

DETERMINATION OF CORROSION AND WEAR BEHAVIOR OF NICKEL COATED HASTELLOY X STEEL

Submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering Degree in
Mechanical Engineering

By

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INSTITUTE OF SCIENCE AND TECHNOLOGY

(DEEMED TO BE UNIVERSITY)

Accredited with Grade “A” by NAAC

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of SALAI SHIVA BALAN T (Reg.No.37150164) and HARIHARAN S (Reg.No.37150072) who carried out the project entitled **"DETERMINATION OF CORROSION AND WEAR BEHAVIOR OF NICKEL COATED HASTELLOY X STEEL"** under our supervision from September 2020 to April 2021.

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1.

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ABSTRACT

In the modern era, the need for new products with novel processing and multipurpose materials is increased. The current market requirements for engineering applications are lightweight, high strength and low-cost materials. The robust opposition within the business aeronautic zone pushes closer to the manufacturing of aircrafts with reduced running fees, specifically, extended provider existence, higher fuel efficiency, elevated payload and flight variety. The project of weight reduction has constantly been one of the most important elements affecting aeronautic format. In the aviation industry, magnesium composite is widely used metal for wings, rudder and exhaust pipes due to its strength-to-weight ratio, high creep resistance, load-bearing stability and rapid manufacturing process. Nickel is a really perfect cloth to be used in these programs because of confined continuing improvements on aluminium weight loss, the excessive price of fibre metal laminates or carbon composites, and the poor effect, and damage houses of low density plastics whilst subjected to extreme temperatures. Nickel can be positioned in the thrust reversers for the Boeing 737, 747, 757, and 767 in addition to in jet engine fan frames, and plane and helicopter transmission casings. The objective of this investigation is to evaluate Electron beam physical vapor deposition coatings by various tribological tests. Corrosion trying out refers back to the processes carried out by using laboratories so one can clear up, save you or mitigate issues associated with corrosion. Expert's center went to discovering more current material and diverse progressed fabricating like combinations and composite material. Combination are created by enslavement of little amount of metal or non-metal, as opposed to the essential constitutions, in approach to improve the mechanical and different exhibitions. With the coming of vehicles and space applications internationally utilizing the new period of material were meet the prerequisite.

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LIST OF SYMBOLS

Ni	-	Nickel
NaCl	-	Sodium Chloride
V_c	-	Cutting Speed
T_c	-	Machining Time
L	-	Length of Cut
D	-	Diameter
M_c	-	Torque
MRR	-	Material Removal Rate

CHAPTER I

INTRODUCTION

1.1 INTRODUCTION

The financial fee of corrosion is vast, and has been envisioned that, the 40% of metallic production is going to update corroded parts and the goods. Further to that, there are also oblique prices related to plant shut down and decrease performance of equipment. A whole lot of this loss is due to the corrosion of metallic. Corrosion is the reaction of an engineering cloth with its environment leading to consequent deterioration inside the properties of cloth. Degradation by means of hot corrosion and erosion are the principle failure modes of components within the warm sections of gas mills, boilers, industrial waste incinerators, metallurgical furnaces, petrochemical installations, and so forth. Exceptional alloys had been developed for high temperature programs, however they are not capable of meet the requirements of excessive temperature energy, excessive temperature erosion and corrosion resistance concurrently.

Erosion is an extreme hassle in lots of engineering structures, including steam and jet mills, pipelines and valves used in slurry transportation count number and fluidized mattress combustion systems. Gas and steam generators operate in environments in which the ingestion of stable debris is inevitable. In business programs and energy generation, which includes coal burning boilers, fluidized beds and gas generators, stable debris are produced at some point of the combustion of heavy oils, synthetic fuels, and pulverized coal.

The protection of metals or alloys towards corrosion and put on may be done by improvement and the usage of higher corrosion and put on

resistant thermal spray coatings. Those corrosion and put on resistant coatings can add cost to products with the aid of allowing the mechanical residences of the substrate substances to be maintained even as protective them in opposition to put on or corrosion. Thermal barrier coatings (TBCs) have been developed to protect metallic and silica primarily based ceramic additives in turbine for high temperatures.

1.2 BACKGROUND OF STUDY

For maximum oldsters, corrosion is described due to the fact the destruction or deterioration of a metallic because of response with environment that is frequently referred to as rust and is a curse we need to undergo helplessly. Corrosion is electrochemical techniques wherein a current leaves a shape at the anode internet web page, passes via an electrolyte, and reenters the form on the cathode website. Differences in capability at awesome points along the pipe start to make bigger. For example, because it's far in a soil with low resistivity in comparison to the relaxation of the road, modern would go away the pipeline at that anode site, bypass through the soil, and reenter the pipeline at a cathode internet site on line. These potentials generate corrosion currents which depart the pipe to enter the soil at positive selective locations. Corrosion then happens at these selective locations of the pipe shape. Internal or outside corrosion of underground pipelines in soil or water effects in selective and concentrated attacks at coating defects. There may be no need to replace an entire piece of pipe if corrosion may be managed at those selective places (Gibala, R., Tireell, M., and Wert, C., 1993).

1.2.1 Corrosion

Corrosion may be described as the degradation of a cloth because of the response with its surroundings. Degradation implies deterioration of bodily properties of the material. Metals corrode in environments in which they are chemically risky. All metals exhibit a bent to be oxidized, some more without problems than others. The corrosion of metals is the natural consequence of their transient lifestyles in steel form. Corrosion is derived from the Latin "corrosus", meaning gnawed away. Corrosion may be in addition defined as a

slow destruction of a material, a substance, or an entity, typically by using answer or other approach attributed to a chemical system. The maximum commonly seen example of corrosion of metals is rusting of iron (ex) the formation of a brown flaky substance on iron items on exposure to wet air.

It is shown in the fig: No: 1.

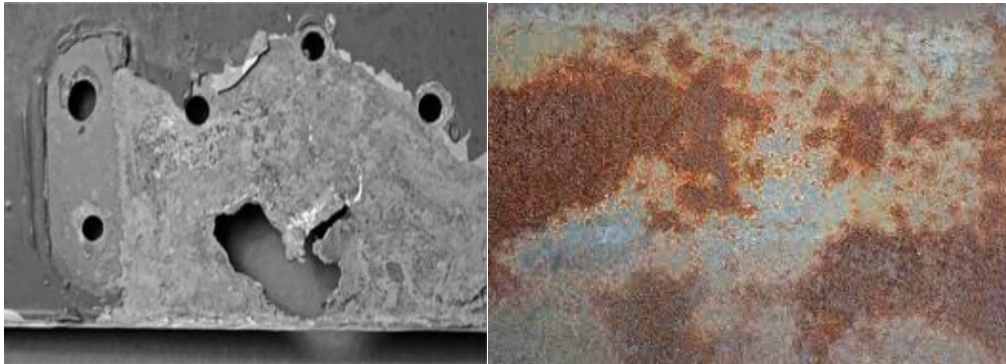


Fig. No. 1. Corrosion in aerospace industry

1.2.2 Formation of Corrosion

Steel corrodes whilst it react with every other substance such as oxygen, hydrogen, an electrical contemporary or even grimy and microorganism. Corrosion also can show up whilst metals like metallic are positioned beneath too much pressure causing cloth to crack. The most common sort of corrosion occurs when its miles exposed to oxygen and the presence of water, which creates a purple oxide corrodes typically referred to as rust. Rust also can impact iron alloys together with metallic. The rusting of iron also can arise whilst iron reacts with chloride in an oxygen-deprived surroundings, even as green rust, that is every other form of corrosion, may be shaped without delay from steel iron or iron hydroxide.

1.2.3 Effect of Corrosion

The yearly worldwide cost of steel corrosion is predicted to be over \$2 trillion, but specialists accept as true with 25 - 30% may be averted with right corrosion protection. Extra than 70% of metallic are tormented by corrosion. Poorly deliberate creation initiatives can lead to a corroded structure desiring to get replaced, which is a waste of herbal assets and contradictory to worldwide concerns over sustainability. Further corrosion can cause protection worries, lack of lifestyles, extra oblique charges and harm to popularity.

1.2.4 ELECTROCHEMICAL CORROSION

This indicates, electrochemical oxidation of metal in response with an oxidant inclusive of oxygen of sulphates. Rusting, the formation of iron oxides, is a well-known example of electrochemical corrosion. This kind of damage commonly produces oxide(s) or salt(s) of the unique metal and results in a distinctive orange coloration. Corrosion also can occur in substances other than metals, consisting of ceramics or polymers, despite the fact that in this context, the time period "degradation" is extra not unusual. Corrosion degrades the beneficial residences of substances and systems including power, look and permeability to drinks and gases. Many structural alloys corrode simply from publicity to moisture in air, but the technique may be strongly stricken by publicity to certain materials. Corrosion may be concentrated regionally to shape a pit or crack, or it could expand throughout a wide area greater or less uniformly corroding the surface. Because corrosion is a diffusion-managed manner, it takes place on exposed surfaces. However, some corrosion mechanisms are less visible and less predictable. The chemistry of corrosion is pretty complex but it is able to be considered basically as an electrochemical phenomenon. At some stage in corrosion at a selected spot at the surface of the object product of iron, oxidation takes vicinity and that spot behaves as an anode. The electrons released at this anodic spot pass through the

metallic and visit any other spot at the steel and decrease oxygen at that spot in presence of H^+ .

It is shown in the fig. No. 2.



Fig. No. 2. Electro chemical corrosion

1.2.5 Types of Corrosion

a. Uniform Corrosion

That is the maximum not unusual shape of corrosion which commonly takes area frivolously over huge areas of a fabric's floor. It is shown in the fig. No. 3.



Fig. No. 3. Uniform Corrosion

b. Pitting Corrosion

One of the most competitive kinds of corrosion, pitting may be difficult to predict, stumble on or characterise. This localized sort of corrosion occurs when a neighborhood anodic or cathodic factor bureaucracy a corrosion cell with the encircling surface. This pit can create a hollow or cavity which generally penetrates the cloth in a vertical direction down from the floor. Pitting corrosion can be resulting from harm or a damage in the oxide film or a defensive coating and also can be brought on through non-uniformities inside the shape of the metallic. This risky shape of corrosion can cause a shape to fail despite a noticeably low lack of metal. It is shown in the fig. No. 4.



Fig. No. 4. Pitting Corrosion

C. Crevice Corrosion

This is shape of corrosion occurs in areas wherein oxygen is constrained which includes underneath washers or bolt heads. This localized corrosion generally effects from a difference within the ion awareness between two regions of metal. The stagnant microenvironment prevents circulate of oxygen, which stops re-passivation and reasons a construct-up of stagnant answer shifting the pH balance far from neutral. The imbalance between the crevice and the rest of the material contributes to the high quotes of corrosion. Crevice corrosion can take region air lower temperatures than pitting corrosion, but may be minimized with the aid of proper joint design. It is shown in the fig 5.



Fig. No. 5. Crevice Corrosion

d. Intergranular Corrosion

Intergranular corrosion takes place whilst impurities are present on the grain boundaries which shape inside the course of solidification of an alloy. It can additionally be because of the enrichment or depletion of an alloying detail at the grain limitations. This shape of corrosion takes place alongside or adjacent to the grains, affecting the mechanical residences of the steel regardless of the majority of the cloth being unaffected. It is shown in the fig. No. 6.

