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COMPARATIVE STUDIES ON MECHANICAL PROPERTIES OF NICKEL CHROMIUM CARBIDE (CR_3C_2-NICR) COATED INCONEL 600, 625, 718 SPECIMEN

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Abstract

In this present work, Nickel Chromium Carbide (Cr_3C_2-NiCr) was coated on three Inconel specimen, Inconel 600, 625, 718 and the mechanical and morphological properties of the specimen were investigated by conducting Brinell hardness test and Tensile test experiments respectively. It was found that Inconel 625 has maximum hardness and maximum tensile strength as compared to the remaining two coated Inconel specimen, 600 & 718. The three coated surfaces specimen were analysed by using Scanning Electron Microscope (SEM) and XRD techniques.

Keywords: Brinell hardness, Tensile Test, SEM, XRD, Inconel specimens etc.

1. INTRODUCTION

A coating is a covering that is applied to the surface of an object, usually referred to as the substrate. The purpose of applying the coating may be decorative, functional or both. The coating may be an all-over coating, completely covering the substrate, or it may only cover parts of the substrate. An example of all of these types of coating is a product label on many drinks bottles- one side has an all-over functional coating and the other side has one or more decorative coatings in an appropriate pattern (the printing) to form the words and images. Paints and lacquers are coatings that mostly have dual uses of protecting the substrate and being decorative, although some artist’s paints are only for decoration, and the paint on large industrial pipes is presumably only for the function of preventing corrosion.

For a range of applications, industry has an increasing requirement for sophisticated coatings (aerospace, special machinery, medicine, etc.). Surfaces are coated primarily for ornamental, protective, or utilitarian reasons, though these functions are typically combined. The phrase "functional coatings" refers to systems that have additional functionality in addition to the traditional coating features of protection. This

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supplementary functionality could take many different forms and be dependent on how a coated substrate is actually used. Various techniques can be used to apply functional coatings. One of the most popular techniques for applying thin films and functional coatings on a variety of substrates is chemical vapour deposition.

One of the best ways to protect a material against wear, high-temperature corrosion, tensions, and erosion is through thermal spraying, which also extends the useful life of the material. One method of thermal spraying recognized for producing dense, hard, and wear-resistant micro structured coatings is detonation gun spraying. The application of thick coatings to change the surface properties of the component using thermal spraying is efficient and affordable. Automotive systems, boiler parts, power generation equipment, chemical process equipment, aircraft engines. Detonation Spray (DS) and High Velocity Oxy Fuel (HVOF) spray are the best options among commercially available thermal spray coating processes to obtain hard, thick, and wear-resistant coatings. The present work focuses on developing a corrosion resistant coating for automobile components, Initial trials were carried out on various grades of Nickel based super alloys(Inconel 600,625 and 718) as substrates and Nickel Chromium Carbide as coating materials using D Gun Technique. The Coated test coupons were done Hardness and tensile test and corrosion studies were carried out and Inconel 625 has shown good Hardness, tensile and corrosion resistance compared to other grades. Also morphological studies were carried (SEM /EDS/XRD) which revealed a uniform coating in Inconel 625 Specimens. Also the Inconel 625 coated specimens can be used in automobile industry in making exhaust couplers, Spark plugs etc., due to the excellent hardness and corrosion resistant properties.

Thermal spraying is an effective and low cost method to apply thick coatings to change surface properties of the component. Coatings are used in wide range of applications including automotive systems, boiler components, power generation equipment, chemical process equipment, aircraft engines, pulp and paper processing equipment and ships [1] Among the commercially available thermal spray coating techniques, Detonation Gun Spray and High Velocity Oxy Fuel (HVOF) spray are the best choices to get hard, dense and wear resistant coating as desired [2] Detonation Gun (D-Gun) Spraying is one of the thermal spray processes, which gives an extremely good adhesive strength, low porosity, and coating surface with compressive residual stress [3] Detonation Gun (D-Gun) offers highest velocity (800–1200 m/s) for the sprayed powders that are unattainable by the plasma and HVOF condition. The higher particle velocity during deposition of coating results in desirable characteristics such as lower porosity and higher hardness of the coating [4] Inconel 625 when powder coated with different metallic or non-metallic alloys, the coating resulted in outstanding erosion–corrosion resistance [5]. It was learned from the literature that Inconel 600, 625 and 718 is a widely used engineering material due to its better resistance to hot corrosion, high temperature strength and weld ability [6] Because of its high thermal stability, Cr_3C_2-NiCr coatings are often employed at high temperatures [7, 8] It occurs when solid

