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Evaluation of HVOF Thermal Sprayed $Cr_3C_2NiCr75/25$ and NiCrBSi Coatings and Hard Chrome Plating

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ABSTRACT

Hard chrome plating is traditionally used to restore the original dimensions of worn surfaces of components; however, it exhibits harmful environmental effects which affect the public health and the process also has intrinsic technical limitations. The High Velocity Oxy-Fuel (HVOF) thermal spray process is environment friendly, reduces production costs and the cost of repairing the worn out components, shafts etc. Hence, the HVOF processes are predominantly used as alternative to hard chrome plating to repair worn parts or components. In this work, the HVOF sprayed $Cr_3C_2NiCr75/25$, NiCrBSi, coatings and hard chrome plating were evaluated using Hardness tester, Optical Microscope, Scanning Electron Microscope (SEM / EDS) and XRD. The study results revealed that the thermal spray coating exhibits better mechanical and tribological properties than the hard chrome plating.

Keywords:— *HVOF thermal spray, Hard chrome plating, $Cr_3C_2NiCr75/25$, NiCrBSi, Wear, 50CrMo4*

I. INTRODUCTION

The wear out of running parts or components of any operating equipment is inevitable and at the same time, it has to be protected or delayed by giving wear resistant coating by using suitable material and process. One such conventional solution is hard chrome plating used in industries for many years. It provides protection against corrosion, wear resistance, erosion and dimensional reclamation. This protection extends the service life of the components.

Nowadays each and every industry is expecting a faster, cheaper and better solution for any of their production problems. The cost of chrome plating is steadily escalating due to environmental regulations, growing industrial pressures and legislations imposed on the chrome plating process and the disposal of the plating solution. To overcome this critical industrial problem, an alternate solution or process that offers similar or better characteristics of hard chrome plating is to be thought of. Extensive studies have revealed that the thermal spray coating as a suitable process to salvage the excessively worn components ensuring reliable and better performance surface coating with a fast mode of reclamation without any environmental and employee health hazards.

The present analysis or work aims to enhance the hardness, wear resistance and other mechanical properties of 50 Cr Mo4 (DIN - 1.7228) alloy steel using HVOF sprayed coatings of Cr_3C_2 NiCr 75/25,NiCrBSi and alloy and their powders to substitute or alternate to hard chrome plating.

II. Literature Review

Schroeder et al. [1], Tahar Sahraoui et al. [2] and Kim et al. [3] reported that NiCrBSi /Cr_3C_2–NiCr 75/25 alloy powder coatings carried out using High Velocity Oxy Fuel (HVOF) process as viable options for cost effective repair of the worn out metallic components.

Espallargas et al. [4] carried out thermal spray coating to replace the hard chromium coatings in applications under erosion-corrosion atmosphere. Both HVOF sprayed WC-Ni and Cr_3C_2- NiCr have been found as promising alternatives.

Crawmer [5], Murthy et al. [6] and Kaur et al. [7] have experimented and reported that the Thermal spray coatings are produced by rapidly heating the feed stock material in a hot gaseous medium and simultaneously projecting it at a high velocity and temperature on a prepared surface where it builds up the desired coating. The Cr_3C_2NiCr coatings are being applied on a wide range of industrial components like shafts, steam and gas turbine blades and boiler tubes against corrosion and erosive wear.

Wang et al. [8] and Li et al. [9] reported that the Cr3C2-NiCr coating could be used in corrosive environment for high temperature services up to 800°C. It exhibited good erosion resistance up to 800°C but its hardness decreased at temperature above 600°C. Hence, Cr_3C_2 NiCr coating is suitable for protective layers at elevated temperature and corrosive environment.

Khanna et al. [10] and Roy et al. [11] reported that the conventional methods of coatings such as carburizing, nitriding, electroplating are being used over a century to protect the tools and other components from wear. However, CVD, PVD, Thermal spray and Laser Cladding discovered in the 60s have become popular because of their large throughput in the shortest possible time. Thermal spraying in particular offers an effective and economic way to make the coating without affecting the properties of the components.

Tillmann et al. [12] reported that the HVOF coating produces sophisticated wear resistant cermet coatings generally with exceptional high quality microstructures. The coatings generally feature very low porosity, low oxidation, low carbide decomposition and carbide matrix dissolution, resulting in high hardness and high abrasion resistance. The corrosion resistance of the coating is better than that of the other thermal spray processes.

Cho et al. [13] highlighted the constraints of hard chrome plating and carried out the thermal spray coatings using HVOF gun, Co based alloy and Tribaloy-800. They reported good friction and wear resistant properties at a high temperature of 500°C.

III. Experimentation

3. 1 Preparation of Test Coupons and Powders Selection [16]

Test coupons of thickness 6 x 8 x 8 mm and 6 x ϕ100 mm were cut from the 50 Cr Mo4 (DIN- 1.7228) alloy steel to carry out the evaluation. The test samples were grit blasted with Al_2O_3 having a grit size of 24 µm. Based on the works of Picas et al. [14] and Abdi et al. [15] for wear resistant applications, the spray powders selected for the HVOF coating were NiCrBSi and Cr_3C_2NiCr 75/25 with the particle size of 20 - 53 µm.

3.2 HVOF Coating

HVOF JP 5000 Praxair gun was used for HVOF coating. The powders were pre heated at 100 °C for ½ hr. The powders were combusted by using the heat generated by burning kerosene mixed with oxygen producing gases with temperature up to 3000° C in the gun. The powder was accelerated by a carrier gas and injected onto the flame and the powders were heated and accelerated with high velocity and sprayed on the substrate.

3. 3 Hard Chrome Plating

The test samples of hard chrome plating were cleaned by scouring with fine pumice powder. A composition of chromic acid 250g/L, Sulphuric acid, and 2.5 g/L with a ratio of 100:1 was maintained with the bath temperature of 48- 50°C and the cathode current density was 22A/dm^2. The average coating rate of thickness achieved was 7.5µ/hr.

3. 4 Testing

The coated samples were evaluated using roughness test, hardness test, abrasion wear test, sliding wear test, optical microscopy. Micro-hardness and thickness of the spray coated and electro plated samples were measured on the polished cross sections of coatings. AFFRI micro hardness tester with 300 gf load with dwell time of 10 sec was used for the study. Scanning Electron Microscopy (SEM/EDS) and X-ray diffraction (XRD) was done and the images were captured with 200X, 300X 500X, 1000X and 2000X magnifications.

The coated samples were polished for highlighting microstructure features for optical and SEM observations. The metallographic etchant 2ml HF +20ml HNO_3+20ml H_2O was used for NiCrBSi and etchant 4 ml HNO_3+15ml HCl was used for both Cr_3C_2NiCr75/25 and electroplated samples as per ASTM E407 E1.

IV. Results and Discussion

4. 1 Optical Microscopic (OM) Analysis of Coatings [16]

The microstructure and thickness of the coatings were evaluated by using the optical microscope. Microstructure of hard chrome plating is homogeneous and no micro cracks are observed. It has excellent adhesion and there are no interfacial defect/ cracks due to the controlled process parameters maintained during hard chrome plating. Also, the interface region for Cr_3C_2NiCr75/25 and NiCrBSi coatings are free from cracks or porosities.

The images of the coatings were captured by optical microscope having Metal plus software version 4.5 for image analysis as per standard E45 and the porosity was evaluated. The porosity values of the coated samples of Cr_3C_2NiCr75/25, NiCrBSi and chrome plating was 2.43%, 1.96% and 0.70% respectively. The porosity analysis indicates that HVOF sprayed Cr_3C_2NiCr 75/25 and NiCrBSi powder coatings have uniform carbide distribution and also have a very dense microstructure with marginally higher porosity than the hard chrome plating. There are no clearly detectable spots indicating that the powder was not excessively melted in the spraying process, and it adhered to the underlying coating.

The surface roughness of coated samples was measured by using surface roughness testing unit (Mitutoya SJ 400 tester), following IS 3073-1967. The measured values for coated samples of Cr_3C_2NiCr75/25, NiCrBSi, chrome plating and uncoated samples are 4.5µ, 5.5µ, 0.15µ and 1.45µ respectively. As per the measurements, the roughness values for HVOF coated samples are higher than that of the base material and chrome plating.

The surface hardness was measured using Vickers hardness tester. The surface hardness measurement on the coated samples of Cr_3C_2NiCr75/25, NiCrBSi, chrome plating and uncoated samples are 544, 549, 419 and 345 respectively. The surface hardness values of HVOF coatings are higher than that of base material and chromium plating and are above the required hardness of 513$HV_{0.3}$. The micro hardness of the coated samples of Cr_3C_2NiCr75/25, NiCrBSi, chrome plating and uncoated samples are 1105, 756, 855 and 367 in $HV_{0.3}$. Scale respectively. The consolidated results of the work are given in Table 4.