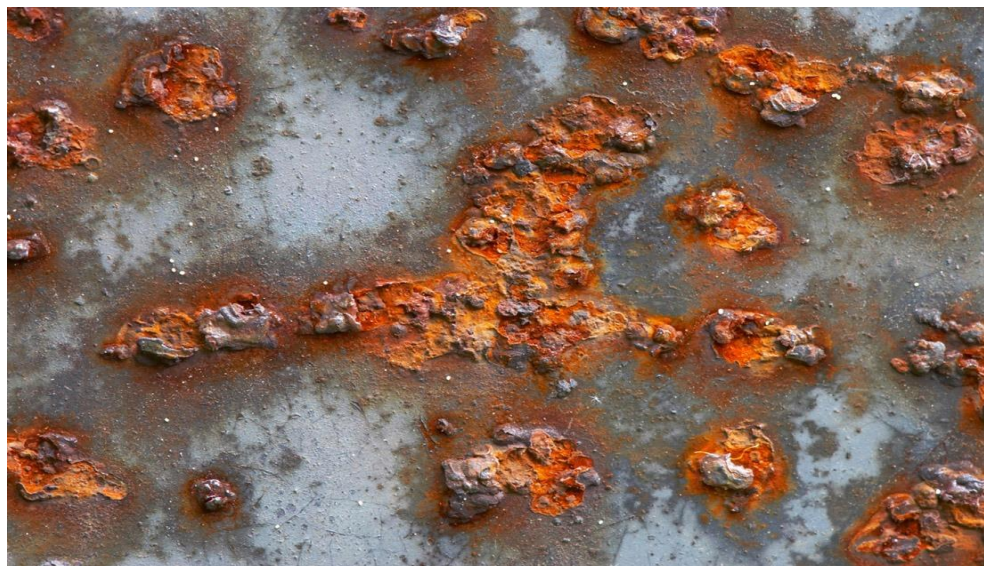


Fig. No. 6. Intergranular Corrosion

e. Stress Corrosion Cracking (SCC)

Stress corrosion cracking refers back to the increase of cracks because of a corrosive surroundings that can result in the failure of ductile metals while subjected to tensile stress, particularly at high temperatures. This sort of corrosion is extra common among alloys than with herbal metals and is relying on the right chemical surroundings whereby simplest small concentrations of energetic chemical materials are required for catastrophic cracking. It is shown in the fig. No. 7.

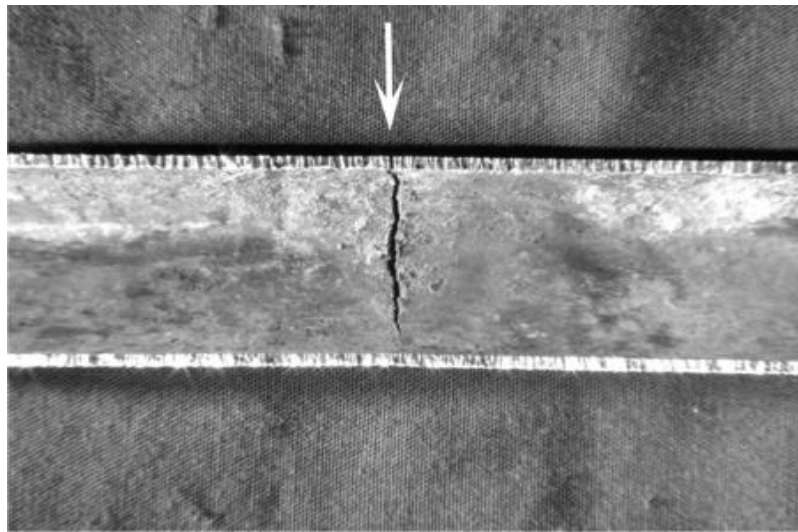


Fig. No. 7. Stress Corrosion Cracking

f. Galvanic Corrosion

This shape of corrosion takes place while two extraordinary metals with bodily or electrical contact are immersed in a common electrolyte (together with salt water) or while a metal is uncovered to distinctive concentrations of electrolyte. In which two metals are immersed together, known as a galvanic couple the greater energetic steel (the anode) corrodes fast than the more noble metal (the cathode). The galvanic collection determines which metals corrode faster, that's beneficial while using a sacrificial anode to shield a shape from corrosion. It is shown in the fig. No. 8.



Fig. No. 8. Galvanic Corrosion

1.2.6 Prevention of corrosion

There are various effective ways to prevent corrosion. Use non-corrosive metals, which include stainless steel or aluminium. Make sure the steel surface remains easy and dry. Use drying marketers. Use a coating or barrier product at the side of grease, oil, paint or carbon fibre coating. Lay a layer of backfill, as an instance limestone, with underground piping. Use a sacrificial anode to offer a cathodic safety device.

1.3 HASTELLOY X

HASTELLOY X alloy is a nickel-chromium-iron molybdenum alloy that possesses an super aggregate of oxidation resistance, material functionality and excessive-temperature power. It has additionally been decided to be in particular evidence against pressure-corrosion cracking in petrochemical programs. Hastelloy has appropriate resistance and excessive metallurgical balance, which makes it high material for excessive-temperature applications of thermal electricity storing and electricity generating devices together with gasoline mills. Similarly, it has low cycle fatigue resistance advanced to that of

maximum robust solution-bolstered alloys and it has an exquisite resistance to warm corrosion. The alloy is used to fabricate high-temperature fuel course additives alongside turbine combustors, flame holders, and liners, strain vessels of a few nuclear reactors, chemical reactors, and pipes/valves within the chemical enterprise. Numerous floor treatment strategies are available to beautify the floor residences of metal alloys; however, laser treatment is taken into consideration to be one of the maximum efficient techniques with improved usual overall performance in comparison to traditional techniques in phrases of chemical cleanliness, thermal penetration, and floor profile. HASTELLOY X alloy has wonderful forming and welding tendencies. It could be solid and, due to its actual ductility, may be bloodless labored. X alloy can be welded with the resource of every guide and automatic techniques which includes shielded metal arc (included electrodes), gas tungsten arc (TIG) and gasoline steel arc (MIG). The alloy also can be resistance welded. It is shown in the fig. No. 9.



Fig. No. 9. Hastelloy X



Fig. No. 10. Samples of Hastelloy X

1.3.1 Heat-Treatment of Hastelloy X

Wrought types of HASTELLOY X alloy are provided in the solution warmth-dealt with circumstance until otherwise precise. X alloy is solution heat-dealt with at 2150°F (1177°C) and fast cooled. Shiny annealed merchandise are cooled in hydrogen. It is shown in the fig. No. 10.

1.3.2 Characteristics of Hastelloy X

a) Resistance to corrosion

The extraordinary oxidation resistance of HASTELLOY X is illustrated underneath. assessments were executed by using manner of exposing samples to dry air at 2000 Deg. F. and to dry air pressurized to three hundred psi at 1750 Deg. F. Standards for comparing oxidation resistance are weight exchange and depth of corrosion penetration. HASTELLOY X excels in each respects because of the formation of a shielding, tenacious oxide film.

1.3.2(b) Resistance to carburization and nitriding

HASTELLOY X additionally resists carburization and nitriding, not unusual situations which frequently result in early failure in excessive-temperature alloys. After a hundred hours in petroleum coke, four different materials were clearly penetrated by carburization; whilst, Alloy X specimens confirmed no carburization in any respect. Of ten materials evaluated in an environment of hydrogen, nitrogen and ammonia at 1100 Deg. F. and 2500 psi for 64 days, Alloy X had a nitride case much less than one-fourth as thick due to the fact the closest aggressive material without interangular attack.

1.3.3 Application

HASTELLOY X reveals use in petrochemical procedure gadget and fuel turbines inside the warm combustor sector sections. Also used for structural additives in business furnace packages because of the outstanding oxidation resistance. HASTELLOY X is suggested mainly for use in furnace applications because it has uncommon resistance to oxidizing, reducing, and neutral atmospheres. Furnace rolls fabricated from this alloy were nonetheless in desirable situation after running for 8700 hours at 2150 Deg. F. Furnace trays, used to guide heavy masses, have been uncovered to temperatures as much as 2300 Deg. F. in an oxidizing atmosphere without bending or warping. Alloy X is equally suitable for use in jet engine tailpipes, afterburner additives, turbine blades, nozzle vanes, cabin heaters, and different plane components. Fuel turbine combustion cans and ducting, warmth-treating gadget. Alloy X has huge use in fuel turbine engines for combustion area additives including transition duct, combustor cans, spray bars and flame holders in addition to in afterburners, tailpipes and cabin warmers. It's far endorsed for use in industrial furnace programs as it has uncommon resistance to oxidizing, reducing and impartial atmospheres. HASTELLOY X is also used inside

the chemical method industry for retorts, muffles, catalyst aid grids, furnace baffles, tubing for pyrolysis operations and flash drier additives. Beneficial homes for plane and Furnace components - HASTELLOX X is usually recommended in particular for use in furnace programs as it has uncommon resistance to oxidizing, lowering, and impartial atmospheres.

1.4 ELECTRON BEAM PHYSICAL VAPOR DEPOSITION

Electron beam bodily vapor deposition (EB-PVD) is a way in which excessive power electron beam changed into used to heat the intention material, and the target fabric become deposited at the ground of substrate in the molecular shape below immoderate vacuum conditions. it is a form of bodily vapor deposition in which a target anode is bombarded with an electron beam given off by using way of a charged tungsten filament under excessive vacuum. The electron beam causes atoms from the goal to transform into the gaseous section. Those atoms then precipitate into strong form, coating the whole lot inside the vacuum chamber (inside line of sight) with a skinny layer of the anode cloth. Ordinary applications encompass aero-engine and commercial fuel turbine blades and vanes. It is shown in the fig. No. 11. And 12



FIG. No. 11. Electron beam physical vapor deposition

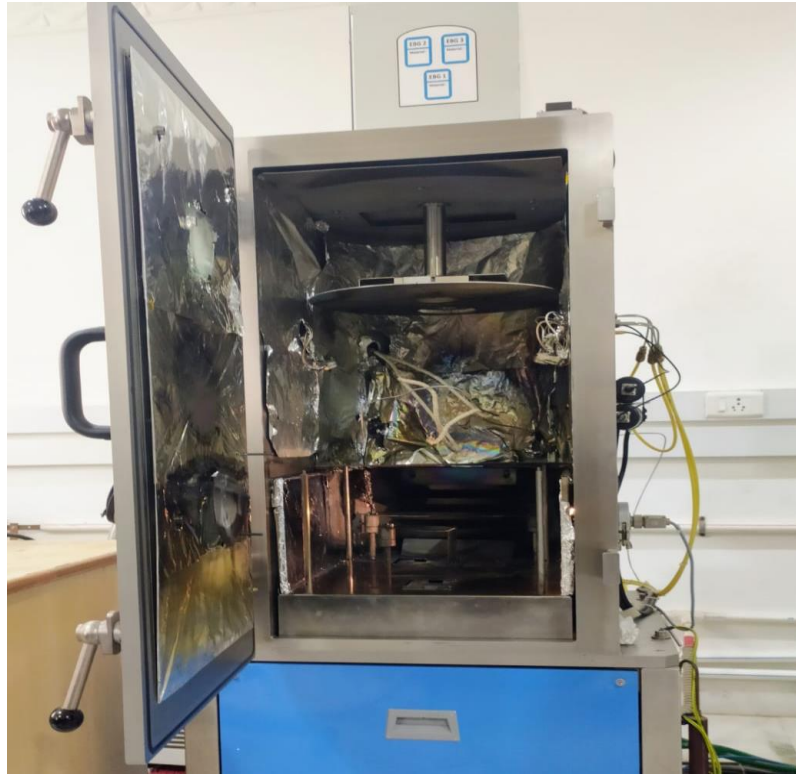


Fig. No. 12. Electron beam physical vapor deposition

1.4.1 Thin-film deposition process:

In an EBPVD gadget, the deposition chamber have to be evacuated to a strain of as a minimum 7.5×10^{-5} Torr (10^{-2} Pa) to allow passage of electrons from the electron gun to the evaporation cloth, which may be within the form of an ingot or rod. rather, a few modern-day EBPVD systems make use of an arc-suppression machine and can be operated at vacuum stages as little as 5.0×10^{-3} Torr, for situations such as parallel use with magnetron sputtering. Multiple styles of evaporation substances and electron guns may be used concurrently in a unmarried EBPVD machine, each having a strength from tens to masses of kilowatts. Electron beams may be generated with the aid of thermionic emission, subject electron emission or the anodic arc method. The generated electron beam is expanded to an excessive kinetic strength and directed toward the evaporation cloth. Upon hanging the evaporation material,

the electrons will lose their energy very unexpectedly. [Three] The kinetic power of the electrons is converted into different styles of electricity via interactions with the evaporation cloth. The thermal electricity this is produced heats up the evaporation material causing it to soften or sublime. Once temperature and vacuum degree are sufficiently high, vapor will end result from the soften or stable. The resulting vapor can then be used to coat surfaces. Accelerating voltages may be among 3 and forty kV. When the accelerating voltage is 20–25 kV and the beam cutting-edge is some amperes, eighty five% of the electron's kinetic power may be transformed into thermal power. a number of the incident electron power is lost via the production of X-rays and secondary electron Emission There are three foremost EBPVD configurations, electromagnetic alignment, electromagnetic focusing and the pendant drop configuration. Electromagnetic alignment and electromagnetic focusing use evaporation cloth that is within the form of an ingot, even as the pendant drop configuration makes use of a rod. Ingots are enclosed in a copper crucible or fireplace, [4] while a rod might be mounted at one end in a socket. Each the crucible and socket must be cooled. That is normally accomplished by way of water movement. In the case of ingots, molten liquid can shape on its surface, which can be stored consistent with the aid of vertical displacement of the ingot. The evaporation price may be at the order of 10^{-2} g/ (cm²·s). It is shown in the fig. No. 13.