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surfaces are in sliding or rolling motion relative to each other. In well-designed tribological systems, the removal of material is usually a very slow process but it is very steady and continuous [9] Wear related failure of machinery components counts as one of the major reasons for inefficient working of machines in a variety of engineering applications [10] Serviceable engineering components not only rely on their bulk material properties but also on the design and characteristics of their surface [11]. Surface engineering can be defined as the branch of science that deals with methods for achieving the desired surface requirements and their behavior in service for engineering components [12] The effect of surfacing on component life and performance will depend upon the surface material, alloy, service conditions and the application process [13] The development of coatings over the years is mainly aimed to improve the corrosion resistance coatings and reduce the coating thickness [14] The objective of metalizing techniques is to place metal on the substrate for appearance or protection of some sort. The classes of metallization are many and complicated, but may be separated by their process details. Processes that apply metal to surfaces may use metal as individual atoms or ions, as the fluid molten metal, or as the solid metal. We deal with each separately [15]

2. EXPERIMENTAL WORK

2.1 Material Used

In the present work, Nickel Chromium Carbide (Cr3C2-NiCr) coated on three different Inconel 600, 625, 718 Specimen are used.

2.2 Coating Thickness

The Coating of Cr_3C_2-NiCr is done on three different Inconel specimens 600, 625, and 718 then the instrument used for measuring thickness of the coatings is Elektro Physik thickness gauge and is shown in Figure 1 and was used to measure the thickness of the coated layer of Cr_3C_2-NiCr for all Inconel specimens. The pointer of the gauge having magnetic sensitivity was pressed against the coated Inconel specimen to measure layer thickness in μm. Digital indicator displayed the value of the thickness in micrometers. The same procedure is repeated for all specimens and the important reason for selecting this coating thickens is to prevent the waterproofing properties, corrosion resistance, and adhesion performance on tricky surfaces.

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Figure 1: Elektro Physik Thickness Gauge

2.3 Hardness Test

Brinell hardness test has been done in accordance with the ASTM E10 standards for three different grade coated (i.e Cr_3C_2-NiCr) specimens 600, 625 & 718. Under Untreated and Heat Treated specimens. By the experiment the indentation is measured and hardness calculated by using formula $BHN = \frac{2P}{\pi D(D-\sqrt{D^2-d^2})}$ here P is applied load in N, D is diameter of indenter in mm and d is diameter of indentation in mm Example BHN= $2*750/\pi*5(5- \sqrt{(5^2-2.4^2)}) = 155.60$ The values of BHN at different loads of all three different grade specimens are listed in Table 1 & 2 and the average of the three specimen of Brinell hardness values are tabulated and are compared. The average hardness of Inconel 625 specimen has been found 272.99 BHN and average BHN of Inconel specimen 600 & 718 has been found 226.56BHN & 209.72BHN respectively, which is lesser than the average hardness of coated Inconel 625 specimen. Hence it is observed that hardness of the coated Inconel 625 specimen is more. This is due to good bonding of Cr_3C_2-NiCr coating. The Brinell hardness testing machine shown in Figure 2.

Figure 2: Brinell hardness Testing Machine

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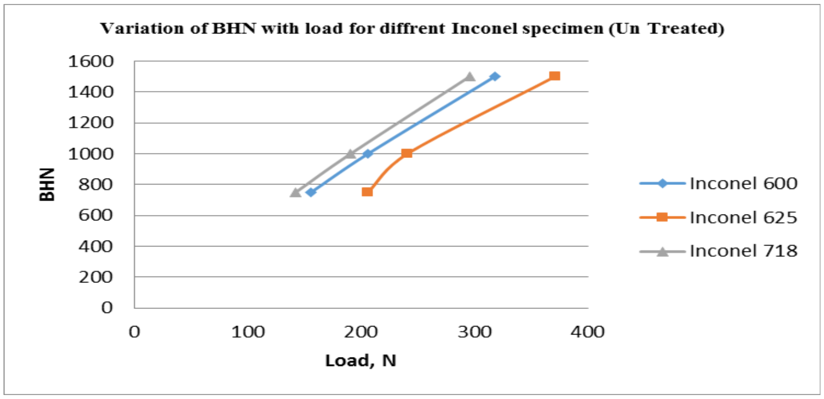
Case: 1: Specimen: Untreated Inconel Steel 600, Inconel Steel 625 & Inconel Steel 718 **Dimensions**: 15mm*20mm*6mm