4. 2 Abrasion and Sliding wear -Pin on Disc Test (ASTM G 99)

Abrasion wear testing [16] was done as per ASTM Standard D4060-10 test method for relative resistant to wear using taber abraser. The test coupons are subjected to abrade against a pair of hard AH-22 coarse calibrated wheels under set load conditions for fixed number of revolutions. The relative weight loss after 5000 cycles of the coatings were 0.3 g, 0.27 g, 0.14 g and 1.3 g respectively for Cr_3C_2NiCr75/25, NiCrBSi, chrome plating and the substrate respectively. As per the observations, the weight loss of Cr_3C_2NiCr75/25 and NiCrBSi coated specimens are slightly higher than that of hard chrome plating. Though the hardness of chromium carbide plating is lower than the other HVOF coatings, the weight loss is lower due to smooth and uniform surface film observed on the surface of chrome plating.

Sliding wear tests were also carried out under dry sliding condition as per ASTM G99-05 standard on a DUCOM pin-on-disc tribometer, model TR-20-LE-PHM. A comparison of the trends of percentage mass loss, wear rate and coefficient of friction, the HVOF coated samples indicated the lowest wear rate. Both HVOF coatings and substrate material had lower weight loss than the wear rate of Cr_3C_2NiCr75/25 coating and it was closer to that of chrome plating. As per the observations, the chrome plating seems to have the lowest weight loss, wear rate and coefficient of friction. This is due to better surface finish, uniform and denser coating of chrome plating. However, the HVOF coatings have lower weight loss, wear rate and coefficient of friction than the uncoated metal.

4. 3 Scanning Electron Microscopic (SEM / EDS-SE / BSE) Study

The HVOF sprayed Cr_3C_2NiCr 75/25 and NiCrBSi samples and hard chrome plated samples were evaluated for their morphology / microstructures and the quantitative elemental analysis was done by using SEM S 3000H. The microstructure of the polished and slightly etched cross section of coating was also examined. The Secondary Electron (SE) and Back Scattered Electron (BSE) images with various magnifications were taken and evaluated.

The Cr_3C_2NiCr75/25 coating (figure 2, 3) had uniform and dense microstructure and exhibited layered morphologies containing metallic binder NiCr solid solution and dispersed carbide CrC due to the deposition and re-solidification of molten or semi molten droplets. The coating also possessed some voids and oxide inclusions that are typical characteristics of the HVOF sprayed coating. The dark phase contained a little higher amount of Cr than the white phase. However both NiCr (bright area), CrC (dark area) phases have rich chromium content. The coatings have a dense structure with the porosity randomly distributed in the coatings. No crack or delamination is observed in the Cr_3C_2NiCr75/25 powder coating. Cross sectional image shows typical lamellar structures and flattened splats. The coating indicates uniform distribution of Cr and Ni with comparable bonding as that of chrome plating.

The NiCrBSi thermal spray coatings (figure 8, 9) have a dense structure with the porosity (black areas) randomly distributed in the coating. Adherence between substrate and coating seems to be good with no presence of either cracks or voids in the interface. Precipitate dissolution is promoted by elevated flame temperature and a high time particle residence in flame. These precipitates revealed that they are chromium borides and carbides. HVOF spraying with the highest velocity of the powder particle combined to a perfect matrix melting enhances its better lamellae depositions. It is observed that the repartition of the different elements had taken place. The phase composition is strongly dependent on the particle temperature. The microstructure of the coating showed almost uniformly distributed spherical shaped fine grained micro structure and elements.

In the SEM microstructure, SE images of hard chrome plating (figure 16, 17), possess a very homogenous micro structure. No significant differences were noticeable in the coatings. Excellent adhesion with almost no interfacial defects were seen on the grit blasted substrate. The hard chrome plating, on grit blasted surface was smooth. In the back scattered electron and secondary electron images, the elements like Cr, CrO were present uniformly. Very fine or smooth coating was obtained in hard chrome plating which increased the toughness and hardness of the coating.

The SEM morphology, SE / BSE image, quantitative elemental analysis and the elements image mapping (EDS) for Cr_3C_2NiCr 75/25, NiCrBSi and hard chrome plating are shown in Figures 1– 18.

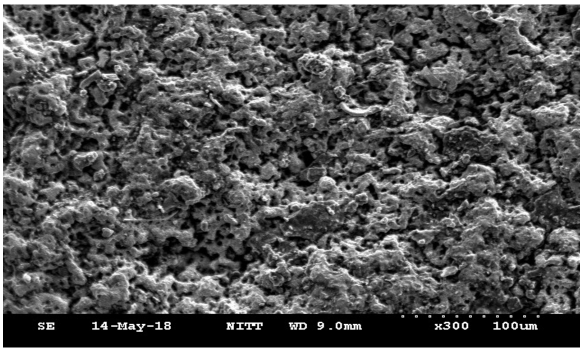
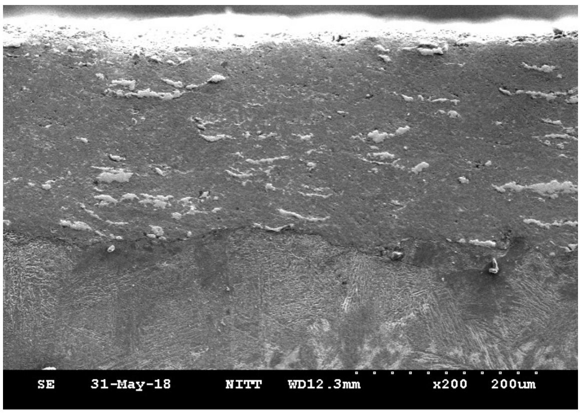