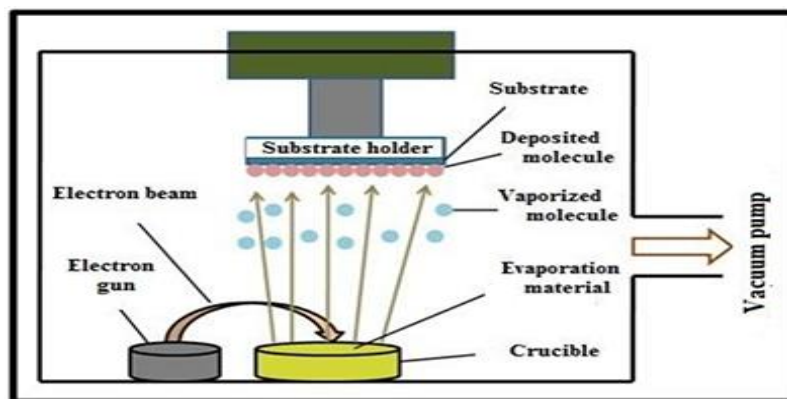


Fig. No. 13. Thin flim deposition process

1.5 SUBSTRATE MATERIAL REQUIREMENTS

Substrate substances need to be properly matched with immoderate vacuum situations at improved temperatures, and want to have a ground that is prepared for a metallurgical bond to the coating. Uncoated regions need to be well suited. Additives ought to be free of oxidation to ensure robust adhesion of the coating. It's far strongly encouraged to blast all scales off the component after warm temperature remedy and in advance than final grinding of finished dimension heat cope with scale, Black oxide end, floor oxides from Nitriding or Carburizing processes, ground oxides from vacuum heat treating (venting too warm), Rust and corrosion, Grinding burns following oxides should save you adhesion. Beneficial regions should be free of burs and overlapped cloth as a result of aggressive grinding. Those imperfections may additionally get included after which destroy off afterwards, leaving an obvious void inside the coatings. Elements need to be freed from ground contaminants which incorporates silicone oil, wax or grease, motor oil, format die, Teflon, or other coatings, glues and adhesives, paint, high quality plating such as Cadmium plating, tape or tape residue, etc. The shaping machine may be followed without delay through a ground activation machine. The methods of surface activation are abrasive grit blasting, water-jet treatment, laser ablation and chemical attack.

The bond coat is generally a steel layer made from a nano-installed ceramic-metallic composite that adheres the layer to the metallic substrate and is responsible for producing the second one coating layer of thermally grown ceramic oxide, which takes vicinity even as the coating is subjected to a excessive temperature. Bond coatings must be ductile so that it will soak up stresses, in place of hard.

1.6 METHODS OF COATING'S CHARACTERIZATION

The coatings are characterised very well via the usage of many techniques. The first-rate manner of controlling the coating's fine is careful assertion of its ground. The homes of coatings determine their conduct for the duration of company. The first rate viable take a look at is the best made below conditions simulating 'real-carrier' conditions. However, the sort of check is pricey and sprayed coatings are most frequently characterized by using the usage of sorting out their physical or chemical houses.

1.6.1 Thermal Cyclic Test

Thermal wonder Resistance (TSR), also referred to as thermal pressure resistance, describes the potential of a brittle cloth to face as much as fast temperature variations without failure. The TSR depends at the situations of heating (normal- country float, transient heating, heating via convection or radiation, and plenty of others.) and can be expressed because the most allowable temperature distinction in the body. In practice, TSR is tested for the machine of a coating onto a substrate. Maximum of the tests simulate the conditions of the service of the coatings. A ordinary thermal cycling furnace check rig is used to test covered turbine blades. Thermal Cyclic Fatigue test became carried out thru Furnace cycle test. In Furnace Cycle check [13] every thermal cycle include a 10-minute warmth as much as the ordinary-state temperature, a forty five-minute soak on the steady-nation temperature and a 5-minute compelled air relax. The chosen steady- kingdom temperature changed into 1150°C. The peel off determines the start of the harm.

1.6.2 Coating Thickness Measurement

The utility of coating is decided by way of one or extra characteristics inclusive of corrosion resistance, porosity, hardness, wear resistance, electric conductivity, inner pressure, roughness and look. The beneficial lifestyles increases with increasing thickness due to which thickness measurement becomes a should in coating industries. Coating to extra thickness effects in a greater fee of manufacturing, at the same time as lesser thickness manner poorer provider performance of covered substrates. Its miles consequently essential to have expertise of thickness of coatings implemented at the fabric. Size of film thickness can be executed with many one-of-a-kind units. There is no method suitable for accepted programs. the choice of the approach for use relies upon on attention on the nature of the substrate metal, the accuracy of measurements required, the cost of the device, the time taken to perform the test and whether the deposits can be destroyed or now not. Generally used measuring techniques for cured organic films encompass non-destructive dry movie methods including magnetic, eddy modern, ultrasonic or micrometre measurement and also negative dry movie techniques together with cross-sectioning or gravimetric (mass) dimension.

Magnetic pull-off gauges use a everlasting magnet, a calibrated spring and a graduated scale. The appeal among the magnet and magnetic metallic pulls them collectively. Because the coating thickness separating the two increases, it turns into easier to pull the magnet away. Coating thickness is decided by way of measuring this pull-off force. Thinner coatings will have more potent magnetic enchantment while thicker movies can have relatively much less magnetic attraction. Trying out with magnetic gauges is sensitive to floor roughness, curvature, substrate thickness and the make-up of the metal alloy. Magnetic pull-off gauges are rugged, simple, cheaper, portable, and typically do now not require any calibration adjustment. They are an excellent, low-price opportunity in situations where nice dreams require only a few readings in the course of manufacturing. Pull-off gauges are typically pencil-kind or

rollback dial fashions. Pencil-kind fashions as shown in discern 1.6, use a magnet that is mounted to a helical spring that works perpendicularly to the covered surface. Most pencil-kind pull-off gauges have big magnets and are designed to work in most effective one or two positions, which partially make amends for gravity. A more correct version is to be had, which has a tiny, specific magnet to degree on small, hot or tough-to-reach surfaces. A triple indicator guarantees accurate measurements while the gauge is pointed down, up, or horizontally with a tolerance of $\pm 10\%$. It is shown in the fig. No. 14.

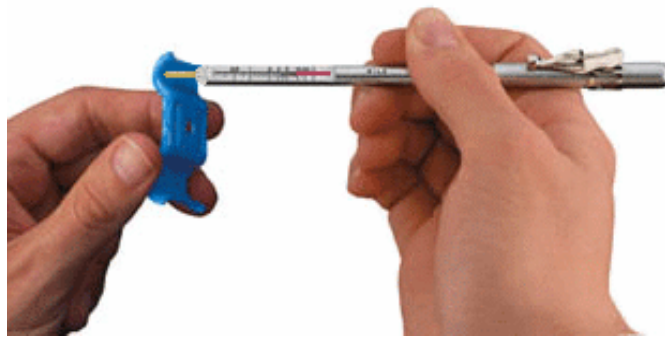


Fig. NO. 14. Pencil-type magnetic pull-off thickness gauge

Rollback dial fashions are the maximum not unusual shape of magnetic pull-off gauge. A magnet is hooked up to one quit of a pivoting balanced arm and associated with a calibrated hairspring. By rotating the dial with a finger, the spring will growth the pressure at the magnet and pulls it from the ground. Those gauges are easy to apply and function a balanced arm that lets in them to artwork in any function, independent of gravity. They are safe in explosive environments and are normally utilized by painting contractors and small powder coating operations. Traditional tolerance is $\pm 5\%$.

1.6.3 Porosity Measurement

Voids (pores) are commonly fashioned in thin movies irrespective of the film education approach as long as the deposition technique involves a segment transformation from the vapor to the solid state. These voids can be extremely small

and high in density. In most cases, porosity is unwanted. Pores can reveal substrates to corrosive marketers, reduce mechanical homes, and deleteriously have an impact on density, electrical residences and diffusion characteristics. Any coatings containing pre- existing porosity or voids are concern to assets degradation. There are many methods for measuring porosity, a few of which are mentioned here.

a. Chemical Tests

Color checks involve use of a reagent which reasons a coloration trade inside the presence of corrosion products from the substrate, forming a specific spot at every pore. An instance of that is the traditional ferroxyl check for metal which makes use of a solution of sodium chloride and potassium ferricyanide. Chemical analysis checks depend upon quantitative willpower of substrate corrosion merchandise via chemical analysis, including the use of an ammonia-ammonium persulfate solution which assaults a copper substrate however no longer a gold overcoat, so the amount of dissolved copper is a degree of the porosity of the coating.

b. Exposure Tests

Fuel publicity porosity checks provide two ability benefits over liquid immersions tests. The gas has a higher capability to penetrate small pores, on the grounds that floor tension outcomes should inhibit such penetration by bulk beverages. Many gaseous porosity exams simulate pore corrosion mechanisms that may absolutely arise in provider. Gas tests that have been used are, 10percentsulphur dioxide test and the nitric acid vapor check. The ten% sulphuric dioxide test ecosystem is generated with the aid of blending a 50% solution of concentrated sulphuric acid with a 20% (by means of weight) answer of sodium thiosulphate. The ratio of the sulphuric acid option to that of the thiosulphate is normally 1:4. The nitric acid vapor check relies on corrosive vapor produced immediately from focused nitric acid that has been positioned within the bottom of the check vessel. This take a look at is limited to gold and platinum coatings.

c. Microscopic Techniques

Microscopic strategies, which consist of optical metallography, [16] Scanning electron microscopy and transmission electron microscopy, allow direct remark of both remoted voids and thru pores. Voids intersecting the movie surface can be detected by means of optical metallography and scanning electron microscopy while transmission electron microscopy is greater beneficial in inspecting both small and massive voids which may be remoted inside a film or positioned at the movie surface. With the use of defocus contrast approach in transmission electron microscopy, high density, very small voids were discovered in thin films prepared by means of spray coating methods. The hobby is that, this demonstrates that voids are typically formed in skinny movies. No matter the film coaching method as long as the deposition process entails a section transition from the vapor to the solid stat.

