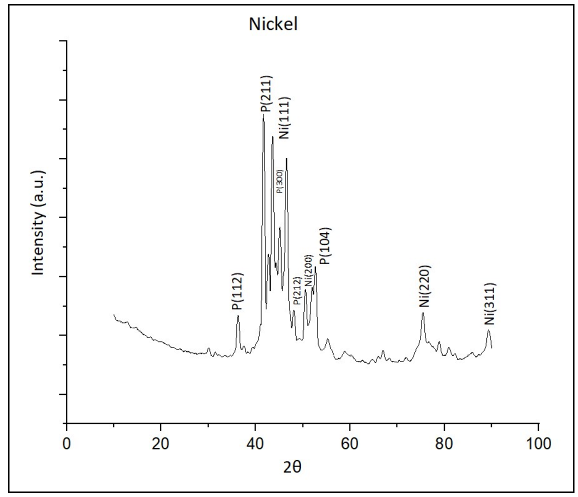


Figure 18 XRD graph for Nickel

As per the literature survey and comparing to standard diffraction peak for Nickel [23] the peak for Nickel coating done on substrate EN19 as shown in Figure 18 is observed at 2θ = 36.26 (1175.71) corresponds to Phosphorus P(112) plane, 2θ = 41.68 (2880.19) corresponds to P(211) plane, 2θ = 43.61 (2692.5) corresponds to Nickel Ni(111) plane, 2θ = 45.13 (1925.94) corresponds to P(300) plane, 2θ = 48.06 (1215.95) corresponds to P(212) plane, impurity peak at 2θ = 50.55 (1394.88), 2θ = 51.99 (1409.71) corresponds to Ni(200) plane, 2θ = 52.66 (1586.29) corresponds to P(104) plane, 2θ = 75.48 (1194.27) corresponds to Ni(220) plane, 2θ = 89.33 (1045.81) corresponds to Ni(311) plane. This graph has narrow sharp peaks, and no peak is broad which represents that Nickel coating is crystalline in nature. The impurity peak may be due to traces of electrolytic environment or due to base material.

From the XRD graph of all specimen EN19, Hardchrome, and Nickel it has been found that they have narrow sharp peak which represents that they have crystalline structure. The XRD graph results of the coated Nickel, Hardchrome and substrate EN19 agree with that of their EDS results. XRD also confirms the composition of coating on substrate. It is found a=b ≠c and $\alpha = \beta = \gamma = 90^{o}$ (a=4.221, b=4.09, c=3.791, λ= 1.5405). It has been found that coatings are tetragonal, slightly monoclinic in symmetry.

4.0 CONCLUSION

To increase the efficiency of rolling process in heavy steel industry the rolls which is the basic and most important tool of rolling process should have a very good life, but due to high load dynamic rolling application, wear and tear of rolls occurs frequently which decreases the productivity, efficiency of the process and thus there is a huge capital loss, too.

EDS result shows the presence of Nickel, hardchrome coating on the substrate EN19.

SEM images revealed the wear occurrence on the specimen is due to adhesive and abrasive wear which is the cause of wear out of rolls.

The XRD graph reveals that coatings are crystalline in nature. Coatings are tetragonal slightly monoclinic in symmetry. By experiments on pin on disk wear machine Mass wear rate of hardchrome, Nickel, EN19 was found to be 1.66667×10^{-07},

2.66667×10^{-07} & 2.53333×10^{-06} (gm/Nm) respectively. It means substrate EN19 worn out at a faster rate followed by Nickel and hardchrome was found out to be the best coating with least wear amongst these. Nickel gives 9.49 times more life than substrate EN19. Hardchrome gives 15.19 times more life than substrate EN19 and 1.6 times more life than Nickel coating.

It can be concluded from the conducted experiments that Hardchrome is one of the best materials which if coated to rolls can increase its life substantially and thus can minimize capital and time loss due to wear out of rolls in heavy steel industries. Hardchrome plating has a low friction. It has a good corrosion resistance and excellent wear resistance.

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