THERMODYNAMIC MODELING AND MATERIAL INVESTIGATION OF ZINC COATED C.I. PLATE FOR MITIGATION OF SENSIBLE HEAT LOSS IN BOILER

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CANDIDATE'S DECLARATION

I, **Pulkit Mann** (Roll no: 2K20/THE/16) student of M.Tech (Thermal Engineering) hereby declare that the project Dissertation titled "Thermodynamic Modeling And Material Investigation Of Zinc Coated C.I. Plate For Mitigation Of Sensible Heat Loss In Boiler" submitted in partial fulfillment of the requirement for the award of the degree of Master of Technology (MTech.) in Thermal Engineering to the Department of Mechanical Engineering, Delhi Technological University (DTU), Delhi is an authentic work of my own carried out under the supervision of **Dr. Pushpendra Singh** (Associate Professor) at Department of Mechanical Engineering, Delhi Technological University, Delhi, India. The current work has not been submitted to this or any other institution for the award of any degree, diploma, or fellowship or other similar titles of any sort.

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Place: Delhi

Date: 31.05.2022

CERTIFICATE

This is to certify that to the best of my knowledge, this thesis entitled **"Thermodynamic modeling and material investigation of Zinc coated C.I. plate for mitigation of sensible heat loss in boiler"** submitted by Pulkit Mann (2K20/THE/16) is his original work and has not been submitted for the award of any other degree in this or any other Institute/University.

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ABSTRACT

The life of the material and the cost associated with it is an important parameter on which our day to day engineering structures depend upon. One of the easiest and universally used methods is that of coating. The coating acts as a sacrificial barrier on substrate material to protect it from various harsh conditions that the specimen is subjected to. The function of the coating is to render protection against the degrading effects of the working environment on the specimen. This paper reviews theoretical and experimental aspects of corrosion and wear resistance of electroplated zinc on cast iron using material characterization. Also, the effect of high temperature on electroplated zinc is modeled using ANSYS software. Zinc coating is a universally used method to protect the material from corrosion because of its low cost and adhesive nature and has its application in nuts, bolts, metal stamping, automobile industry etc.

CONTENT

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Heat losses in a Boiler

No boiler is 100 % efficient, and the boiler systems undergo various kinds of heat losses which are responsible for lowering the boiler efficiency and at the same time maximize operational costs. There are various factors which contribute to boiler inefficiency and energy loss. Some of these have been outlined below:

1) Radiation and Convection Losses
2) Incomplete combustion of fuel
3) Losses due to dry flue gas
4) Deviation from ambient air temperature
5) Steam losses
6) Moisture losses
7) Losses due to excess air

1) *Radiation and Convection Losses :* These losses are incurred because of difference in the temperature of boiler surface and the surrounding environment. The surrounding environment has a lower temperature compared to the boiler and therefore, boiler losses heat to the surroundings.

2) *Incomplete combustion of fuel :* Non uniform fuel size, poor fuel distribution or surplus of fuel can lead to incomplete fuel consumption resulting in unburnt carbon being present in ash.[1]

3) *Losses due to dry flue gas :* Flue gas temperature, also known as stack temperature, measures the heat loss that occurs from the hot combustion gases that leave the boiler. Higher stack temperature results in higher losses and lower efficiency of the boiler.[2]

4) *Deviation from ambient air temperature :* Ambient air temperature refers to the temperature of the incoming air. It directly affects the net stack temperature and therefore lower values

result in lower flue gas temperature. However, changes in ambient temperatures negatively affect the boiler efficiency.[3]

5) *Steam losses :* Steam traps of leakages in pipes can lead to hot water or steam escaping the boiler and leading to energy loss.[4]

6) *Moisture losses :* Moisture in air or fuel decrease the boiler efficiency.[5]

7) *Losses as a result of excess air :* Excess air absorbs the combustion heat from the fuel in the combustion chamber. This results in reduced efficiency of heat transfer as this heat could have been used to raise steam.[6]

Of all the heat losses, which reduce efficiency by somewhere between 20-25%, 60-70% of these percentage can be accounted to heat loss as a result of exhaust gas or the dry flue gas. These losses are incurred because of difference in the temperature of inlet and outlet air. Lower heat absorption of the boiler and high temperature of the inlet air both result in increased loss from the outlet of high temperature flue gas. Therefore, reducing the stack temperature is a viable strategy to reduces the heat losses and increase boiler efficiency.

STACK LOSS

The heat losses in the stack of the boiler are the major losses in the boiler having about 20- 25 % loss. the flue gases leaving the system pass through the stack and are released in the environment. These flue gases have higher temperature then the ambient temperature and therefore a potential to be used as useful work

The heat loss that occur due to release of hot flue gas is huge and impacts the efficiency of the boiler as well as on the environment. The heat flue gases can be divided into 2 parts :-

1) Latent heat loss of flue gas
2) Sensible heat loss of flue gas l

Sensible heat loss of flue gas is also known as heat loss due to dry flue gas. It contains flue gases at superheated temperature and there is no moisture present

WASTE HEAT RECOVERY

Water heat recovery systems are used to extract the heat from flue gases to elevate the water temperature or to generate steam. The exhaust from boiler in the form of hot flue gases has to be released in environment. Since these flue gases have high temperature, a lot of heat is wasted to the environment. The heat water heat harmful effects on atmosphere as well. So the waste heat recovery system is installed in boilers to extract the maximum heat possible leaving in the form of flue gases. The heat extracted is used to generate steam or to increase the temperature of boiler. Hence the heat recovery system are installed to improve the system efficiency. They are because they are

1) energy efficient

2) cost effective

3) eco friendly

4) economic

They return their cost of installation in a very short span of time.

The amount of waste heat from the source depends upon -

1) fuel composition

2) amount of fuel used

3) exit temperature of flue gases

4) amount of flue gases leaving from exhaust in boiler

1.2 Introduction to coating

The surface of the material is continuously eroded by the corrosive environment to which a material is subjected. The material is subjected to harsh conditions and fractures due to stresses developed on the material. The specimen is not able to perform to its optimal level and fails beforehand. For allowing the material to perform its function without any interference, we coat the material with a layer of another material which acts as a sacrificial barrier and increases the life of the substrate and helps in the proper functioning of the specimen. This type of coating can be done by various processes such as paint, electroplating, high velocity oxy-fuel technique, plasma spray technique, etc. The type of coating and process used for coating is influenced by a range of factors which makes the coating a viable option.[7]

Electroplated Zinc is one such coating. In this process, we cover the substrate with zinc material by passing a current through the solution containing zinc. The process is a universally accepted process for protecting the material from corrosion because of its high corrosion resistant properties and lower cost.[8] Corrosion puts a huge strain on our economy, and a huge amount of wealth is spent on protecting our surfaces from corrosion. The application of electroplated zinc is in many sectors such as military, automobile, construction etc. Its usage is common in nuts, bolts, metal stamping etc. The common test to check the corrosion resistant nature of the specimen is the usage of salt spray test. The test aims to expose the specimen to a harsh corrosive environment with five percent sodium chloride at 35 degrees Celsius temperature. It gives the result in the amount of time required for the specimen to corrode. In zinc, the corrosion occurs when the white rust is formed, also known as zinc hydroxide.

Wear is the removal of the material when 2 or more than 2 materials come into contact with each other when there is relative motion between them. The pin on disc wear test is utilized for measure the wear of the material when there is a relative motion between the disc and the pin. The information obtained from this test is the wear rate, frictional force, coefficient of friction and variability of temperature on disc and pin.

In high temperature applications, we need to prevent heat loss because as per the second law of thermodynamics heat at higher temperatures is more effective. To enhance the efficiency of energy of vehicle engines, various aluminum alloys substituting steel components have been developed widely for the reduction in weight in the last few decades. But surface protection is a big concern and needs to be implemented to some aluminum alloy components. Zinc oxide shows good resistance to the high heat around temperature range from 100-300 degrees Celsius.[9]

1.3 Zinc

The barrier formed by the zinc prevents the corrosive nature of the environment to reach the underlying material and therefore zinc is also known as corrosion prevention workhouse zinc coating is an eco friendly and has gained widespread use in recent years around 1980, before that cadmium wasted which is much more corrosion resistant as compared to the zinc but is also toxic in nature and cannot be used everywhere, therefore the cadmium is replaced by the zinc in widespread use. But still, cadmium is mostly used where zinc is unable to provide the desired corrosion resistance. Zinc is one of the most abundant naturally occurring elements found in the arts crust and has a shiny blue-white appearance. It was first discovered by the German scientist Andrea Marggrafin in 1746. Zinc was used in ancient times to be mixed with copper to form brass. In its metallic form zinc is a very hard metal. Zinc's widespread use comes from its ability to form corrosion byproducts and these byproducts formed are commonly known as zinc patina. Zinc is known to keep the moisture at minimum levels which helps to reduce the rate of corrosion when compared to the metal surface that is not coated.[10] Zinc is assumed to corrode at a rate 100 percent slower as compared to cast iron depending on the environment.

1.4 Zinc and Corrosion

Zinc is one of the metals which is easily available and can be harnessed easily. Usage of zinc can be linked back to around 2500 years ago whereas in India it can be dated back to the 15th century zinc ores were mixed with brass to be used as copper by the early people after that zinc was used as an individual metal for the first time. In today's era, zinc has most of its usage as sacrificial metal and is used in the process of galvanisation zinc plating is the most common method that is utilized by most of the people to protect their metal surface from rusting. In today's time, almost 1/3 rd of the zinc used is for protecting the metal surface from the influence of corrosion which can harm the life of any metal. Zinc has the most widespread use as a protective layer for metals through the method of electroplating.[11] The most prevalent use of zinc coating is seen in the region of high moisture content applications such as marine areas and is used for bolts, nuts and automotive parts. Apart from protecting the surface of the metal, zinc coating also provides a lustrous finish to the metal surface and can provide the surface different colors such as yellow, blue, black or white. The extraordinary resistance to rusting and its low cost have made zinc to be a frequently used and favorite methods for metal protection from corrosion. The economic harm resulting from corrosion to the income of a nation as estimated by NASA is about I trillion dollars. It is the greatest enemy to any metal and impacts production and manufacturing, transportation, infrastructure etc.[12]

1.5 Zinc Rusting

When we think about whether zinc is affected by corrosion or not, the answer is simple, yes zinc does get rusted but not in a similar manner as iron. Iron reacts with oxygen and moisture present in the atmosphere to corrode away this process is known as 'rusting'. Iron reacts with the oxygen and water vapour present in our environment to be recognised as hydrated iron (III)oxide which is a brittle material that means it does not deform plastically when stress are induced in the body. Rather, it fails so the formed hydrated iron (III) oxide formed from the oxygen and water vapour in the atmosphere leads to brittle failure and are removed from the surface of the material as flakes. After removal, the surface is again exposed to the corrosive environment hence making it a continuous eroding process which completely destroys the metal and sorted its life.[13]

But when we look at corrosion reaction in zinc, they are a bit different from the above stated process. The zinc layer first undergoes a reaction with oxygen present in the atmosphere to become zinc oxide. This zinc oxide itself is a harder surface than pure zinc. The formed zinc oxide further reacts to hydrogen present around the atmosphere to become zinc hydroxide, which then finally reacts with carbon dioxide present in the nature to become zinc carbonate. This newly formed zinc carbonate has properties of a ductile material and is a protective coating which protects the substrate from corrosion. Zinc carbonate is chemically stable, resilient and sticks firmly to the surface of the substrate hence preventing the material to erode away like flakes of hydrate iron oxide. The zinc carbonate reacts with the environment but does it at a considerably slower rate due to which it is used for resistance against corrosion. Since this upper layer doesn't react to the lower layer of substrate, it is not able to come in contact with the moisture and oxygen present in the atmosphere. Though carbonate forms a protective layer, zinc keeps on reacting to the environment causing it to erode. Steels corrodes at a rate 30 times faster when compared to the zinc therefore in an open environment zinc coating is much more stable for the sample and increases the service life of the sample.[14]

Zinc has two types of rusting. One of them is white rust and the second one is red rust. When the rusting happens in an open environment where there is a complete flow of air over the surface of the material the rust formed is red in the coulee and is known as red rust. This is the zinc reacting with the environment to form rust while on the other hand if there is no free flowing air over the specimen the type of rusting happens is known as white rust. This white rust is the zinc hydroxide formed due to failure of reacting of zinc hydroxide with the carbon dioxide particles in the free flowing air over the specimen to become zinc carbonate. The white rust formation has a simple remedy and that is simply keeping the specimen in open free flowing air so that red rust can form or brush it off the materials surface.

1.6 Zinc Plating

The zinc not only acts as a physical obstruction from the environmental corrosion, but also acts as a sacrificial metal by reacting with the atmospheric oxygen to become zinc oxide. This furthermore reacts with moisture in the atmosphere resulting in formation of zinc hydroxide. Next reaction with carbon dioxide in the air leads to form zinc carbonate. This zinc carbonate is one of the most significant reasons that zinc is able to protect stem and cast iron from corroding away in a corrosive environment by sacrificing themselves

1.6.1 Electroplating

Zinc plantings are used to protect iron and steel against the harmful effects of corrosion. The process simply involves covering the metallic surface with zinc using the process of electrolysis. A narrow coating of zinc metal is deposited onto the surface of another metal that has to be saved from the deadly effect of corrosion.[15] Zinc plating basically consists of 5 steps following which electroplating can be achieved. The process includes various equipment and machinery and requires highly skilled labor as it is a very technical process.[16] The components needed are an ancillary tank, rectifier, reservoir and a plating station. The steps of electroplating can be listed as follows:

A) Soak clean

B) Electroclean

C) Acid pickle

D) Rinse

E) Zinc electroplate

F) Chromate

G) Warm rinse

H) Dry

<u>1) Cleaning The Surface</u>

Cleaning of the surface is a very important process because a surface full of dirt can will not allow the zinc to be deposited on the surface of the sample and will peel off in the form of flakes causing harmful effects to the coating. Mostly oil, dust and rust are eliminated from the surface. Alkaline detergent is used to keep the zinc intact to the surface of the specimen otherwise peeling and blistering are the 2 problems that can be faced when the coating is dried. This process simply involves putting metal into the bath for 10 minutes at a temperature between 20-30 degrees Celsius above ambient temperature. Then rust is mainly removed by acid treatment, this process is commonly known as acid pickling. Further electrocleaner is used when we have to remove particles at microlevels. This process is mainly used when we have accurate dimensions and longer life.

<u>2) Setting Up Electrolyte Solution</u>

A process known as a plating bath is used in which various chemicals and a zinc metal ionic solution are added and the substrate is immersed in this solution giving it a specified thickness of coating and characteristics

Type of zinc electrolyte includes:-

Acid Zinc: - this technique is very popular for high efficiency, fast deposition and better covering power though it can provide uneven thickness distribution

Alkaline Zinc: - Though the rate of deposition is slower compared to acid zinc it provides an even and uniform thickness of zinc on to the metal surface.

3) Zinc Plating

Zinc plating involves the passing of DC current through an aqueous solution for a pre defined time period. The current is applied at the anode end and the metal is kept at the cathode end. The zinc ions rebased from the aqueous solution sticks to the substrate present on the cathodic end. The aqueous solution also helps in distributing the current uniformity throughout and giving a uniform thickness to all components.[17]

Basically, there are 2 methods of electroplating known as rack plating and barrel plating, rack plating is used for large size components where the movement of the specimen is difficult on the other hand barrel plating involves rotation of the barrel to produce homogeneity because of their small size.

4) Effect Of Chemical Agent

Different chemical agents are used to produce different physical and chemical traits. Variation in thickness and characteristics can be caused by the change in current, soaking time, different chemical agents, variation in temperature and time.

5) Post Treatment for the Finished Product

The final product that is substrate coated with zinc is then washed under running water to completely remove potential surface contamination, this cleaning by running water may be required many times. Then the final product is dried in a machine having a high number of rotations.

Fig 1.1:- Electroplating Barrel Machine

Fig 1.2 :-Drying Machine

1.6.2 Factors to be Considered for Zinc Plating

These different factors are solely responsible for the variation of the physical characteristics of zinc plating. These factors affect the thickness color characteristic. Most of these factors can be controlled by the operator of the machine.

1) Current Density: - The amount of current flowing from anode to cathode highly affects the thickness of coating onto the substrate material. The higher the current higher will be the thickness of the coating but if the current exceeds its practical limit of coating it can result in the formation of wrinkles on the surface of the substrate

2) Temperature: - Temperature affects zinc coating by causing variation of hydrogen diffusion on the cathode which leads to enrichment of additives and higher consumption of brighteners. A brighter zinc deposit can be obtained by increasing the current density and temperature simultaneously; on the other hand, stable current density with an increase in temperature results in large metallic crystals formation.

3) Concentration of Zinc Deposit: - Brightness of zinc coating depends inversely on the concentration of zinc; a higher concentration leads to a dull surface and lower concentration results in the bright coating on the surface of the substrate.

More factors contributing to zinc coating are as follows: -

1) Cathode and anode positioning

2) Condition of the substrate surface

3) Agitation of the bath (or lack thereof)

4) Use of additives such as surfactants and brighteners

5) Concentration of hydrogen ions

6) Time duration of actual plating

7) Degree of filtration of the zinc plating bath

8) Efficiency of the rinsing operation

9) Concentration of pollutants and contaminants in the plating bath

Zinc coatings mostly are of dull grey color but can be achieved in different colors such as yellow, black, and blue color by using suitable chromate.

1.6.3 Electroplating Solution

There are 3 major ways to electroplate the surface of the substrate using zinc by the process of:-

1) Cyanide
2) Alkaline non-cyanide
3) Chloride

1) Alkaline Cyanide Zinc Plating

It was the most used process for electroplating for a long time. The conditions required for running this process are easy as compared to the other processes. there are 2 ways to make the bath for electroplating using this process. The first one is to use caustic, sodium cyanide and zinc cyanide. This is the process that involves more labour force and needs proper caution as the temperature can reach upto 120 degrees Celsius.

The next process involves a larger material cost but less labour and is much hastier as compared to it. The process requires to soak alkaline cleaning followed by electro cleaning. In this process, if cleaning is not done up to the mark it is not of much damage as the plating bath will clean it completely itself. After the step of cleaning is finished, we focus onto the acid pickling which is done using HCl (20-30%) at ambient temperature. chromate coatings are a must after this process is over.

Equipment and operating parameters: - Tanks made for electroplating need to be covered with the rubber so that it is not able to conduct the electricity on the passage of electricity. The material of tanks can either be low carbon steel or PVC.

The current and voltage requirement varies for the barrel and rack process. For the barrel process, the current ranges from 25-55 A and the voltage varies from 6-15 V whereas for the rack process the voltage varies from 3-9 V and the current varies from 55-210A.The ductility, uniformity and chromate receptivity that we receive after using the alkaline cyanide zinc plating process is higher and better when compared to the chloride process. More singing zinc deposits may be good for appearance but it increases the stress on the surface and hence impacts the performance of the coating. Brighter deposits are a result of a higher number of organic deposits.

2) Alkaline Non-Cyanide Zinc

Using the low and high metal bath we can obtain a uniform coating with varying thickness and higher productivity. The most essential criteria to keep in mind for this process is to maintain constant zinc levels as it is the most critical factor. this type of process can be performed via making bath makeup in the following ways:-

a) Utilizing caustic soda and zinc oxide

b) Utilizing ready made zinc concentrate

c) Utilizing anodes of zinc

Filters are mandatory for the following process. Low carbon steel is often the material for the anode.

3) Chloride Zinc Plating

This is one of the oldest processes used in zinc plating and has the highest efficiency of about 95%. The most important parameter to use this process is its efficacy for coating materials like cast iron. But it has a major disadvantage that the thickness of the deposited zinc layer is not uniform and maximum at the contour, also the solution is corrosive In nature and requires corrosion resistant equipment. In this process, zinc chloride is used as the source for zinc in the bath. Potassium chloride and ammonium chloride are the 2 important solutions for the bath. Potassium chloride provides conductivity on the other hand that later helps with waste treatment problems and also provides a wide range of application.[18]

1.6.4 Type of Zinc Plating

Zinc plating is covered with chromate coating because of zinc, which is a reactive material and chromate is also responsible for imparting colours to the coating and therefore can be classified according to the different colours visible on the coating after passivation. The colour ranges from blue, yellow, and olive drab to black. Different colours have different intensities of resistance to corrosion varying from the maximum for yellow to the lowest for blue. The intensity to white rust corrosion means that the chromate coating has been vanished or penetrated and zinc is being corroded. The zinc coating can be distributed in the following way according to the colour of the plating.

1) Yellow Zinc Plating:- Mostly used in the automobile sector this coating provides the most resistance against the corrosion in comparison to the three of them

2) Blue-Clear Zinc Plating:- This remains the most frequently used zinc coating that is available on the nut, bolts, metal stamping, etc. It provides the lowest level of resistance to corrosion.

3) Black Zinc Plating:- This advantage of this is that it provides a moderate type of resistance against corrosion.

1.6.5 Benefits of Zinc Plating

Apart from its excellent corrosion resistant properties, there are many more factors that make zinc an incredible material to coat the surface of the substrate, some of the factors are: -

1) Low cost:- We can get incredible coating from many different materials such as gold, palladium etc., but when we calculate the expenses related to this type of coating it is better to change our specimen after corrosion rather than applying a coating of gold or palladium. Therefore keeping the economical factor into mind the zinc coating along with its excellent corrosion resistant properties is economically viable because of its abundance in nature. It is the 34 most abundant material present on earth which makes it easier and cheaper to extract it.

2) Increased strength: - Zinc being a relatively light material provides strength to the substrate with a lower weight ratio that is the strength increased is much in respect to the ratio of material added.

3) Low stress deposit: - A zinc coating will relieve the substrate material of unwanted stress accumulated on the surface of the material.