Table 1: BHN for Untreated Inconel Steel 600, Inconel Steel 625 & Inconel Steel 718

Sl. no	Material	Load P (N)	Diameter of Indenter D (mm)	Diameter Of Indentation d (mm)			Mean d (mm)	Brinell Hardness Number (BHN)	Avg. BHN
				Trail 1	Trial 2	Trial 3			
1	Inconel 600	750	5	2.4	2.4	2.6	2.4	155.60	226.56
2	Inconel 600	1000	5	3	3	2.9	2.9	206.05	
3	Inconel 600	1500	5	3.1	3	3	3	318.04	
4	Inconel 625	750	5	2.1	2.1	2.3	2.1	206.52	**272.99**
5	Inconel 625	1000	5	2.7	2.7	2.8	2.8	241.28	
6	Inconel 625	1500	5	2.9	2.7	2.8	2.7	371.18	
7	Inconel 718	750	5	2.6	2.5	2.7	2.6	142.62	209.72
8	Inconel 718	1000	5	3.1	3	3	3	190.98	
9	Inconel 718	1500	5	3.2	3.2	3.1	3.2	295.56	

Figure 3: Variation of BHN with load for different Inconel specimen (Un Treated)



Case: 2: Specimen: Heat Treated Inconel Steel 600, Inconel Steel 625 & Inconel Steel 718 Coated with Nickel Chromium Carbide **Dimensions**: 15mm*20mm*6mm

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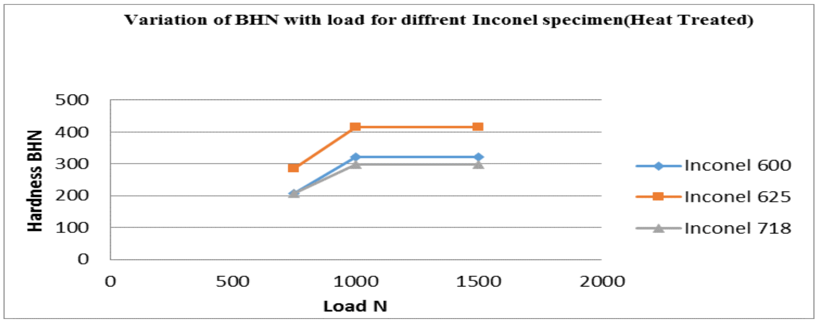
Table 2: BHN for Heat treated Inconel Steel 600, Inconel Steel 625 & Inconel Steel 718

Sl. no	Material	Load P (N)	Diameter of Indenter D (mm)	Diameter of Indentation d (mm)			Mean d (mm)	Brinell Hardness Number (BHN)	Avg. BHN
				Trail 1	Trial 2	Trial 3			
1	Inconel 600	750	5	2.8	3	2.9	2.9	206.40	283.21
2	Inconel 600	1000	5	2.7	2.8	2.8	2.7	321.65	
3	Inconel 600	1500	5	2.7	2.7	2.7	2.7	321.60	
4	Inconel 625	750	5	2.5	2.5	2.6	2.5	285.10	**371.67**
5	Inconel 625	1000	5	2.4	2.4	2.6	2.4	414.96	
6	Inconel 625	1500	5	2.4	2.4	2.6	2.4	414.95	
7	Inconel 718	750	5	2.8	3	2.8	2.8	206.38	266.75
8	Inconel 718	1000	5	2.8	2.9	2.8	2.8	296.95	
9	Inconel 718	1500	5	2.8	2.8	2.8	2.8	296.94	

Figure 4: Variation of BHN with load for different Inconel specimen (Heat Treated)



2.4 Comparison of Hardness of uncoated and coated Inconel Substrates

Based on the graph comparison of the Brinell hardness number for the three different Inconel specimens 600, 625, and 718 Untreated and heat treated with Nickel Chromium Carbide. The highest hardness of BHN has been observed from Inconel 625 coated substrate as shown in figure5.