Figure 1: SEM Morphology of Cr_3C_2NiCr 75/25



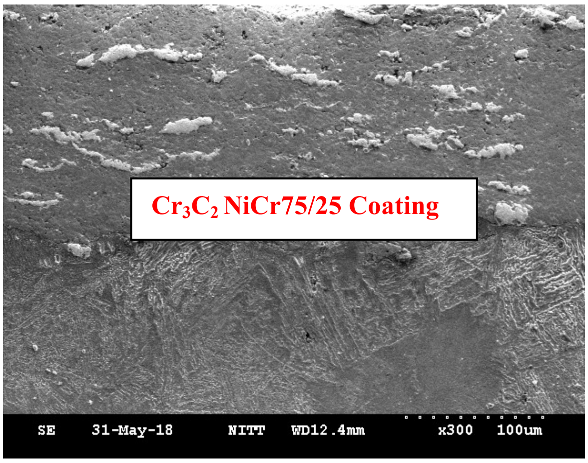


Figure 2: SEM / SE Image of Cr_3C_2 NiCr75/25 Coating across Section

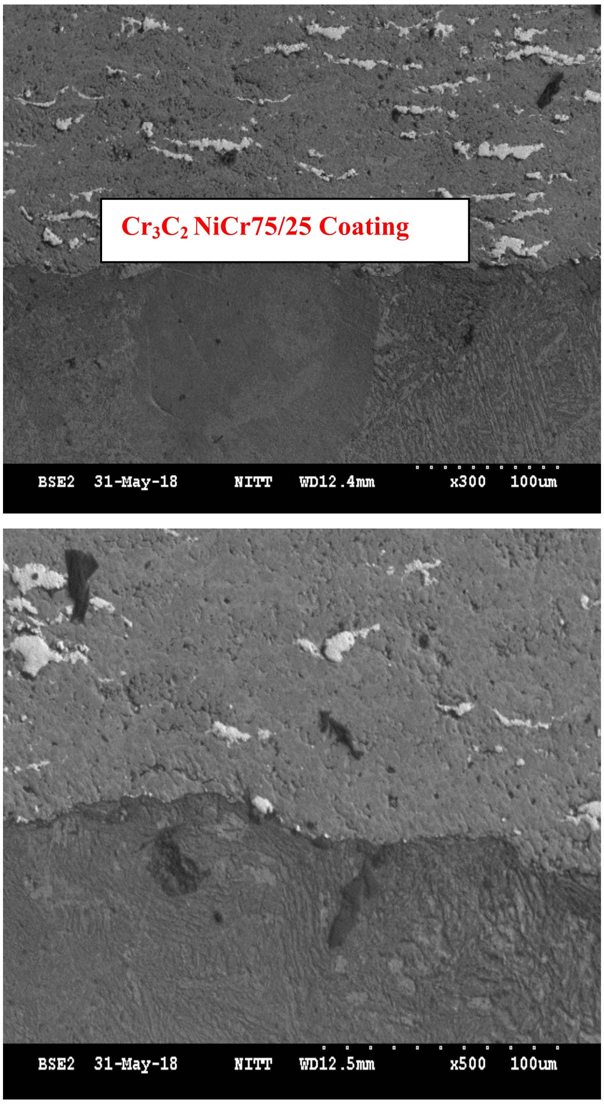


Figure 3 : SEM / BSE Image of Cr_3C_2 NiCr75/25 Coating across Section

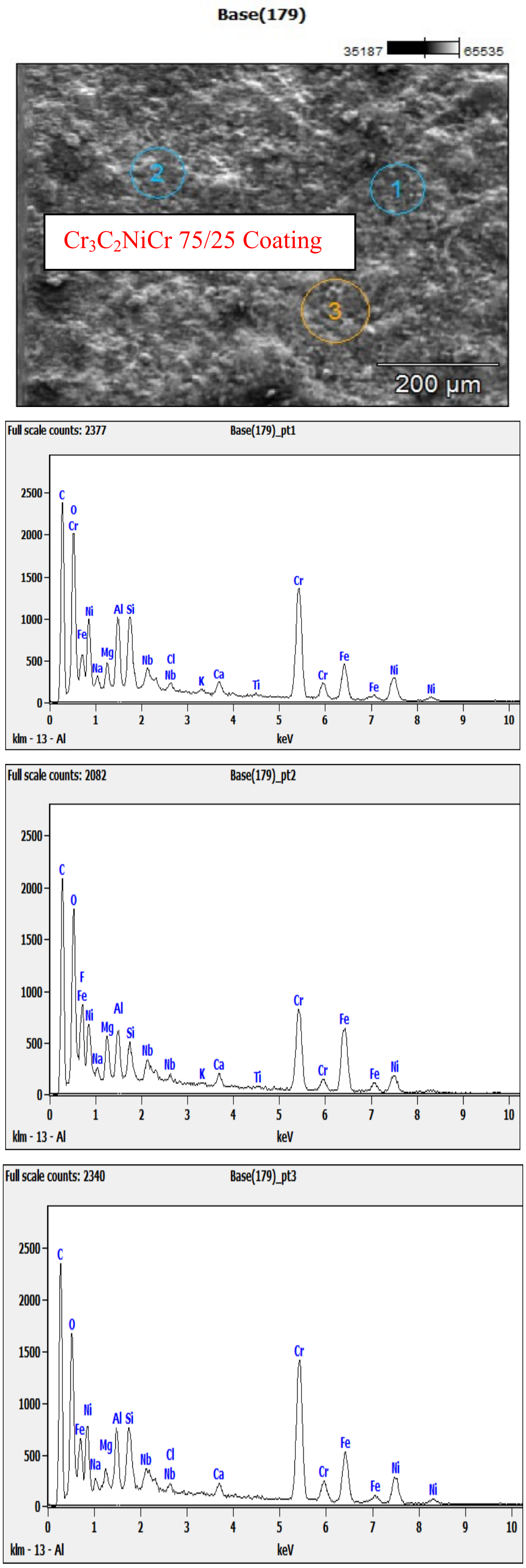


Figure 4 : Quantitative Elemental Analysis of Cr_3C_2 NiCr75/25 Coating at Different Points

Table 1 : Quantitative Elemental Analysis of Cr_3C_2 NiCr75/25 Coating at Different Points

	C-K	O-K	F-K	Na-K	Mg-K	Al-K	Si-K	Cl-K	K-K	Ca-K	Ti-K	Cr-K	Fe-K	Ni-K	Nb-L
Base(179)_pt1	18.39	14.76		0.10	1.46	3.70	4.12	0.76	0.35	1.10	0.26	25.28	11.84	14.67	2.21
Base(179)	18.07	14.65	2.02	0.81	2.86	2.51	1.89		0.17	1.03	0.21	17.88	24.33	11.04	2.52
Base(179)_pt3	18.36	12.98		0.77	0.95	2.54	3.27	0.53		0.94		27.52	15.87	14.13	2.14

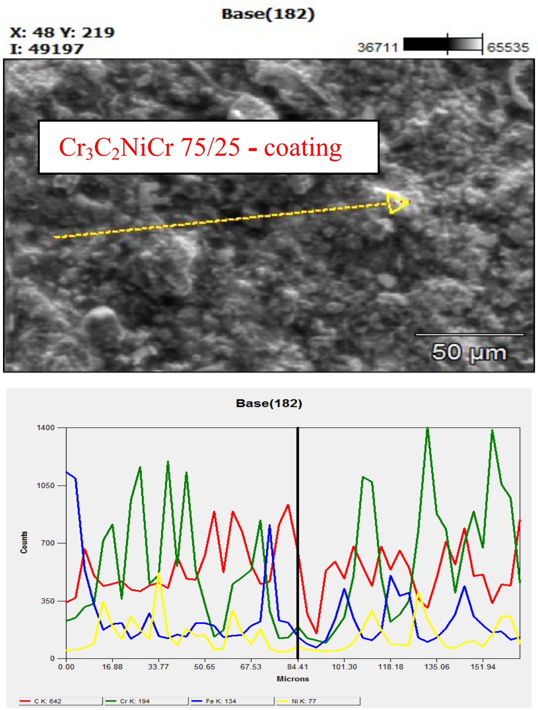
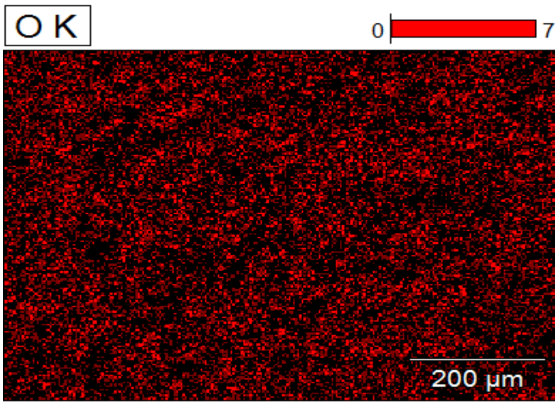
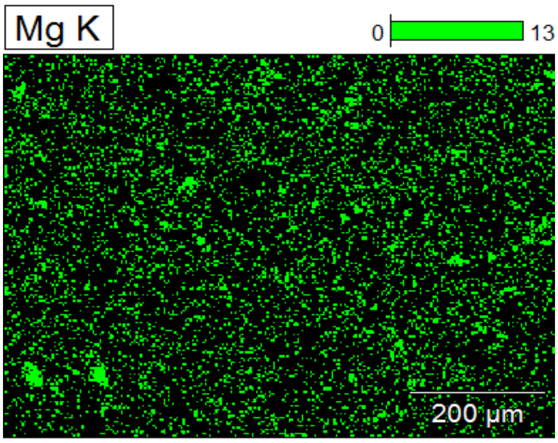
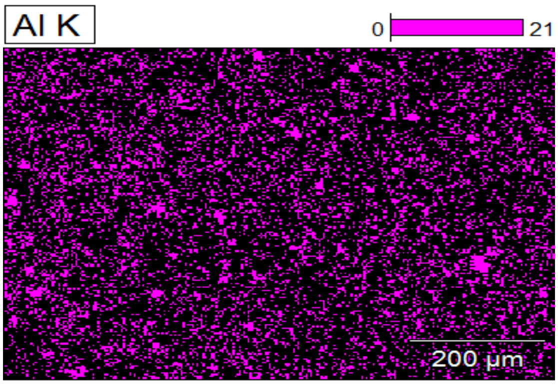
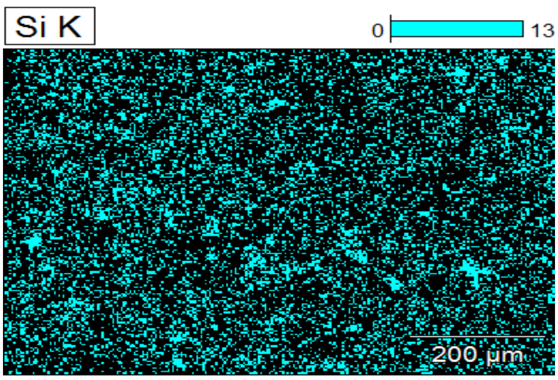


