Comparative Studies on Mechanical Properties and Corrosion Rate of Nickel Chromium Carbide (Cr3C2-NiCr) Coated on Inconel 600, 625, 718 Specimen

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Abstract

In this present work, Nickel Chromium Carbide (Cr3C2-NiCr) coated on three different Inconel 600, 625, 718 Specimen are used and the mechanical properties, corrosion resistance and morphological properties of the specimen were investigated by conducting Brinell hardness test, Vickers Hardness Test, Tensile test and electrochemical test experiments respectively and found that Inconel 625 has maximum hardness, maximum tensile strength and less corrosion resistance as compared to the remaining two coated Inconel specimen 600 & 718. And then coated surfaces of Inconel 600, 625 and 718 specimens were analyzed by using Scanning Electron Microscope (SEM), XRD, EDAX and optical microstructure techniques.

Keywords: *Brinell hardness, VHN, Tensile Test, SEM, XRD, EDAX Inconel specimens.*

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 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 vapor 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, Cr3C2- NiCr coatings are often employed at high temperatures [7, 8]. It occurs when solid 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 as individual atoms or ions, as the fluid molten metal or as the solid metal and deal with each separately [15].

2. Experimental Work

2.1 Coating Thickness

Nickel Chromium Carbide (Cr_3C_2-NiCr) coated on three different Inconel 600, 625 and 718 Specimen are used. Coating thickness refers to the measurement of the thickness of a thin layer of material, known as a coating, applied to a substrate or surface. Coatings are applied to various objects and structures for a multitude of reasons, such as protection, decoration, functional enhancement, and more. It is essential to determine and control the thickness of the coating to ensure its effectiveness and proper performance in specific applications.

The coating thickness is typically expressed in units of length, such as micrometers (µm).

The Instrument Mini Test-650 used to measure coating thickness is made by Elektro Physik and is depicted in Figure 1 for all specimens; the coated layer of Cr3C2-NiCr was measured at a thickness range of 0 to 2000 µm. To measure layer thickness, the specimen was placed up against the magnetically sensitive gauge's pointer. The thickness in micrometers was shown on a digital indicator. For each specimen, the same steps are repeated.

Table 1 Specification of Mini Test-650 ElektroPhysik

The smallest measurement area	20mm
Sample Thickness Minimum	0.05 mm
Model Name / Number	MiniTest 650
Resolution	0.1 um
Measuring Range	0 - 2000 um
Accuracy	1 % of reading
Power Source	3 x 1.5V AA batteries

Fig.1 Mini Test-650 Elektro Physik Thickness Gauge

2.2 Brinell Hardness Test

A standard technique for assessing a material's hardness is the Brinell hardness test. The Brinell hardness test involves indenting a hard steel or tungsten carbide ball into the surface of the material being tested. The diameter of the ball and the applied force are standardized. The hardness of the material is determined by measuring the diameter of the indentation left on the surface after the removal of the load. It helps determine if the coating has the required hardness to withstand wear, abrasion, and other mechanical stresses in real-world applications.

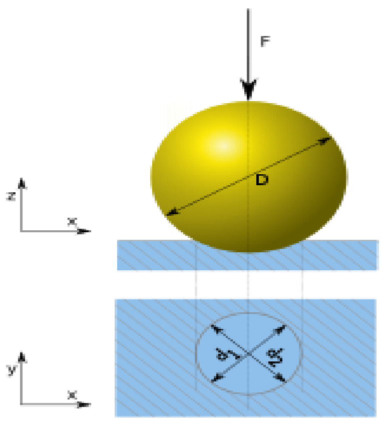


Fig.2 Brinell Indentation

Fig.3 Brinell hardness Tester

Brinell Scale: The Brinell scale is a hardness testing method used to measure the hardness of metallic materials. The Brinell hardness is determined by measuring the diameter of the impression made by a spherical indenter on the surface of the material under a specific load. The Brinell scale determines the indentation hardness of materials by measuring the depth of penetration of an indenter placed onto a material test piece and is one of many scientific definitions of hardness. In engineering and metallurgy, it was the first commonly used hardness test that was also standardized. And It was created in 1900 by Swedish engineer Johan August Brinell. The size of the indentation and any possible harm to the test component limit its effectiveness. However, it also possessed the helpful property of calculating the approximate UTS in ksi for steels by dividing the hardness value by two. This characteristic helped it gain early popularity.Using a typical Brinell hardness testing machine, the specimen's hardness was determined and Brinell hardness machine shown in Figure 3 the hardness tests done with ASTM E10 standards. diameter specimen is 20 mm and a thickness of 6 mm were subjected to a load of 250 Kg for 30 seconds using an indenter ball with a diameter of 5 mm. Six readings were collected, two at each of the periphery, middle, and center, in order to reduce the mistake caused by the segregation effect of the particles.