4) Ductility: - The phenomenal ductile nature that is to show high plastic deformation when load Is applied to it helps to cover the surface of metal completely.

5) High temperature tolerance: - Zinc cannot be used at very high temperature though it has phenomenal properties at ambient conditions. Zinc can be used in the temperature range of ambient to 100 degrees without much decrease in corrosion resistance ability. It cannot be used above 260 degrees Celsius and shows a considerable dip in its corrosion resistance ability over a temperature of 100 degrees Celsius.

6) Control of hydrogen embrittlement: - Hydrogen diffusing on the surface of the materials causes the material to lose its ductility and become more brittle and therefore loses its ability to deform plastically which leads to a sudden failure by cracking and there are no symptoms beforehand causing fatal accidents. The hydrogen embrittlement on zinc coating has negligible effect and therefore does not affect its ductility, making it a reliable coating for application in various important projects.

7) Friendly to environment: - Zinc pate is bio friendly material in comparison to its cadmium counterpart, which though more corrosion resistant is harmful to the ecosphere. In today's generation where there is a major focus on sustainable development and protecting our environment zinc has come as a shining new option which not only provides long life to the substrate material but is also friendly to the biosphere giving the coming generation a chance to live life to the fullest.

8) Aesthetic appeal: - Though the zinc itself is dull grey metal, the usage of chromate or colours post treatment can help achieve lustrous and customised finished products.

1.6.6 Zinc Alloys

There are different alloys that are available for zinc that can be used according to the desired physical and chemical properties required. One of the alloys available is zinc -nickle alloy which has an excellent corrosion resistant property and can be seen to be mostly used in the automobile sector. The next coating that can be used tin-zinc alloy which in combination with excellent corrosion has ideal weldability and electrical conductivity.

Similarly, we can use zinc-chromate so that we can have higher corrosion resistance and wear resistance also it is useful for providing us with different colours.

1.6.7 Application

Electroplating is used in the oil field, marine, military, medical and automobile sectors with intended application in large format photographic printers, valves, and pump parts. Electroplating can be used on small as well as large size substrates. The widespread use of zinc plating is visible in automobile parts such as brake callipers, brake pipes and most of the nuts, bolts, washers, metal stampings, fasteners are zinc plated giving them a higher lifeline and making them more economical. Zinc coating also has its application in general hardware materials.

Zinc is used for coating materials by painting them due to their high adhesion property. By depositing as a layer on the substrate it keeps the material safe from corrosion by acting itself as sacrificial material.

Zinc has its application in military vehicles and equipments like tanks, armoured personnel carriers, etc which are required in different weather conditions for proper use.

The thickness of commercially plated zinc varies from 0.1 mm to 1 mm. It is affected by various factors like intensity of current, time duration of current applied etc. So, managing various parameters the operator can get the required thickness accordingly.

1.6.8 Drawback of Zinc Plating

There are no major problems with the zinc coating. Though it shows excellent results against corrosion in the case of seawater the salt acts as a catalyst in the process of corrosion and in comparison to silicon shows less corrosion resistance. Also, though zinc has excellent adhesive properties, it might not be able to get deposited on the internal parts of the sample and hence be subjected to early failure in complex objects.

1.6.9 When to Avoid Zinc Coating

Zinc coating has plenty of benefits but in some situations, zinc plating is not advisable and is not able to protect the substrate from harm. Specifically, at a temperature higher the 260 degrees Celsius, zinc plating cannot be done on the steel components. Also, properties like corrosion resistance are not as effective above the temperature of 100 degrees Celsius and a decrease can be observed in protection against corrosion.

Another area where there is a restriction on the optimum usage of zinc coating is the seawater or tropical environment because the rate of corrosion increases due to the presence of salt in water and it affects the life of coating in a highly degrading rate. High moisture content does affect the coating but not at a rate similar to the salt water which degrades the coating at a much quicker rate.

In the application of moving parts also zinc coating may not be an ideal material to be used because of the abrasive nature of the particles the upper coated layer of zinc is removed causing the formation of crack which becomes a breeding ground for the material to fail.

1.6.10 Health Impact

Since electroplating involves a lot of chemicals therefore safety is a major area that requires undivided concentration. More than that every zinc product should be treated with precaution and proper cleaning of the sample is highly recommended one of the most important to keep in mind is to ever let cyanide and acid to come in contact with each other nor they both can be stored together as this can lead to formation hydrogen cyanide gas which is a deadly gas .apart from above instructions everyone entering the lab should wear proper gloves, helmets, goggles aprons etc when they are operating near solutions

1.7 Salt Spray Test

The salt spray test is the most used test for checking the corrosive resistant property of the material. It is one of the most performed experiments, not only because of its ease to perform the procedure but also due to its low cost. Salt spray test is done to check the corrosion resistant nature of a material. This test involves keeping the specimen in a controlled corrosive environment where an atmosphere of high moisture is maintained. The pH of the test is maintained to be a little bit acidic by adding the five percent sodium chloride solution which is higher when compared to the marine environment or sea water where the maximum limit of the salt percentage varies from 1.9 percent to 3.1 percent as stated by Akin Akinci et al [6]. It is a simple test which involves keeping the specimen in 5 percent of NaCl solution at a given fog level. The standard ASTM B-117 method is the most used specification. The temperature maintained for the procedure is 35 degrees Celsius. The specimen is kept in a closed cabinet to keep it under constant or stable condition. This is the most frequently used test to determine the resistance against corrosion by the specimen. The procedure is carried out till we can see the build up of white rust on the specimen surface. The white rust formed is analyzed under a microscope to determine whether there is a formation of white rust or not. Sometimes we check for the formation of more deadly red rust.[19]

Though it is a universal test the results from this test are debatable and cannot be matched with the results when the specimen is kept in an open atmosphere. In the natural atmosphere, the condition differs from time to time and day to day. In the middle of the day, there is a high temperature which increases the rate of corrosion. On the other hand, there are nights where temp decreases and the rate of corrosion also decreases. On some days there is high moisture content in the atmosphere and some days are very dry. Therefore, the corrosion process varies from day to day and there are no fixed parameters which can be set for the experiment for the result to give the exact same result. So, the result obtained from the salt spray test cannot be used when we are calculating the material's life in the actual environment and it only gives a rough indication of whether a material will be rusting in a range of time depending on the environment. Still, it is commercially used at a large scale and the results inferred from the test are used to indicate the ability of the material to resist corrosion

Advantages: -

1) This test is to perform and does not require any complex procedure to be performed.

2) The procedure involved remains the same for all the experiments.

3) Material required does not interfere with the process involved.

4) The cost related to this procedure is low as compared to other experiments.

5) The results achieved do not take a long period of time to be achieved and can be generated faster than when the specimen is kept in the open atmosphere.

6) The shape of the material is not a problem for successfully performing the experiment.

7) It is a universal test and can be performed anywhere and does not require high temperature instruments so the cost involved is low.

8) Gives appreciable results even in case the material is coated.

9) It is an easy process which gives results which are easily understandable and can be used directly without using any mathematical formulation.

10) It is a boon for engineers who want to test the area that will be corroded first so that they can make it stronger by plating or adding extra material.

Disadvantages:-

1) It is a specimen destroying test that is after performing the experiment the specimen cannot be used to give its optimal result because its surface gets corroded and the strength of the specimen decreases.

2) The results produced from the test are debatable as the environment created by these tests is not completely similar to the natural atmosphere which changes from time to time.

3) Welding or other manufacturing operations can impact the result of the test.

4) Stress can alter the corrosion resistance properties of the specimen.

5) 2 different materials giving a result in a set spray test can be assumed to give the same result when they are corroded in the atmosphere and therefore, the relation set in the salt spray test between two materials cannot be used in the same manner in practical usage.

6) A specimen kept in a salt spray test may give different results as in an actual environment, meaning, for example, we can see a steep increase in the corrosion of the specimen in a small time scale in a salt spray test but in real life, we cannot see such a steep increase in such a short period of time. The difference is simply maybe because continuous immersion in salt water has an effect on the specimen surface.

The surface of the specimen is cleaned with ethanol and then rinsed with water. The parts containing cuts or designs having major cuts are covered with the tape so that corrosion does not affect these parts. Due to the presence of cuts, the corrosion will have a higher impact on these parts as compared to other areas of the specimen.

The test also is helpful in engineering applications where we have to find the area which is most weak and prone to attack. This helps engineers to keep their focus on that specific part of the structure. This part of the structure can be treated in various ways so that the part does not lead to the failure of the structure. The part can either be coated to increase their life or the thickness of the parts can be increased in comparison to where we have to increase the thickness of the complete structure to increase the life of the specimen. This not only saves the structure but also decreases the cost associated with a project proving to be a vital experiment that not only saves them money but also gives a fair amount of idea about the weakest point of the structure.

1.8 Wear Test

1.8.1 Tribology

Tribology is the study of surfaces coming in contact and having relative motion between them at a specific load. It deals with friction, wear and lubrication when there is relative motion between surfaces of specimen coming into contact. This is an important subject as the three factors that are lubrication, friction and wear are very important factors not only considering the life of the structure but also considering the cost related with it. A balance is required between all of these factors for optimal results. As we know that all of these factors have advantages as well as disadvantages. Without friction and wear we will not be able to perform our basic mechanics processes such as cutting, grinding, cutting, polishing, rolling etc. We can think of any process that requires motion that will not be possible without friction. Simultaneously, large values of friction and wear lead to spike in the power usage for machining. This directly results in increased removal of metal from structure, reduce the life of the material and restrain the motion. Hence for a given range of the above factors, we try to get the optimal use by studying tribology.[20]

1.8.2 Wear

Removal of metal from the point of contact of 2 metals when there is relative motion between them is what we call wear.[21] This phenomenon is much more visible in a soft material in comparison to a hard material, though the hard material also may suffer from the removal of metal but it will always be less in comparison to the softer material with which it comes into contact. Hardness itself is material property to withstand surface scratches or indentation. It can also be defined as resistance to abrasion or can also be defined as resistance to shaping or deformation hardness is a valuable parameter which affects the surface of the material. Therefore, we can conclude that hardness is a surface phenomenon and not a volume phenomenon. The harder the material the less will be wear. Harder materials are more wear resistant whereas softer materials do not resist wear as well as harder materials. There exists a direct proportionality between wear resistance and hardness of a material, while wear and hardness of the material are inversely proportional to each other. Wear is a complex phenomenon and cannot be defined in a simple way on how wear actually will occur it consists of many mechanisms that can be micro-ploughing, welding, micro-cutting, plastic deformation, fracture, melting of specimens when they are in contact with one another and it is not always that wear occurs only due to any one of the above mentioned mechanisms it may be a combination of 2 or more of the above mentioned mechanisms.. controlled wear has its advantage and is used in various mechanical processes such as marching, grinding, polishing etc. wear is defined on the basis of the type of wear that occurs. Wear can be divided into following types:-

1) Abrasive wear
2) Adhesive wear
3) Surface wear

4) Fretting wear
5) Erosive wear
6) Corrosion and oxidation wear
7) Impact wear
8) Cavitation wear
9) Diffusive wear

1. Abrasive wear:- This type of wear occurs as a result of relative motion between a hard material and a soft material and the hard material cuts and plows the surface of the soft material or it may also be possible that a foreign particle enters between the surfaces of materials that are in relative motion to one another . It mainly involves plowing and cutting mechanisms. It can be divided into 2 types that are two body abrasive wear and three-body abrasive wear.

2. Adhesive wear:- This type of wear occurs when the peak of surfaces of the materials comes into direct contact with each other, the materials of the peaks automatically gets welded known as micro welding due to the high temperature caused by the rubbing action of the surfaces that came into contact. To avoid this type of wear, lubrication is used which acts as a barrier and do not allow the materials to come in direct contact with other.

3. Erosion wear: - This type of wear occurs when the kinetic energy of the particles in the flow is targeted and repeatedly impacts on the surface of the material. This occurs when there is a fluid flow, so it is mostly observed in places like pumps, turbines, impellers, fans, nozzles etc. It has a huge impact on the surface of the body. The most important factor to be considered in erosion type of wear is the hardness factor which decides how much the material will erode. The harder the material lower will be erosion and vice versa. It can be classified into 3 types 1) solid particle erosion 2) cavitation erosion and 3)liquid impact erosion.

Erosion may many times occur with corrosion and is known as corrosion erosion. In this process, the material is degraded by both processes of corrosion and erosion.

3. Fretting wear: - This type of wear is similar to adhesive wear the only difference between them is that In fretting wear the wear occurs due to vibration between the material surfaces. The vibration causes the movement of the specimen within a range of some micrometres. Due to less movement, the debris formed falls at the place of specimen positioning and then plays a factor in wear.

4. Surface or Fatigue wear: - Fatigue occurs when the material is exposed to cyclic loading. The stresses developed either due to rolling or due to rolling and sliding causes the cracks to develop on the material surface and mitigates the repeated effect of stress cycles to complete failure of the material. The stresses induced may be due to the thermal cycling

5. Corrosion wear: - Corrosion wear is the type of wear where the corrosion formed by the corrosive environment which is what in nature is wore by the action of sliding. The most common type of wear that is encountered is oxidation wear where the oxide layer is deposited on the metal surface and when motion occurs between the surface of the particles the layer is worn out. The corrosion formed is mainly due to the effect of a humid environment and high temperature.

6. Impact wear:- It occurs when there is a dynamic contact by another solid body. Its importance is easily understandable in the process of mining where 2 hard materials come into contact and there is relative motion between them. In such type of situation, the answer t high wear is to select material with higher wear.

1.9 Pin On Disc Wear Test

Pin on disc experiment is a simple experiment which is used to calculate the wear and friction on the surface of the material.[22] It is one of the most used tests to calculate the wear and friction in the material because of the ease involved with the experiment. The experiment involves a pin and a disc. The disc is rotated and the oil is kept stationary on the surface of the disc. The material of the pin depends on the hardness of the disc in most cases the pin is taken to be harder than the material of the disc. As the disc rotates there is wear on the surface of both disc and pin. The shape of the pin chosen can differ from spherical to cylindrical depending on the user and these shapes are taken due to their simplicity. The dimension of the disc can be adjusted but mostly varies from 30- 45 mm length wise and for diameter, the dimensions possible are 8, 10 and 12 mm. The dimension of the disc is taken to be 100 mm. The mass of the pin is measured before and after each and every experiment. After every time the pin rotates on the disc it is cleaned in acetone and then the mass is measured. The difference in mass generally occurs in milligrams so the weighing machine used has to be sensitive for the small change in mass and the reading of mass has to be taken at least 3 times in a single take and then the average of the obtained values is taken. There are different parameters that are considered in the pin on disc wear test. These parameters include weight or load, wear radius, temperature, sliding distance, revolutions per minute, time, and velocity. Keeping one parameter as constant, we can observe and analyse the changes that occur in the wear of the material. The machine is connected to the computer where we can obtain the values of friction, coefficient of friction, wear and change in temperature of disc and pin as the experiments goes on. The graph is plated of the above parameters with respect to change in time. To change the temperature heater is incorporated in the machine and the facility to change the temperature of both disc and pin is provided. The temperature range varies from ambient to a few hundred depending upon the machine. The coefficient of friction shows a higher value at starting but then becomes almost stable. The reading of the coefficient of friction is taken to be at the stable curve region because the higher values in starting are due to the roughness on the surface of the disc and is known as running. It is simple rubbing a pin on a disc experiment but there are some important factors that are to be considered. Following are the factors that are considered when performing the pin on disc experiment: -

1) Pin shape:- Any pin shape can be used from spherical to cylindrical. For flat faced pin we have to take the angle formed by the oil with the disc within 2 degrees otherwise the result will be affected.

2) Pin alignment:- For a flat pin the edges should not be so much sharp that it causes chipping rather than wear.

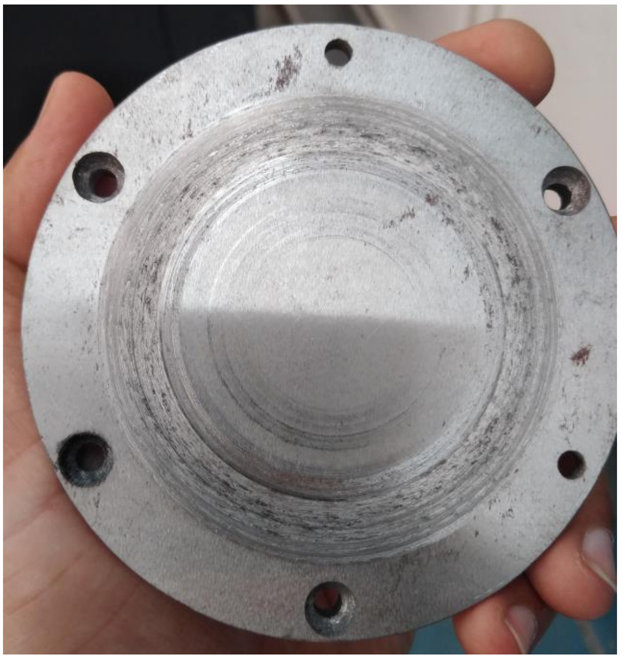

Fig 1.3:- Disc For The Pin On Disc Wear Test

3) Pin material: - The choice of the material simply depends on whether the disc is treated as harder or softer in comparison to the pin. The wear on the surface of the material occurs mainly on the material that is soft and therefore the material is taken softer will wore faster in comparison to harder material. If the disc is softer then ploughing action on the disc will be more considerate. If the pin is softer then the decrease in height of the pin will be more significant.

4) *Pin location: -* The object of the pin on the disc is to merely touch the surface of the material of the disc but to avoid the worn off particles to come in between the pin and disc the pin is forced a bit on the disc surface.

Fig 1.4 :- Experimental Setup For Pin On Disc Wear Experiment

CHAPTER 2

LITERATURE REVIEW

2.1 Research Background

Zinc coating still has a lot of capability to grow and be used further in the field of coating. Zinc nanoparticles are being used in place of conventional zinc as stated by Partha S. Swain et al[23] to be more accurate the zinc oxide nanoparticles and their anti-corrosion property depend on the zinc concentration as stated by R. Aboorvakani et al.[24] Apart from this there are many other zinc alloy coatings that are used for example nano zinc phosphate coatings are used for improving the corrosion resistance of mild steel as also discussed by M. Tamilselvi et. al.[25] Zinc and zinc alloys are used in wear resistance and they provide resistance against wear depending upon the composition of the metal alloy as stated by N.C.Hosking et al.[26]

S No.	**Coating**	**Substrate**	**Method**	**Major finding**
1	zinc-nickel, zinc-cobalt, zinc-iron, zinc-manganese, tin-zinc and zinc-chromium	Steel	Electro plating	• Despite lower the cathode efficiencies of the alkaline processes, a uniform distribution of current to provide uniform electro deposit over the cathode surface is observed. In contrast, the acidic processes possess high cathode efficiency which, of course, means distribution of current and hence throwing power poor.[27]
2	zinc - nickel	Steel	Electro plating	• Decreasing the amount of ammonium chloride in chloride zinc plating can significantly improves cost efficiency and increase the quality of plated parts.[28]

3	zinc - nickel	Steel sheet	Electro plating	● Different phases are observed for electrodeposited zinc-nickel alloy. ● The zinc concentration increases with time, but it results in appearance of the peak value of nickel as well as enrichment of nickel in the coatings.[29]
4	Tin-zinc	Steel	Electro plating	● The tin-zinc electrodeposits display both properties: barrier in form of tin and sacrificial property of zinc. ● Zinc dissolution was observed solely at the bottom of the pores. Meanwhile, on the outer surface, only the hydrogen evolution reaction occurred.[30]
5	Zinc-Cobalt	Steel	Electro plating	● Morphology and composition of the deposits are affected by both temperature and electrolyte composition. ● Alloy is made of single phase of a solid solution of cobalt dissolved in zinc within a hexagonal crystal system.[31]
6	tin-zinc	SS-304	Electro plating	● The less zinc content in the deposit, the more rapidly its OCP increased.[32]
7	tin-zinc	Steel	Electro de posited	● Zinc was seen to dissolve preferentially from the Sn-Zn coating.[33]

8	Zinc–Nickel	mild steel	Electro de posited	● For the zinc-nickel coating sliding against stainless steel, the mechanism was severe surface layer shearing of the coating as a result of the steel pin plowing action.[34]
9	Zn, Zn–Ni, Cd and Cd–Ti	Low carbon steel	Electro de posited	● Resistance of Zn–Ni coatings towards adhesive wear was higher in contrast to cadmium coatings. ● Hardness on the wear track of Zn–Ni coatings led to development of a strain hardened tribo layer.[35]
10	zinc and zinc-alloy	Low carbon steels	Electro de posited	● Electrodeposited Zn and Zn–alloy coatings are found to be cost-efficient. ● Scalable solutions to minimize the surface degradation of mild steel parts, and structures in the marine environment.[36]
11	Chromium and zinc	Steel	Electro de posited	● Decorative chromium coating has the lowest wear resistance.[37]
12	Zinc	Cast iron	HVOF	● The temperature gradient along the disc cross-section is found to be very low independent of time. This happens as a result of the high thermal conductivity of the grey cast iron substrate.[38]
13	Graphite	Cast iron		● The use of natural graphite leads to reduction of the friction coefficient (μ), and it is also directly related to the

				graphite particle size. ● The adhesive and abrasive interactions that occur between the pin and the disc result in friction.[39]
14		Cast iron		● The wear transits from mild to severe as the temperature crosses threshold of 170ºC. ● Wear tracks on the discs derive from wear fragments due to the tribo-oxidation of the disc itself and from the wearing out of the pin material.[40]
15	Plasma sprayed yttria-stabilized zirconia method of coating used	Stainless steel substrates		● The value of thermal conductivity decreased as a result of the contribution of grain boundary in the phenomenon of phonon scattering. ● Nanostructured coatings have splats finer, grains smaller and also nanopores are present due to which interfaces increased and add to phonon scattering and lead to lesser thermal conductivity.[41]
16	Yttria-stabilized zirconia (YSZ) coatings	Ni and Al-based superalloy substrates aluminium		● The greater extent of particle melting ensures improved thermal conductivity and also enhances Shock resistance so need to have control over particle melting rate.[42]

17	Yttria stabilized zirconia (YSZ)	Ni-based superalloy as the substrate		• The thermal conductivity of the coating gets enhanced to a noticeable limit after heat treatment. • The sintering of coating contributes to thermal conductivity comparatively more than that in the traditional coating.[43]
18	Boiler Efficiency Improvement through Analysis of Losses			• The major losses in boiler are due to dry heat gas loss and are about 7.302% • The other major losses are due to hydrogen and loss due to moisture and partial combustion of C to CO.[44]
19	Boiler efficiency			• The existing flue gases from the boiler should be maintained at a temperature as low as possible and optimally in the range of 150-200 degree Celsius • The loss of flue gas is dependent on the final flue gas temperature and volume of flue gas.[45]
20	Influence of air staging stratergies on flue gases sensible heat losses and gaseous emissions of a wood pellet boiler: an			• Elimination of infiltration air resulted in flue gas sensible heat loss reduction by 31.6 % • The flue gas sensible heat loss is the major loss in the boiler. • The efficiency of boiler depends on flue gas outlet temperature • By decreasing the flue gas outlet

	experimental study			temperature by 10 degrees Celsius on decreasing sensible heat loss efficiency is improved by 1 percent.[46]
21	waste heat recovery technologies and applications			● Regenerative and recuperative burners optimize energy efficiency by incorporating heat exchanger surfaces to capture and use waste heat from hot flue gases.[47]
22	Evaluation of combustion model for determination of refinery furnaces efficiency			● Lower stack gas temperature are presented for higher efficiency of combustion and this temperature decreases when air excess percentage is increased.[48]
23	Effects of the changes of load and flue gas temperature on the emission of particulate matter from the coal fired unit			● Reduction of flue gas temperature without sacrificing high operation load on of coal fired units positively affects the reduction in total PM emissions.[49]

Table 2.1 : Literature Review

2.2 Research Gap

Large percentage of heat losses occur in power plant leading to lower efficiency of plants .one of the major loss is loss in the stack of boiler where there are loss in sensible heat of flue gas which leads to lower heat for waste heat recovery leading to lower efficiency. The effect of this sensible heat loss is a major loss and To reduce this heat loss there are many coatings which are used in power plant. The use of zinc coating for corrosion resistant has many applications . But use of zinc coating for slightly higher temperature than ambient condition in stack of boiler is a topic for investigation.