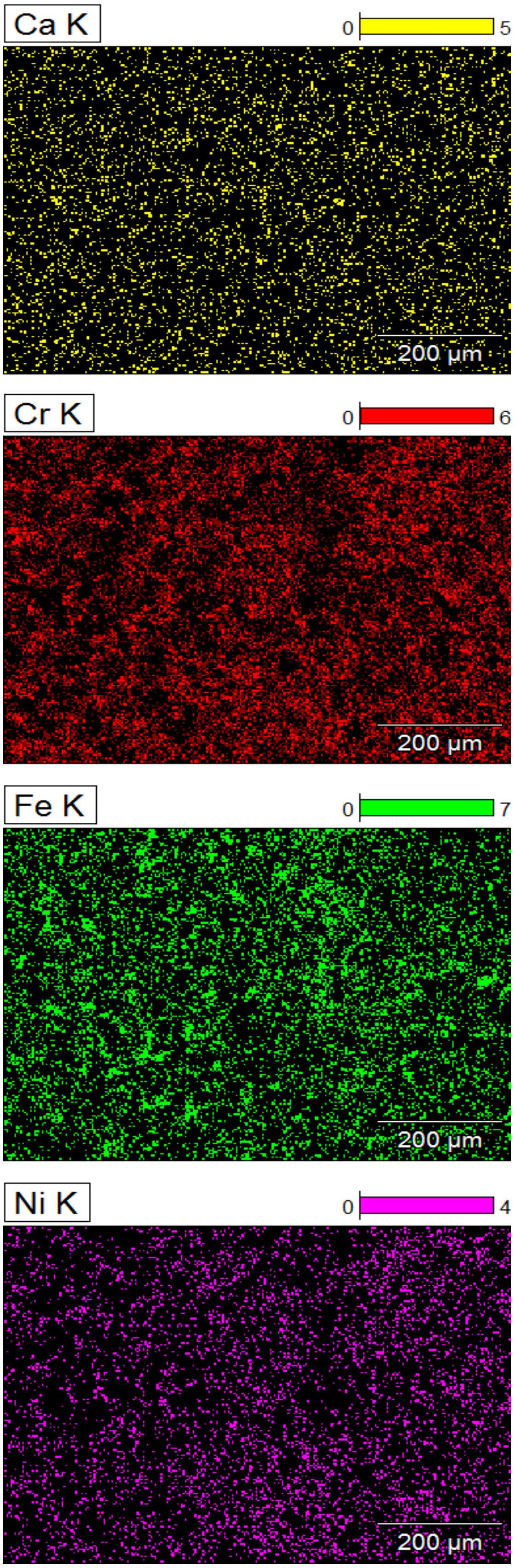
Figure 5 : Quantitative Analysis of Elements in Cr_3C_2NiCr75/25 Coating along the Line