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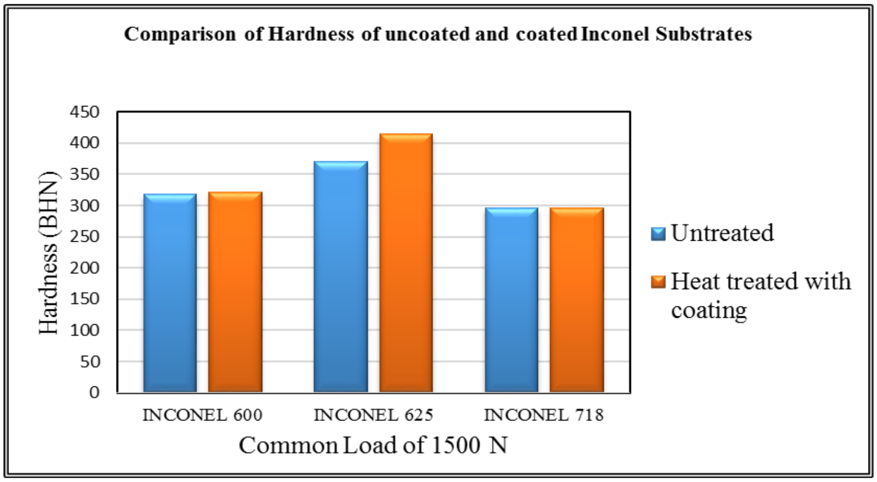
Figure 5: Comparison of Hardness of uncoated and coated Inconel Substrates



2.5 Tensile Strength

Tensile tests to examine coating strength were conducted using UTM (Universal Testing Machine) as shown in Figure 6. In this experiment a 10 Ton capacity UTM machine is used and as per ASTM E8:2016 standards and ISO 6892-1:2016 the specimen dimension is length 95mm, height 20mm and the Coating thickness 25 to 30μm was held by the supporting grippers and tightened firmly. Speed of testing was set to 5mm/min. and experiment was done on three different Inconel coated specimen 600, 625 and 718 grades and tensile strength values are noted at different loading rate and tabulated and showed in table 3 among three grades Inconel 625 specimen achieved maximum tensile strength as compared to remaining Inconel specimen 600 & 718. & Table 3 gives the tensile strength of Cr_3C_2 – NiCr coated Inconel substrates.

Figure 6: Universal Testing Machine

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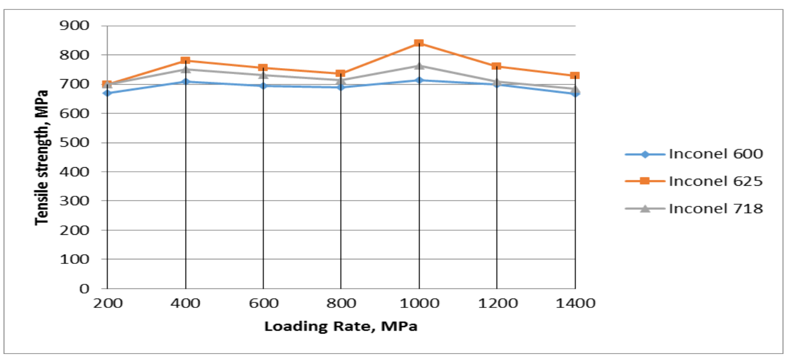
Table 3: UTS Vs loading rate mm/min loading rates tested at room temperature (30°C)

Expt. No	Inconel	Loading Rate (mm/min)	Tensile Strength MPa)
1	Inconel 600	200	670
2		400	708
3		600	695
4		800	688
5		1000	714
6		1200	700
7		1400	667
1	Inconel 625	200	700
2		400	780
3		600	755
4		800	735
5		1000	**840**
6		1200	760
7		1400	728
1	Inconel 718	200	700
2		400	750
3		600	730
4		800	715
5		1000	762
6		1200	710
7		1400	685

Figure 7 Comparison of Tensile Strength of Coated Inconel Substrates



3. RESULTS AND DISCUSSIONS

3.1 Micro Structure Characterization

Scanning Electron Microscope (SEM) Figure 8 was used to obtain the morphology of the surface of the coatings. SEM is a dynamic tool, which can generate highly magnified images with resolution down to about 2nm. The coated specimens were trimmed to the appropriate size of 1cm x 1cm to ensure the correct mounting on the SEM stub and

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then the specimen were washed thoroughly with acetone to get rid of loosely adsorbed particles.