2.3 Tensile Test

Tensile measurement for coatings is a testing method used to evaluate the adhesion and mechanical properties of coatings applied to substrates. Coating is applied to the surface of materials to enhance their properties, protect against corrosion, improve aesthetics, or provide specific functionalities. Tensile testing of coatings is crucial to ensure their performance and reliability in real-world applications.

Tensile testing of coatings helps determine their ability to adhere to the substrate and withstand mechanical stresses without delaminating or cracking. It is an essential part of quality control during the coating application process and is also used for research and development to optimize coating formulations for specific applications.

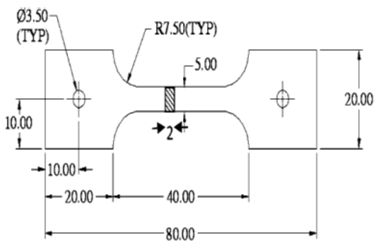


Fig.4 Universal Testing machine   Fig.5 Tensile Specimen size   Fig.6 Fractured tensile specimens

Tensile strength testing for coatings is typically conducted using a standard tensile testing machine, which applies a gradual and controlled pulling force to a prepared test specimen. The specimen is usually in the form of a strip or dog bone shape, with the coating covering the central section. During the test, the machine measures the applied force and the resulting deformation (strain) of the specimen. The cross-sectional area of the coating can be determined from the dimensions of the test specimen. A high tensile strength indicates that the coating has excellent adhesion to the substrate and is less likely to fail or delaminate under tensile loads. On the other hand, a low tensile strength may indicate poor adhesion or a weak bond between the coating and the substrate, which can lead to coating failures in real-world applications.

2.4 Vickers Hardness Test

A substance's hardness is determined by its capacity to withstand repeated deformation caused by events like indentation, wear, abrasion, and scrape. Because of the connection between hardness and other material qualities, hardness testing is crucial. A metal's resistance to plastic flow, as determined by the hardness test and the tensile test, may, for instance, yield findings that are quite comparable. Because it is simple, straightforward, and essentially destructive-free, the hardness test is chosen. Today, a variety of hardness tests are in use.

The two types of hardness testing are now known as macro hardness and micro hardness. The phrase "macro hardness testing" describes tests with applied loads on the indenter of more than 1 kg, such as tests of tools, dies, and sheet material in the heavier categories. The material being examined in micro hardness tests is very thin (down to 0.0125 mm, or 0.0005 in.) with applied stresses of 1 kg or less. Applications include plated surfaces, incredibly small parts, thin, superficially hardened sections, and individual material components.

The Vickers hardness test method is conducted (Figure 9) and It is frequently used for small components, thin sections, case depth work, etc. It is also referred to as a micro hardness test method. In this experiment material used is Cr3C2-NiCr coated Inconel 600, 625 and 718 used. The purpose of conducting this test is to know the hardness strength of all three Inconel coated specimen. The Vickers indenter is a diamond pyramid with a 1360 square base. This procedure is more Accurate because the Vickers indenter produces a clearer impression than the Brinell indenter.

2.5 Electrochemical Corrosion Test

Electrochemical corrosion test is carried out (CHI660E serial -|1318 US model) on coated Nickel chromium carbide (Cr3C2NiCr) of Inconel 600, 625 and 718 specimens at room temperature to understand corrosion rate of all three coated materials. Figure 7 shows the electro chemical test setup.

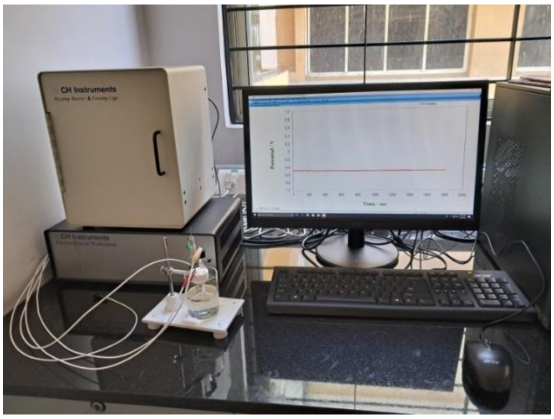


Fig.7 Electrochemical Corrosion test setup

2.6 Morphology Study

Figure 9 shows the use of a scanning electron microscope (SEM) to determine the morphology of the coating surface. 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 then the specimens were washed thoroughly with acetone to get rid of loosely absorbed particles. The specimens were tested and coating cross-sectional details were also studied using SEM.