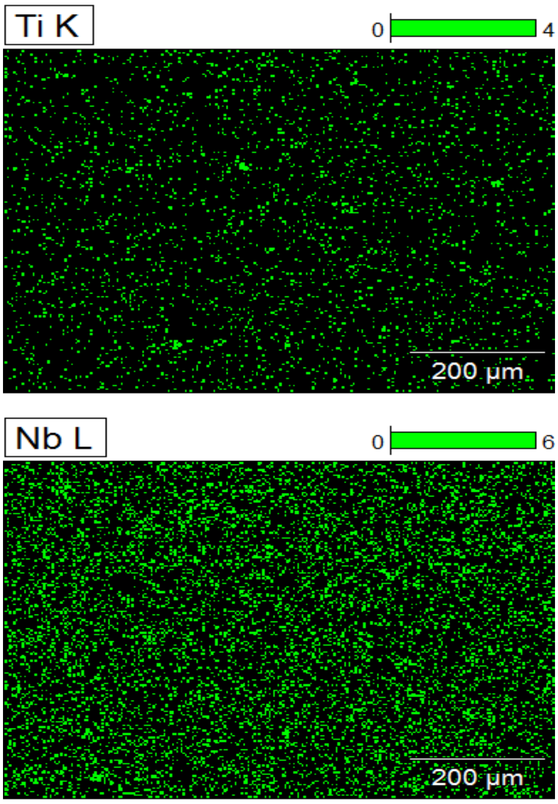


Figure 6 : Elements Image Mapping of Cr_3C_2 NiCr 75/25 Coating by EDS

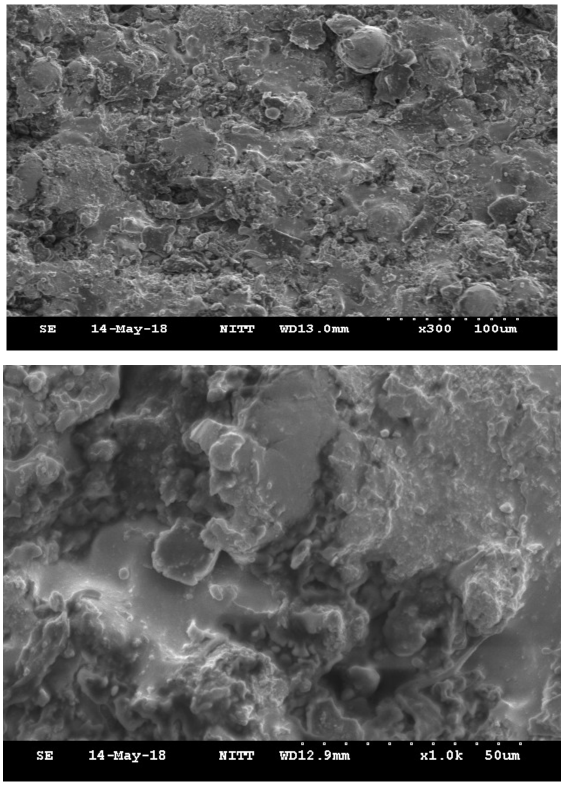


Figure 7 : SEM Morphology of NiCrBSi Coating

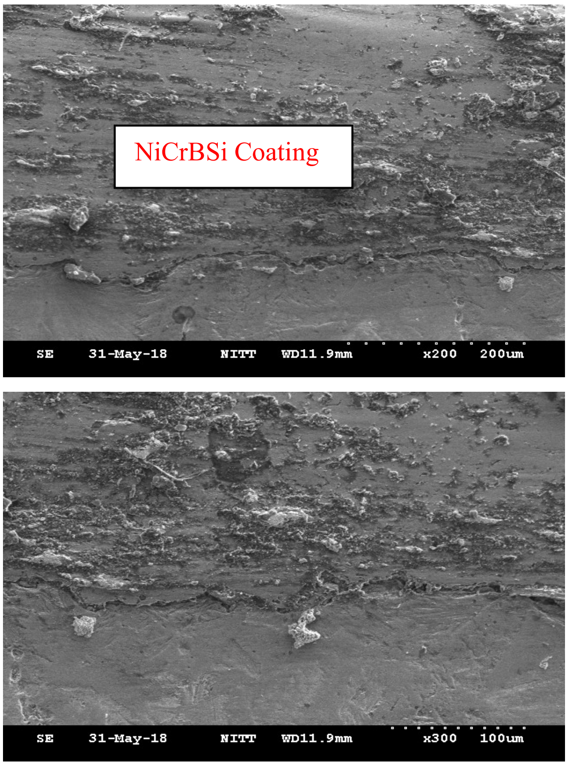


Figure 8 : SEM / SE Images of NiCrBSi Coating across Section

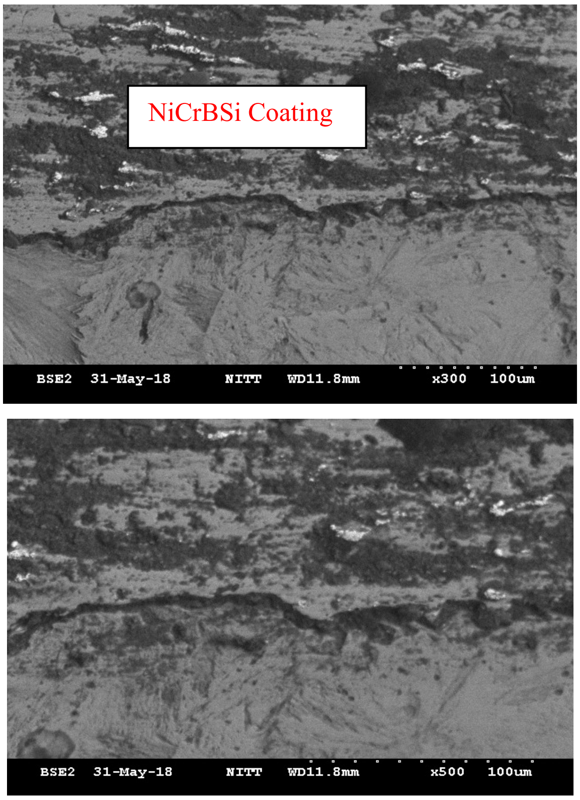


Figure 9 : SEM / BSE Images of NiCrBSi Coating across Section

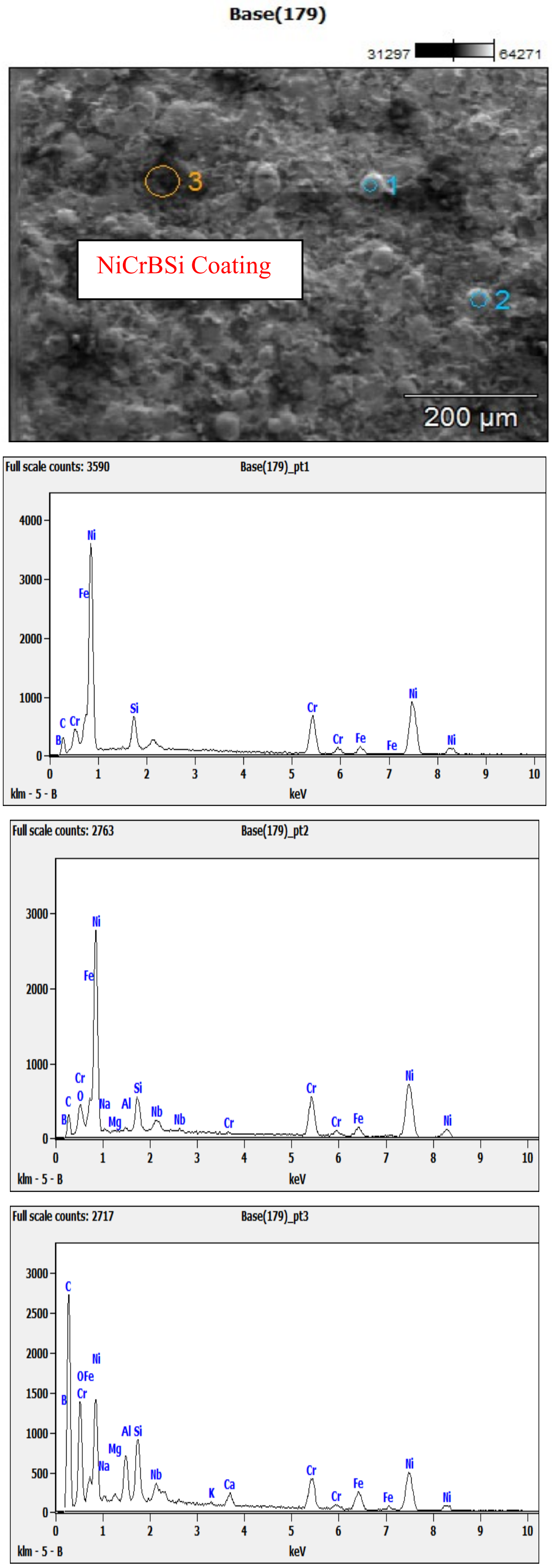


Figure 10 : Quantitative Elemental Analysis of NiCrBSi Coating at Different Points

Table 2 : Quantitative Elemental Analysis of NiCrBSi Coating at Different Points

	B-K	C-K	O-K	Na-K	Mg-K	Al-K	Si-K	K-K	Ca-K	Cr-K	Fe-K	Ni-K	Nb-L
Base(179)_pt1	0.00	4.29					4.63			17.21	3.98	69.89	
Base(179)_pt2	0.03	4.60	2.83	0.72	0.18	0.32	4.18			15.54	5.47	63.46	2.67
Base(179)_pt3	0.13	25.56	15.08	0.50	0.46	3.09	4.40	0.18	1.36	8.87	7.77	30.23	2.37

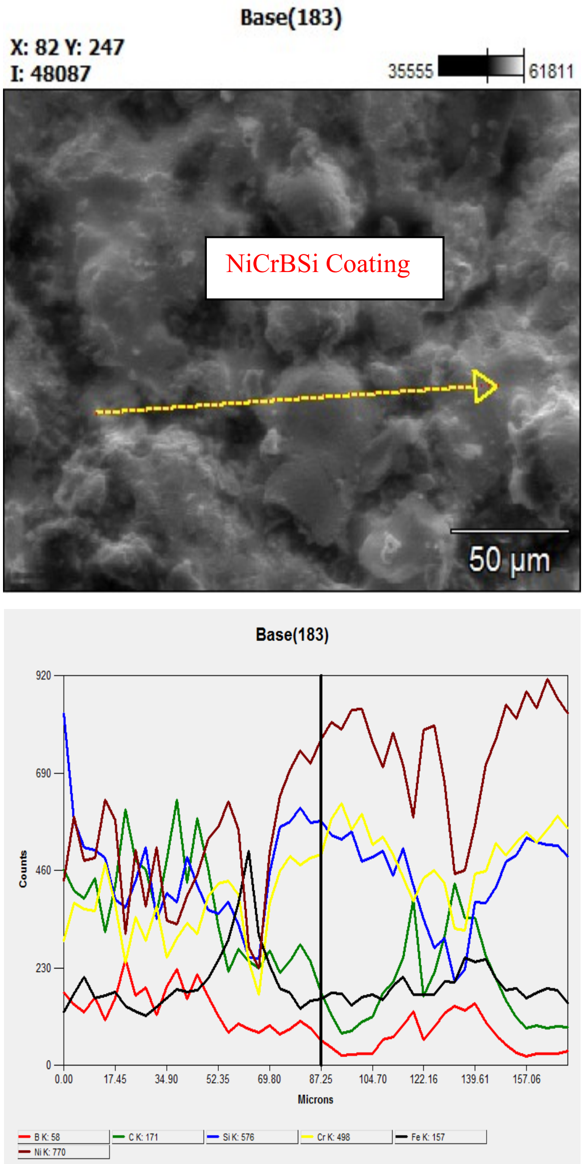
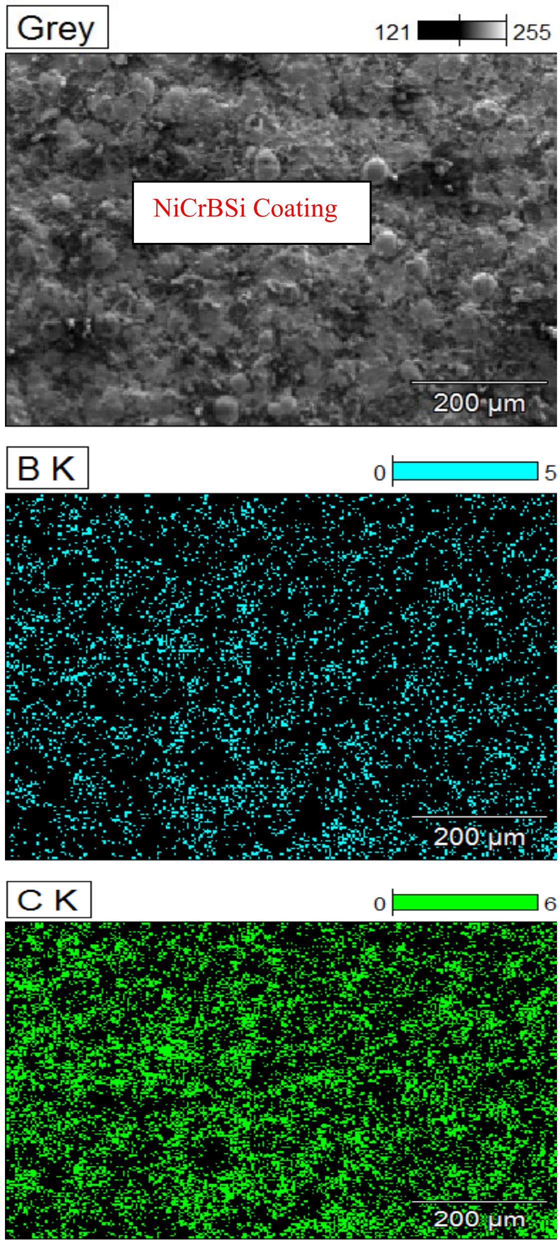
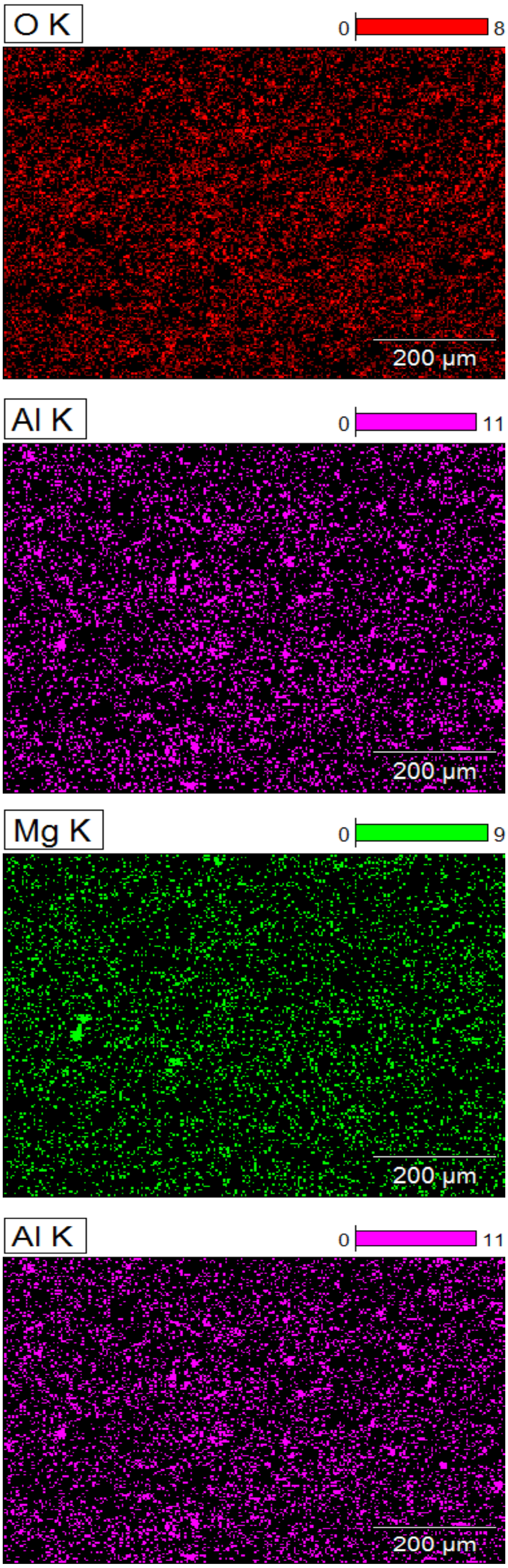