Figure 8 Hitachi SU-1500 – SEM

Scanning Electron Microscopy provides a direct structural evidence of the growth and perfection of the film. This is one of the most useful methods for the investigation of the surface topography, micro structural feature etc. It is based upon the fact that the electrons are absorbed or diffracted homogeneities and thus reveals these in homogeneities as contrast effect. The secondary electrons are generated by the interaction of loosely bound electrons of the surface atoms. The emission of secondary electrons is sensitive to the incident beam direction and the topography of the surface layer. The contrast hence depends on the rate of secondary electron yields and the incident angle of primary beam to the surface being examined. The specimen were tested at BMSCE, Bengaluru and Coating cross-sectional details were also studied using SEM.

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Figure 9: SEM images of corroded coated Inconel 600 specimens

SEM: Inconel 600

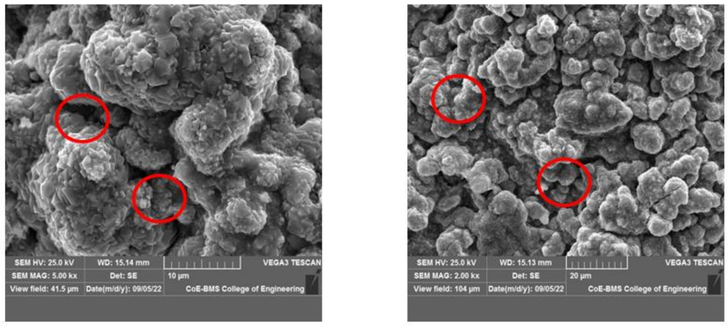

Figure 10: SEM images of corroded coated Inconel 625 specimens

SEM: Inconel 625

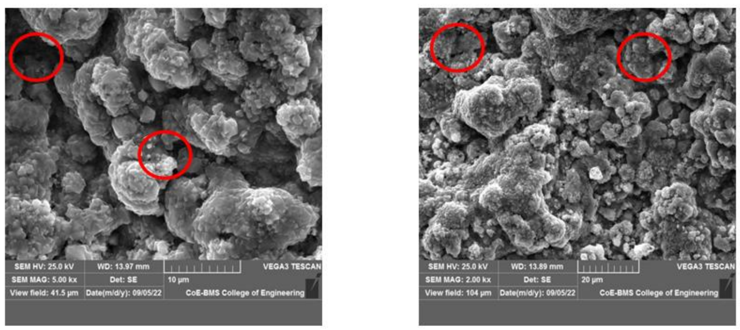

Figure 11: SEM images of corroded coated Inconel 718 specimens

SEM: Inconel 718

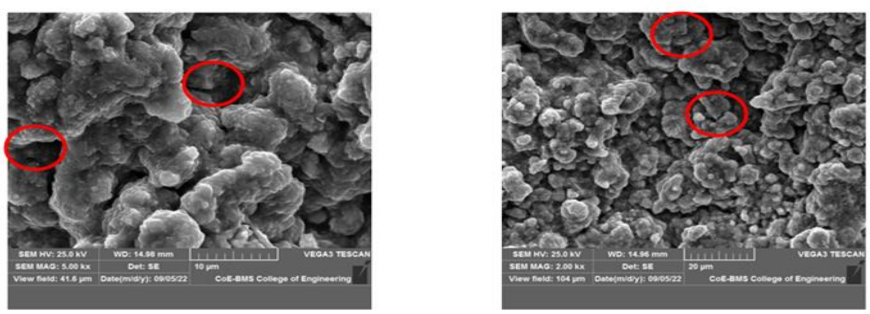

Figure 9, 10 and 11 shows the SEM images of corroded Cr_3C_2–NiCr coated Inconel 600, 625 and 718 specimens. The corrosion product region exhibited faceted grains while the attacked region exhibited porous morphology. The corrosive action of the salt is clearly in seen all the images. The chromium depletion can occur by the formation of chromium compound at the surface and by the subsequent removal of chromium from the substrate, leaving depleted regions forming deep voids. More depletion and voids are found in Inconel 600 and 718 specimens compared to Inconel 625, owing to less corrosion in Inconel 625 coated substrates compared to other substrates. This indicates that Inconel 625 is potential material for automobile applications. Inconel specimens