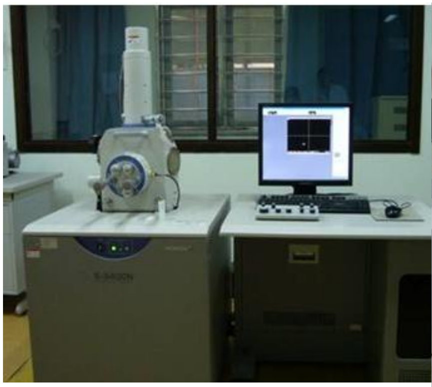


Fig.8 Hitachi SU-1500 – SEM

Fig.9 Panalytical X'Pertx-ray diffract meter

2.7 EDAX (Energy Dispersive X-Ray Spectroscopy) Studies

The analytical method known as EDAX (Energy Dispersive X-ray Spectroscopy) is employed in the field of materials science and other disciplines to ascertain the elemental makeup of a sample. It is frequently used in conjunction with scanning electron microscopy (SEM) to offer thorough details regarding the chemical composition of a material at the microscale or nanoscale level. X-ray energy dispersive spectroscopy was utilized to assess the implanted reinforcement particles (EDAX). Figure 8 shows the EDAX which is integrated with SEM. The chemical analysis capability of EDX enables to process range of metals and materials. Before being examined with a SEM, the specimens were gold sputtered to improve the coating conductivity.

2.8 XRD Studies

XRD stands for X-ray Diffraction, and XRD studies refer to the application of X-ray diffraction techniques in materials science and various scientific fields. X-ray diffraction is a powerful analytical method used to determine the crystallographic structure and phase composition of materials. Applying X-ray diffraction (XRD) with the JEOL JDX-8030 X-ray diffraction meter methodology, the chemical composition and crystallographic orientation of the coated specimen were studied. (Figure 8) the coated specimens were trimmed to approximately 1cm x 2cm and then the loosely absorbed particles were removed by cleaning with acetone. The prepared specimens were subjected to the X-rays generated from the specimen and detector rotated the strength of the reflected X-rays was measured. 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.

3. Results and Discussions

3.1 Coating Thickness Measurement

Using an electrophysik gauge, the coating thickness on the specimen was determined. To calculate the thickness along the Z-axis, a set of fixed reference coordinates were employed along the X and Y axes. The naming X, Y, and Z stand for the width, length, and thickness of the specimen respectively. The electrophysik gauge variation in coating thickness for Inconel 600, 625, and 718 is shown in the table below. To determine the precise thickness, two readings were made on the coated Inconel as showed in Table 2.

Table 2 Coating thickness on Inconel substrates

Position	**Coating thickness in μm**		
	Inconel 600	Inconel 625	Inconel 718
1	61.21	67.82	60.78
2	61.47	68.12	60.90
Average	61.34	67.97	60.84

3.2 Brinell Hardness Test

Test 1: Specimen: Untreated Inconel 600, 625 and 718 (**Dimensions**: 15mm*20mm*6mm)

Sl. no	**Specimen**	**Load P (N)**	**Indenter Diameter D (mm)**	**Indentation Diameter 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

		1000	5	3	3	2.9	2.9	206.05	
		1500	5	3.1	3	3	3	318.04	
2	Inconel 625	750	5	2.1	2.1	2.3	2.1	206.52	**272.99**
		1000	5	2.7	2.7	2.8	2.8	241.28	
		1500	5	2.9	2.7	2.8	2.7	371.18	
3	Inconel 718	750	5	2.6	2.5	2.7	2.6	142.62	209.72
		1000	5	3.1	3	3	3	190.98	
		1500	5	3.2	3.2	3.1	3.2	295.56	

Table 3 BHN for Untreated Inconel 600, 625 and 718

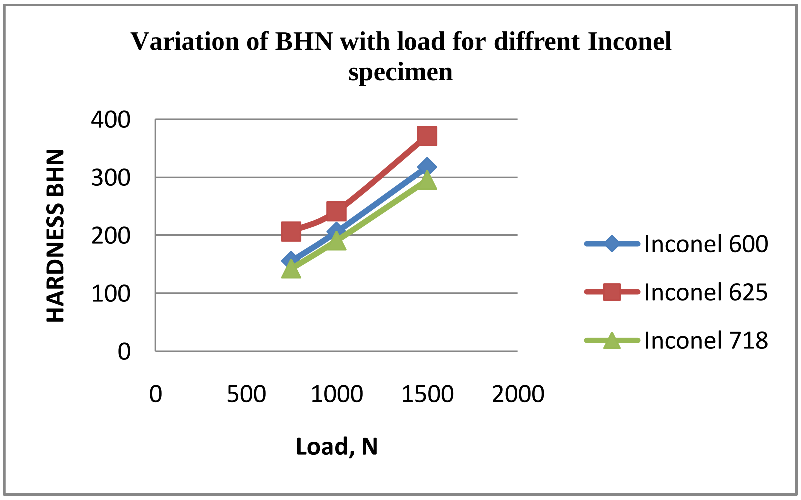


Fig.11 Variation of BHN with load for different Inconel specimen (Un Treated)

Figure 11 shows that, after conducting heat treatment process on uncoated Inconel specimen 600, 625 and 718 the highest average BHN (272.99) has been observed from Inconel specimen 625 as compared to Inconel 600 and 718 specimens.