1.6.4 Micro Hardness Measurement

Hardness is the belongings of a cloth that enables it to withstand plastic deformation, commonly with the aid of penetration. However, the time period hardness may additionally check with resistance to bending, scratching, abrasion or cutting. A hardness belongings cost is the end result of a described size manner. The time period micro hardness test commonly refers to static indentations made with masses now not exceeding 1 kgf. The indenter is either the Vickers diamond pyramid or the Knop elongated diamond pyramid. The method for trying out could be very similar to that of the same old Vickers hardness take a look at, except that it is finished on a microscopic scale with better precision instruments. The floor being tested typically calls for a metallographic finish; the smaller the burden used, the higher the floor finish required. Precision microscopes are used to measure the indentations; these usually have a magnification of round X500 and degree to accuracy of ± 0.5 micro meters. Also with the identical observer differences of ± 0.2 micro meters can usually be resolved. It need to, however, be brought that massive care and enjoy are

essential to obtain this accuracy. Micro hardness dimension determines the hardness over very small regions, as an example, character ingredients, Stages. Those require hardness checking out machines in micro or sub-micro scales.

1.6.5 Surface Roughness Measurement

Roughness performs a critical role in figuring out how a real object will engage with its environment. Tough surfaces normally put on speedier and feature better friction coefficients than easy floor. Roughness is usually a top predictor of the overall performance of a mechanical factor, on the grounds that irregularities inside the floor may form nucleation web sites for cracks or corrosion. There are a number of beneficial strategies for measuring floor roughness.

Observation Methods;

Human notion is quite relative. Business units of standards are to be had to offer the human tester a reference for what they are touching. Comparison must be made against matched same surfaces. Finger nail assessment of roughness and touch technique is utilized in car enterprise.

a. Stylus based Equipment

Essentially this technique uses a stylus that tracks small modifications in floor height and a skid that follows massive adjustments in surface top. Using the 2 together, reduces the effects of non- flat surfaces on the floor roughness dimension. The relative motion among the skid and the stylus is measured with a magnetic circuit and induction coils. The induction coils pressure amplifiers, and different signal conditioning hardware. Then amplified sign is used to power a recorder that shows stylus position and a virtual meter that presentations the Ra and Rz values.

1.6.6 Electro Chemical Properties Measurement

Corrosion is an electrochemical process of oxidation and reduction reactions. As corrosion happens, electrons are released by way of the steel (oxidation) and won through elements (discount) within the corroding solution. When you consider that there is a drift of electrons (present day) in the corrosion response, it may be measured and controlled electronically [18]. Therefore, controlled electrochemical experimental strategies may be used to signify the corrosion residences of metals and steel additives in aggregate with various electrolyte answers. The corrosion characteristics are unique to each steel answer machine.

CHAPTER II

LITRATURE REVIEW

2.1 INTRODUCTION

Plasma sprayed ceramic coatings are considerably used for thermal barrier, put on, corrosion resistant and chemical barrier programs. The selection of the particular ceramic fabric is determined via its thermal stability, chemical stability inside the working surroundings. A Ni-based totally splendid alloy is used as the turbine blade materials. Maximum of the investigators have studied the checking out of Aluminum oxide coatings. There's very confined published literature on the low percentage addition of cerium oxide mixed zirconia powder coatings. The Zirconia Ceria powder coatings have been used in high temperature programs.

2.2 SURFACE ROUGHNESS BEHAVIOUR OF COATINGS

Mahesh Chand et al. (2011) studied roughness size the usage of optical profiler with self-reference laser and stylus instrument. For contact method the measurements had been taken by means of stylus profiler (PerthometerS6P) having tip radius of 5 μm . The traced period became set at 5.6 mm with a reduce off length 0.eight mm. The floor turned into evaluated by using averaging ordinates over a length of four mm. TEN profiles were recorded and Ra fee was predicted.

2.3 CORROSION BEHAVIOUR OF COATINGS

Cabrera in (2010) studied the improvement of electrochemical surface homes in steel substrates using a nanostructured CrN/AlN multilayer

coating. development of corrosion residences on AISI D3 metal surfaces covered with $[\text{CrN}/\text{AlN}]_n$ multilayered system deposited for diverse durations (k) thru magnetron sputtering has been studied on this work exhaustively. The coatings were characterized via Tafel polarization curves, and electrochemical impedance spectroscopy [1].

Anwar Ul HAmid in (2020) studied the corrosion conduct of ZrN skinny films. ZrN coatings of varying thicknesses had been deposited on 316 stainless substrates by using Cathode Arc Evaporation, in a reactive nitrogen environment. The effects of lamellae thickness on corrosive houses of the films were investigated. The corrosion resistance of coatings were examined. The potentiostatic anodic polarization check turned into used to degree the corrosion traits of the coatings. The end result indicated that the corrosion houses of the films had been depending on lamellae thicknesses in movie structure. Corrosion resistance became no longer best dependent on thickness but also on the deposition parameters such as internal stresses and high porosity within coating Zhang Jialing et al (2005) studied the corrosion resistance of $\text{Al}_2\text{O}_3 + \text{ZrO}_2$ composite coatings sprayed on stainless-steel 304 substrates. It suggests that the composite thermal coatings had been deposited with the aid of gasoline tunnel kind plasma spraying. The potentiostatic anodic polarization test became used to measure the corrosion characteristics of the coatings. The coating porosity and the thickness performed the crucial roles on corrosion behavior of the lined substrate [2].

Dasappa Ramesh in (2012) studied the corrosion conduct of Al6061-frit particulate metal matrix composites in sodium chloride answer. Corrosion tests were conducted by using Potentiostat version SEP238C in which three.5% NaCl answer become used as corroding. All corrosion is an electrochemical procedure of oxidation and reduction reactions. As corrosion occurs, electrons are released with the aid of steel (oxidation)

and won with the aid of elements (discount) within the corroding answer. Due to the fact there may be a waft of electrons (contemporary) inside the corrosion response, it may be measured and managed electronically. Controlled electrochemical experimental methods may be used to signify the corrosion residences of metals and steel additives in mixture with diverse electrolyte solutions. Potentiostat changed into used to behavior the corrosion check. The electrodes had been related to an electronic device called potentiostat. The working electrode, the reference electrode and the counter electrode had been used as electrodes. The operating, reference, and counter electrodes are located inside the electrolyte answer. The experiments have been performed in 3.5% solution of sodium chloride (NaCl). The specimens were fixed to running electrode and corrosion assessments were conducted [3].

2.4 THICKNESS MEASUREMENT OF COATING

Kazuya Otsuka in (2004) measured the consequences of dislocation on the Oxygen Ionic Conduction in Yttria Stabilized Zirconia. The pattern length became 2.5x2.5x5.0mm³. With the intention to remove the have an effect on of the shape exchange on the electrical conductivities with the aid of plastic deformation, the shape of samples turned into adjusted by way of mechanical sprucing, so that the shape will become a square parallelepiped. Eventually, the scale of samples was measured the use of the micrometer (the accuracy of the micro- meter become within the order of 1mm) [4].

2.5 MOTIVATION OF THE PRESENT WORK

Exceptional alloys have been evolved for excessive temperature applications, however they are no longer capable of meet the requirements of high temperature power, high temperature erosion and corrosion resistance concurrently. Coatings in gasoline turbine serve a variety of functions,

whether in jet engines, land based energy generation turbines or marine engines. A first requirement to operate generators at better temperatures became, of path, advanced power. Unluckily, these conditions additionally imply severe oxidation/corrosion problems. EBPVD method coating is broadly used due to the fact thin coatings may be carried out at excessive deposition prices and due to its tremendous surface finish and excessive adhesion to the substrate.

2.6 LITERATURE SURVEY ON OPTIMIZATION

Akhilesh Kumar Yadav in 2016 did The Corrosion-Resistant HASTELLOY alloys are widely used by the chemical processing industries. The need for reliable performance ends in their recognition and growth within the areas of power, health and environmental, oil and gasoline, pharmaceutical and flue fuel desulfurization industries. The attributes of HASTELLOY alloys encompass excessive resistance to uniform assault, superb localized corrosion resistance, splendid stress corrosion cracking resistance, and simplicity of welding and fabrication. HASTELLOY fasteners, inclusive of HASTELLOY C276 fasteners, are made from nickel-molybdenum-chromium alloy that is typically considered a flexible exceedingly corrosion resistive alloy. HASTELLOY fasteners have exceptional corrosion resistance in each oxidizing and decreasing media which makes it nicely desirable for an expansion of sturdy corrosive applications. HASTELLOY fasteners also have exceptional resistance to both sulfuric acid and hydrochloric acid. The paper review and studies tendencies carryout regarding HASTELLOY alloys such as the further scope for its studies so one can utilize it similarly and improve its machinability [5].

C. Camba in 2011 compares the abrasive put on behavior of nickel alloys (Hastelloy and Refractalloy). Wear become calculated through weight reduction using pin-on-disk checks that have been carried out at certain values of load,

velocity, and temperature variety. The study is finished with metallographic observations at extraordinary temperatures of the wear and tear tracks earlier than and after the exams. Also, the version of the coefficient of friction with temperature is calculated inside the alloys studied [6].

M. Hashim in 2012 The Hastelloy C-276 was laser surface dealt with in argon ecosystem to improve the tribological residences. The have an impact on of laser power and scan velocity on the metallurgical and mechanical houses are evaluated. The laser dealt with sector typically includes coarse dendrites whilst treated with low laser strength which transformed into best equiaxed grains at most efficient strength and test velocity combination. The cooling price discovered to be greater influential than the thermal gradient in determining the microstructural capabilities. An improvement in hardness of 447 HV0.3 turned into determined within the laser handled sector which yielded an improvement in put on resistance as much as 4 elements. The absence of elemental segregation or new alloy formation after laser floor treatment showed the renovation of inherited bulk homes, an essential function to extend the software in tribo corrosion [7].

A.K. Syamimi in 2009 Chloride-brought about corrosion at increased temperature is the major downside of commercialization of biomass fired energy era. The incapacity of the biomass-fired boilers to increase the temperature has led to a lower efficiency of the power plant. Hastelloy C22 is one of the capacity substances for superheater due to the high content of Ni-Cr which offers a first rate corrosion resistance. The aim of this paintings is to attain greater information on corrosion behavior of Hastelloy C22 at excessive temperature in alkali salt surroundings with the have an impact on of air humidity, consequently to justify the suitability of this alloy as a superheated fabric for better operating temperature. Corrosion assessments have been completed within the artificial salt containing eighty wt% KCl and 20 wt% K₂SO₄ underneath every day and dry air conditions. The test become performed at temperature 650o C for 218 hours. The floor morphology, elemental distribution and the corrosion merchandise were

characterized the use of field Emission Scanning Electron Microscope (FESEM) equipped with energy Dispersive X-ray (EDX). The phase identification became accomplished the use of X-ray Diffraction (XRD) analysis. The consequences discovered a tremendous effect of humidity at the corrosion behavior of the alloy in which the presence of air moisture reduces the protective functionality of the chromium oxide (Cr_2O_3) scale. A formation of volatile chromium (IV) hydroxide in addition to the volatilization of Cr_2O_3 led to the oxide spallation, accordingly reducing the corrosion resistance of the superalloy [8].

M. Sugimoto in 2009, they proposed a new approach fabricating low-price and automatically sturdy tapes for covered conductors. In this method, Hastelloy tape, that's a strong nickel alloy, is plated with a nickel movie. A two-step plating was carried out to achieve a textured nickel movie. Within the first step, a strike tub changed into used so that it will plate a nickel movie on Hastelloy surface. In the 2nd step, the movie turned into plated in a low cost watts tub. We controlled various plating situations along with pH-circumstance, thickness, and present day density within the watts tub to fabricate a textured nickel film. The crystal orientation of the nickel films changed into characterized via an X-ray diffraction method (XRD) with Cu Ka radiation. Desired orientation of the movie depends on pH of watts bath, nickel film thickness, and current density. The optimum situations for acquiring a textured nickel movie are pH of four.5 for the watts bathtub, modern-day density of 500 A/m², and thickness of ninety two lm. Sooner or later, we succeeded in acquiring nickel films with 96% c-axis orientation [9].