Figure 11 : Quantitative Elemental Analysis of NiCrBSi Coating along the Line





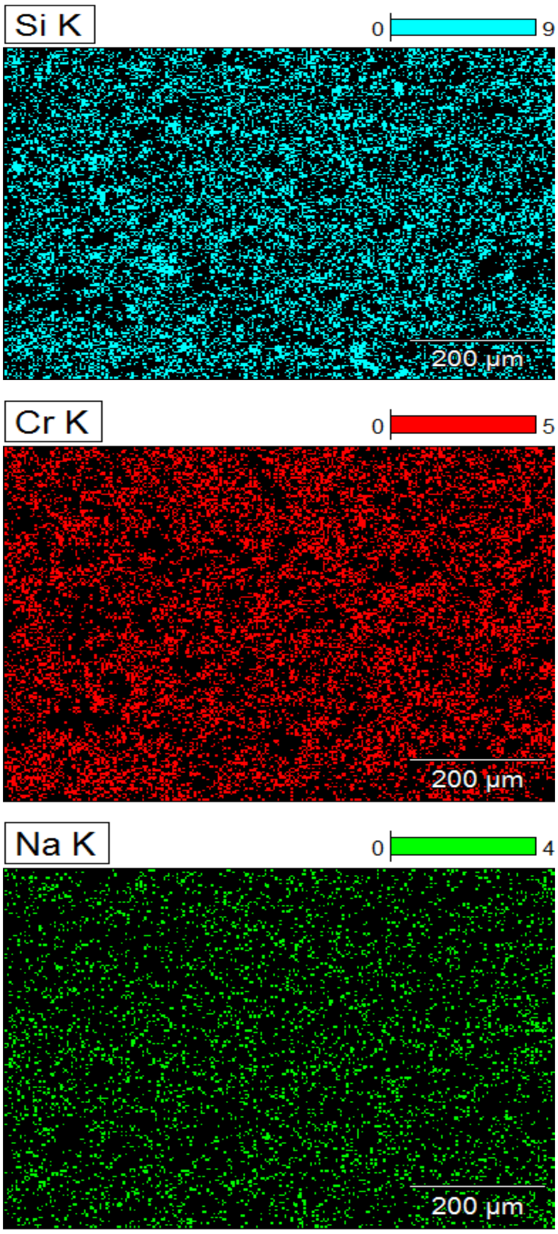


Figure 12 : Elements Image Mapping of the NiCrBSi Coating by EDS

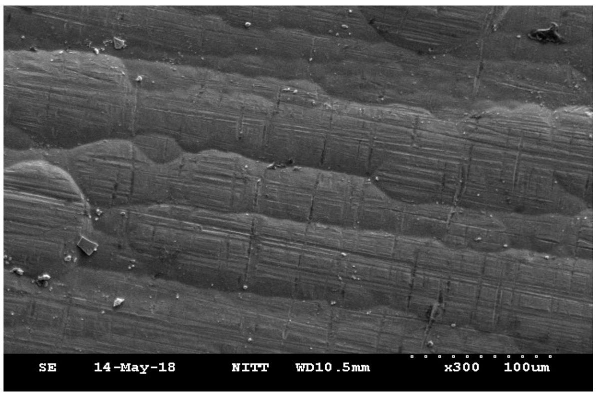


Table 3 : Quantitative Analysis of Elements Present in Hard Chrome Plating at Different Points

	C-K	O-K	Si-K	Cr-K	Fe-K	Nb-L
Base(183) _pt1	0.89	5.58	0.12	90.69	0.56	2.16
Base(183) _pt2	0.84	3.54	0.08	92.81	0.39	2.34
Base(183) _pt3	0.62	5.40	0.08	91.78	0.01	2.11

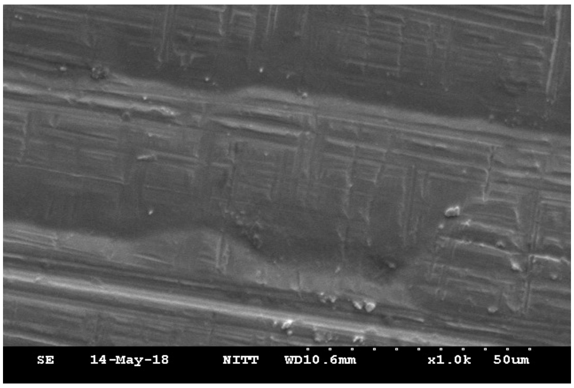
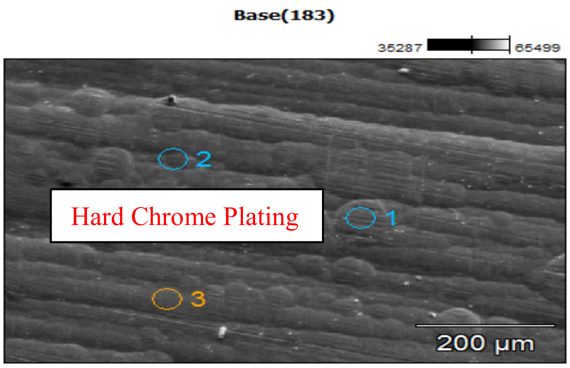
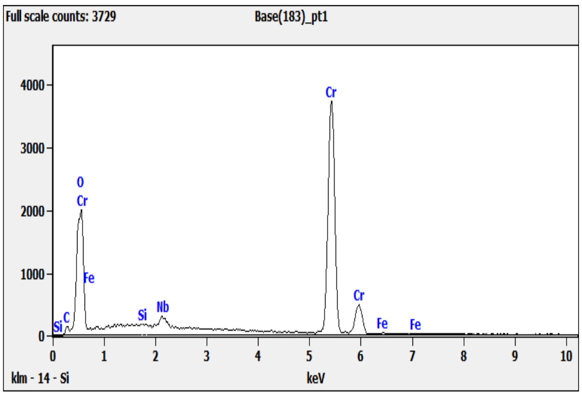
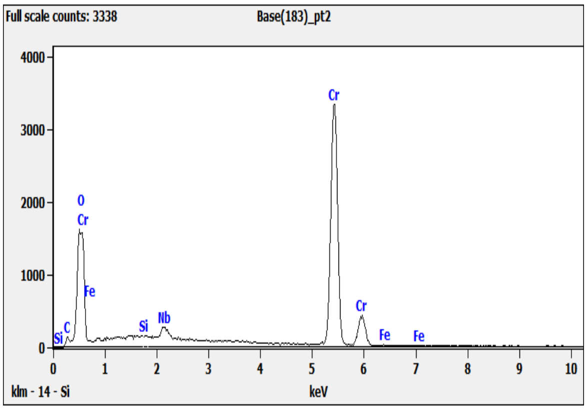