Latent heat of flue gases is also a loss in heat of boiler leading to its lower efficiency. The corrosion property of coated zinc for latent heat of flue gas is a topic for investigation.

2.3 Objective

The objective is to determine whether the use of zinc coating for Stack material in boiler will be an energy and cost effective method . the high temperature of sensible heat of flue gas at waste heat recovery system is important to reduce the heat loss in the boiler. Also, the favourable properties of coating material is necessary for heat reduction and long life of the substrate material. In this report followings objectives are set:-

1. to determine effect of high temperature heat on material with and without zinc coating using ANSYS software. So that we can increase the sensible heat of flue gases at outlet and heat at high temperature can be transferred to waste heat treatment system and optimal use of high temperature heat can be done to increase the temperature of water or to generate steam.
2. To analyse the corrosion resistant behaviour of zinc coated specimen. The corrosion resistant behaviour of zinc will help us determine the use of zinc coating for reduction in latent heat of flue gases .
3. To investigate the wear resistant and coefficient of friction for zinc coated specimen to ensure a smooth flow of flue gases through the stack. Smooth flow will help in decrease in pressure drop across the length of the stack which will reduce the chances of flow separation. Less wear and low coefficient of friction will have a positive impact on the stack by improving its life as well reducing the power required for flow of flue gas through the stack.

CHAPTER 3

MATERIALS AND METHODS

3.1 Sample preparation

Cast Iron sample disc was electroplated with Zinc as per ASTM B633. The substrate is placed at cathode and zinc metal is taken as anode. For electroplating, zinc oxide is used to prepare the electrolytic bath solution. The temperature was set at 180 degree Celsius with a voltage of 2.5 V. The current was maintained at 200 amp for 20 min.

3.2 Sample Characterization Methods

The morphology of the coated and corroded samples was studied using scanning electron microscopy (SEM) which provides information about the sample surface topography. The SEM analysis was performed using ZEISS EVO 18 Scanning Electron Microscope which was operated in the range 20 ~ 25 keV. Energy Dispersive X-ray (EDX) analysis probes the top 5 μm of the surface composition provides information about its the chemical characterization. The analysis was performed using RONTEC EDX system Model QuanTax 200 with energy resolution of 127 eV at Mn K alpha.

3.3 Salt Spray Test

The salt spray corrosion test (ASTM B-117) was performed over the zinc coated C.I. sample. The coated sample was cleaned and subjected to corrosive conditions. They were placed in a chamber filled with 5 % NaCl solution which was maintained at a temperature of 35±2 degree Celsius. The pH of the solution varied from 6.5-7.2 and quantity of fog was maintained as $1.0mL/80cm^2/hour$. After the completion of the experiment, the sample was cleaned and dried immediately.

3.4 Pin On Disc Wear Test

The pin on disc test is one of the universal tests that is done to test the wear and coefficient of friction of a material. The test simply involves a rotating disc that is in direct contact with a pin. The material of the pin is SS-316. The length of the pin is taken to be 44mm including the circular arc of 4mm formed at one of the extreme end of the pin. The pin is set in the holder above the rotating disc. The disc is a simple specimen clamped to the rotating body. The experiment has been done on 3 specimens that are cast iron, zinc electroplated cast iron and corroded zinc electroplated cast iron. The temperature of the pin is increased by connecting it with the heater via a thermocouple. The readings of the specimen are taken at an elevated temperature and the tribological studies related to the experiment are made on basis of the result obtained on a computer. the test helps us to measure the different parameters at a different time in an experiment. The first Parameters measured are coefficient of friction and friction with respect to the change in time at a fixed load. The second parameter measured is the change in temperature of the disc and the pin during the process with respect to time. The third parameter measured is the wear with respect to the change in time. The values obtained from the test for the 3 specimens are analyzed. The velocity and sliding distance are kept constant that is the distance covered by the disc is similar for every wear radius. The wear radius is the distance measured from the centre of the disc to the centre of the pin. The wear radius is changed and the revolution per minute are changed to keep the velocity to be constant.

CHAPTER 4

RESULTS and DISCUSSION

4.1 Characterization of Specimen

The effect of corrosion is visible from the SEM and EDX of the specimen. From SEM it can be observed the effect of corrosion before, during and after corrosion. The data shows the layer of zinc electroplated on cast iron fig 7.2. Fig 7.3 shows the surface topography of zinc electroplated cast iron after the specimen has been kept in salt spray test for 48 hours. Fig 7.4 shows the surface topography of zinc electroplated cast iron in which the zinc layer has been breached and zinc hydroxide is formed on the surface of the material which is visible In the form of white rust.

EDX of the specimen before and after the corrosion shows the elemental composition of the specimen with zinc coating. In table 3 we see the presence of zinc and chromate in large quantities but in the table 4 it can be seen that the elemental composition of chromium vanishes, hydrogen is the new element added to the list which reacts with zinc and oxygen to form zinc hydroxide which is seen on the surface of the specimen in the form white chalky substance that sticks itself to the surface of the specimen. This white layer is known as white rust.

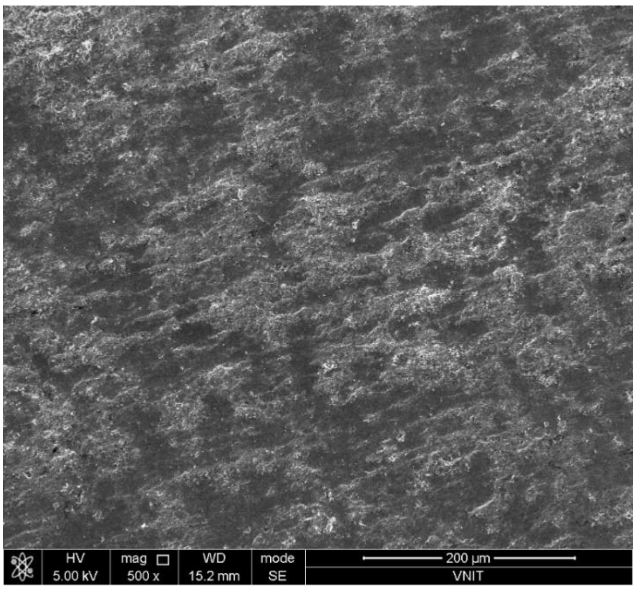

Fig 4.1 :-SEM Of Electroplated Zinc On Cast Iron Before Salt Spray Test

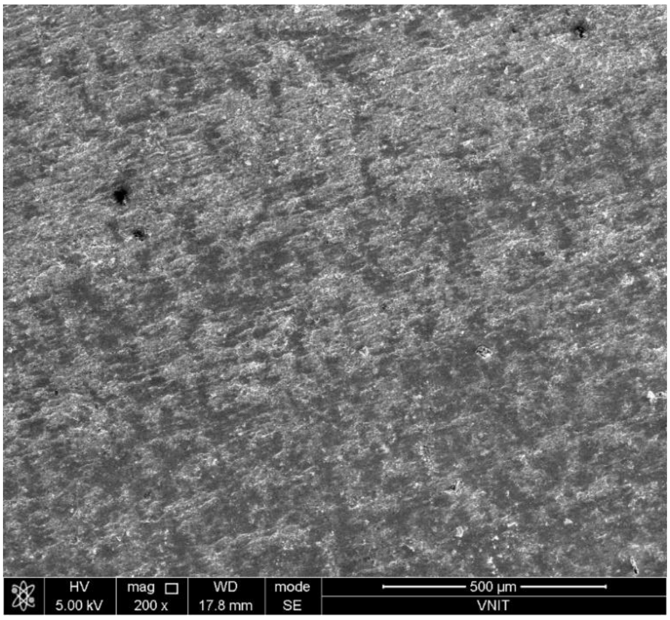

Fig 4.2 :- SEM Of Electroplated Zinc On Cast Iron Before After 48 hours of Salt Spray Test

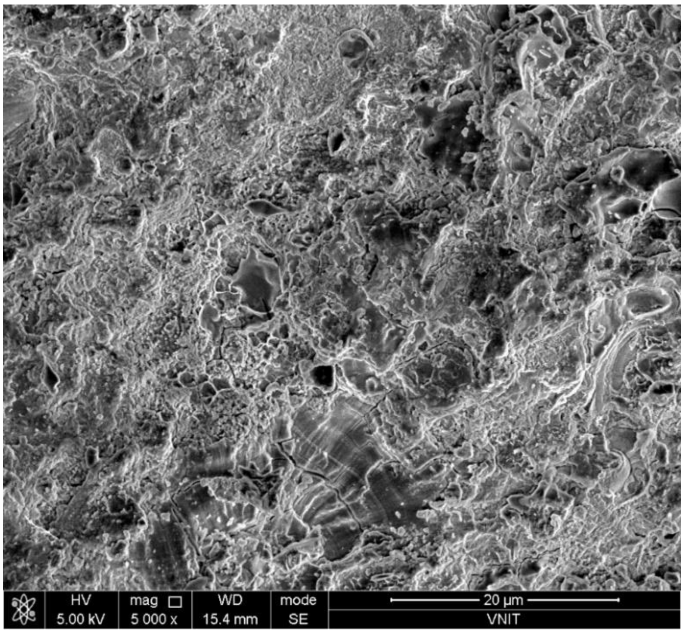

Fig 4.3 :- SEM Of Electroplated Zinc On Cast Iron Before After 72 hours of Salt Spray Test

Element	Symbol	Atomic Mass	Mass percent (%)
Iron	Fe	55.84	93.15
Carbon	C	12.01	3.50
Silicon	Si	28.09	2.50
Manganese	Mn	54.94	0.50
Molybdenum	Mo	95.95	0.15
Copper	Cu	63.55	0.30

Table 4.1: EDX data of Cast Iron

Element		Symbol	Atomic Mass	Mass percent (%)
Zinc		Zn	65.41	36.06
Chromium		Cr	51.99	28.64
Oxygen		O	15.99	35.28

Table 4.2: EDX data of Zinc Chromate

Element	Symbol	Atomic Mass	Mass percent (%)
Zinc	Zn	65.41	65.79
Oxygen	O	15.99	32.19
Hydrogen	H	1.01	2.03

Table 4.3: EDX data of Zinc Hydroxide

4.2 Salt Spray Test

The result of the test shows the duration for which we first observe the white rust formation for the first time. The specimen is kept at 35 degrees Celsius in a five percent sodium chloride solution in 1 ml/80 centimetre square per hour quantity of fog. The specimen is exposed to such harsh conditions for a time period of 72 hours. The rusting formation of cast iron is visible in the first 10 hours of the salt spray test whereas the white rust formation on the zinc coating takes 72 hours which is a remarkable increase in the increase in corrosion resistant property of a material

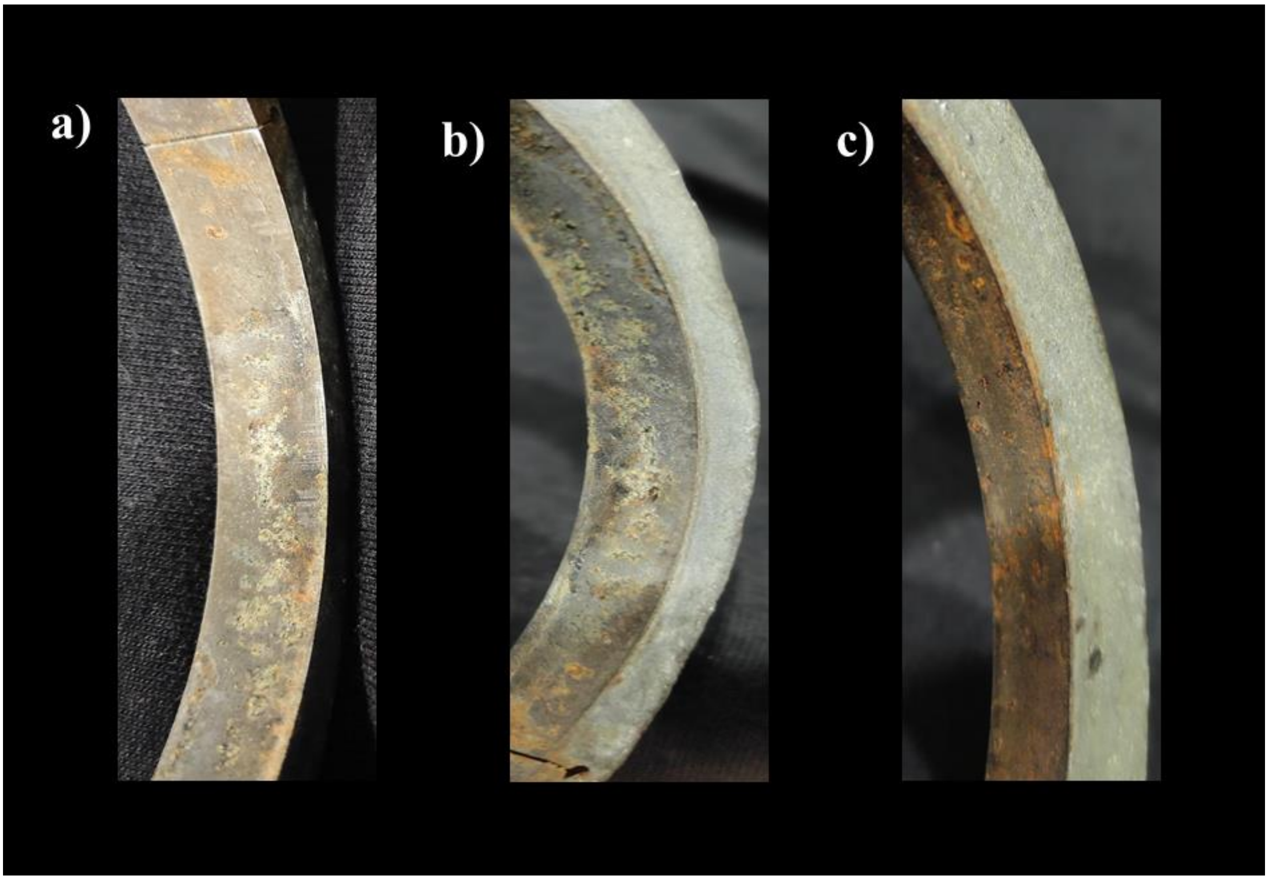

Fig 4.4:- a) Rust On Cast Iron After 24 Hours In Salt Spray Test; b) Rust On Cast Iron After 48 Hours In Salt Spray Test; c) Rust On Cast Iron After 72 Hours In Salt Spray Test

The increase in the life of a sample after it is electroplated with the zinc coating is remarkable as compared to a non-coated cast iron plate. The rate of corrosion falls down to 7 to 8 times in the case of zinc coating which not only increases the life of the specimen but also decreases the cost related to the project as zinc electroplating is a relatively low-cost process in comparison to other processes that are used for covering the top surface of the substrate


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TESTING OF FOOD | WATER | CHEMICALS | PETROLEUM PRODUCTS | BUILDING MATERIAL | ENVIRONMENT

TEST CERTIFICATE

(This certificate is not valid without a hologram)

Sample : Cast Iron with Zinc Coating
Sample Description : Cast Iron with Zinc Coating
Ref. No.: Nil
Issued To Delhi Technological University
Bawana Road, Delhi Technological University,
Shahbad Daulatpur Village, Rohini, New Delhi.
Haryana.

Report No.:21006933
Report Issue Date: 24/05/2022
Job Code STRC/21006930
Date of Testing: 20/05/2022 to 24/05/2022
Sample Received on: 20/05/2022
Sampling Qty : 1 pc
Page 1 of 2

1. **Salt Spray Test:-**

Sample Description	:	Cast Iron with Zinc Coating
Test Required	:	Salt Spray Test
Test Method/Specification	:	ASTM B-117
Salt Solution	:	5 % NaCl Solution.
pH of Solution	:	6.5- 7.2
Temperature	:	35 ± 2°C
Quantity of Fog	:	1.0 ml/80 cm²/Hour
Test Start Date	:	20/05/2022
Test End Date	:	23/05/2022
Exposing Duration	:	72 Hours

Examine the appearance of specimen (s) by Visual check after 24 Hours salt spray test accomplished up to 72 hours

Test Results

Check Specimens	**Appearance check (visual check) Does a Corrosion or oxidation phenomenon occur on the surface of specimen?**	**Functional Check & Performance Check**
Cast Iron with Zinc coating (after 24 hrs.)	No Corrosion found on Zinc coating	NA
Cast Iron with Zinc coating (after 72 hrs.)	Corrosion found on Zinc coating	NA

NA=Not Applicable
Remarks : The corrosion has been seen on specimen after 72 hours salt spray test accomplished.

STRC/7.8/F/TC/Z/00

(PRIYANCA)

Santram Rajput
Technical Manager

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(1) The Test results listed refer only to tested samples and applicable parameters. Endorsement of product is neither inferred nor implied.(2) Total liability of our Lab is limited to the invoiced amount. (3) Sample(s) are retained for 7 days (in case of perishable items) and 30 days for non perishable samples or unless otherwise specified. (4) This Test Report is not to be reproduced wholly or in part and cannot be used as an evidence in the court of Law and should not be used in any advertising media without our special permission in writing. (5) The Test Report refer to the sample submitted to us and not drawn by Sigma Test & Research Centre unless mentioned otherwise.

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Fig 4.5 :-Result Of Salt Spray Test After 48 Hours

The result from the salt spray test clearly depicts the advantage of electroplating the base material with zinc.

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Page 1 of 2

1. **Salt Spray Test:-**

Sample Description	:	Cast Iron with Zinc Coating
Test Required	:	Salt Spray Test
Test Method/Specification	:	ASTM B-117
Salt Solution	:	5 % NaCl Solution.
pH of Solution	:	6.5- 7.2
Temperature	:	35 ± 2°C
Quantity of Fog	:	1.0 ml/80 cm²/Hour
Test Start Date	:	20/05/2022
Test End Date	:	22/05/2022
Exposing Duration	:	48 Hours

Examine the appearance of specimen (s) by Visual check after 24 Hours salt spray test accomplished up to 48 hours

Test Results

Check Specimens	Appearance check (visual check) Does a Corrosion or oxidation phenomenon occur on the surface of specimen?	Functional Check & Performance Check
Cast Iron with Zinc coating (after 24 hrs.)	No Corrosion found on Zinc coating	NA
Cast Iron with Zinc coating (after 48 hrs.)	No Corrosion found on Zinc coating	NA

NA=Not Applicable
Remarks : The corrosion has not been seen on specimen after 48 hours salt spray test accomplished.

STRC/7.8/F/TC/Z/00

Sharma
(PRIYANKA)

Santram Rajput
Technical Manager

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(1) The Test results listed refer only to tested samples and applicable parameters. Endorsement of product is neither inferred nor implied.(2) Total liability of our Lab is limited to the invoiced amount. (3) Sample(s) are retained for 7 days (in case of perishable items) and 30 days for non perishable samples or unless otherwise specified. (4) This Test Report is not to be reproduced wholly or in part and cannot be used as an evidence in the court of Law and should not be used in any advertising media without our special permission in writing. (5) The Test Report refer to the sample submitted to us and not drawn by Sigma Test & Research Centre unless mentioned otherwise.