BIN TANG in 2014, they did electro less plating on nickel. Electro less plating has been considered as an effective method to offer protection and enhancement for metallic materials with many wonderful residences in engineering. This paper begins with a short introduction of the fundamental factors underlying the technological standards and traditional manner of electro less nickel–phosphorus (Ni–P) coatings. Then this paper discusses divergent electro less nickel plating, inclusive of binary plating, ternary composite plating and nickel plating with

nanoparticles and rare earth, with the purpose of enhancing the surface overall performance on metallic substrate in recent years in detail. Based totally on divergent coating manner, the numerous functions depending on the processing parameters are highlighted. One after the other, numerous coaching techniques aiming at improvement of plating efficiency are summarized. Moreover, in view of the first rate performance, together with corrosion resistance, abrasive resistance and fatigue resistance, this paper seriously evaluations the behaviors and capabilities of diverse electro less coatings beneath different conditions [10].

2.7 SUMMARY OF LITERATURES

Around 100 studies papers posted in popular global journals, country wide journals, worldwide meetings and national conferences associated with coating manner and trying out of coatings were collected and the crucial findings were critically reviewed. The assessment suggests that the studies on the coatings resisting excessive temperature and corrosion is been carried out in the course of the sector.

It is understood from the overview that the hardness and thickness of the coated specimens turned into measured by using profilometer tester and right surface end helps in lowering fatigue load, enhancing corrosion resistance and creep existence. The coating porosity and the thickness play the essential roles on corrosion behavior of the covered substrate. Corrosion and wear resistance had been not only dependent on thickness however also at the deposition parameters which include excessive porosity inside coating.

CHAPTER III

AIM AND SCOPE

3.1 AIM

The aim of this project is to study the corrosion and wear behaviour of Nickel coated hastalloy x.

3.2 SCOPE

Cars, vans and Aircraft are not the most effective parts that have incorporated Nickel in their designs. The aerospace industry has an extended history of using the steel in lots of applications both civil and military. It is vital to lower the weight of air and area craft, in addition to projectiles, to aid in lowering emissions and growing gas performance – see the lifestyles Cycle look at for aircraft components by using Simone Ehrenberger German Aerospace center (DLR) for extra information. Those modifications will bring about a lower operational price as nicely. Nickel is a really perfect choice to be used in these programs because of confined continuing improvements on aluminum weight loss, the excessive price of fibre metal laminates or carbon composites, and the poor effect, and damage houses of low density plastics whilst subjected to extreme temperatures.

Nickel may be located inside the thrust reversers for the Boeing 737, 747, 757, and 767 as well as in jet engine fan frames, and plane and helicopter transmission casings. Current modifications to the aircraft Seat layout well known SAE AS8049C now allow using Nickel alloys, meeting specific FAA (Federal Aviation Administration) flammability standards, in passenger aircraft seat frames and investigations are underway to allow broader use inside the cabin.

Spacecraft and missiles also contain Nickel and its alloys. Elevate-off weight reduction is of high importance in layout and a cloth is wanted which could face up to the extreme situations confronted at some stage in operation. Nickel is capable of withstanding quick wave electromagnetic radiation, publicity to ozone and the effect of excessive electricity particles and count. Dimensional balance is also a key component whilst utilized in optical imaging devices carried through satellites

CHAPTER IV

MATERIALS AND METHODS

The materials and methods of this investigation is to evaluate EB-PVD coatings by various tribological tests. The experimental has been planned in the following sequence:

- (i) Selection of base metal which withstands high temperature and resists corrosion.
- (ii) Preparation of base metal samples for coating confirming to ASTM standards.
- (iii) Coating the base metal samples by EB-PVD process.
- (iv) Metallurgical analysis using Scanning Electron Microscope and coating thickness measurement.
- (v) Evaluation of various properties such as micro hardness, porosity and surface roughness, corrosion resistance, wear resistance of coatings.
- (vi) Evaluation of residual stress over the coated sample.

4.1 METHODOLOGY

The scheme of research followed in the present investigation is illustrated in the flowchart as shown in **Figure.No.15**. The detailed experimental procedures involved in each stage of experimental work are briefed in the subsequent sections.

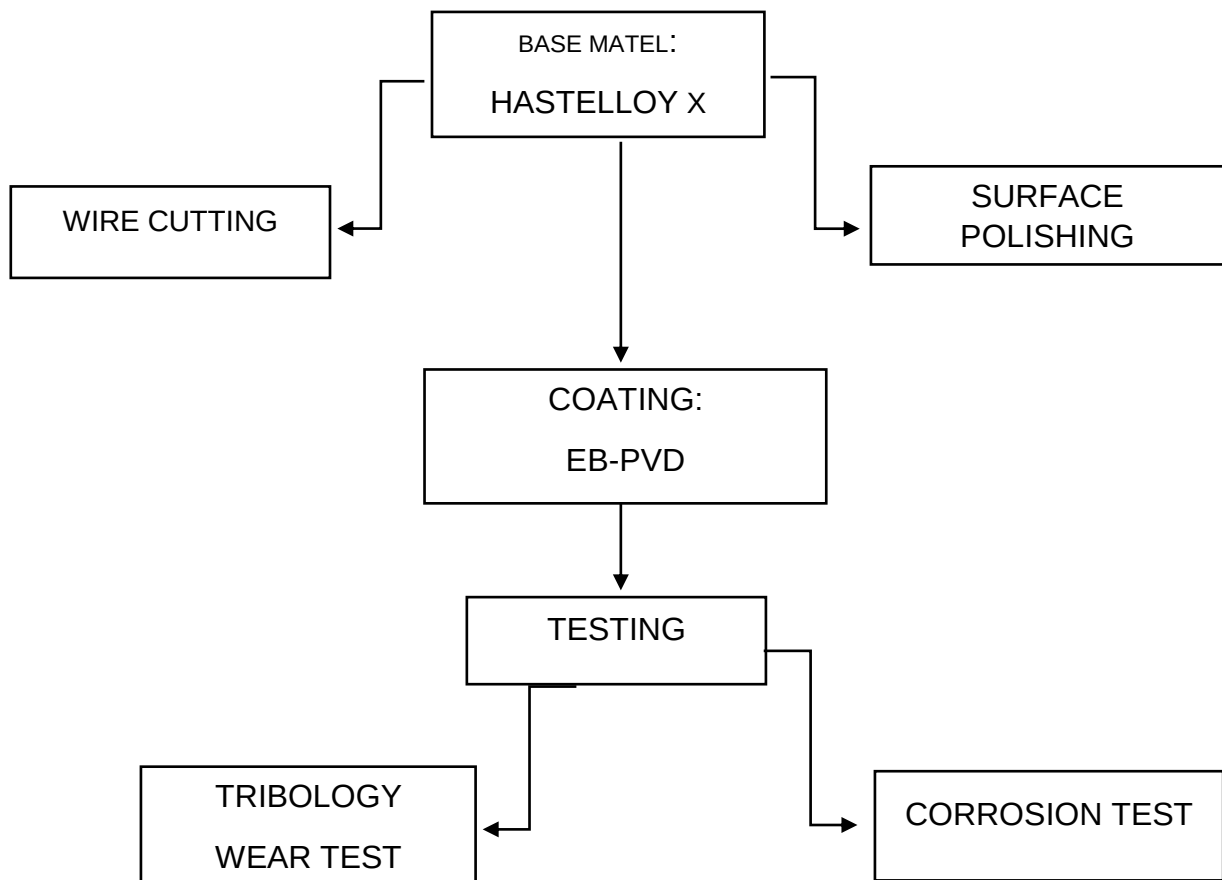


Fig. No. 15. ELECTRON BEAM PHYSICAL VAPOR DEPOSITION PROCESS

4.2 SELECTION OF BASE METAL

Exceptional alloys are metal substances for service at high temperatures, mainly inside the hot zones (turbine blades) of gas mills. Such materials permit the turbine to operate extra efficiently through withstanding better temperatures. Those high stress turbine blades are made up of Nickel and Chromium. Due to the fact that Hastelloy X contains Nickel and Chromium and additionally it is commercially to be had, the bottom metal is taken as Hastelloy X. Hastelloy X grade is taken as base metallic because it withstands high temperature and resists corrosion. Hastelloy X grades are low-priced.

4.3 SPECIMEN PREPARATION

Hastelloy X is taken as a specimen material. Different samples of varying size were taken for analysis. The samples with dimensions are shown in **Figure.No.16**. The metallic substrate should be treated before coating. The substrate should be cut in the dimension of 20mm x 10mm and the thickness should be 1.5mm.

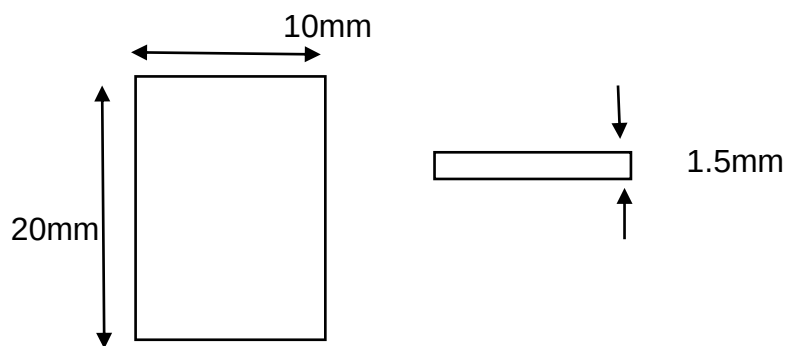


Fig. No. 16. Specimen Preparation

This method of cutting the Hastelloy x substrate is known as wire cutting. Next step is surface polishing, here we polished our substrate for the mirror finishing which make the substrate smooth and polish. The substrate is usually covered with grease that protects the surface against corrosion. The grease was removed in the cleaning process. Cleaned pieces are shaped in order to obtain desired dimensions to avoid sharp angles that are difficult to be coated. The remaining area other than the area to be coated was covered with 'masks' during coating.

4.3.1 Surface Cleaning

Degreasing of latest metallic substrates changed into executed with the aid of the usage of natural solvent acetone. The manner turned into executed in an easy room and the closing liquid changed into carefully recycled. Every care became taken to guard the operator from risky exposure.

4.3.2 Substrate Shaping

The substrates want to be formed in order to meet the dimensional specs. A touch material must be removed within the locations in which the coating is to be deposited. Shaping is likewise essential to keep away from sharp angles or sharp ends wherein it's far tough to spray a coating or, then again, in which adherence to the substrate is negative. The adherence becomes lower due to the excessive attention of thermal stresses within the coatings sprayed in such places. Substrate shaping changed into carried out via twine reducing approach.

4.3.3 Surface Activation

Surface roughness is the parameter which is intently related to grit blasting and, alternatively, strongly impacts the adhesion of the coating to the substrate. A boom in the roughness outcomes in an increase in the adhesion.

4.4 PRE-TREATMENT PROCESS

A bond coating or 1st layer coating of Nickel is carried out on the bottom metal (Hastelloy-X) by way of using EBPVD method. On this manner Nickel become heated and vaporized. Then it got lined on the bottom steel. An improvement in oxide coating adhesion may be done by using the utility of bond coatings. The primary layer of the coating is referred to as the bond coat. It allows the coating to bond over the substrate and therefore plays an indispensable function in forming a thermal barrier.