Test 2: Specimen: Heat Treated Inconel 600, 625 and 718 (**Dimensions**: 15mm*20mm*6mm)

Table 4 BHN for Heat treated Inconel 600, 625 and 718

Sl. no	**Specimen**	**Load P (N)**	**Indenter Diameter D (mm)**	**Indentation Diameter 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
		1000	5	2.7	2.8	2.8	2.7	321.65	
		1500	5	2.7	2.7	2.7	2.7	321.60	
2	Inconel 625	750	5	2.5	2.5	2.6	2.5	285.10	**371.67**

		1000	5	2.4	2.4	2.6	2.4	414.96	
		1500	5	2.4	2.4	2.6	2.4	414.95	
3	Inconel 718	750	5	2.8	3	2.8	2.8	206.38	266.75
		1000	5	2.8	2.9	2.8	2.8	296.95	
		1500	5	2.8	2.8	2.8	2.8	296.94	

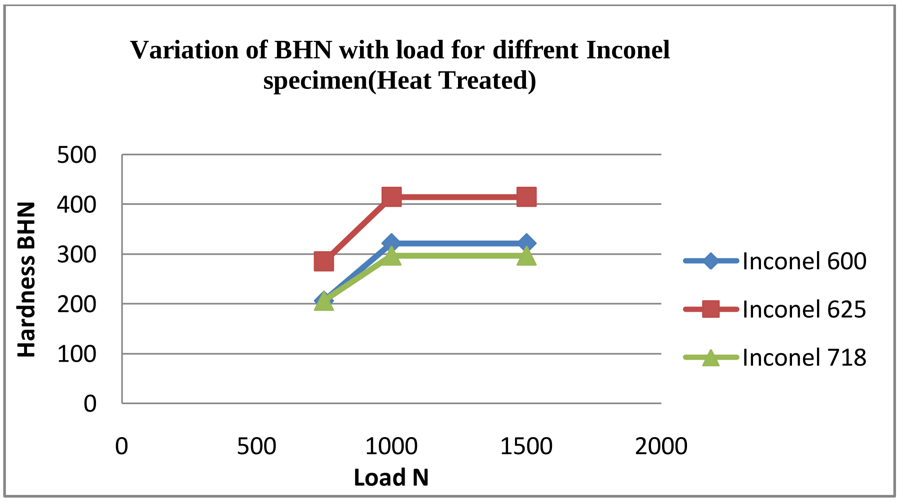


Fig.12 Variation of BHN with load for different Inconel specimen (Heat Treated)

Figure 12 shows that, after conducting heat treatment process on coated Inconel specimen 600, 625 and 718 the highest average BHN (371.67) has been observed from Inconel specimen 625 as compared to Inconel 600 and 718 specimens.

3.3 Comparison of Hardness of uncoated and coated Inconel Substrates

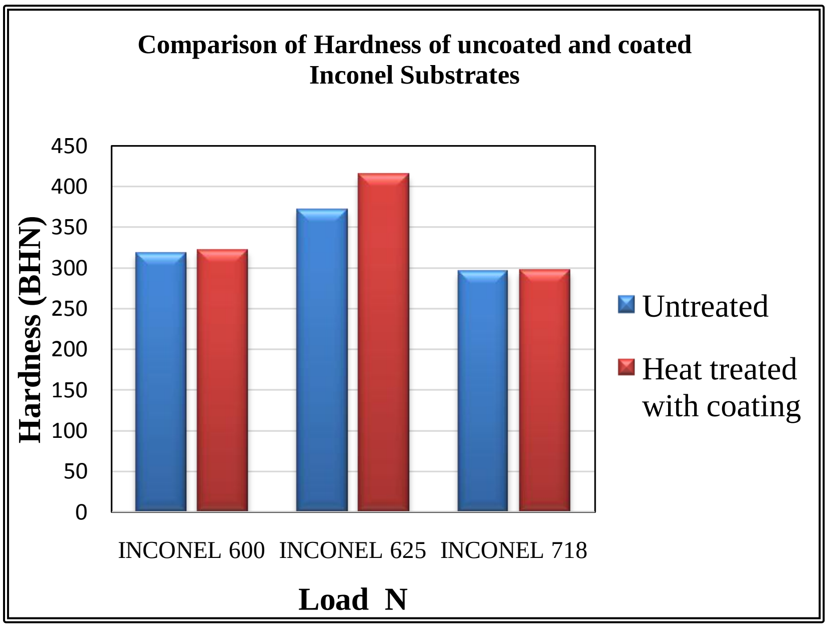


Fig.13 Comparison of Hardness of uncoated and coated Inconel Substrates under common load of 1500 N

The hardness of uncoated and coated Inconel substrates can vary significantly depending on the type of coating, its thickness, and the specific coating process used. Based on the graph comparison of the Brinell hardness number for the 600, 625, and 718, three distinct Inconel specimens Untreated and heat treated with Nickel Chromium Carbide. The highest hardness of BHN has been observed from Inconel 625 coated substrate as shown in figure 13.