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Fig4.6:-Result Of Salt Spray Test After 48 Hours

4.3 ANSYS SOFTWARE

Using the ANSYS software it can be clearly seen that the zinc oxide coating on the surface of cast iron acts as a thermal barrier. The change In temperature for the same fixed maximum and minimum temperature and same thickness we observe that the specimen containing zinc oxide coating has a lower effect due to heat at high temperature in comparison to the specimen that does not have a coating. The cast iron has a thermal conductivity of 54.5 W/(mK) and is coated with zinc oxide having a thermal conductivity of 23.2 W/(mK). The maximum temperature is set to be 100 degrees Celsius for both the specimen and the lowest temperature is set to be ambient temperature i.e 22 degrees Celsius. The thickness of both the specimen is taken to be 25 cm, the only difference is that at the starting, the specimen that contains coating has a layer of zinc oxide that has a thickness of 1 millimetre. As viewed from the ANSYS software it is clearly visible that the temperature gradient in the case of cast iron coated with a zinc oxide layer is much higher on the side that contains maximum temperature as compared to the specimen that does not contain a coating whose temperature gradient is much lower as at the side which is exposed to maximum temperature. This property of zinc oxide is useful to protect the material from the effect of heat at high temperatures. Though in the case of electroplated zinc the maximum temperature theoretically for the working is kept below 500 degrees Celsius. But in many cases, the maximum temperature is kept below 300 degrees Celsius because the zinc coating starts to lose its corrosion resistant property .so in the temperature range of ambient to 300 degrees Celsius the electroplated zinc along with its corrosion resistant property also protects the material from the effect of heat at high temperature.

Here for the thermal modelling, a specimen is taken of dimension having a thickness of 25 cm and an area of 1 metre square. The maximum and minimum temperature for both the models is taken to be 100 degrees Celsius and 22 degrees Celsius. The thickness of both materials is taken to be equal. The change in both the models is that one mode is coated and the other model is uncoated. The substrate taken as cast iron has a thermal conductivity of 54.5 W/(m k) whereas the coating is taken to be iron oxide having a thermal conductivity of 23.2 W/(m K).. the thickness of the coating is taken to be 1 cm. In an actual application, the electroplated zinc coating is mainly of a few micrometres to a maximum of 2 mm.

The thermal modelling also shows the heat flux associated with the above modelling is obtained. It depicts that there is more heat transfer per unit area of material when there is no coating in comparison to the case when there is coating. It can be deduced from the above result that electroplated zinc can also reduce the heat loss to the environment when working in the range of its working temperature.

The law for control volume states that there is no loss of heat above or below the given material and therefore heat transfers in a single direction which is stated as first law of control volume as (for 0 shaft work)

$$\sum \dot{Q} = 0$$

For the heat conduction where there is no heat generation inside the body , the equation for the heat transfer to the left side of slab is

$$\dot{Q}(x) = -k\left(A\frac{dT}{dx}\right)_x$$

The heat transfer to the right side of slab is

$$\dot{Q}(x+dx) = \dot{Q}(x) + \left.\frac{d\dot{Q}}{dx}\right|_x dx + \cdots$$

Where k is a constant thermal conductivity of material , which means value of ‘k’ is constant with respect to time

From the above equations we obtain the net value of heat flow through the slab as

$$\dot{Q}(x) - \left(\dot{Q}(x) + \left.\tfrac{d\dot{Q}}{dx}\right|_x dx + \cdots\right) = 0$$

For the very small thickness of slab we take the limit for dx approaches zero

$$\frac{d\dot{Q}(x)}{dx} = 0$$

Or

$$\frac{d}{dx}\left(kA\frac{dT}{dx}\right) = 0$$

Or the above equation can be written in the following manner for a constant value of ‘k’ (that is ‘k’ is independent of temperature)

$$\frac{d}{dx}\left(A\frac{dT}{dx}\right) = 0$$

Integrating the above equation we obtain the temperature field for quasi-one-dimensional flow

$$\frac{d^2T}{dx^2} + \left(\frac{1}{A}\frac{dA}{dx}\right)\frac{dT}{dx} = 0$$

For the slab we keep the area to be independent of x direction and therefore change in 'A' is zero $\frac{d^2T}{dx^2} = 0$

On double integrating the above equation with respect to 'x' we obtain

$$\frac{dT}{dx} = a$$

$$T = ax + b$$

For x=0

$$T(0) = T_1$$

For x=L

$$T(L) = T_2$$

On Solving we obtain

$$b = T_1$$

$$T_2 = aL + T_1$$

$$a = (T_2 - T_1)/L$$

The change in temperature obtained with distance i.e. temperature gradient will be

$$T(x) = T_1 + \left(\frac{T_2 - T_1}{L}\right)x$$

And heat transfer per unit area that is heat flux for the material is

$$\dot{q} = -k\frac{dT}{dx} = -k\ \frac{T_2 - T_1}{L} = constant$$

BOUNDARY CONDITION

T(0) = 22 degree Celsius

T(L) = 100 degree Celsius

L = 0.25 m

A = 1 meter square

K (iron) = 54.5 W/(m.K)

K (coated zinc) = 23.2 W/(m.K)

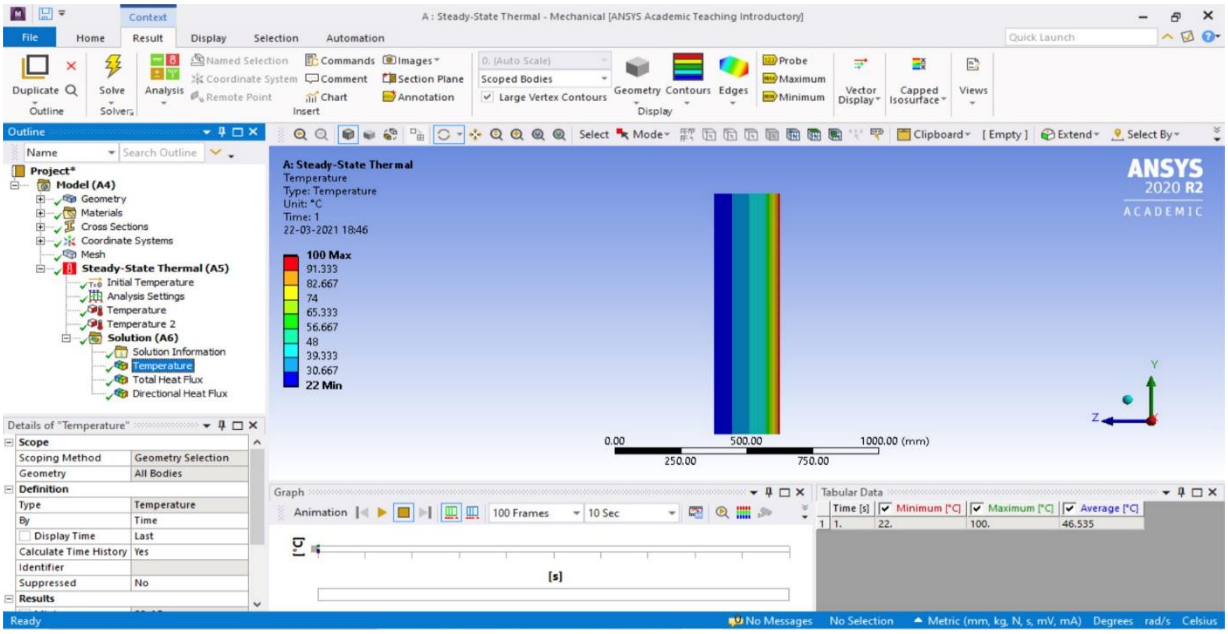

Fig 4.7:- Thermal Modelling Of Zinc Coated Cast Iron On ANSYS Software

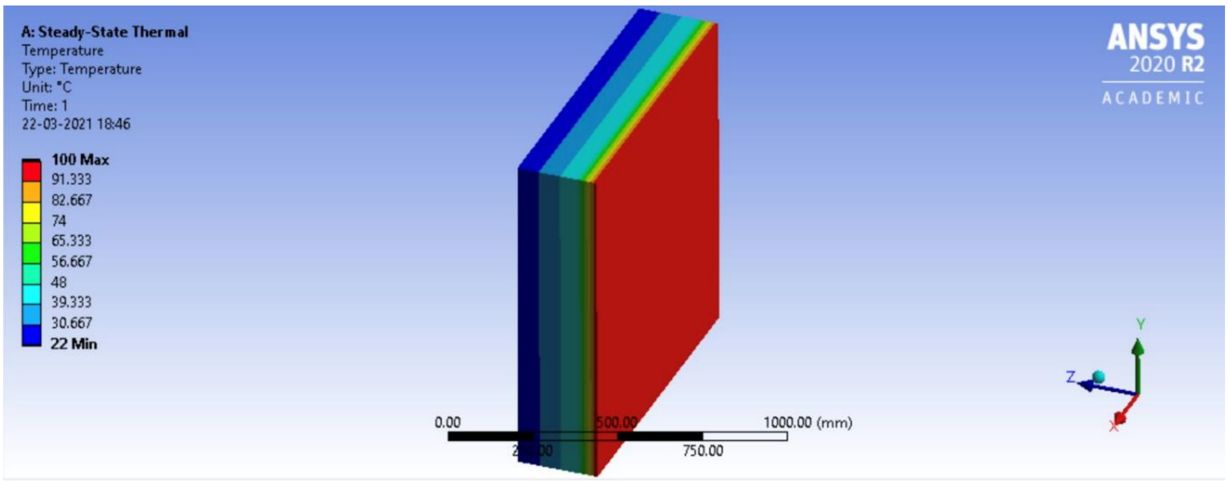

Fig 4.8:- Thermal Modelling Of Zinc Coated Cast Iron On ANSYS Software

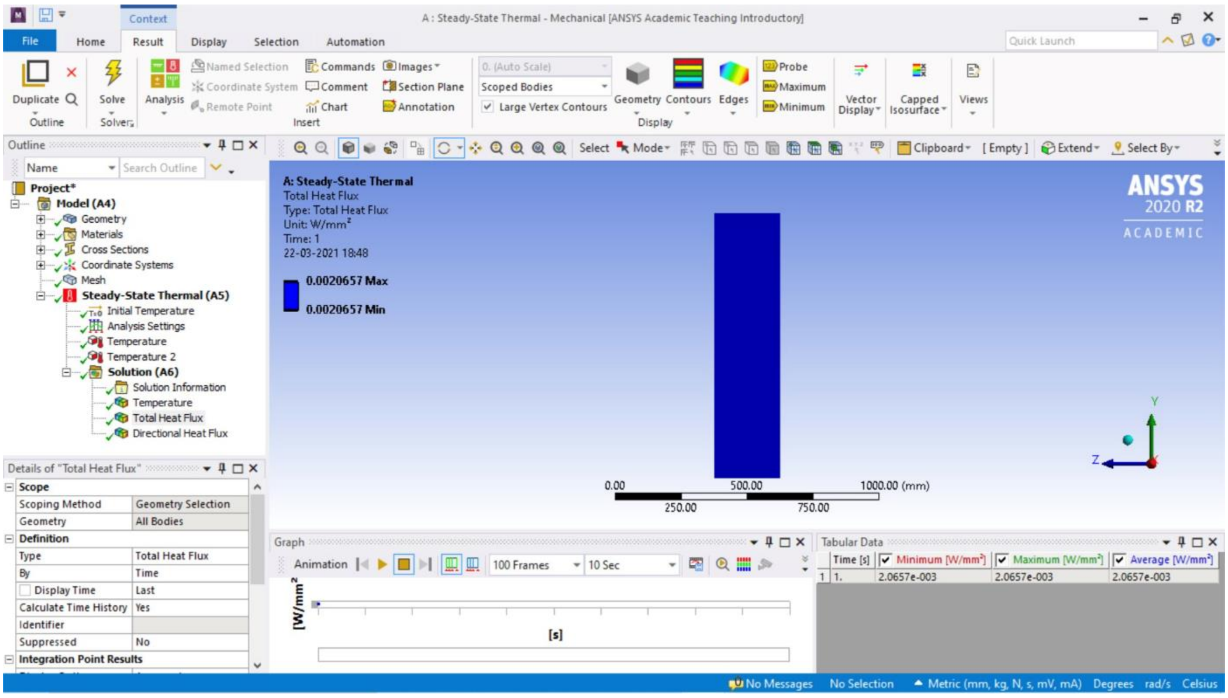

Fig 4.9:- Heat Flux For Of Zinc Coated Cast Iron On ANSYS Software

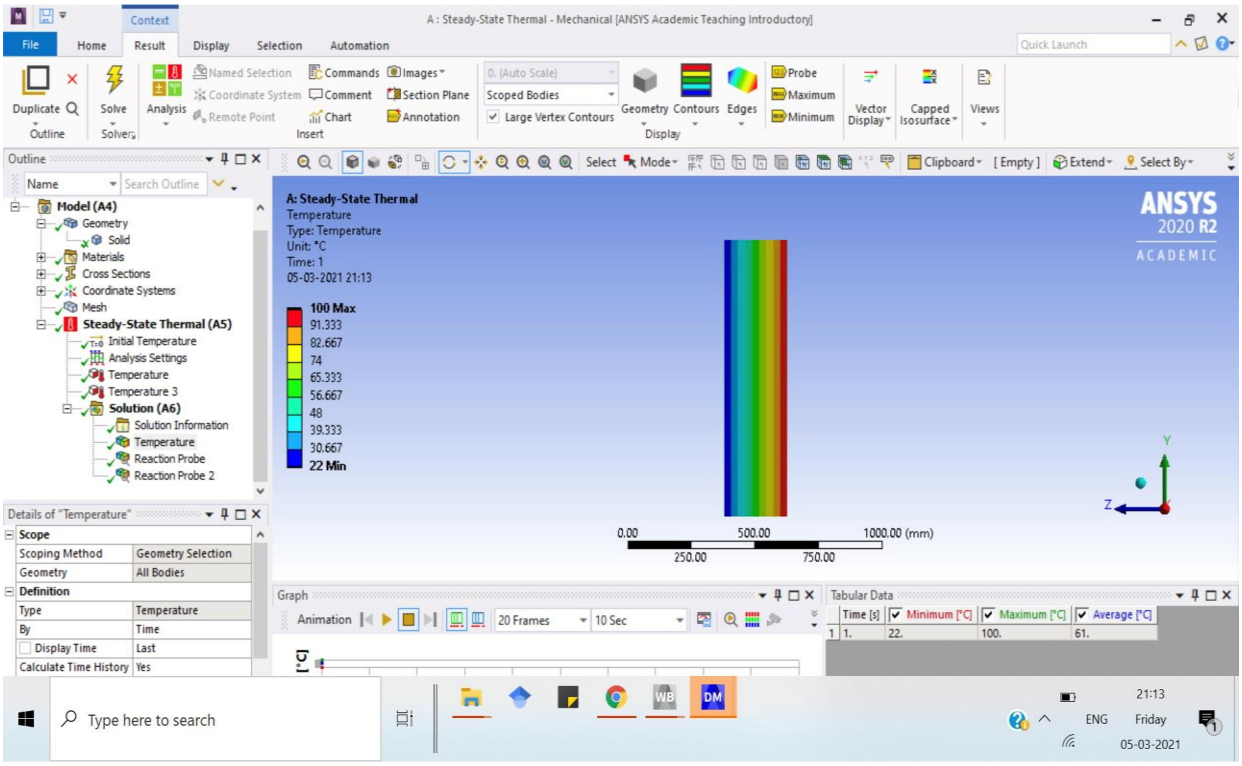

Fig 4.10:- Thermal Modelling Of Uncoated Cast Iron On ANSYS Software

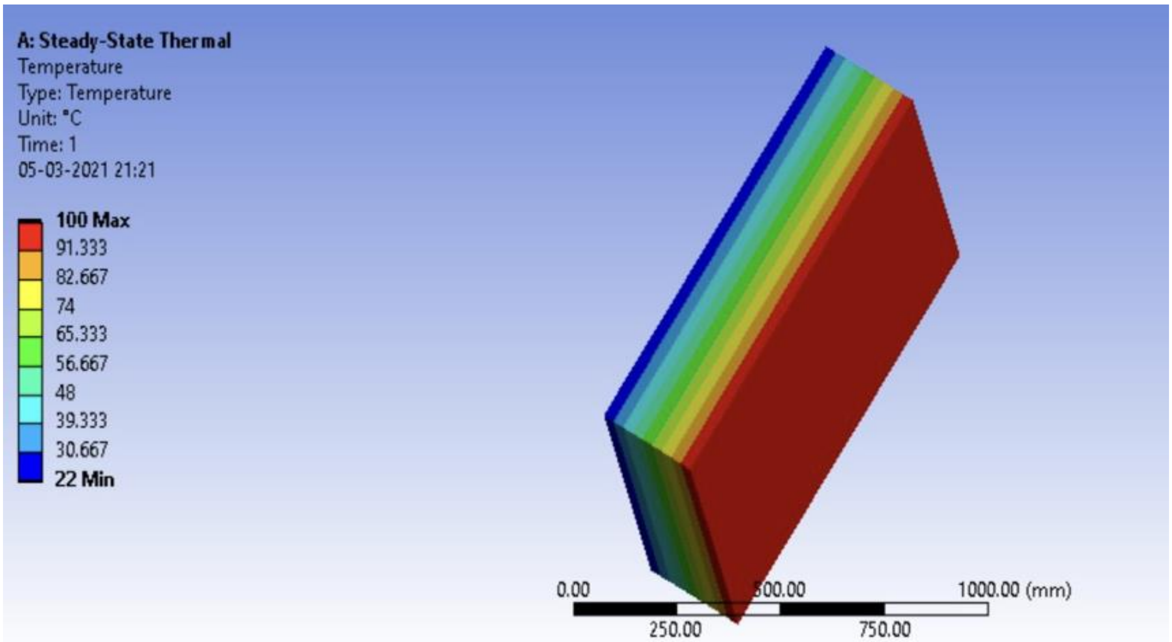

Fig 4.11 :- Thermal Modelling Of Uncoated Cast Iron On ANSYS Software

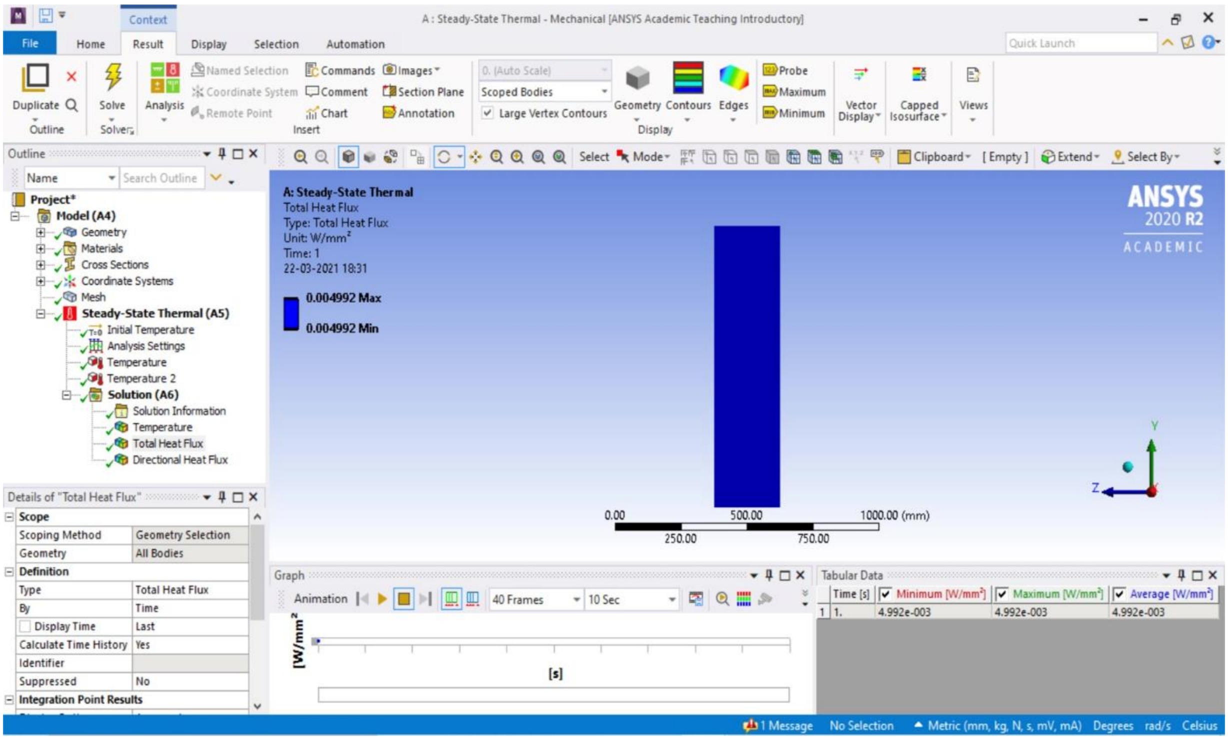

Fig 4.12 :- Heat Flux For Of Uncoated Cast Iron On ANSYS Software

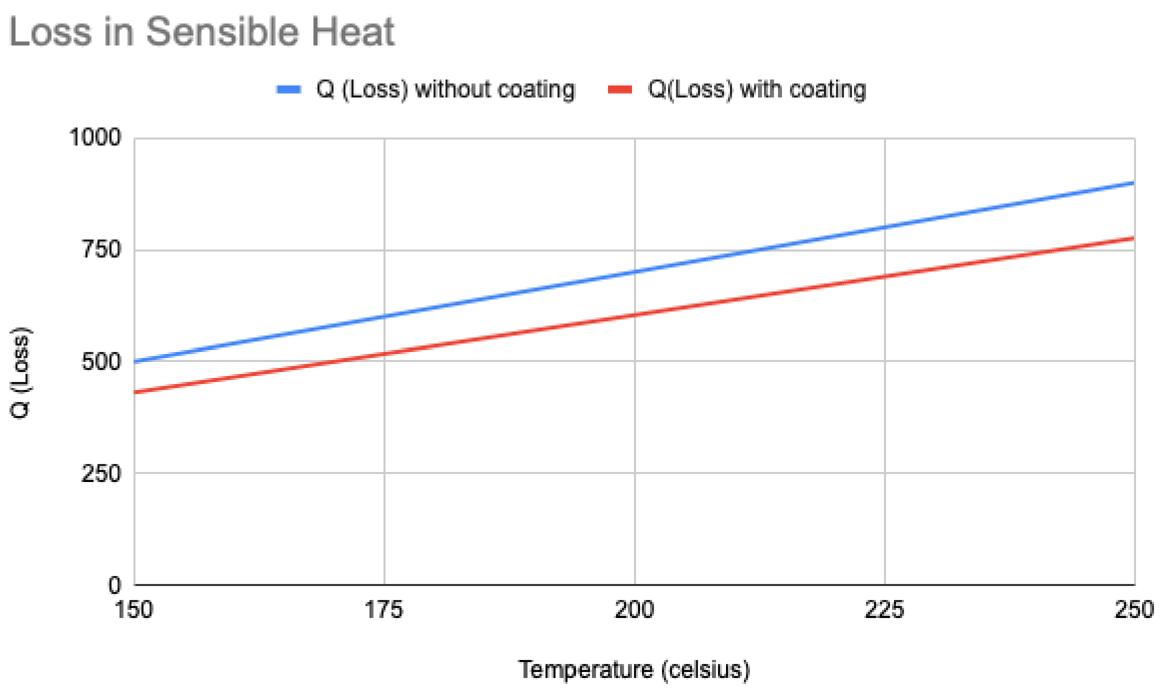

Fig 4.13 :- Heat vs Surface temperature Graph for coated and non-coated cast iron