4.5 EB-PVD

Electron beam physical vapor deposition (EB-PVD) is a technique in which high energy electron beam was used to heat the target material, and the target material was deposited on the surface of substrate in the molecular form under high vacuum conditions. It is a form of physical vapor deposition in which a target anode is bombarded with an electron beam given off by a charged tungsten filament under high vacuum. The electron beam causes atoms from the target to transform into the gaseous phase. These atoms then precipitate into solid form, coating everything in the vacuum chamber (within line of sight) with a thin layer of the anode material. Typical applications include aero-engine and industrial gas turbine blades and vanes.

Thin-film deposition is a process applied in the semiconductor industry to grow electronic materials, in the aerospace industry to form thermal and chemical barrier coatings to protect surfaces against corrosive environments, in optics to impart the desired reflective and transmissive properties to a substrate and elsewhere in industry to modify surfaces to have a variety of desired properties. The deposition process can be broadly classified into physical vapor deposition (PVD) and chemical vapor deposition (CVD). In CVD, the film growth takes place at high temperatures, leading to the formation of corrosive gaseous products, and it may leave impurities in the film. The PVD process can be carried out at lower deposition temperatures and without corrosive products, but deposition rates are typically lower. Electron-beam physical vapor deposition, however, yields a high deposition rate from 0.1 to 100 $\mu\text{m}/\text{min}$ at relatively low substrate temperatures, with very high material utilization efficiency.

4.6 Testing of Coating

4.6.1 Profilometer

A profilometer is a measuring instrument used to measure a surface's profile, in order to quantify its roughness. Critical dimensions as step, curvature, flatness are computed from the surface topography. While the historical notion of a profilometer was a device similar to a phonograph that measures a surface as the surface is moved relative to the contact profilometer's stylus, this notion is changing with the emergence of numerous non-contact profilometry techniques. Non-scanning technologies are able to measure the surface topography within a single camera acquisition, XYZ scanning is no longer needed. As a consequence, dynamic changes of topography are measured in real-time. Contemporary profilometers are not only measuring static topography, but now also dynamic topography – such systems are described as time-resolved profilometers.

4.6.2 Tribology

The tribology of a contact involving surfaces in relative motion can be understood as a process with certain input and output data. Input data are the geometry of the contact both at a macro and micro scale, the material properties based on the chemical composition and structure of the different parts involved and the environmental parameters. Other input data are the energy parameters such as normal load, velocity, tangential force and temperature. The tribological process takes place as the two surfaces are moving in relation to each other, and both physical and chemical changes occur in accordance with physical and chemical laws with respect to the input data. As a function of time the tribological process causes changes in both the geometry and the material composition and results in energy-related output effects: friction, wear, velocity, temperature and dynamic behavior. The complete tribological process in a contact in relative motion is very complex because it involves simultaneously mechanical friction, wear and deformation mechanisms both at a micro scale and a macro scale as well as chemical effects and material transfer. The macro mechanical tribological mechanisms are related to the stress and strain distributions of the whole contact, the total plastic and elastic deformations they result in and the total wear particle formation process and its dynamics. These phenomena are typically of a size level of one micrometer or more, up to millimeter size. The chemical effects take place on a micro scale and are referred to as tribochemical mechanisms.

4.6.3 Corrosion Testing

Corrosion testing refers to the processes conducted by laboratories in order to solve, prevent or mitigate problems related to corrosion. These processes can be applied in industrial materials and infrastructure

products, and are often used in failure analysis. All corrosion laboratories are composed of expert failure analysts, chemists and engineers that are all certified in corrosion testing. Such tests can provide useful information in order to make sound decisions regarding selection of materials, processing and treatment.

4.6.4 Electro Chemical Properties

In this research work, potentiostat / galvanostat polarization cell setup as shown in Figure 3.14 was used to measure electro chemical properties. It consists of an electrolyte solution, a reference electrode, a counter electrode, and the metal sample connected to a specimen holder. The sample is called the working electrode. The electrodes are connected to an electronic instrument called the potentiostat.

The working, reference and counter electrodes are placed in the electrolyte solution. In the solution, an electrochemical potential (voltage) is generated between the various electrodes. The corrosion potential (E_{corr}) is measured by the potentiostat as an energy difference between the working electrode and the reference electrode.

Electrochemical corrosion experiments measure the potential and current of the oxidation or reduction reactions. A potentiostatic experiment imposes a constant potential on the working electrode for a specific time period. The measured current is plotted versus time.

For potentiodynamic experiments, the applied potential is increased with time while the current is constantly monitored. The current density is plotted with respect to the potential. After the potential is scanned to a predetermined current density or potential, the potential scan may be reversed while the current continues to be measured. A potentiodynamic scan is referred to as reverse polarization or cyclic polarization. It is also possible to control the current and measure the resulting potential. Experiments where the current is imposed rather than the potential are referred to as galvanodynamic. It is shown in fig 17.



Fig. No. 17. Electrochemical properties test apparatus

Galvanodynamic methods [35] plot the variation in potential verses the controlled current. Galvanostatic tests maintain a constant current and plot the change in potential with respect to time. Samples for electrochemical corrosion testing must be electrical conductors and must be small enough to fit in the polarization cell. Components can be tested as a whole or as smaller sections.

The electrochemical measurements have been carried out in a single-compartment cell, with a three-electrode configuration comprising a saturated calomel electrode as the reference electrode, and a Pt wire as

the auxiliary electrode and a working electrode as shown in Figure 3.15. The electrochemical measurements were carried out according to ASTM G102. The electrochemical measurements like variation of electrode potential under Open Circuit Potential (OCP) condition with respect to time, Tafel plots and electrochemical impedance analysis were carried out for the ten specimens of each coating composition in freshly prepared solution of 3.5 w% sodium chloride (NaCl).

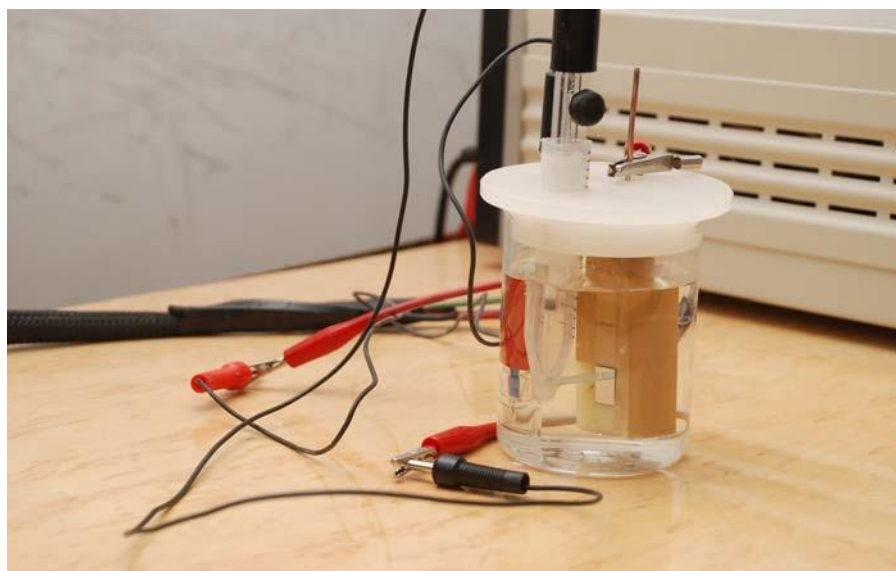


Fig. No. 18. Electrochemical properties test polarization cell

A sample was immersed in the electrolyte solution for about 45 min. to get the stable open circuit potential (OCP). OCP was monitored as a function of immersion time and it was represented as potential vs. time plot. Once the OCP was stable, potentiodynamic polarization studies were carried out for all the specimens in the potential range of ± 200 mV at a scan rate of 0.001 V/s using dedicated software. The polarization experiments were repeated in order to obtain reliable results. Electrochemical Properties measurement was carried out in the Chemistry lab of Anna University. It is shown in the above fig. No. 18.

CHAPTER V

RESULTS AND DISCUSSION

5.1 COATING THICKNESS MEASUREMENT

Specimens were coated by Electron beam physical vapor deposition process. Samples were coated by Nickel (Ni). Coating thickness was measured by means of Profilometer founded by the 600nm. The thickness of the top coating has been confirmed by the Scanning Electron Microscope image and was found to be 600nm. The thickness of the bond coat is found to be 600nm.

5.1.1 PROFILOMETER:

Profilometer measures the deflection of a fine stylus that is raster scanning over features varying in height from 1 mm down to 5 nm is sensed by a profilometer, which tests the thin film thickness of patterned features. It can map phase heights and view topological three-dimensional images of substrates varying in size from 200 mm wafers to small bits. It is shown in the below fig. No. 19.

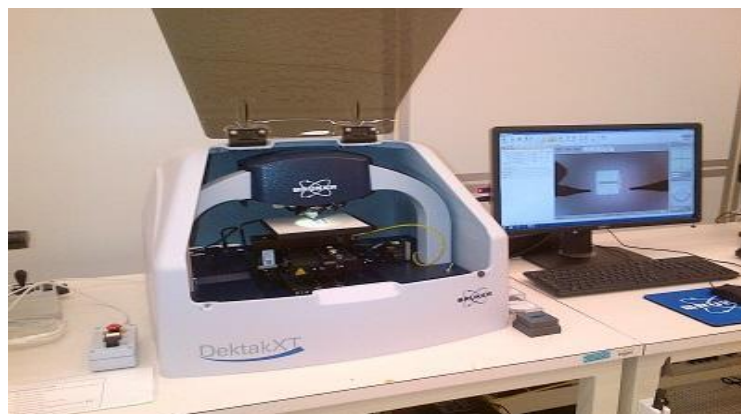


Fig. No. 19. Profilometer

5.1.2 SPECIFICATION OF PROFILOMETER:

These are the steps which are used in the profilometer. Maximum step height: 1 mm, Vertical resolution: 0.1 nm, Scan length: 50 um to 50 mm, 120,000 data points per scan, Scans can be stitched end to end to span up to 150 mm, Stylus force: 0.098 mN to 147 mN (0.01 mgf to 15 mgf), Motorized X-Y-theta stage, Wafer mapping up to 150 mm, 3-D topological imaging.

5.1.3 USAGE OF PROFILOMETER:

The usage of Profilometer are; Maximum wafer diameter: 200 mm (8 in). Small pieces supported: Yes. Maximum thickness: 50 mm.

5.1.4 APPLICATION:

These are the common application used in Profilometer; Measurement of etch rates, deposition rates, and film growth rates. Measurement of surface roughness. Thickness mapping.

5.2 CORROSION TEST

APPARATUS REQUIRED

The apparatus which we were used for turn our coated base metal (hastelloy X) into corrode form are mixture of NaCl with distilled water, Sp200 potentiostat and the connecting wire.

5.2.1 MIXTURE OF NACL:

Here, we are mixing the NaCl solution into the distilled water (500ml). We took approximately 14g of NaCl solution for the mixture in distilled water. It is shown in the fig. No. 20 and in 21.

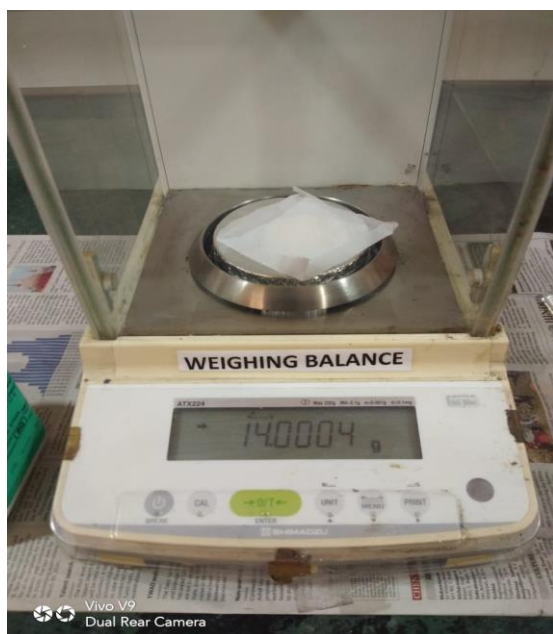


Fig. No. 20. Sodium chloride



Fig. No. 21. Mixture of NaCl in distilled water

5.2.2 Sp300 potentiostat

The SP-300 is a modern-day studies-grade potentiostat with a present day range of 500 mA to ten A, built-in EIS, and excessive-cease features such as 7 MHz maximum frequency, floating mode, analogue filtering, built-in calibration board, and stability bandwidths.