3.4 Tensile Strength

Table 5 show the Tensile strength of coated Inconel 600, 625 and 718 specimens for different loading rate and details given Table 5.

Table 5 UTS versus 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

Tensile strength is an important mechanical property that characterizes the ability of a material to resist breaking under tensile (pulling) forces. It is a crucial parameter in engineering design and material selection, especially for materials like Inconel 600, 625, and 718, which are known for their high strength and excellent mechanical properties at elevated temperatures. From Table 5 it is observed that the maximum tensile strength and highest

UTS were displayed by coated Inconel 625 which measured 840MPa (experiment 5 for Inconel 625) and found less strength for Inconel 600 and 718. From figure 14 it is observed that Inconel 625 specimen has achieved high strength compared to remaining two Inconel specimens 600 and 718.

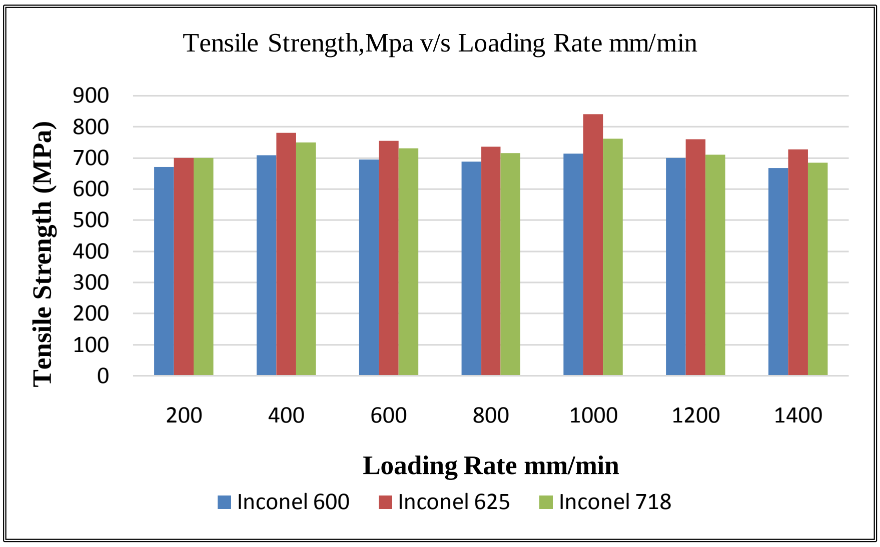


Fig.14 Tensile Strength, MPa v/s Loading Rate mm/min

3.5 Vickers Hardness Test

The constant load of 100, 200 and 300gm is applied with the help of indenter on all three coated Inconel specimen 600, 625 and 718 for 30 seconds. And the average of three readings in each specimen at different places was taken and the Vickers number (HV) is noted.

The Vickers Tester typically includes a microscope that is used to measure the length of the impression diagonal. Hence it is concluded that Inconel 625 is got good hardness as compared to as compared to remaining two Inconel 600 and 718 specimens and values shown in Table 6 and Figure 15 shows that the highest average hardness (1834.6 HV) has been observed from Inconel specimen 625 as compared to Inconel 600 and 718 specimens.

Table 6 Vickers hardness number for coated Inconel specimen 600, 625 and 718

Material	**Load in kg**	**Vickers hardness number**	**Average VHN**
Inconel 600	0.1	871HV	1069HV
	0.2	1013 HV	
	0.3	1323 HV	
Inconel 625	0.1	1136HV	**1834.6HV**
	0.2	1852 HV	
	0.3	2156 HV	
Inconel 718	0.1	886HV	1115.3HV
	0.2	1032 HV	