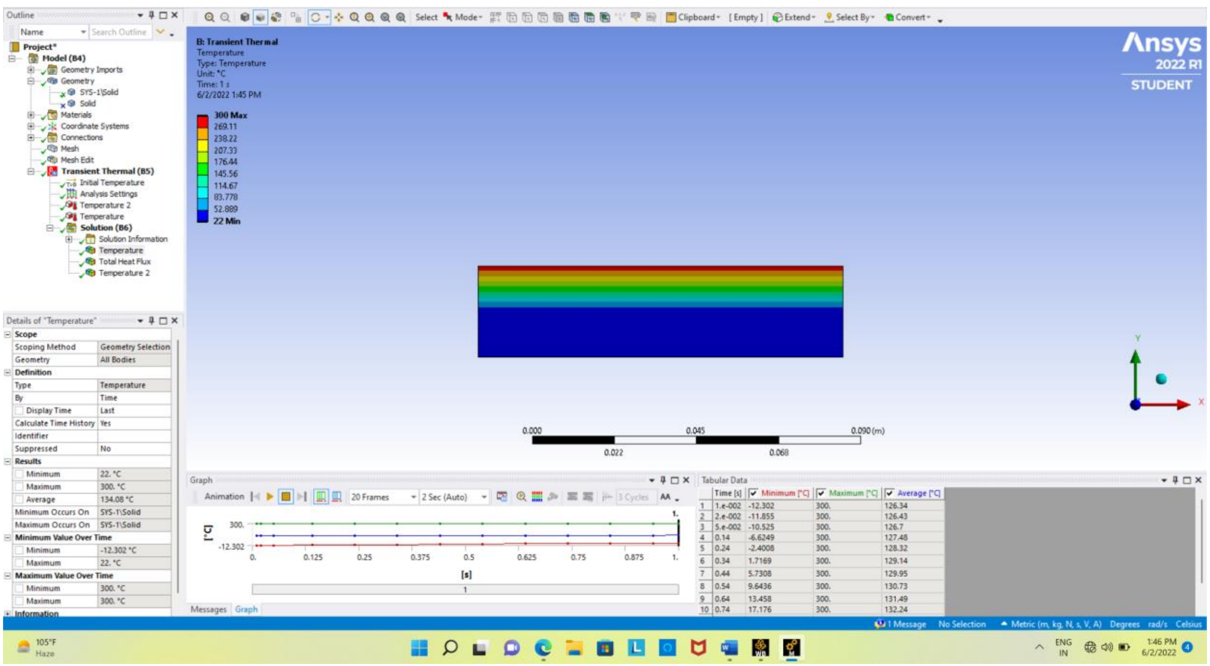

Fig 4.14 :- Change in the Average Temperature of the body for the cast iron sample at 300 °C

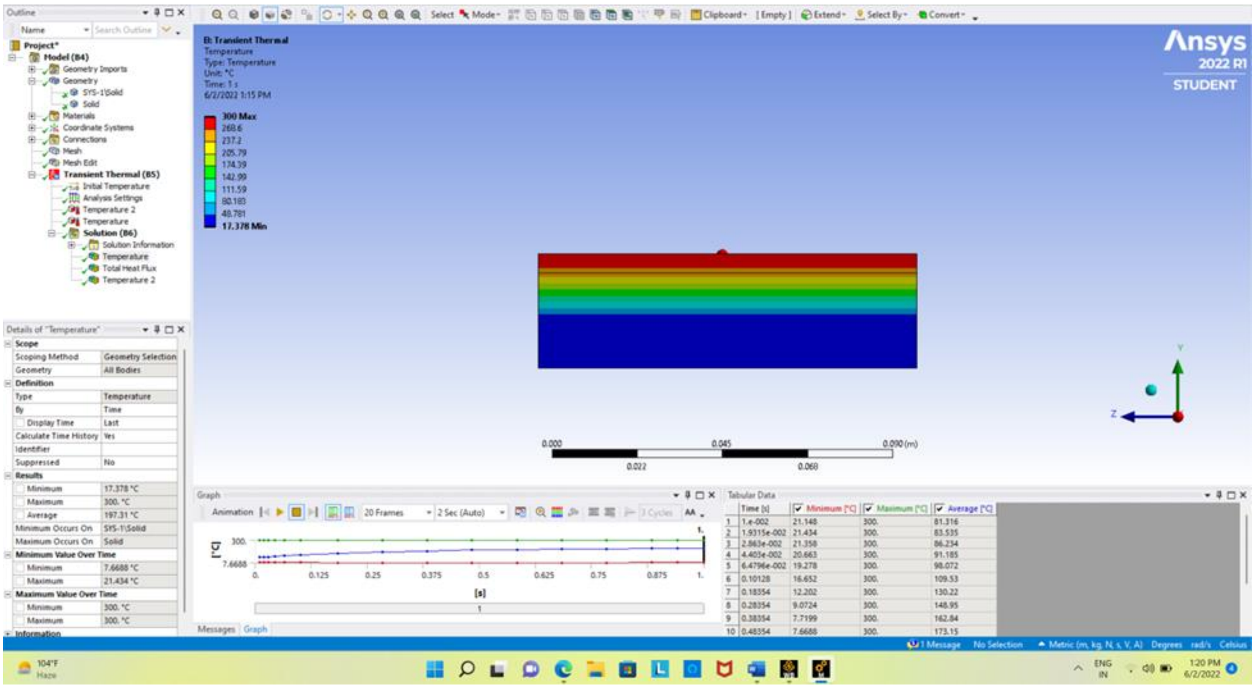

Fig 4.15 :- Change in the Average Temperature of the body for the corroded sample at 300 °C

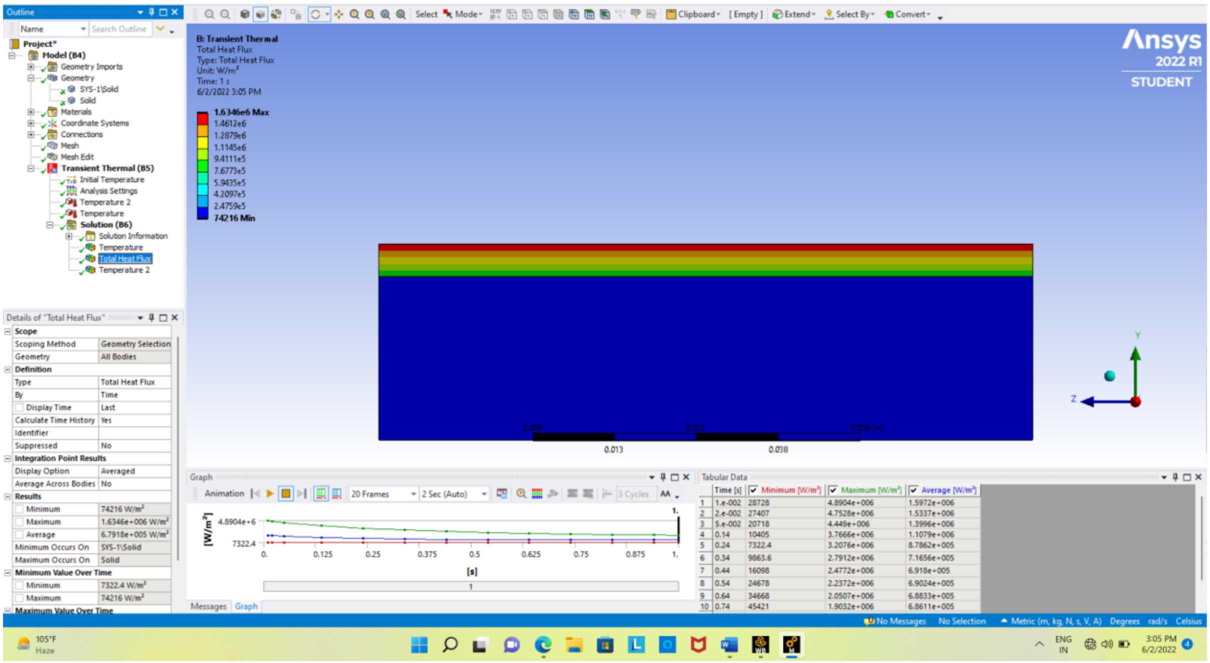

Fig 4.16 :- Change in the Average Temperature of the body for the coated sample at 300 °C

From the table and graph it is evident that the average temperature increases the most for corroded zinc coating and increases the least for zinc coated specimen for the same distance from high temperature end and for the same thickness. From this we can interpret that due to the low thermal resistant provided by the corroded zinc coating the specimen suffers from heat at high temperature and because of high thermal thermal resistant the coated zinc plate will be affected the least by high temperature at the same distance from extreme edge on the side of flue gases. The high resistance is attributed to the zinc coating. Cast iron shows moderate effect of average temperature change.

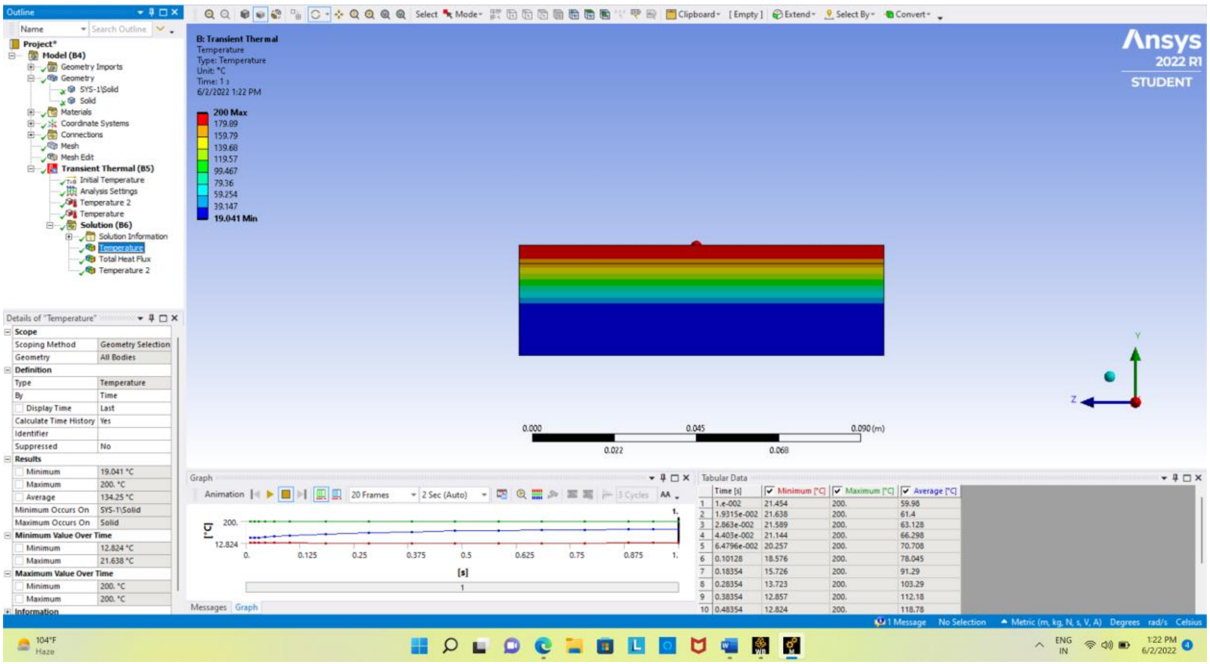

Fig 4.17:- Change in the Average Temperature of the body for the corroded sample at 200 °C

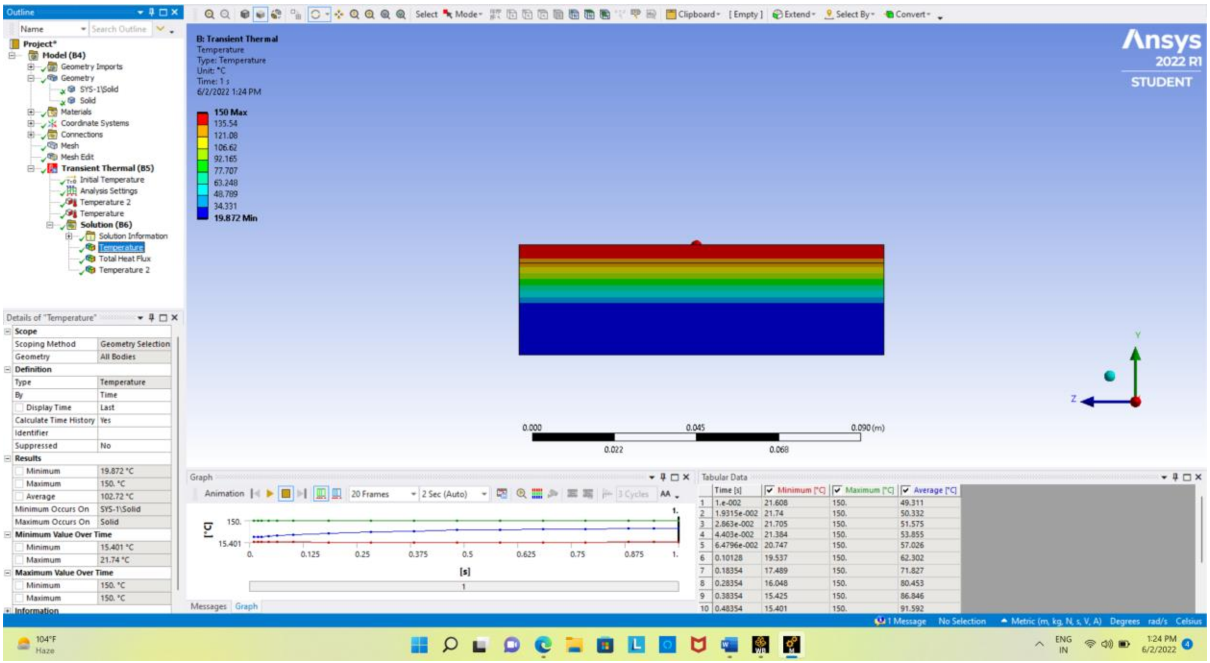

Fig 4.18 :- Change in the Average Temperature of the body for the corroded sample at 150 °C

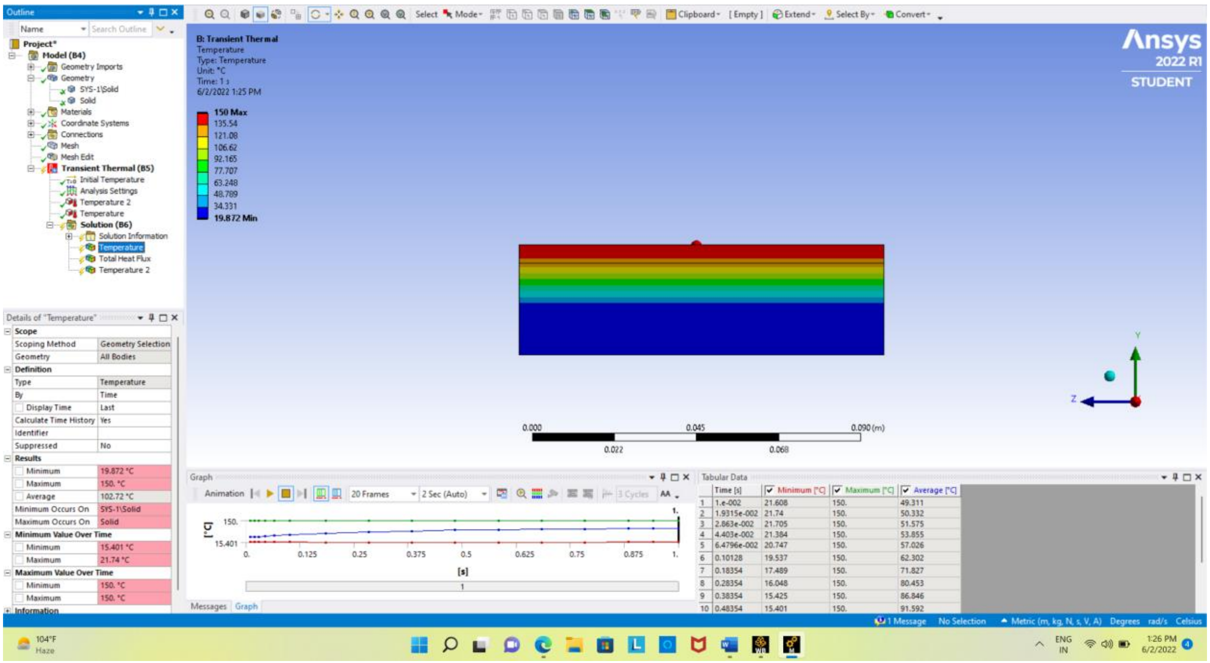

Fig 4.19 :- Change in the Average Temperature of the body for the corroded sample at 100 °C

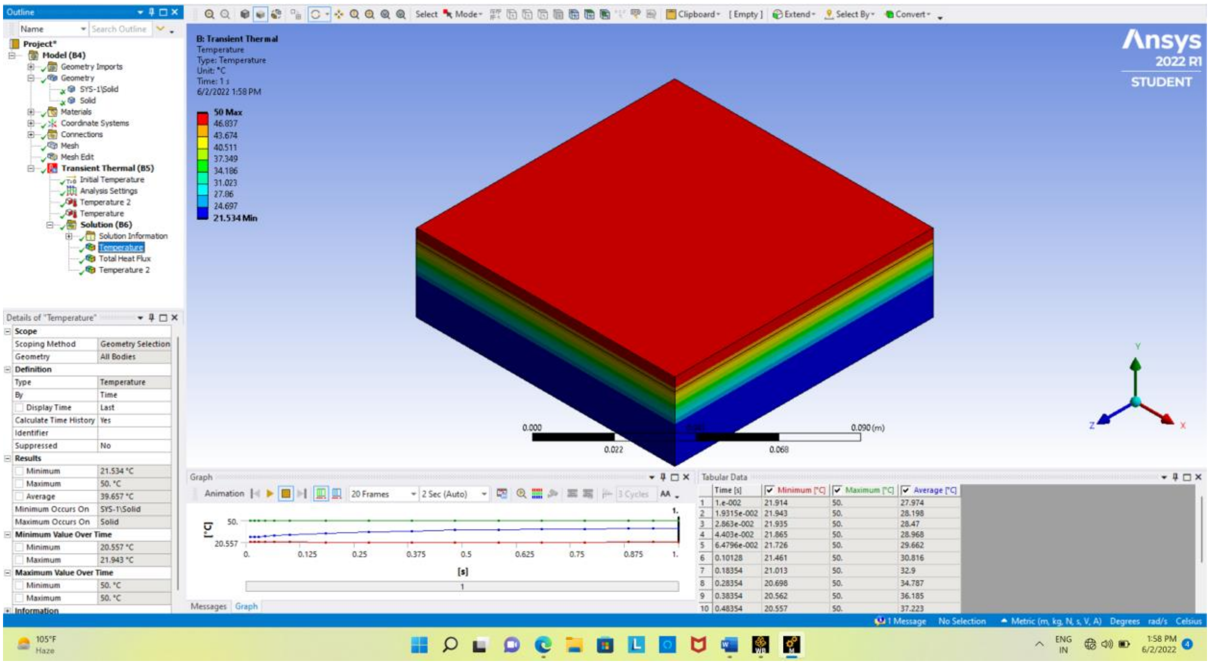

Fig 4.20 :- Change in the Average Temperature of the body for the corroded sample at 50 °C