Figure 13 : SEM Morphology of Hard Chrome Plating







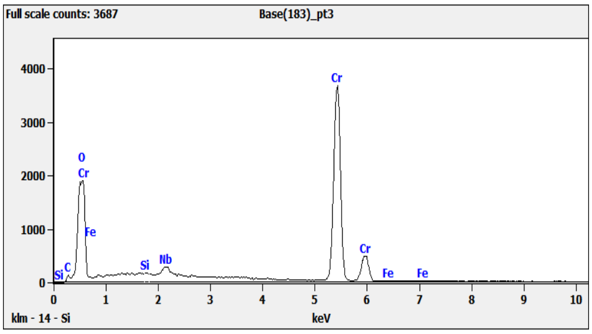
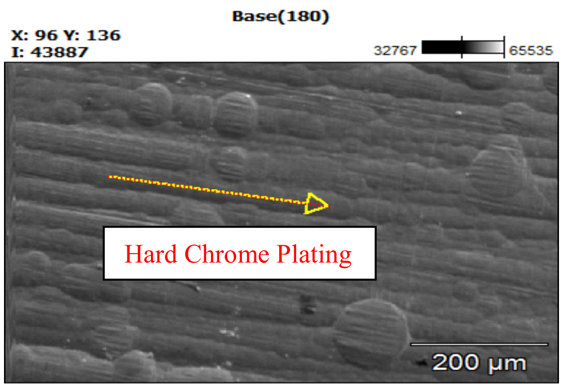


Figure 14 : Quantitative Analysis of Elements Present in Hard Chrome Plating at Different Points



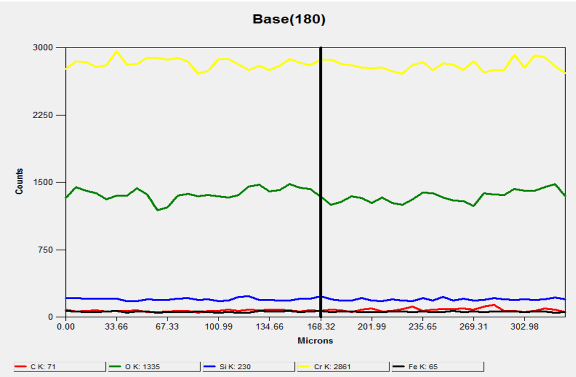


Figure 15 : Quantitative Analysis of Elements Present in Hard Chrome Plating along the line

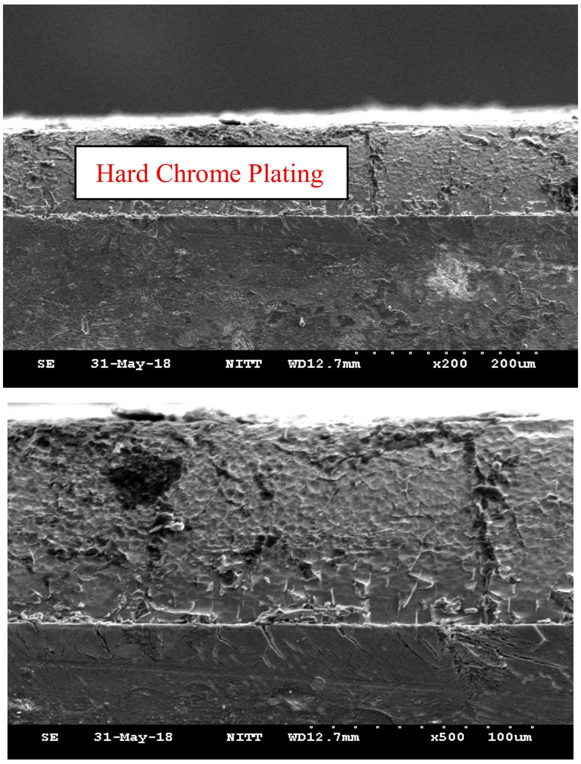
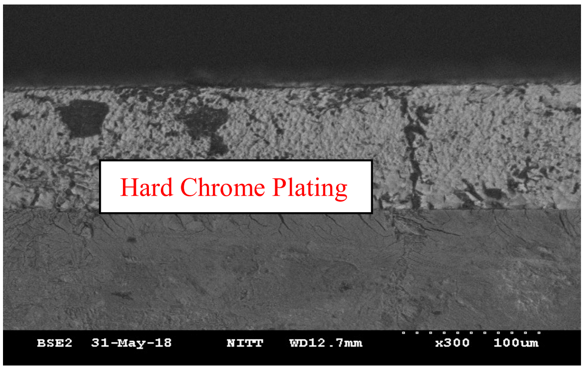


Figure 16 : SEM / SE Images of Hard Chrome Plating across Section



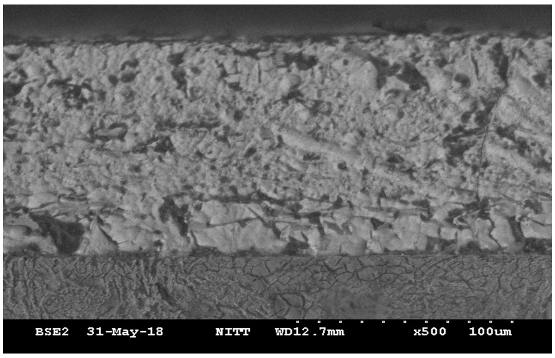
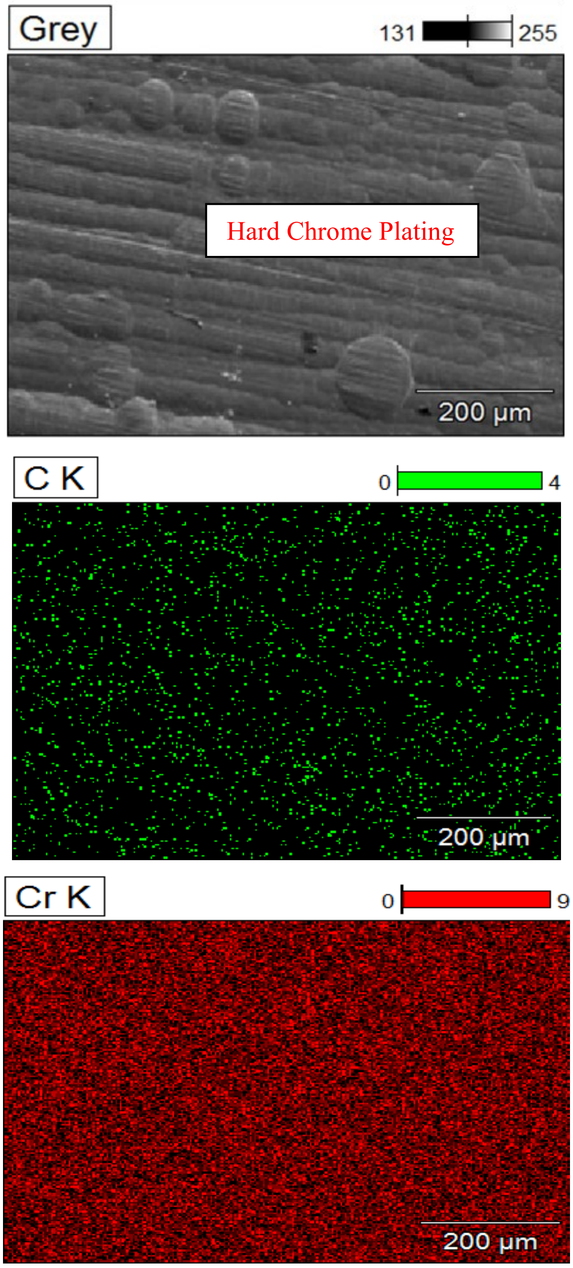