	0.3	1428 HV	

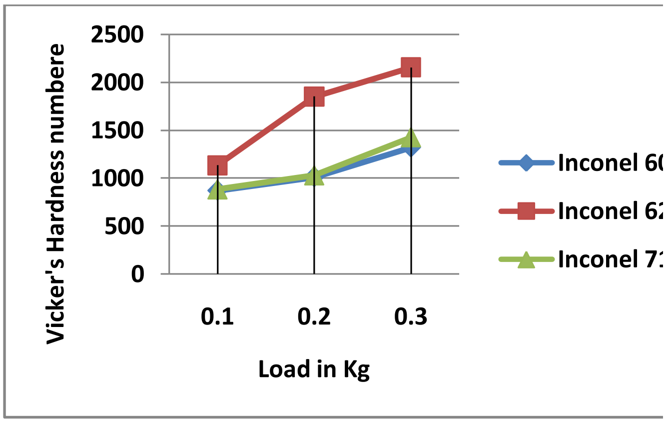


Fig.15 Variation of VHN with load

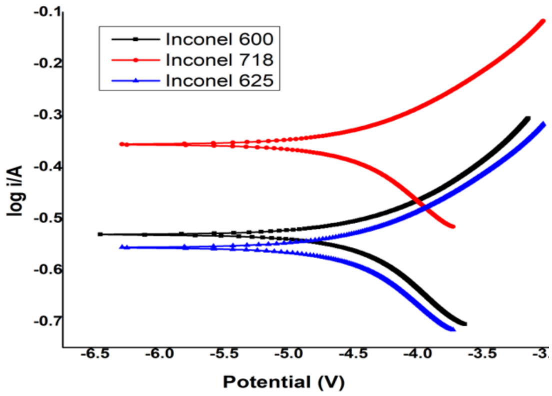


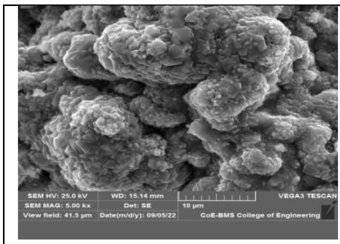
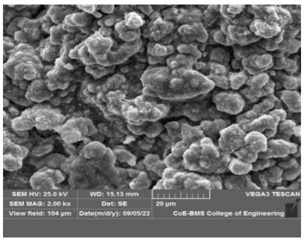
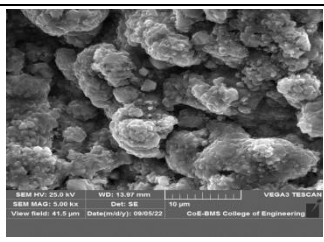
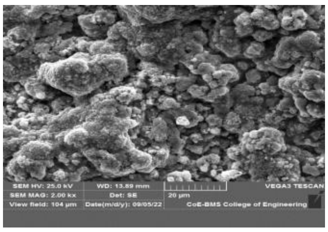
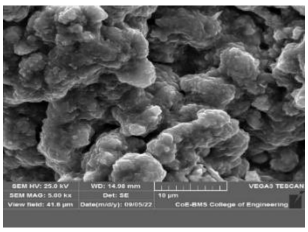
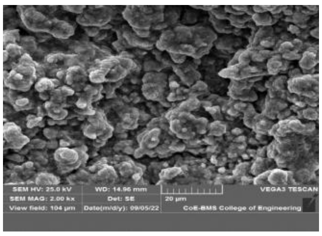
Fig.16 Comparison Tafel Polarization curve of Inconel 600, 625 and 718

It is concluded that the Vickers hardness number for the three different grade Inconel specimens 600, 625 and 718 coating with Nickel Chromium Carbide. The highest hardness has been observed for Inconel 625 coated substrate as shown in Figure 15.

3.6 Electrochemical Corrosion Test

Electrochemical test was conducted in the NaCl solution with 3.5 wt % concentrations at room temperature. Before conducting, the specimens were cleaned as per ASTM standard G1-90 using emery paper and polished on 1cm2 areas on all three specimens and then corrosion rate is examined of all three coated specimens and at the end of the test corrosion rate was calculated in miles per year (mpy) of all three Inconel specimen. i.e found corrosion rate less in Inconel 625 (1.76 mpy) than other two specimens that is in Inconel 600 (7.85 mpy) and 718 (7.35 mpy) The electrochemical behavior of the coated all three specimens is studied by means of Tafel method and electrochemical impedance spectroscopy.

3.7 Micro Structure Characterization

		
a) SEM: Inconel 600 (10μm)	b) SEM: Inconel 600 (20μm)	c)SEM: Inconel 625 (10μm)
		

d) SEM: Inconel 625 (20µm)	e) SEM: Inconel 718 (10µm)	f) SEM: Inconel 718 (20µm)

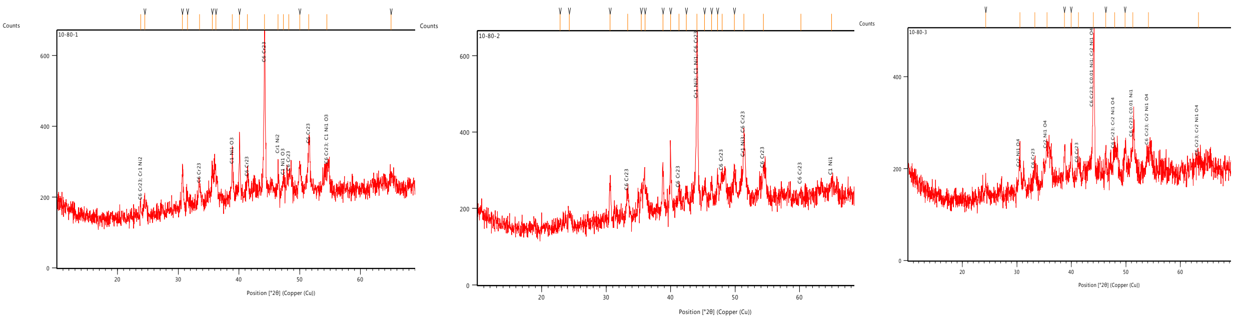
Fig.17 a), b), c), d), e) and f) Corroded coated Inconel 600, 625 and 718 specimens (SEM images)