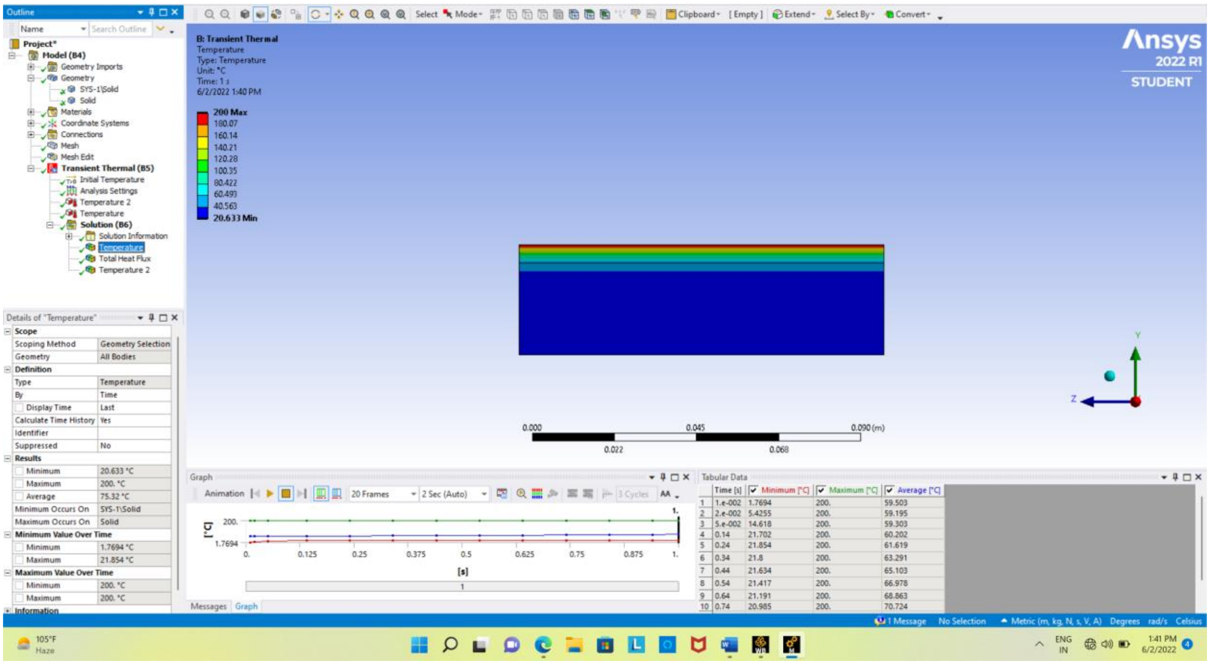

Fig 4.21 :- Change in the Average Temperature of the body for the coated sample at 200 °C

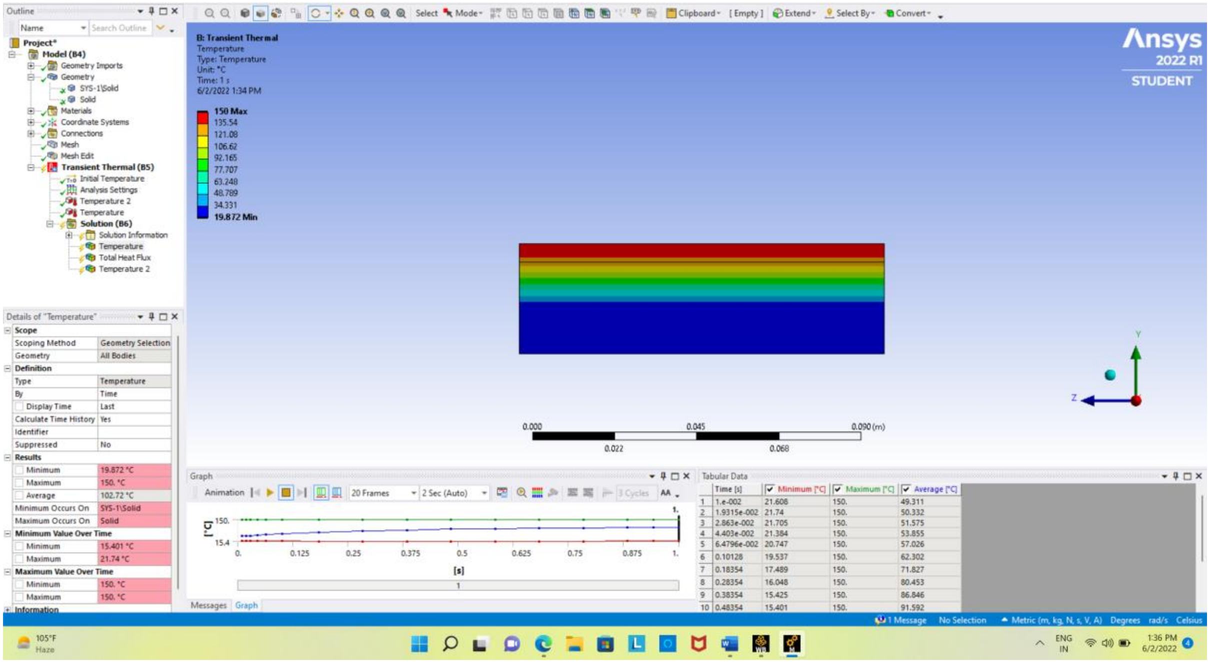

Fig 4.22 :- Change in the Average Temperature of the body for the coated sample at 150 °C

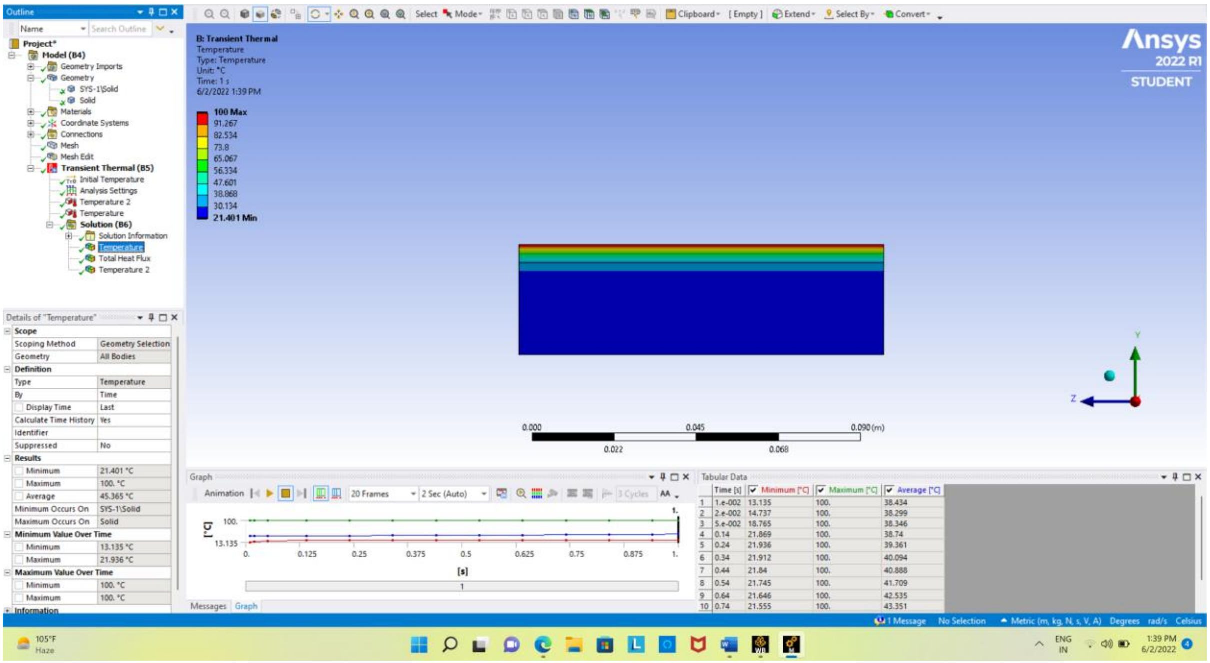

Fig 4.23 :- Change in the Average Temperature of the body for the coated sample at 100 °C

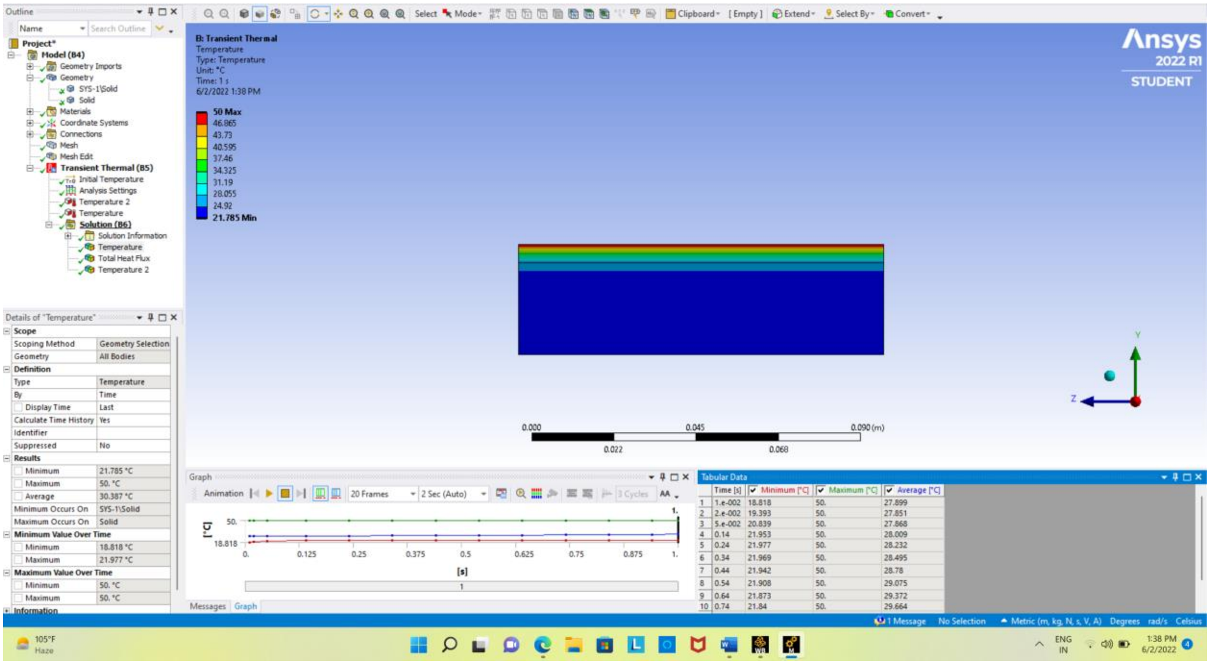

Fig 4.24 :- Change in the Average Temperature of the body for the coated sample at 50 °C

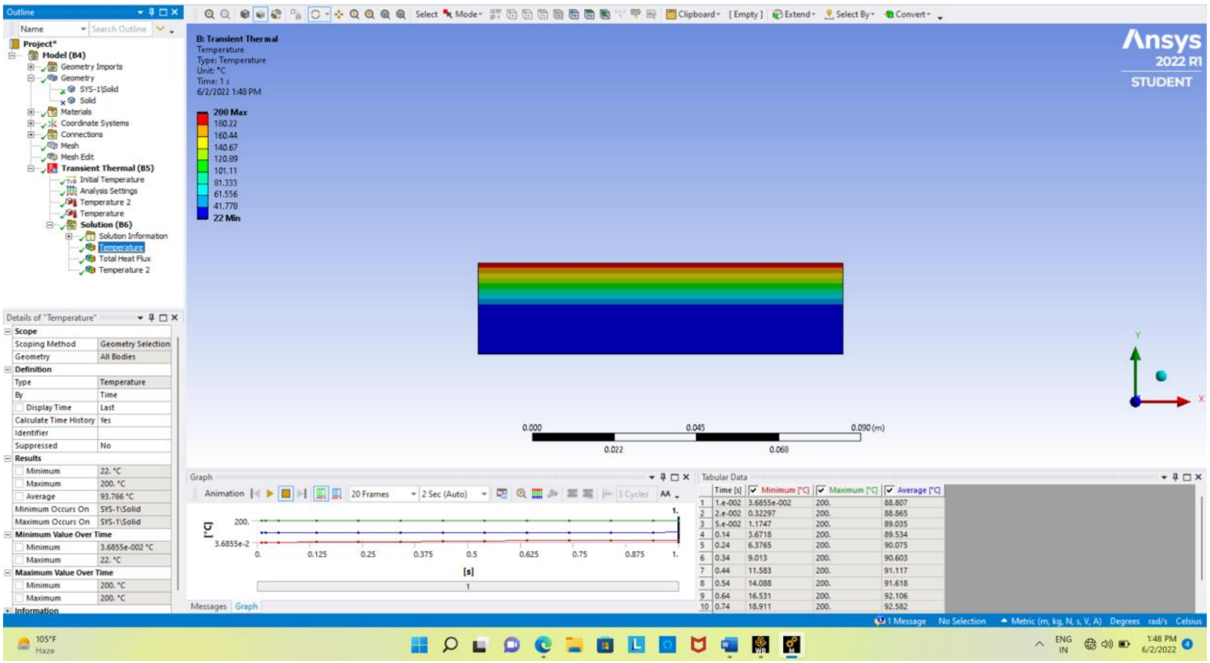

Fig 4.25 :- Change in the Average Temperature of the body for the cast iron sample at 200 °C

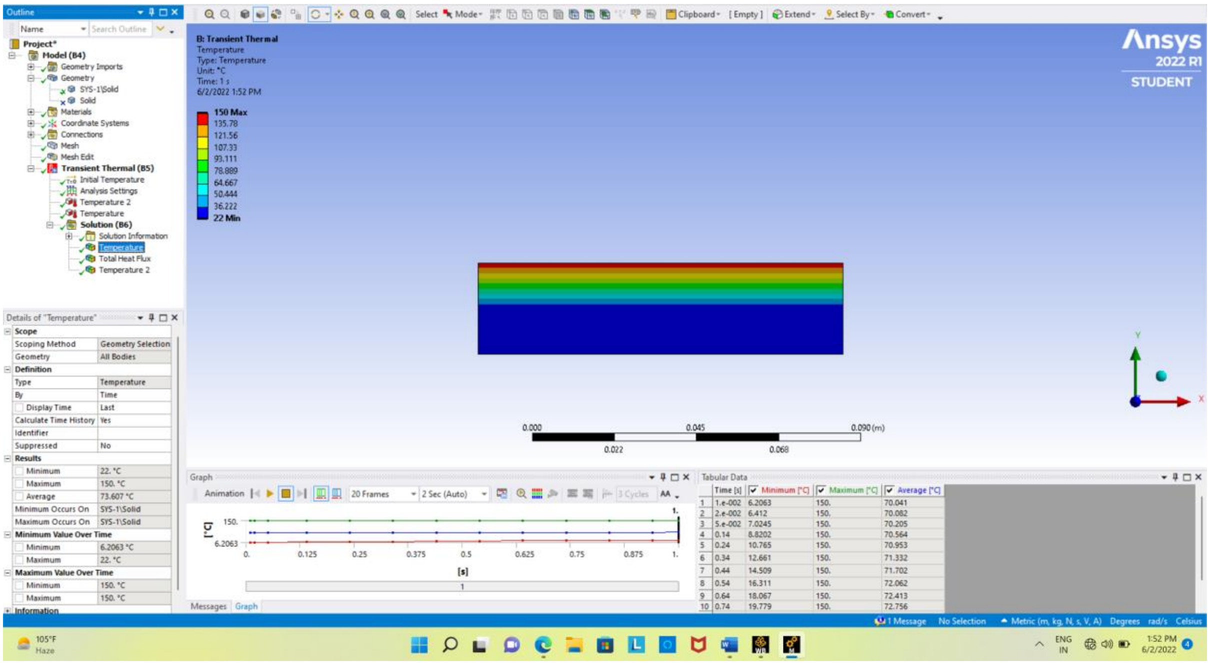

Fig 4.26 :- Change in the Average Temperature of the body for the cast iron sample at 150 °C

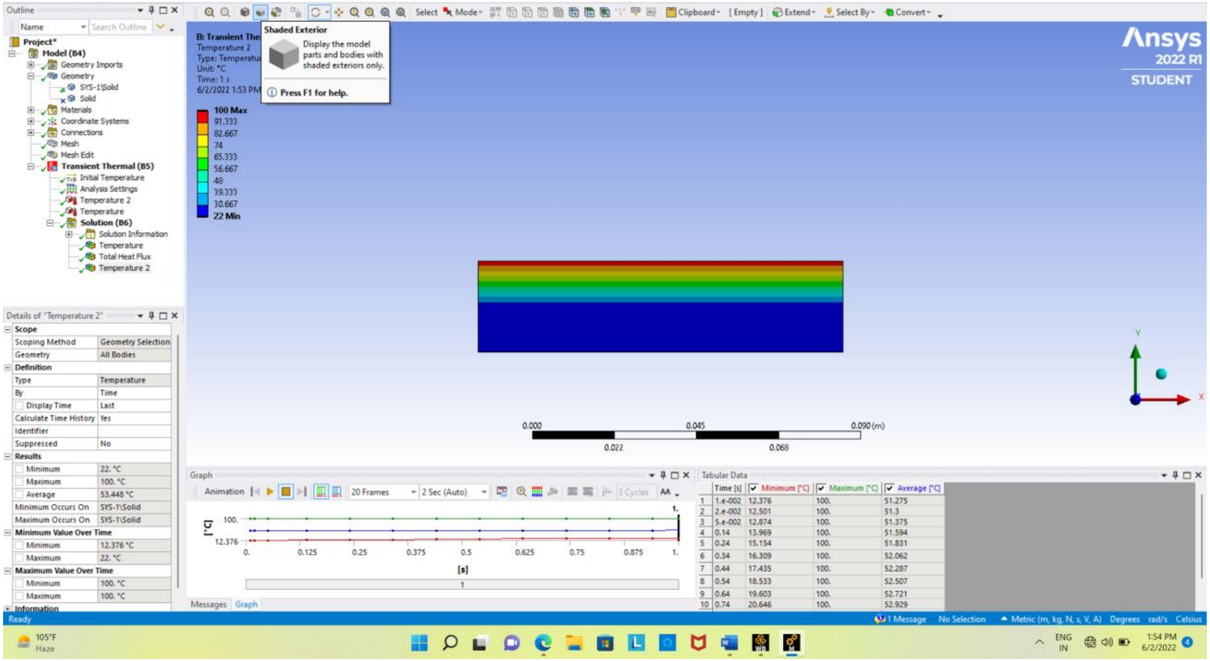

Fig 4.27 :- Change in the Average Temperature of the body for the cast iron sample at 100 °C

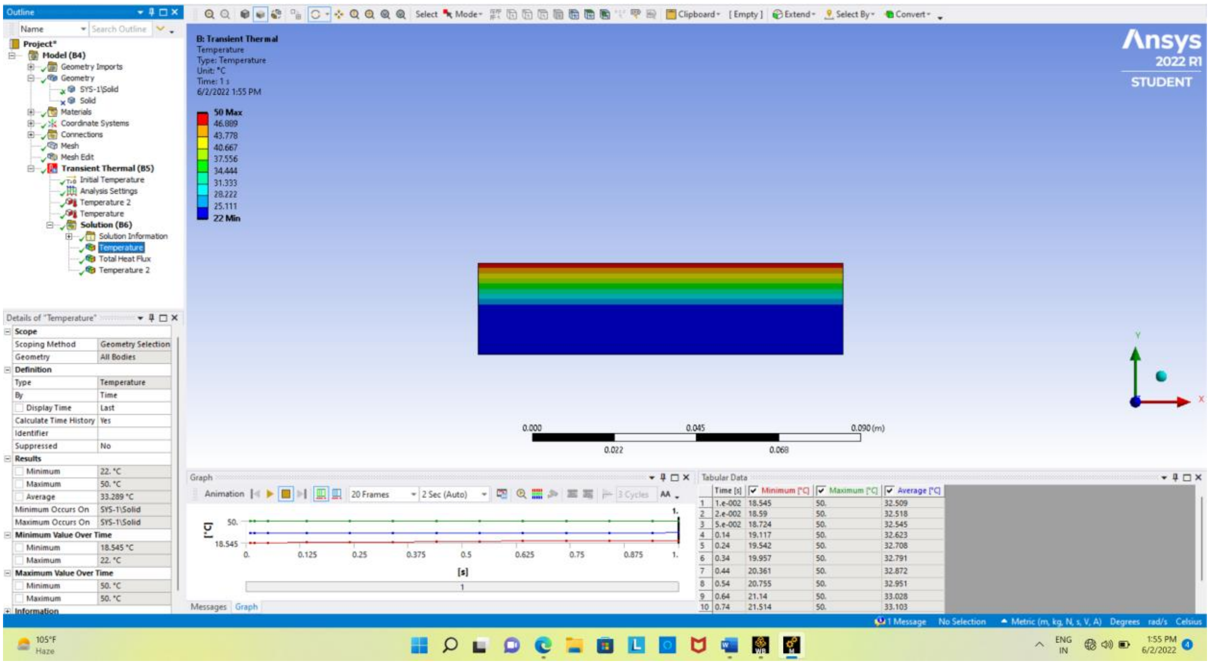

Fig 4.28 :- Change in the Average Temperature of the body for the cast iron sample at 50 °C

On increasing the temperature value of extreme ends the average temperature value increases in each slab that is there is more heat transfer through the material but again the zinc coated material has the least increase in average temperature from high temperature heat end implying that the the high temperature material will have least effect on the substrate material hence increasing its working life