Figure 17 : SEM / BSE Images of Hard Chrome Plating across Section



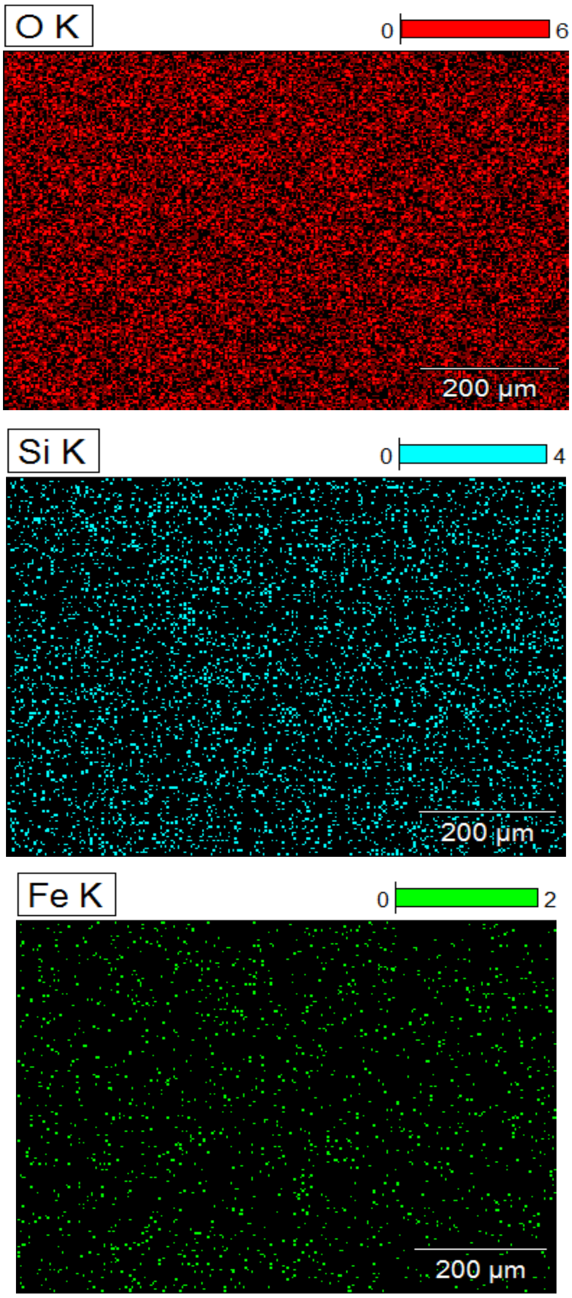


Figure 18 : Elements Image Mapping of the Hard Chrome Plating by EDS

4.4 XRD Study of Cr_3C_2 NiCr75/25 and NiCrBSi Powders and their Coatings and Hard Chrome Plating

X-ray diffraction measurements were done on the coatings and the powders to identify the individual phase composition. The XRD pattern of the HVOF sprayed Cr_3C_2 Nicr75/25 and NiCrBSi powders and their coated samples and the hard chrome plated sample were analysed using Regaku Ultima III.

The XRD pattern of Cr_3C_2 NiCr75/25 and NiCrBSi powders and their coatings, and the hard chrome plating are shown in figure 19. The Cr_3C_2NiCr75/25 coating shows diffused X- ray diffraction patterns with a number of overlapping lines of carbides Cr_3C_2, Cr_7C_3 formed by decarburizing of Cr_3C_2 and binder NiCr. In the XRD pattern CrC / mixed carbides are present in Cr_3C_2NiCr75/25. The XRD analysis of NiCrBSi revealed a number of phases. Both the higher and the lower peaks of Ni and Cr phases in powder can be observed in the X-ray diffraction of the NiCrBSi sprayed deposit. However the magnitudes of the phases in coatings are equal or lower than that of the powder. Similarly, in hard chrome plating, the phase elements like Cr, CrO were present.

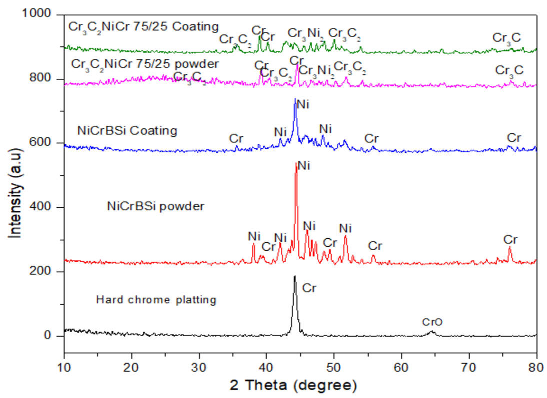


Figure 19 : XRD Pattern of HVOF Sprayed Cr_3C_2 NiCr75/25, NiCrBSi Coatings, Powders and Hard Chrome Plating

4.5 HVOF Coating is an Alternate for Hard Chrome Plating

The consolidated results of the coatings of the present work are given in Table 4. The Table 5 provides the details of similar coatings studied by others. As seen in Table 4, a complete data is not available in line with the evaluation done in this work

Table 4 : Consolidated Results of the Analysis of the Coatings

S. No.	Coating Material	Surface Rough-ness (μ)	Surface Hard-ness (HV0.3)	Co-efficient of Friction	Abra-sion Wear (g)	Slid-ing Wear %	Micro Hard-ness ($HV_{0.3}$)	Poros-ity %	Sur face Fin-ish	Chemical Composition %	XRD Phases
1	Cr_3C_2-NiCr75/25	4.50	544	0.516	0.30	0.032	1105	2.43	4.8	Ni-22, Cr-46, C-12, Fe-8, Si-3 O-7 Al-1,Co-1	Cr_3C_2 Ni, Cr NiC Cr_2C
2	NiCrBSi	5.50	549	0.608	0.27	0.039	756	1.96	5.6	Ni-48, Cr-12, C-14, Fe-10, O-9, Si-4.8,B -0.2,Al-2	Ni, Cr NiCr
3	Hard Chrome Plating	0.15	419	0.300	0.14	0.016	855	0.70	0.17	Ni-0, Cr-93.69, C 0.98 O-5.33	Cr, CrO
4	Uncoated-50CrMo4	1.3	345	0.677	1.30	0.054	367	--	1.4	Ni-0, Cr-1, Fe-82, C-17, Si-0	--

Table 5 : Results of $Cr_3C_2NiCr75/25$, NiCrBSi Coatings and Hard Chrome Plating studied by others

S. No.	Coating Material	Surface Roughness(μ)	Surface Hardness HV10	Coefficient of Friction	Abrasion Wear	Sliding Wear	Micro Hardness HV0.3	Porosity %	XRD Phases
1	Cr_3C_2.20(NiCr)- substrate- Mild Steel Murthy et al.[6]	2.86±0.18	715±20	--	$23x10^{-3}$ CC (0.165g)	--	880±30	1.3±0.6	Cr_3C_2 Ni,Cr Cr_2O_3 Cr_7C_3
2	Cr_3C_2NiCr- Substrate- AlloyT22,Hazoor Singh Sidhu et al.[17]	3.618±0.36	--	--	--	--	840±30	2.5 to 3.5	Cr_3C_2 Ni,Cr NiC Cr_2C
3	Cr_3C_2NiCr-Steel Tahar Sahraoui et al.[2]	8.38±0.61	--	0.23±0.02	--	5*10^-15 m3/mN	854±93	1.47	Cr_3C_2 Cr_3C Cr_3Ni_2 Cr_7C_3
4	Cr_3C_2NiCr-Mild steel Roy et al.[11]	--	--	--	--	--	980	2	--
5	Cr_3C_2NiCr- AISI 316 steel Manjunatha et al.[18]	--	--	--	--	--	621 $HV_{0.1}$	--	Cr_3C_2,Cr NiCr, Cr_3Ni_2
6	NiCrBSi- Substrate Mild Steel Miguel et al.[19]	6.8	--	--	--	0.053 mm^3	819±78	<1	Ni,Ni_3B Cr_7C_3,Cr B
7	NiCrBCSi(Fe)- 60CrMn4 steel Abdi et al. [14]	--	--	0.41	--	--	1090	--	
8	NiCrBSi- Planche et al.[20]	--	--	--	--	--	890±0.63	0.5+	
9	NiCrBSi-APS Substrate C38 Serres et al.[21]	5.2	--	--	--	--	750 $HV_{0.1}$	3.4±0.3	EDS—Fe Ni/Si/
10	Chrome plating OCHN3-MFA steel Maros Martinkovie et al.[22]	--	--	0.71	--	--	820-1120	--	--
11	Chrome plating Substrate Mild steel Pramod Kumar et al.[23]	--	--	--	--	--	1000	--	Cr
12	Chrome Plating- steel Tahar Sahraoui et al.[2]	1.94±0.42	--	023±0.02	--	--	783±51	1.52	--

and their substrates are also different. The HVOF sprayed $Cr_3C_2NiCr75/25$ coatings demonstrated superior performance to NiCrBSi with regard to mechanical and other properties. Considering the factors like lower friction coefficient than the substrate material, clean environment, less production cost and time, less dilution and required hardness, the $Cr_3C_2NiCr75/25$ coating can be used in the place of hard chrome plating.

V. Conclusion

Samples of NiCrBSi and Cr_3C_2NiCr 75/25 HVOF coatings on substrate 50 Cr Mo4 (DIN- 1.7228) alloy steel and hard chrome plated samples were analysed for their elemental composition, phase analysis using SEM and XRD, roughness, hardness, abrasive wear rate, microstructure and porosity.

HVOF coatings have higher volume of carbides dispersed in the matrix than hard chrome plating and hence the micro hardness achieved is slightly higher in HVOF coatings. However, both coatings show higher wear resistant property when compared to the substrate material. Thus the HVOF sprayed $Cr_3C_2NiCr75/25$ coating demonstrated superior performance than the NiCrBSi with regard to mechanical and other properties.

Considering the clean environment, less operation cost and time, less dilution of coating and the required properties like wear resistance, hardness etc., the $Cr_3C_2NiCr75/25$ HVOF spray coating can be preferred in wear resistant application and in that way, it can be considered as an alternative to hard chrome plating.

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