Figure 17 a and b shows the microstructure of coated Inconel 600. Three zones are observed; the first one contains bright small inter metallic phase. In the next zone, inter metallic phases are bigger than in the first zone. Between these phases, the dark area is observed, which the constant solution is probably. The last zone in these layers is the continuous area with good adherence to the base material. Figure 17 c and d shows the microstructure of coated Inconel 625. Two zones strictly adhering to each other are easily noticeable. a large amount of bright inter metallic phases is observed. These phases are also observed in the layer on the Inconel 600. The next zone consists of dark, probably inter metallic phases. The last zone is characterized by good adhesion to the base material. Figure 17 e and f shows the microstructure of coated Inconel 718, the high stability of the gamma between 500ºC - 1000ºC, and at some point, between 1200 ºC - 1250ºC incipient melting takes place. the content of Nb dispersed in the material seems to play an important role in the stability between 1000ºC - 1250ºC and it was detected the presence of Cr in the sigma phase, which confers a brittle behavior. And this phase is associated with loss of mechanical resistance at elevated temperatures.

The attacked zone had porous morphology, while the corrosion product region showed faceted granules. The corrosive action of the salt is clearly seen in all the images. Chromium depletion can happen when chromium compounds are formed at the surface and then removed from the substrate, leaving depleted areas that are 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.

3.8 XRD Analysis

XRD (X-ray Diffraction) analysis is a powerful technique used to study the crystallographic structure of materials. It is widely used in various scientific and industrial applications to determine the composition, phase identification, and crystal structure of solid materials. XRD analysis provides valuable information about the arrangement of atoms within a material, making it an essential tool for material characterization



Inconel 600 Inconel 625 Inconel 718

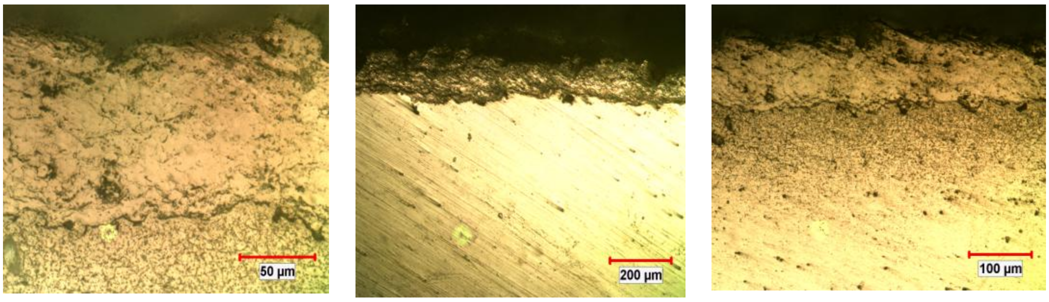
Fig.18 Nickel Chromium carbide (Cr_3C_2-NiCr) Coated Inconel 600, 625 and 718 substrates (X-Ray pattern)

Figure 18 shows that X-ray pattern of the Inconel coating (Cr_3C_2-NiCr) corrosion and observed in this image after the formation of corrosion, two additional oxide phases were discovered in addition to the compositions that were also visible in the coating's structure before corrosion. Chromium oxide (Cr_2O_3) and chromium nickel are responsible for the major peaks of the new oxide phases.

3.9 Analysis of Optical Microstructure of Inconel 600, 625 and 718

Figure 19 optical macrographs for coated Inconel 600, 625, and 718 are displayed. These coatings are determined to be free of any surface cracks. In corrosion investigations, the coatings porosity is of utmost significance. Zeiss Axiovision Release 5.1 (Carl Zeiss Ltd., Germany) is an image analysis programme that was used to do the porosity analysis. Three fields of view per sample at magnifications of 50, 100, and 200 X were obtained in order to calculate the porosity.

The greater kinetic energy of the impacting coating and the partial melting of the coating particles during coating are to blame for the lower value of porosity that was measured. When the partially melted particles strike the substrate at a fast speed, they almost completely lack porosity.



Inconel 600 Inconel 625 Inconel 718

Fig.19 Optical micrographs showing microstructures of coated Inconel 600, 625 and 718

This analysis provides valuable information about the material's grain structure, phases, inclusions, porosity, and other microstructural features. Microstructures and porosities of the samples were observed under optical microscope. For porosity measurement, a cross section images were taken for different magnification from the coating region of all three specimens and observed the porosity levels of all three specimens and found the Inconel 625 coatings is lower (1.1%) porosity than Inconel 600 (2.4%) and 718 (2.2%) specimens.

3.10 EDAX image of coated substrate

An EDAX (Energy Dispersive X-ray Analysis) image of a coated substrate is a micrograph that shows the distribution and elemental composition of the coating and the substrate. EDAX is an analytical technique commonly used in conjunction with scanning electron microscopy (SEM) to perform elemental analysis of materials.

The EDAX image of a coated substrate provides valuable information about the coating's elemental composition, thickness, and distribution on the substrate. This data is crucial for assessing the quality and performance of the coating in various applications.