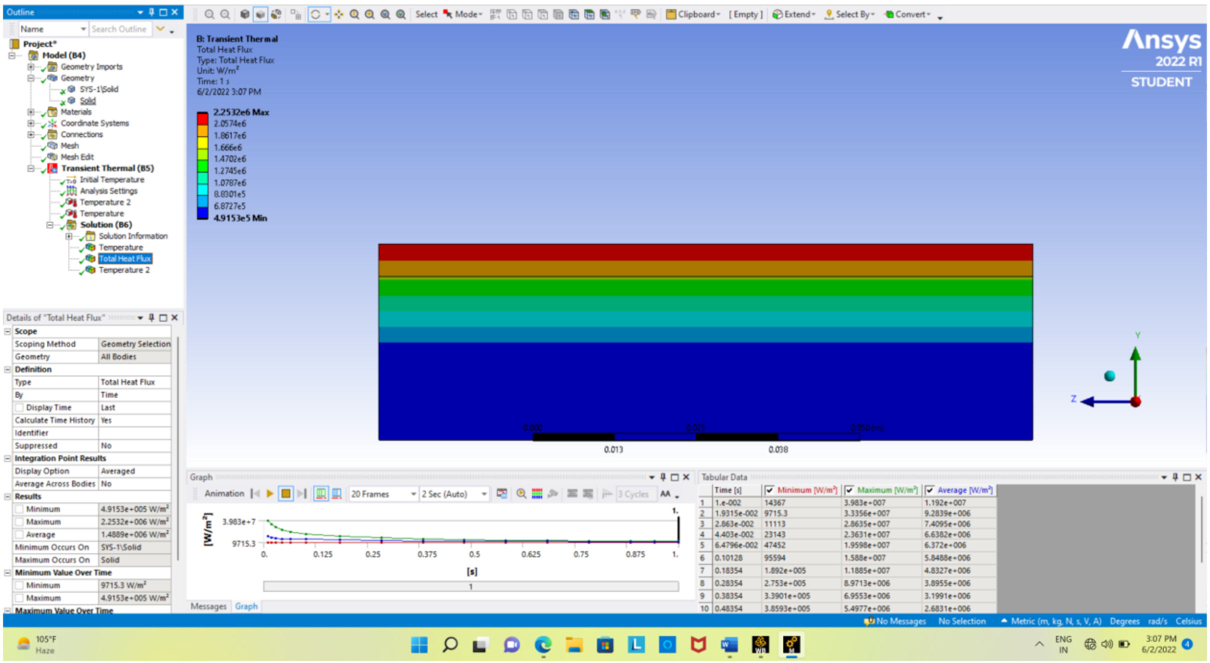

Fig 4.29 :- Change in the Heat flux for the corroded sample

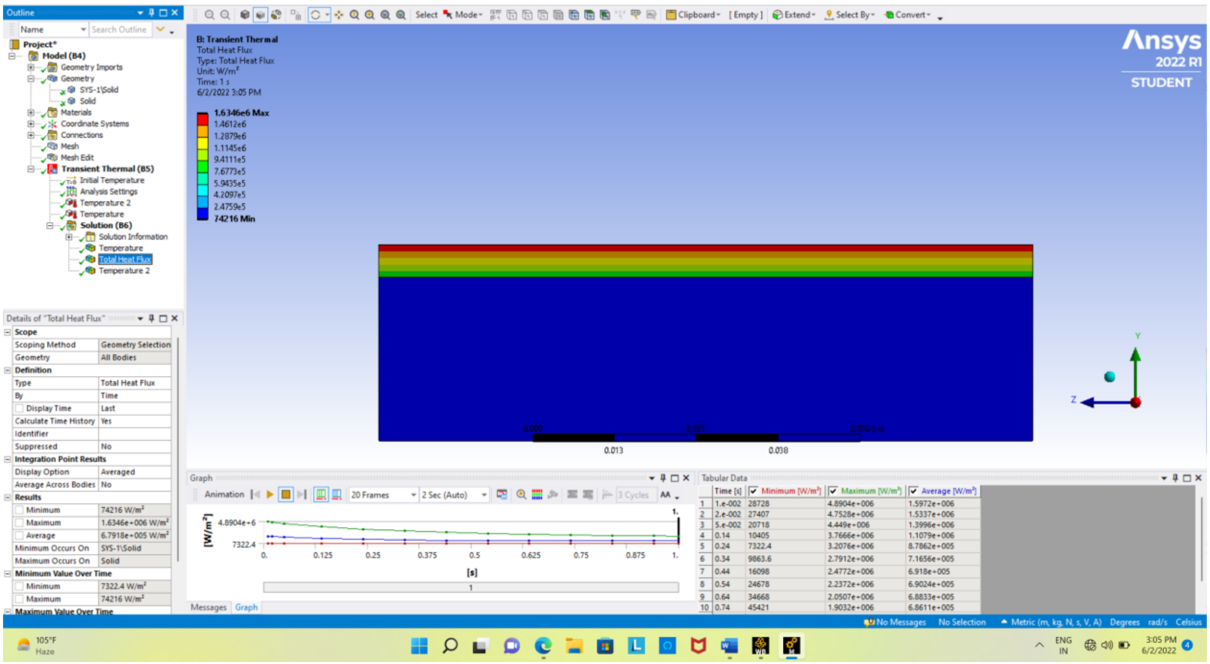

Fig 4.30 :- Change in the Heat flux for the coated sample

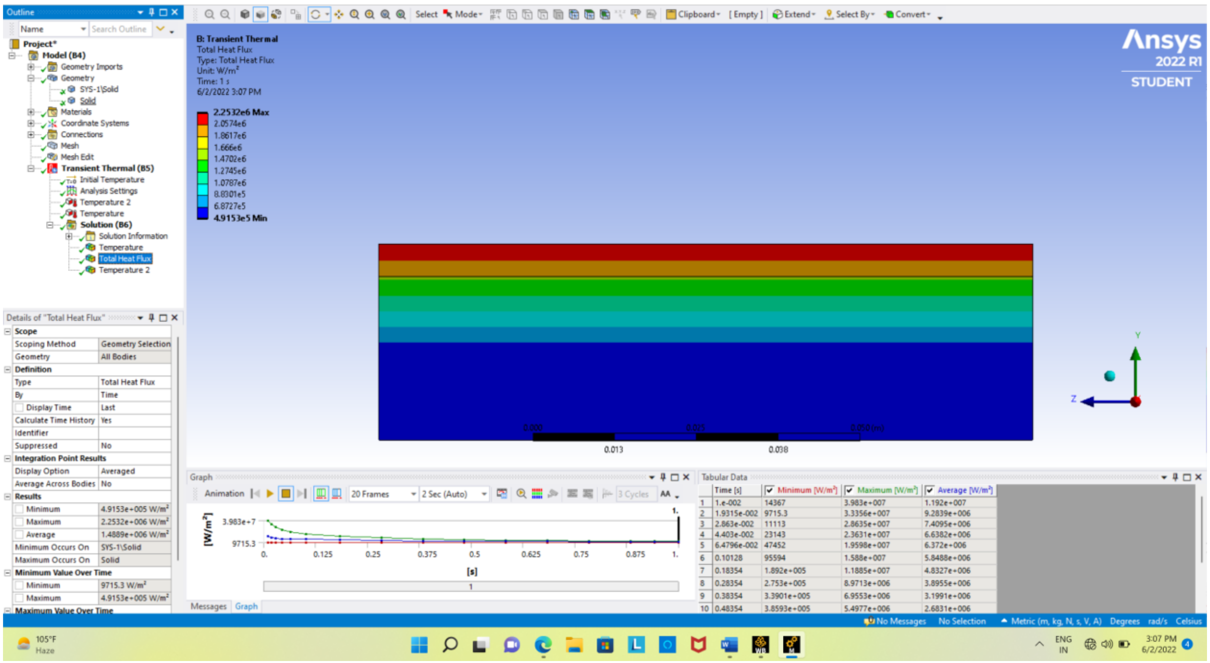

Fig 4.31 :- Change in the Heat flux for the cast iron sample

Lowest heat flux loss value is obtained for the coated zinc on cast iron and the highest heat flux loss is for the corroded zinc coating.

This implies that zinc coating will help flue gas retain more heat when it reaches waste heat treatment system. Therefore we can make the use of high temperature heat for maximum work. This will improve the efficiency of system and decrease the boiler heat losses

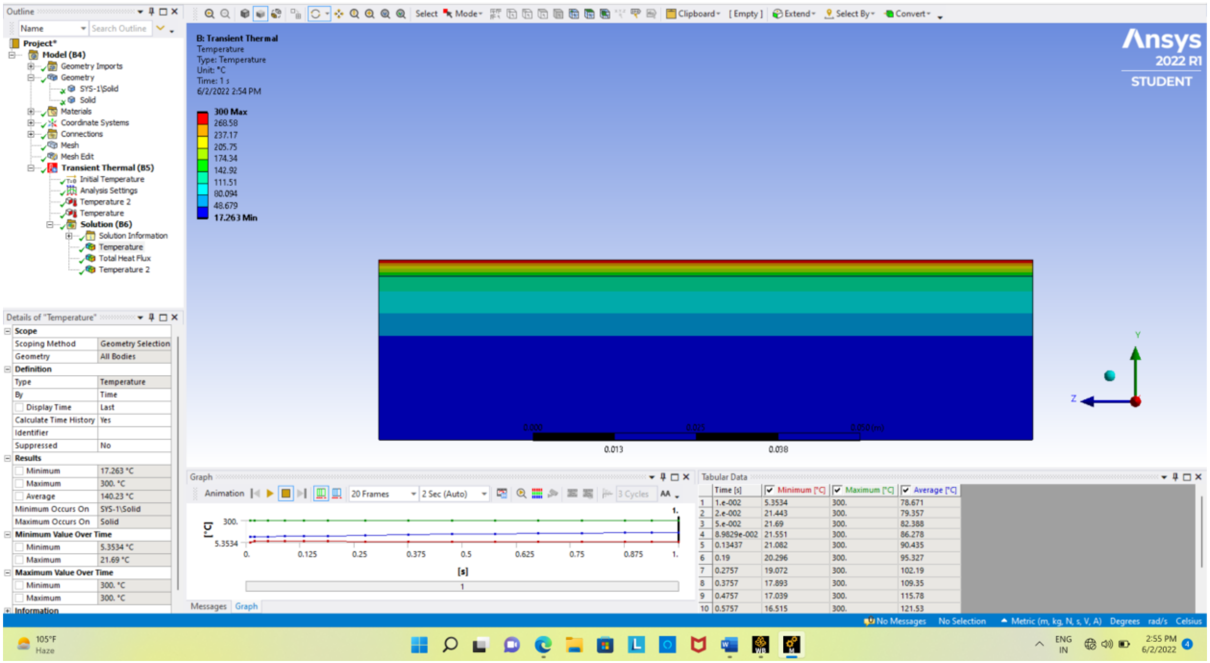

Fig 4.32 :- Change in the Average Temperature of the body with change in thickness from 5mm to 2.5mm

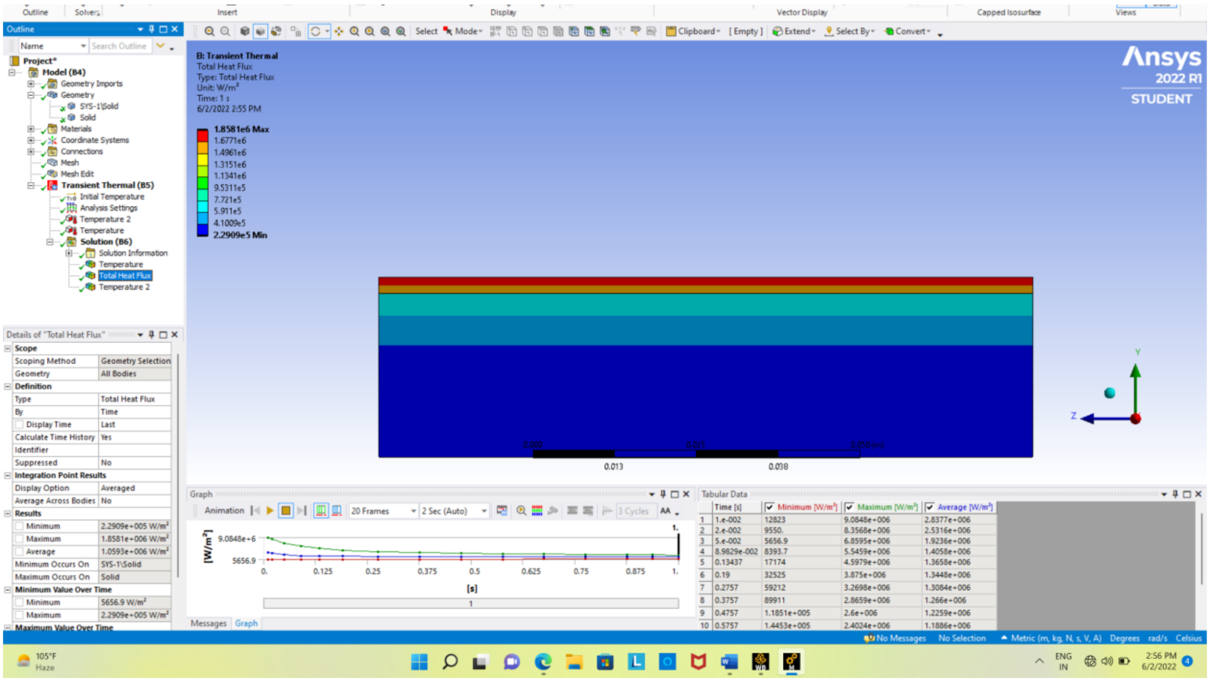

Fig 4.33 :- Change in the Heat Flux with change in thickness from 5mm to 2.5mm

With the change in thickness of coating it was observed that decreasing the thickness of the coating would result in more heat loss. On the other hand the higher thickness although further reduces the heat loss of the system, but would result in higher expenditure on the coating.

In a nut shell it can be concluded that zinc coated cast iron results in lower heat loss in flue gases.

4.4 Pin On Disc Wear Test

The results obtained clearly show the maximum wear resistance of the pin occurs in the case of cast iron specimens. This happens due to the higher hardness value of cast iron. Then the wear resistant material is electroplated zinc on cast iron and the material having the lowest wear resistance is the corroded zinc disc which has the formation of white rust due to exposure to harsh conditions of salt spray test. So, from the wear result of the pin on the disc wear test, it is clearly visible that though the electroplated zinc has better corrosion resistant properties it does not have resistance to indentation of the same level as that of cast iron. It can be also inferred from the test result that the corroded zinc plate is most prone to indentation as compared to the electroplated zinc plate which is not corroded.

As discussed earlier the test also proves that the salt spray test is a destructive test and therefore the plate obtained after receiving hard and harsh conditions of salt spray test requires less force as compared to a non-corroded electroplated zinc plate.

The next result obtained from the pin on the disc test is the value of the coefficient of friction. The value of the coefficient of friction is maximum for corroded zinc plates. The high value of the coefficient of friction for the corroded plate can be related to the destruction and degradation of its surface as an effect of corrosion. We know when corrosion occurs there is a formation of pitting. In the exposition where pitting occurs, the materials corrode away near to pit also and therefore lead to imbalance causing the formation of peaks and valleys which further makes the surface topography of material uneven. Due to the above stated reason, the value of the coefficient of friction is maximum for corroded zinc plates. Though the value of the coefficient of friction becomes stable after some time The Time involved is known as running in.

The value of electroplated zinc plate and cast iron are almost similar with very little difference between the value of these 2 specimens. In most cases, it is visible that cast iron has a little less value of the coefficient of friction as compared to the electroplated zinc coating.

And the last result obtained is the change in temperature of the pin and disc. There is not much change in the temperature of the plate as only the pin Is heated to perform the experiment. Very minute changes are visible in the change in temperature of the pin and disc.

All the graphs are plotted against the time duration which is plotted on the X-axis and is taken in its S.I. unit second.

Another result that is obtained from the pin on disc test is the effect on these properties with the change in temperature.

First is the effect of temperature on the coefficient of friction. With the increasing value of temperature, the value of the coefficient of friction decreases though there is not much of a change but the average value of the specimen decreases with the increase of the temperature of the experiment. It can be explained by the fact that interatomic forces decrease with an increase in temperature and the fictional force required for the metal decreases.

There is not much change in the temperature of the disc and pin with the increases in temperature with the help of the heater.

The last parameter to be analysed for the increase in temperature is the wear. For the increase in temperature of material, there is a increase in the wear of the specimen. This can be related to the formation of micro welds at the specified temperature. Micro weld occurs when the specimen at high temperature comes into contact with each other by the process of diffusion. The micro weld plough off the particles which leaves sharp edges which are worn off easily.

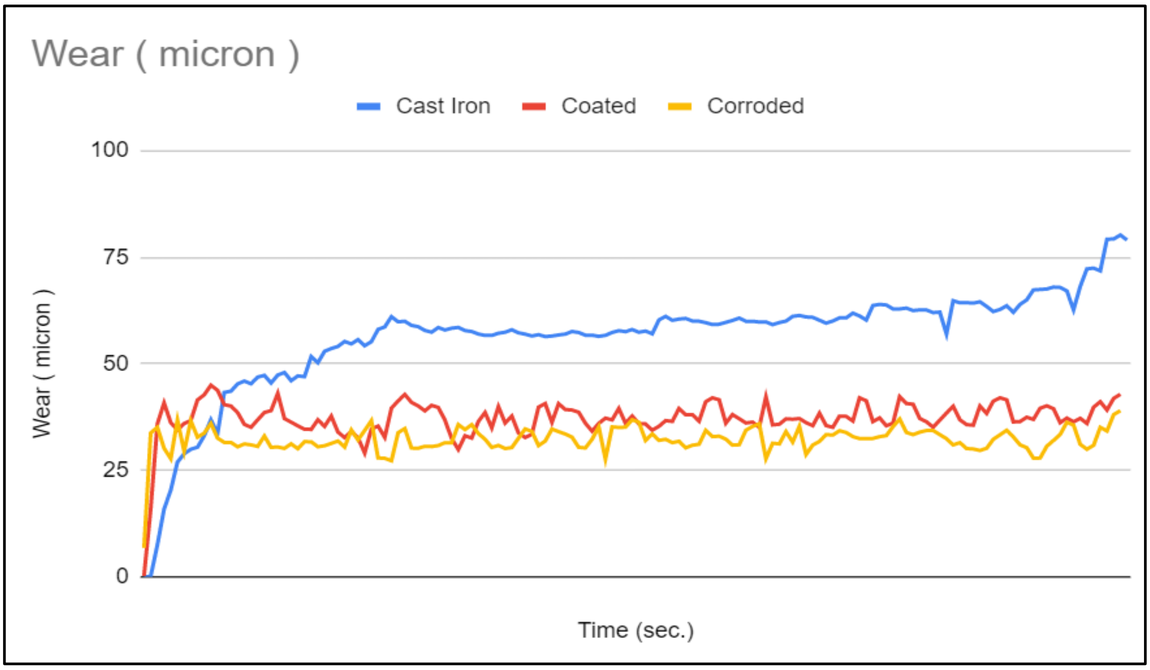

Fig 4.34:- Graph For Wear (in micron) for cast iron , zinc coated cast iron and corroded zinc coated cast iron vs Time (in seconds) For Temperature at 300 degree Celsius

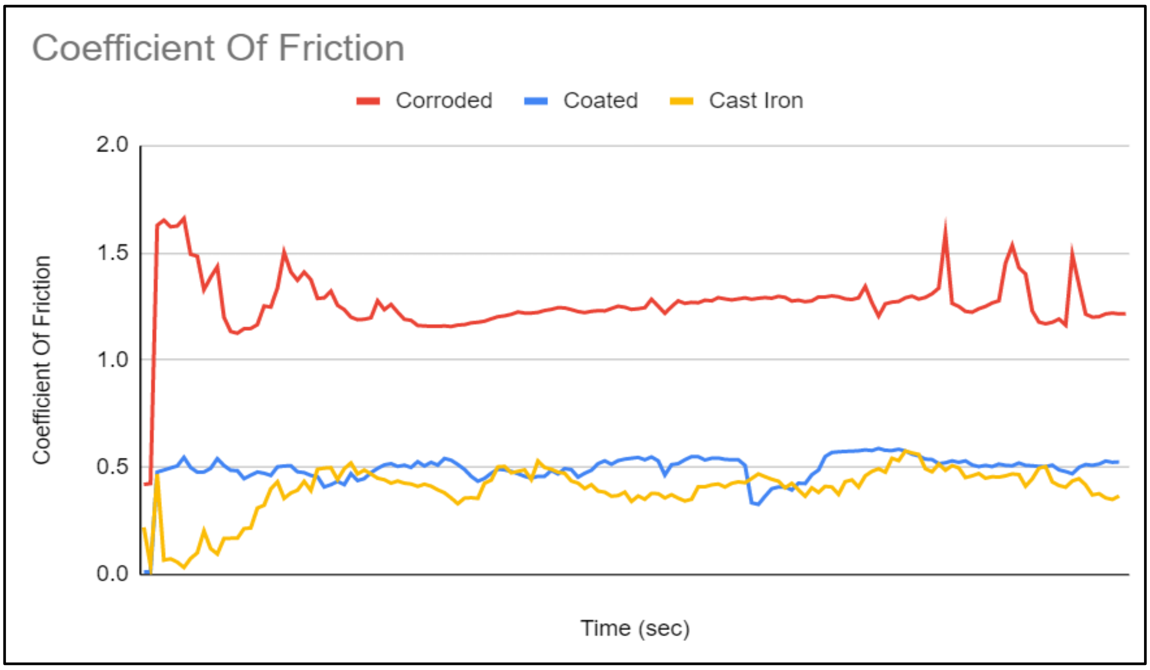

Fig 4.35:- Graph Of Coefficient Of Friction For Cast Iron, Zinc Coated Cast Iron And Corroded Zinc Coated Cast Iron Vs Time (In Sec.) For Temperature At 300 Degree Celsius