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exhibit a uniform splat like microstructure, with splats oriented parallel to the substrate surface. The coating/oxide scale was intact with the surface of substrate which provides a necessary protection against corrosive species. From the SEM images it is observed that the coating has formed a continuous and homogeneous bond with the substrate. The microstructure indicates uniform and dense coating. The coating contains some UN melted and semi melted particles.

3.2 Energy-Dispersive X-Ray (EDAX) Analysis

EDAX is a technique used for finding or measuring the nano particles by SEM. & this analysis of the corroded coated Inconel substrates indicated preferential outward diffusion of elements during salt corrosion. Cross section SEM and EDAX analysis of scales and exposed samples also indicated that the mechanism of corrosion is due to selective outward diffusion of Cr and Ni and formation of Cr and Ni rich layers and subsequent spallation. EDAX analysis confirms the presence of Ni and Cr as the main elements in Cr3C2 – NiCr coatings

Figure 12: EDAX image of Inconel coated substrates 600

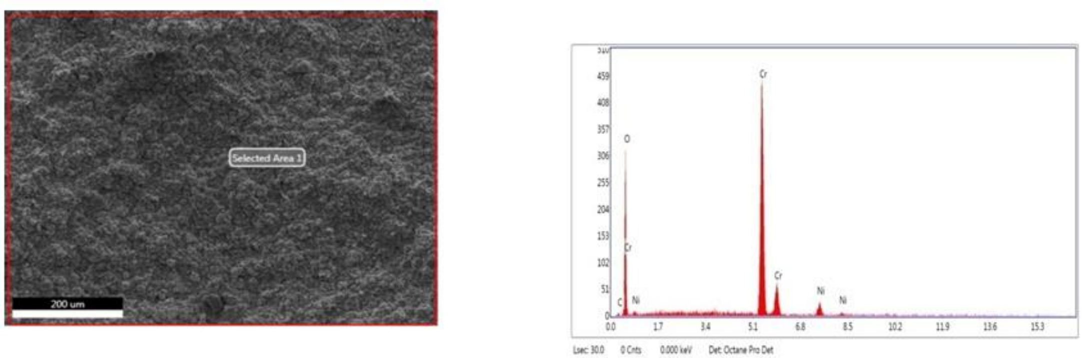

Figure 13: EDAX image of Inconel coated substrates 625

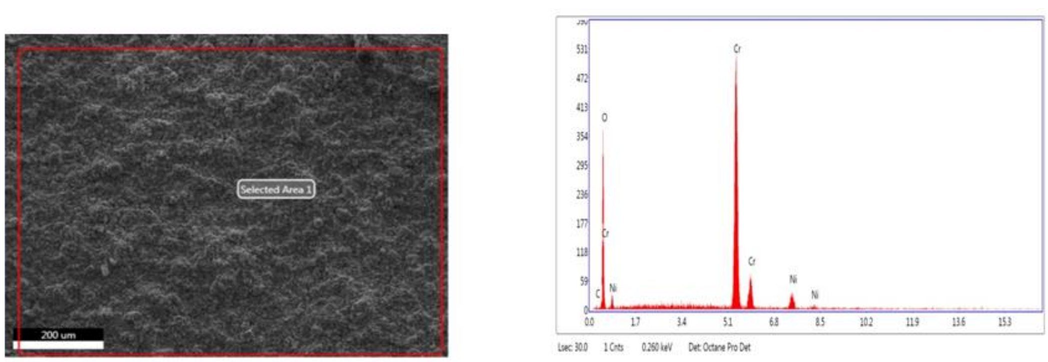

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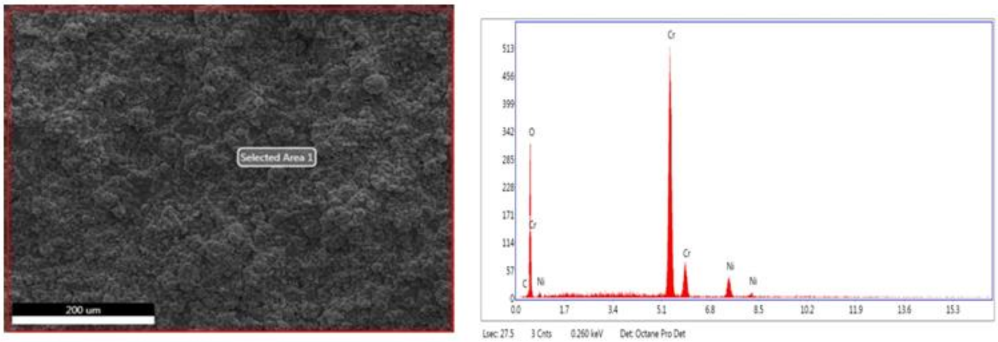
Figure 14: EDAX image of Inconel coated substrates 718



3.3 XRD Analysis

The chemical composition and crystalline orientation of the Ni-WC were examined by applying X-ray diffraction (XRD) technique using JEOL JDX-8030 X-ray diffraction meter system Figure 15 the coated specimens were trimmed to approximately 1cm x 2cm and then the loosely adsorbed particles were removed by cleaning with acetone. The prepared specimens were subjected to the X-rays (Cu Kα radiation) generated from the copper target. The intensity of the reflected X-rays was recorded, as the sample and detector were rotated. The diffracted X-rays intensity was evaluated as a function of the specimen's orientation and the diffraction angle 2θ. The obtained diffraction patterns were checked for position, width and intensity of the peaks for the analysis.