The modular chassis of the SP-three hundred potentiostat can deal with an non-obligatory high contemporary/high voltage alternative board (up to 10 A and 48 V), or a 2nd potentiostat board (both every day or EIS) that may be used as a Bipotentiostat for RRDE experiments. The instrument can also be used as a multi-person tool, as every channel board may be used one at a time by means of separate researchers. It is shown in the fig. No. 22.



Fig. No. 22. Sp-300 Potentiostat

5.3 RESULTS

Wear Test and Corrosion Test has been taken and the tribological test performed to check the Nickel Coated Hastelloy X steel by various stages the wear test performed by SS (stainless steel) ball to check its standard and quality to prove the hardness test for the Nickel Coated Hastelloy X steel and later on the sample undergone Corrosion to check the corrosion properties of the Hastelloy X steel and the values, graphs, tables of the various test was mentioned here.

Wear test and Corrosion test are executed to check the properties of the material.

The wear test is produced on the product named linear reciprocating test rig. Sample taken are copper-hydroxyapatite composite on a stainless steel ball with a constant load of 1N and with 1Hz frequency in a normal room temperature.

Time taken to complete the test is 30 minutes (i.e., 1800 seconds) having a stroke of 3mm. While coming to corrosion test – E_{corr} , I_{corr} , and β_a , β_c values comes under consideration for knowing the clear properties of the material.

The graph between $E_{we}/V - \log (I/mA)$ tells about at which point the material acts ideal. Highest point of E_{we}/V on graph is where more corrosion rate occurs.

5.3.1 WEAR TEST:

TABLE. No. 1. Wear Test Result

Product Name	LINEAR RECIPROCATING TEST RIG
Sample ID	Ni-HA-SS ball
Date	20-Mar-21, 9:44 AM
Remarks	Ball: SS; Dia: 6 mm; Stroke: 3 mm; Freq: 1Hz;
Load (N)	1N; Temp: RT; Duration: 30 min; RH: 45%Test Parameters
Stroke (mm)	3
Frequency (Hz)	1
Time (s)	1800
Temperature	50
Ball Radius	6.00
Frequency (Hz)	1,Stroke (mm) :3.00

The product named **LINEAR RECIPROCATING TEST RIG** and Sample id **Ni-HA-SS ball** and the date and time of the test taken **20-Mar-21, 9:44 AM** and the sample has **Stainless Steel ball** and it has a diameter of **6 mm** and stroke of **3 mm** and the frequency of **1 (HZ)** and the load applied is **1(N)** and the total time taken is **1800 seconds**, the ball radius is **6 cm** and temperature is **50 degree Celsius**.

5.3.2 WEAR TEST VALUES

TABLE. No. 2. Wear Test Values

TIME (MIN)	COF	FF(N)	SPEC	LOAD (N)	STROK E	LAPS	DISTANCE
0.244	-0.091	-0.091	33.881	1	0.198	0.2	0.001
0.449	-0.091	-0.091	33.323	1	0.213	0.4	0.003
0.701	-0.091	-0.091	33.02	1	0.213	0.7	0.004
0.789	-0.091	-0.091	32.67	1	0.213	0.8	0.005
0.946	-0.091	-0.091	32.415	1	0.213	0.9	0.006
1.097	-0.091	-0.091	32.285	1	0.213	1.1	0.007
1.29	-0.089	-0.089	31.729	1	1.512	1.3	0.008
1.46	-0.085	-0.085	30.857	1	1.512	1.5	0.009
1.696	-0.084	-0.084	30.516	1	1.512	1.7	0.01
1.889	-0.082	-0.082	30.267	1	1.512	1.9	0.011
1.947	-0.082	-0.082	30.086	1	1.512	1.9	0.012
2.183	-0.076	-0.076	30.016	1	2.737	2.2	0.013
2.356	-0.073	-0.073	29.98	1	2.737	2.4	0.014
2.456	-0.071	-0.071	29.954	1	2.737	2.5	0.015
2.695	-0.069	-0.069	29.929	1	2.737	2.7	0.016
2.814	-0.068	-0.068	29.92	1	2.737	2.8	0.017
2.954	-0.066	-0.066	30.201	1	2.831	3	0.018
3.194	-0.062	-0.062	30.408	1	2.831	3.2	0.019

The log values of wear test and corrosion test are noted down with time in respect to the seconds and with co-efficient of friction (COF) values and Friction Force (FF) with respect to Newton (N) and Specimen (SPEC) values has been noted and the Load with respect to Newton (N) and time laps noted down with respect to seconds.

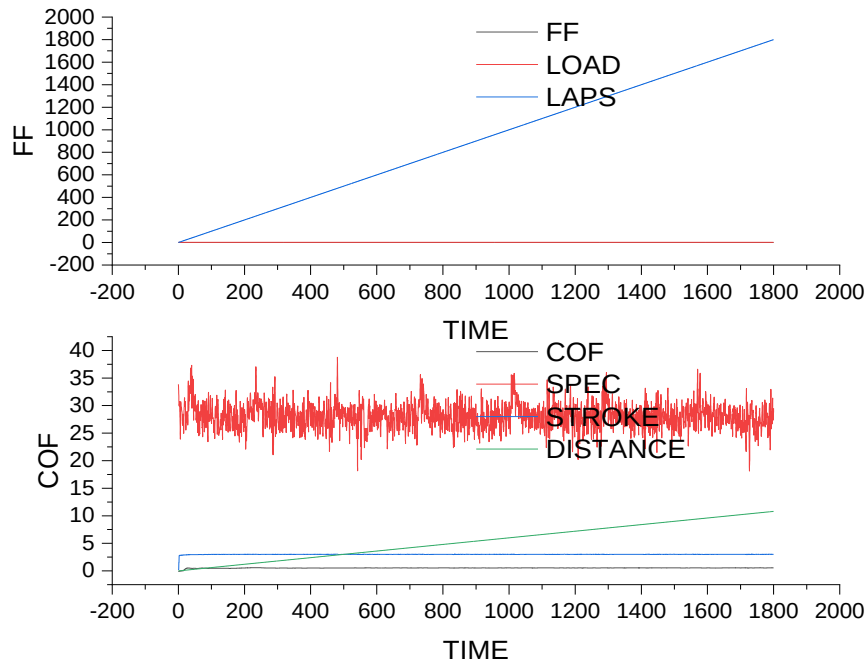


Fig. No. 23. Wear Test Graph

In FF-TIME graph

Black line refers to friction factor (FF)

Blue line refers to the time laps of the specimen

Red line refers to the load acted on specimen

In COF-TIME graph

Black line refers to co-efficient of friction (COF)

Red line refers to specimen reaction Blue line refers to stroke given to specimen

Green line refers to distance of wear (up to which extent, the specimen decreases)

The above graphs are plotted by using x and y values where x as TIME and y as COF is a ratio of the force required to move one surface over another to the total force applied normal to those surfaces. It measures how slick or slippery a surface is. Frictional Force (FF) refers to the force generated by two surfaces that contacts and slide against each other, take this as an example for figure 23.

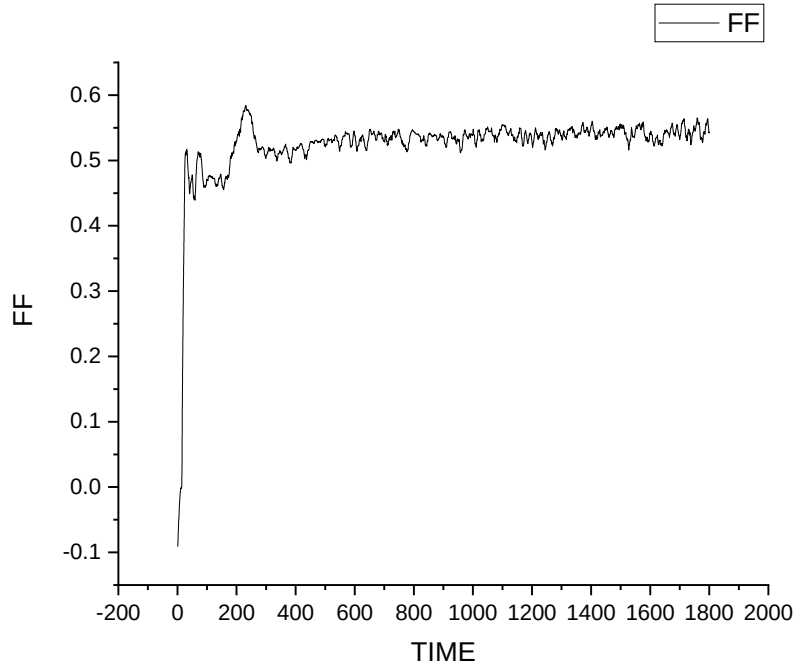


FIG. No. 24. FRICTIONAL FORCE GRAPH FOR WEAR TEST

The above graphs are plotted by using x and y values where x as TIME and y as Frictional force (FF). The time given is in seconds. In different time intervals the friction factor varies with time. There is no constant increase or decrease in the friction factor for the wear test conducted on copper coated Hastelloy-X. Frictional force refers to the force generated by two surfaces that contacts and slide against each other, take this as an example for figure 24.

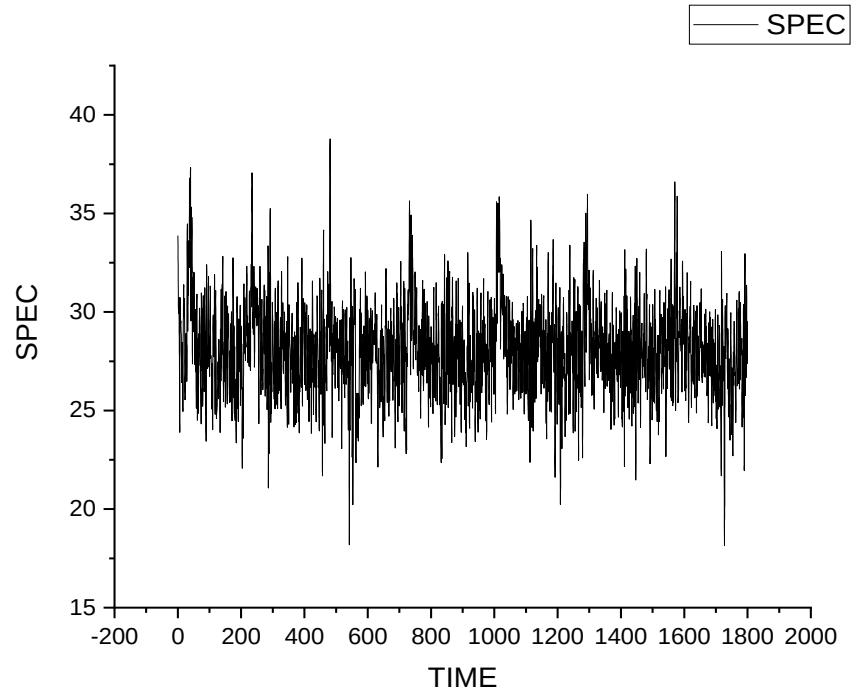


FIG. No. 25. SPEC GRAPH FOR WEAR TEST

The above graphs are plotted by using x and y values where x as TIME and y as SPEC. Time in seconds. In the wear test from the first second onwards the reaction of the specimen is taken and drawn as graph between the time and specimen reaction. Take this as an example for figure 25.