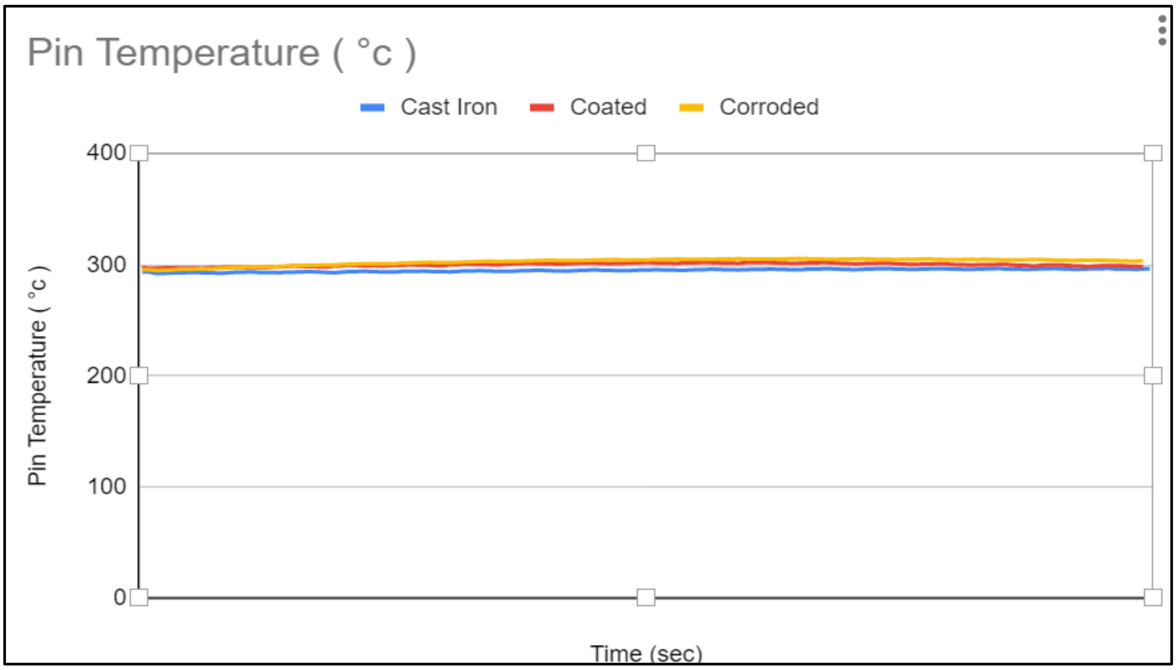

Fig. 4.36:- Graph For Temperature Of Pin For Cast Iron, Zinc Coated Cast Iron And Corroded Zinc Coated Cast Iron Vs Time (In Sec.) For Temperature At 300 Degree Celsius

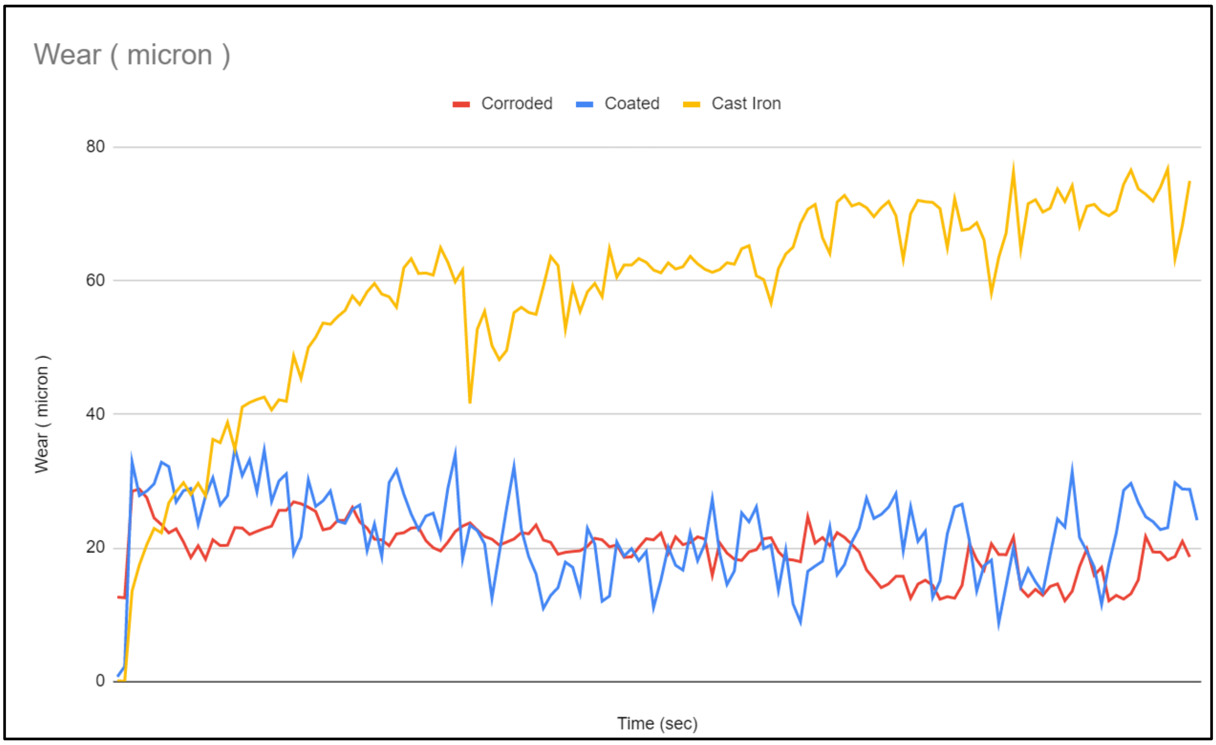

Fig 4.37:- Graph For Wear (In Micron) For Cast Iron, Zinc Coated Cast Iron And Corroded Zinc Coated Cast Iron Vs Time (In Seconds) For Temperature At 200 Degree Celsius

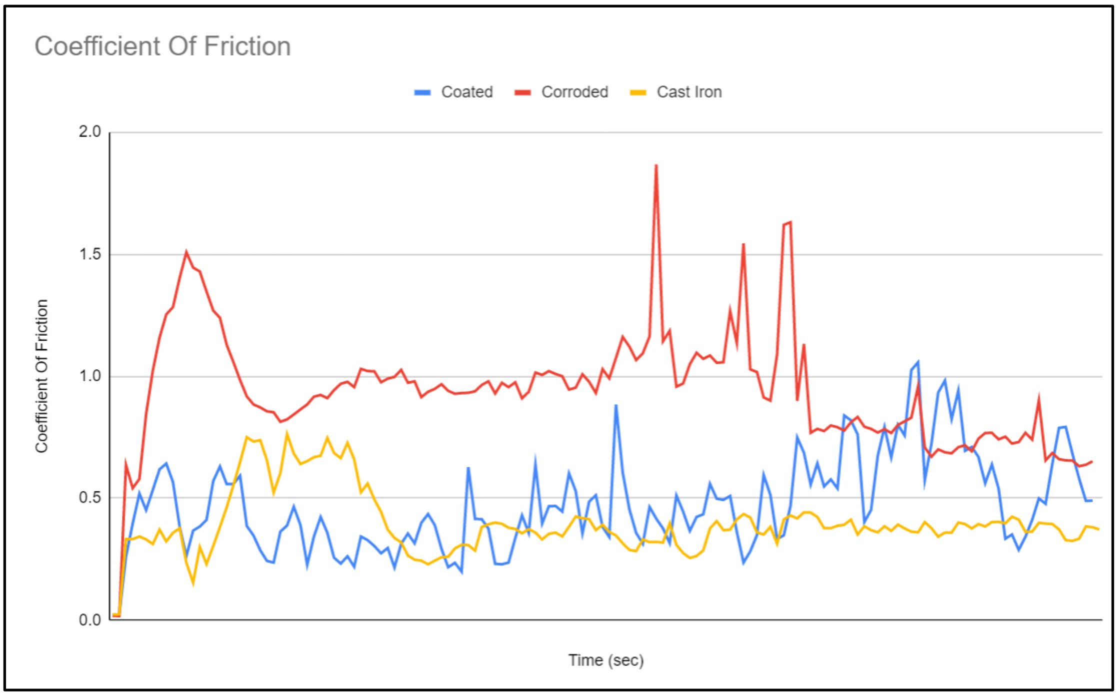

Fig. 4.38:- Graph Of Coefficient Of Friction For Cast Iron, Zinc Coated Cast Iron And Corroded Zinc Coated Cast Iron Vs Time (In Seconds) For Temperature At 200 Degree Celsius

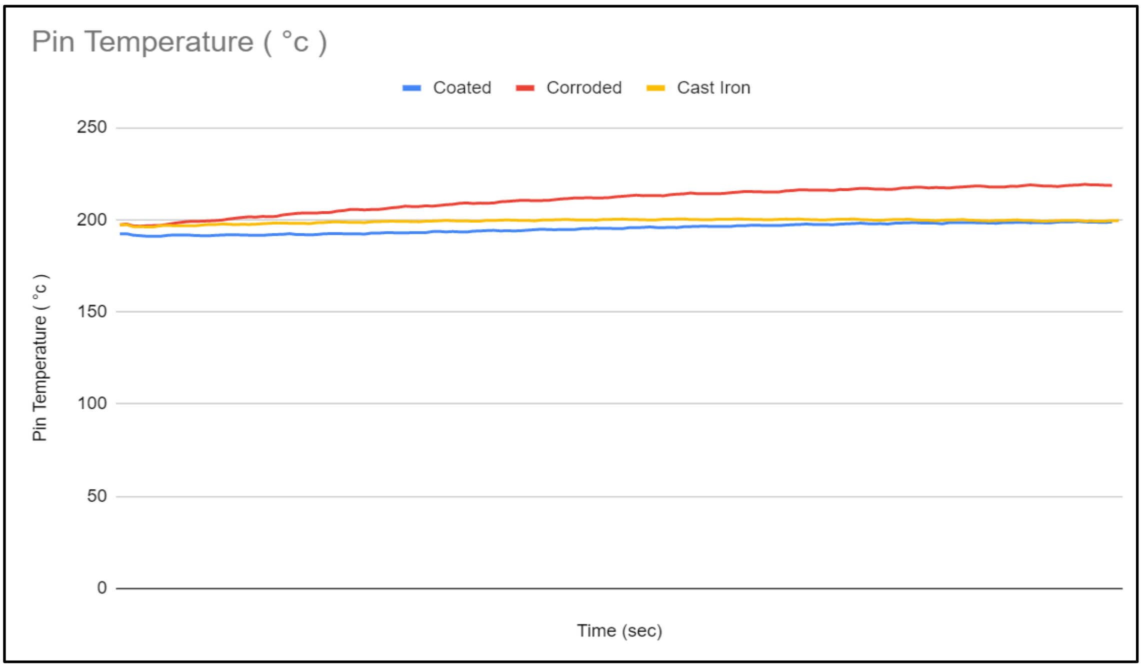

Fig 4.39:- Graph For Temperature OF Pin For Cast Iron, Zinc Coated Cast Iron And Corroded Zinc Coated Cast Iron Vs Time (In Seconds) For Temperature At 200 Degree Celsius\

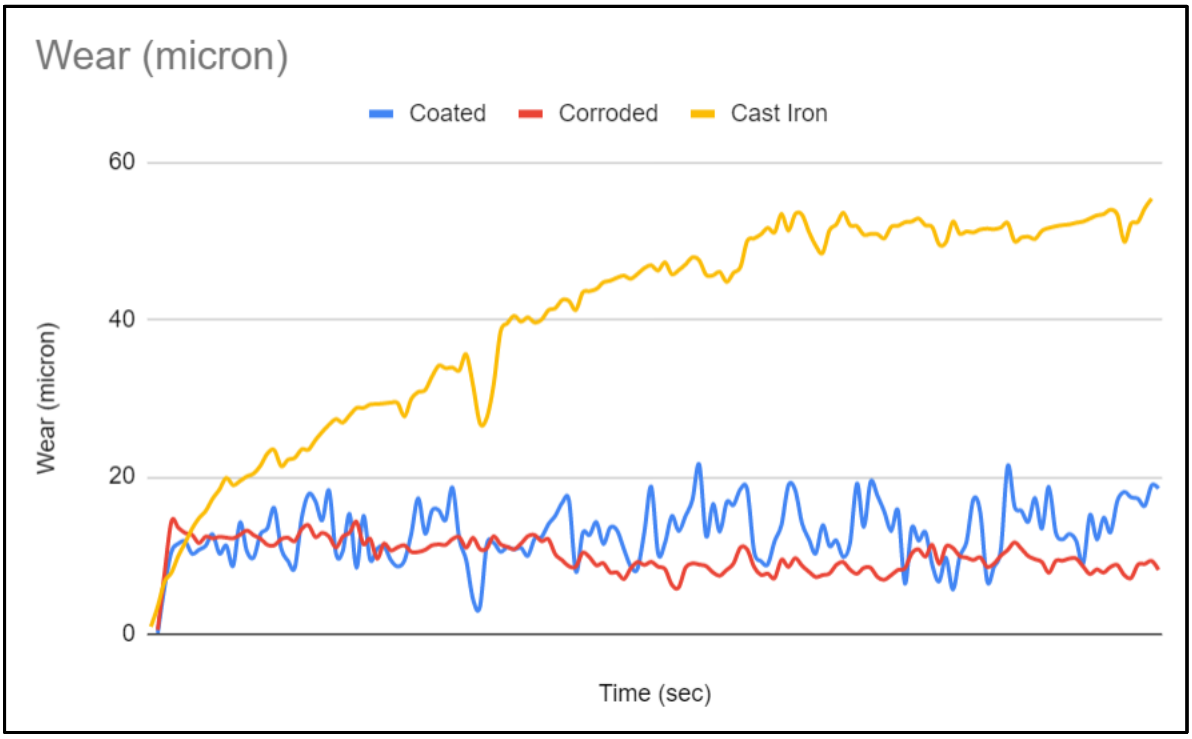

Fig 4.40:- Graph For Wear (In Micron) For Cast Iron, Zinc Coated Cast Iron And Corroded Zinc Coated Cast Iron Vs Time (In Seconds) For Temperature At 100 Degree Celsius

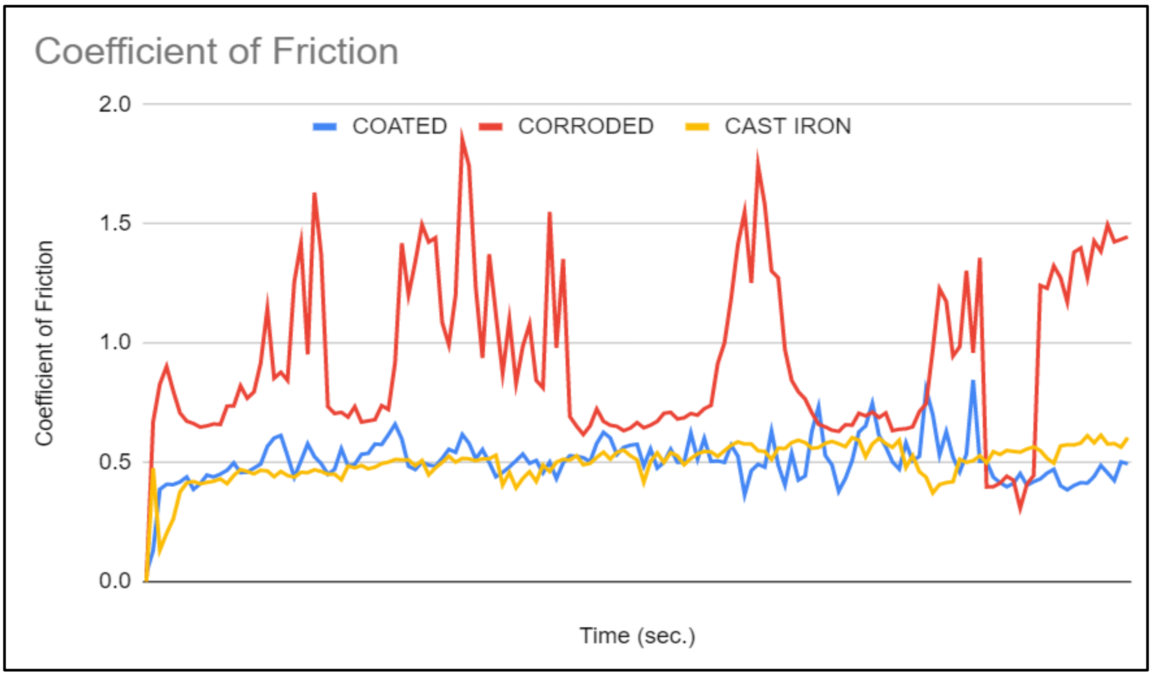

Fig 4.41:- Graph Of Coefficient Of Friction For Cast Iron, Zinc Coated Cast Iron And Corroded Zinc Coated Cast Iron Vs Time (In Seconds) For Temperature At 100 Degree Celsius

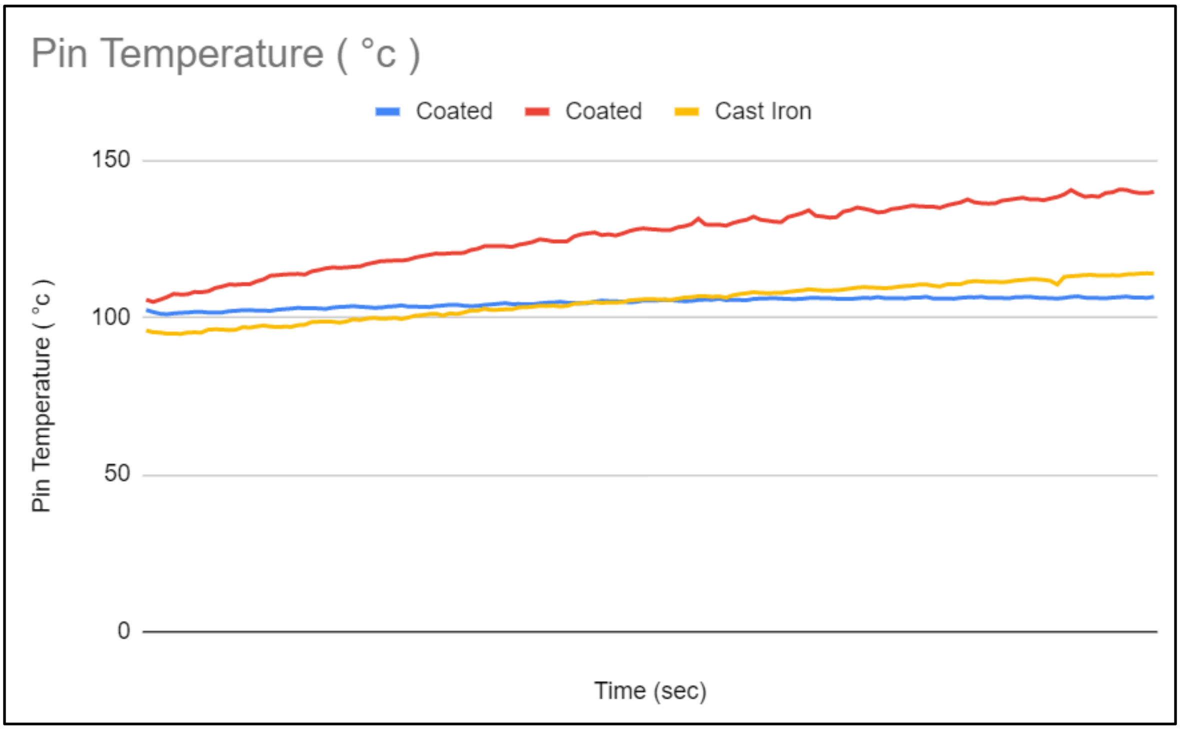

Fig 4.42:- Graph For Temperature OF Pin For Cast Iron, Zinc Coated Cast Iron And Corroded Zinc Coated Cast Iron Vs Time (In Seconds) For Temperature At 100 Degree Celsius

CHAPTER 5

CONCLUSION

After performing the various experiments and thermal modelling of zinc coated cast iron we are able to infer that following points:-

1. Zinc reduces the heat loss from the specimen as specified by ANSYS software, and therefore the temperature of dry flue gas that is sensible heat of flue gas is high when it reaches waste heat recovery system. More heat will be available at waste heat recovery system to increase the steam generation . this will help in increasing the efficiency of the boiler.
2. The salt spray test shows the corrosion resistant behaviour of coated zinc . Zinc coated specimen is more resistant to corrosion than cast iron. Salt spray test shows zinc corrodes after 72 hours in harsh conditions. Zinc coating can be used to reduce the heat loss of sensible heat of flue gases but due to high probability of corrosion the use of zinc coating for reduction in heat loss due to latent heat of flue gas is not recommended.
3. The pin on disc test shows low coefficient of friction value for zinc coated specimen therefore reducing the losses due to friction for flowing gases. This results in smooth flow of flue gases which therefore leads to low pressure drop across the duct due to friction. The low value of pressure drop across the stack length reduces the probability of flow separation and also reduces the power required for the flow of flue gases to occur.
4. The wear test reports moderate values of wear resistance for coated zinc which protects the surface from dust particles mixed with the flue gases and increases the life of stack in boiler.

From the above discussion it can be concluded that coated zinc is a favourable coating for stack for flow of sensible heat of flue gas to the waste heat recovery system and therefore helps reduce heat losses hence making system more energy efficient. But coated zinc is not recommended for latent heat of flue gas as it will lead to corrosion of zinc coating. Low initial cost of coating and increased efficiency makes zinc a viable option.

As discussed zinc coatings has moderate wear resistant value . Research on alloys of zinc can be done to overcome this constraint. Different coatings such as zinc-nickel have higher wear resistant value which can be used for further research.

FUTURE SCOPE

Investigation of material to decrease the loss of latent heat of flue gases in boiler. the property of material must possess high corrosion resistance and low thermal conductivity. This will lead to reduction in heat losses in boiler.

CHAPTER 6

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