Figure 15: Panalytical X'Pertx-ray diffracto meter

X-ray diffraction (XRD) is a rapid analytical technique primarily used for phase identification of a crystalline material and can provide information on unit cell dimensions. The analysed material is finely ground, homogenized, and average bulk composition is determined. X-ray pattern of the Inconel coating after corrosion are depicted in Fig 16 as can be seen in this figure, besides the compositions, which were also presented in the structure of coating before corrosion, two new oxide phases were

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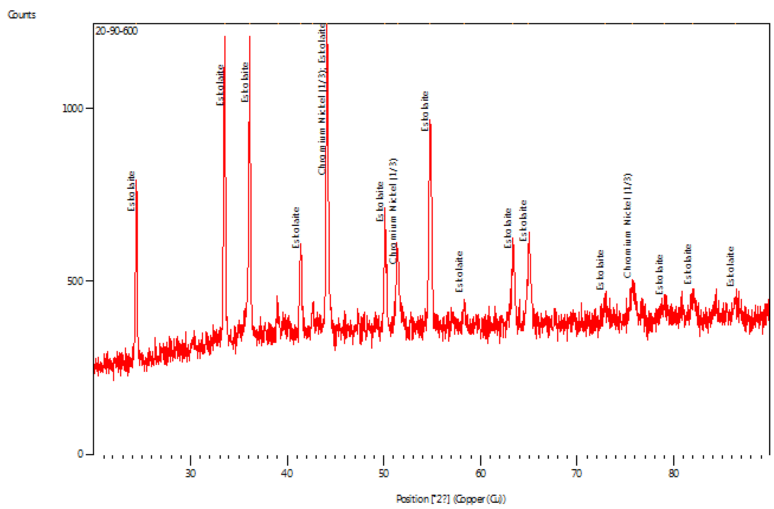
detected after corrosion formation. The main peaks of the new oxide phases attributed to chromium nickel and chromium oxide (Cr_2O_3)

Figure 16: X-Ray pattern of Cr_3C_2 – NiCr coated Inconel substrates



4. CONCLUSIONS

It is concluded that through Hardness test and Tensile Test the **Inconel 625** material exhibited a promising physical, good resistance and structural properties. Also, the bonding of Nickel Chromium Carbide coating to the Inconel 625 was in a strong and effective bonding phase when exposed under X-Ray Diffraction and Scanning Electron Microscope (SEM). Hence it is concluded that the specimen **INCONEL 625** is a promising Metal that has strength to withstand many physical, chemical, and structural tests and can be widely used in many Industries. The applications of the coated material can be widely used in Industrial factories, Thermal Furnaces, Boiler applications, Internal Combustion Engine parts and many other high end Automobiles and various Industrial uses etc.

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