Table 7 EDX Analysis of coated element of 600, 625 and 718 specimen

Specimen	Element	Weight %	Atomic %
Inconel 600	C	3.33	8.90
	O	23.01	46.14
	Cr	66.80	41.22
	Ni	6.86	3.75
	C	3.38	9.02

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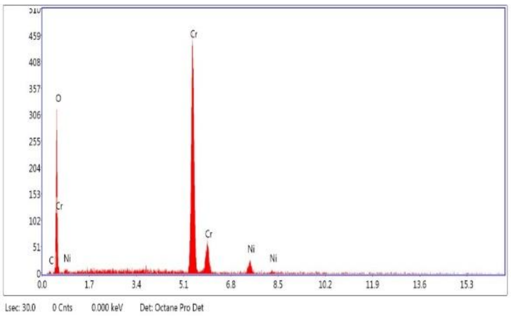
Inconel 625	O	23.15	46.33
	Cr	65.12	52.10
	Ni	10.55	6.07
Inconel 718	C	1.86	5.24
	O	21.71	45.87
	Cr	60.88	45.82
	Ni	8.35	4.55

The scanning electron micrographs showing surface morphologies along with the EDAX composition analysis, at the selected points, on the Inconel coated specimen 600, 625 and 718 are shown in Figure 20 (a) (b) (c).

The surface morphologies of the coated Inconel 600 and 718 (Figure 20 (a) and (c)) are composed of melted NiCr matrix distributed with unmelted particles and globules of partially melted particles at the selected area, and the surface morphologies of the Inconel 625 specimen (Figure 20 (b)) are composed of melted Cr and C matrix distributed with unmelted particles and globules of partially melted particles at the selected area.

The melted particles are found to be rich in nickel in Inconel 625. The compositional analysis of the Inconel 625 Coating (Figure 20 (b) Shows higher amount of Nickel and chromium, which represents the distribution of Cr3C2 and C phases and coating surface indicates that the coatings is having a dense microstructure and are free from cracks. One can see melted, partially melted and pores in the coating and Table 5.8 show the element composition of coating.



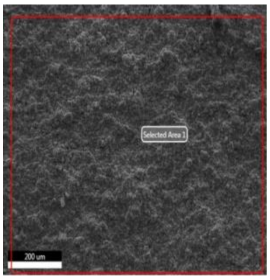
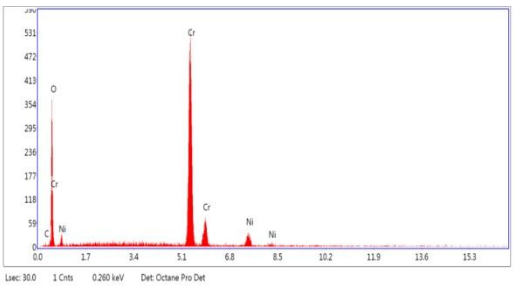


Fig.15 (a) EDAX image of coated Inconel 600 substrate



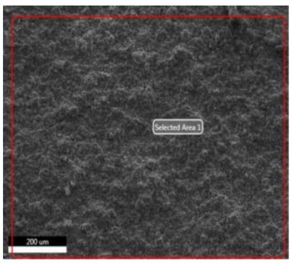


Fig.15 (b) EDAX image of coated Inconel 625 substrate

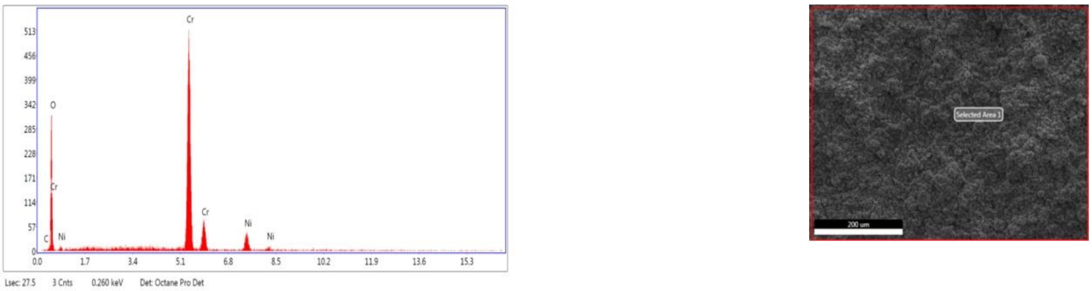


Fig.20 (c) EDAX image of coated Inconel 718 substrate

4. Conclusions

It is concluded that through Hardness test, Tensile Test and electrochemical test, the **Inconel 625** material exhibited a promising physical, good hardness and strength, less corrosion resistance and structural properties as compared to Inconel 600 and 718. Also, thebonding 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 automobile sector where high temperature application like IC Engine parts, exhaust systems, cylinders etc. and many Industries like Thermal Furnaces, Boiler applications, turbine blades.

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