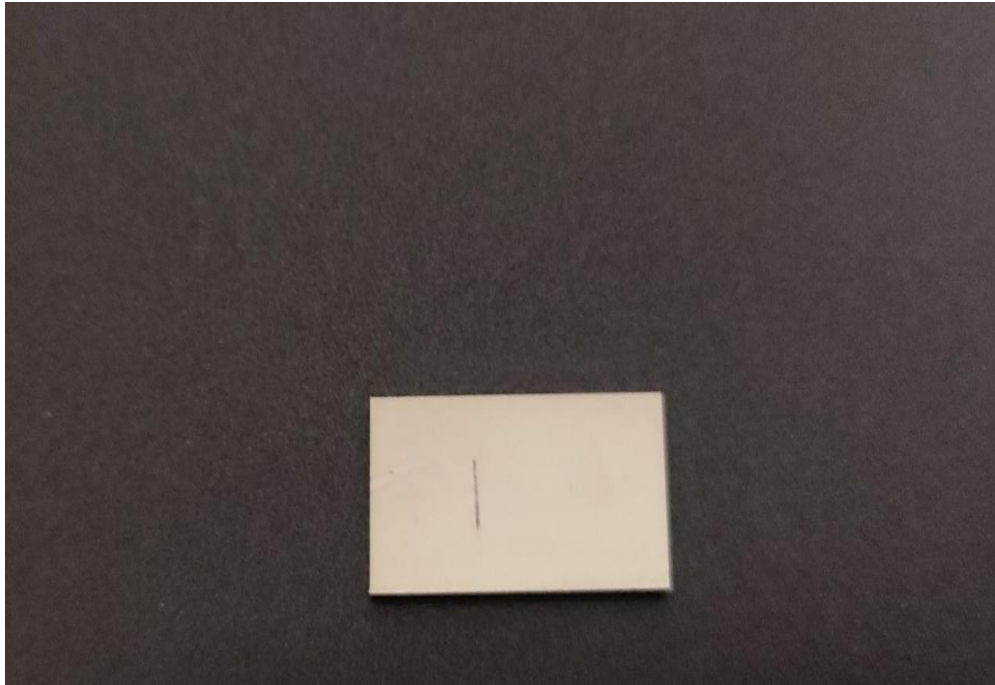


Fig. No. 26. WEAR SPECIMEN

5.4 CORROSION TEST

Corrosion testing refers to the processes conducted by laboratories so as to resolve, forestall or mitigate issues associated with corrosion. These processes may be applied in industrial materials and infrastructure merchandise, and area unit usually employed in failure analysis

5.4.1 Ni coating Corrosion

TABLE. No. 3. Corrosion results

E _{corr}	I _{corr}	beta c	beta a
587.895 mV	7.712 uA	458.6 mV	154.1 mV

E_{corr} can be defined as the potential at which the rate of oxidation is exactly equal to the rate of reduction.

Icorr is a crude attempt to say something about the corrosion process as one artificially pushes the potential either positive or negative relative to its rest potential.

Beta c – cathodic corrosion

Beta a – anodic corrosion

5.4.2 Ni coating IMP

TABLE. No. 4. Impedance results

Rs	Rct
2 ohm	568 ohm

Rs – Electrical resistance of solution

Rct – Charge transfer resistance

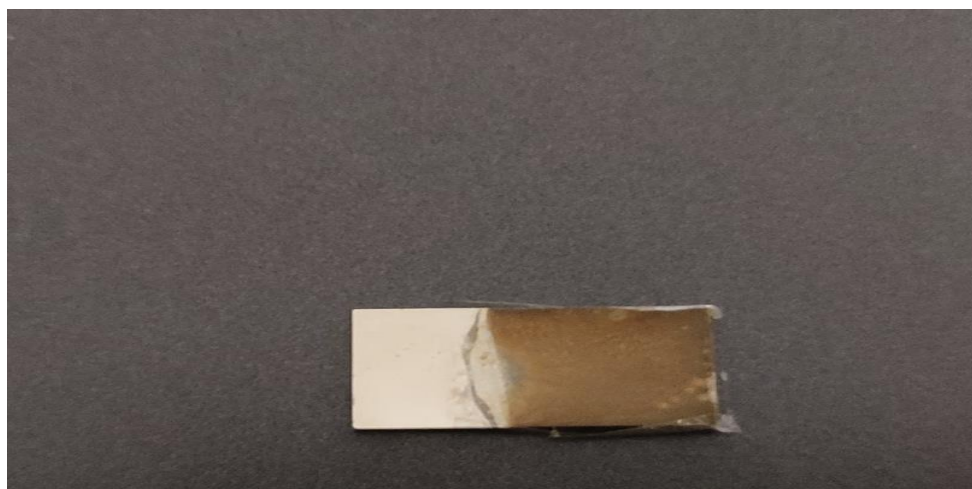


Fig. No. 27. CORROSION SPECIMEN

TABLE. No. 5. CORROSION TEST VALUES

log ($ i $ /mA)	Ewe/V
5.841404552944677	0.650566876
-1.208891913019167	0.400158346
-0.978190258745018	0.174092203
-1.007602665618071	0.175707325
-1.032123743236926	0.177294821
-1.052870944529353	0.178988412
-1.071081010171744	0.180589482
-1.087501458549732	0.182252347
-1.102468636925126	0.183891535
-1.115835151836468	0.185620382
-1.128571221027777	0.187226057
-1.140433443262691	0.188875988
-1.151493605928199	0.190583184
-1.161740878953036	0.192266077
-1.171764602327850	0.193881229
-1.181114482147773	0.195594102
-1.189780553244690	0.197234526
-1.198729114188959	0.198905513
-1.206940571812395	0.200562879
-1.215049974833081	0.202203438
-1.222429787023778	0.203868687
-1.230169678813003	0.205550835
-1.237204111824609	0.207198188

The values of corrosion test and the log and Ewe/v is noted down and the log value represents the Current density and the Ewe/v represents the potential of the working load.

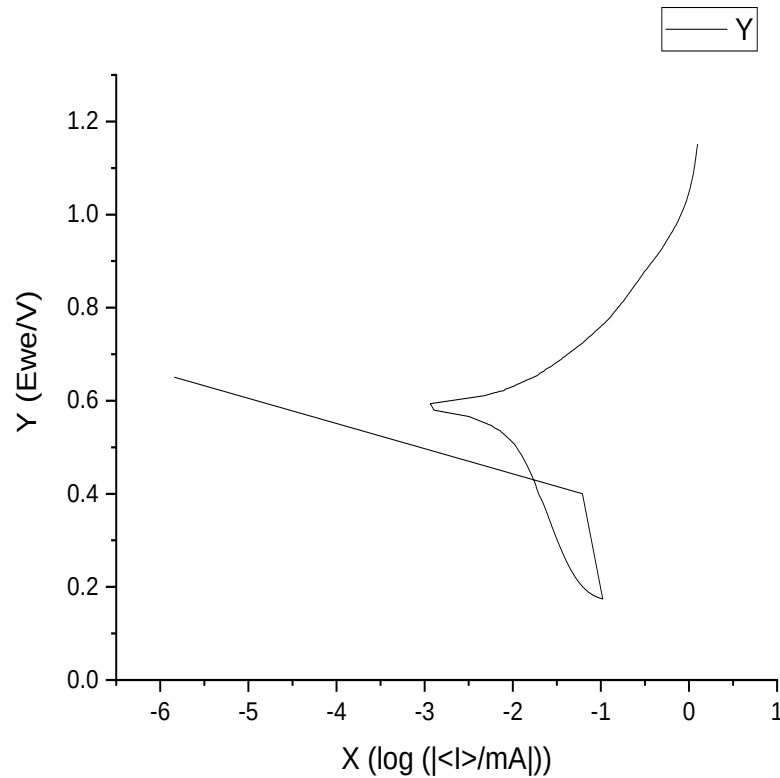


FIG. No. 28. CORROSION GRAPH

The above graphs are plotted by using x and y values where x as $\log (|<I>/mA|)$ and y as Ewe/v. If Ewe/V value is high then corrosion rate will be high at that point of $\log (|/mA|)$. The Y represents the time taken and the X represents the current density. Take this as an example for figure 28.

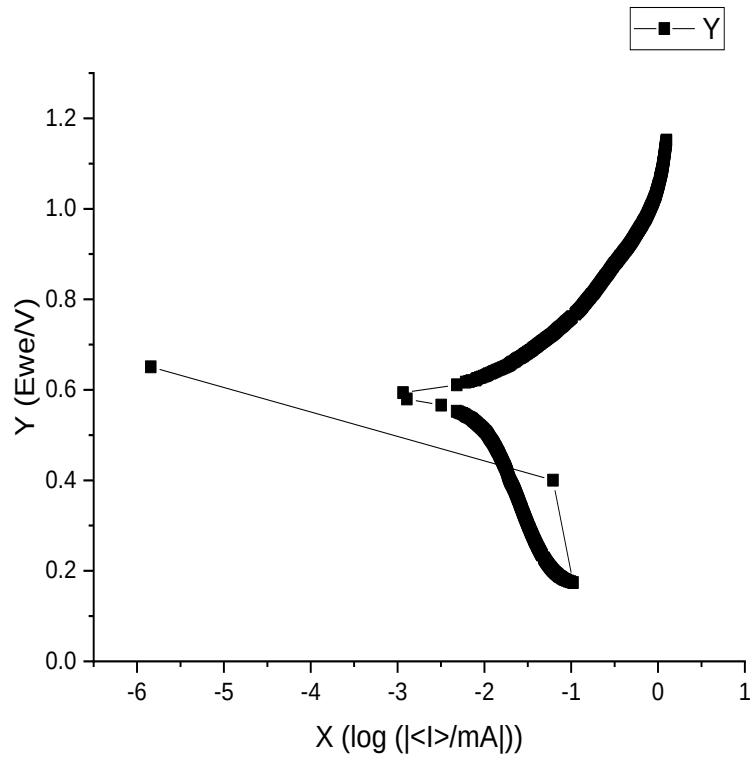


FIG. No. 29. CORROSION LOG GRAPH

The above graphs are plotted by using x and y values where x as $\log(|I|/mA)$ it represents the current density and y as E_{we}/v represents the time taken, take this as an example for figure 29.

CHAPTER VI

SUMMARY AND CONCLUSION

6.1 SUMMARY

In the present research work, Hastelloy x is been used in various industries and many vehicles in order to make it cost efficient and strong. Mainly it is been used in in aircraft industries to make it light weight it and more reliability. Nickel is used for coating in hastelloy x to make it more cost efficient and a more strong alloy. The Nickel coated hastelloy x has undergone wear test and corrosion test to understand the gear and corrosion behaviour of the Nickel coated hastelloy x.

6.2 CONCLUSION

The idea adopted by various researchers in the process of developing new Nickel alloys for creep resistance is to reduce the Stainless steel content in order to reduce the volume of Hastelloy x; as well as by adding alloying elements, which introduce thermally stable intermetallics.

Many alloy systems like Ni-Cr alloys (with Fe and other alloying elements) with right corrosion resistance. The top notch-diagnosed are Alloy six hundred (united statesN06600) and Alloy 601 (united states of americaN06601) Ni-Cr alloys with excessive-temperature electricity and creep resistance, usually age-hardenable, which encompass Alloy X-750 (united statesN07750), and so forth., are developed based on this concept.

In the present investigation, it is observed that the Al addition is also capable of improving both tensile and creep properties of Ni alloys. Therefore it is worth to study the effect of Ni addition on the low Hastelloy containing SS alloys to explore the possibility of developing cost effective high corrosion resistance alloys.

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