

EXPERIMENTAL INVESTIGATION OF ZIRCONIA COATING OF A METAL ROOF SHEET AND COMPARING FEA ANALYSIS OF VARIOUS CERAMIC COATINGS

Submitted in partial fulfillment of the requirements for the award of Bachelor of
Technology degree in Chemical Engineering

by

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SCHOOL OF BIO & CHEMICAL ENGINEERING**

SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY

(DEEMED TO BE UNIVERSITY)

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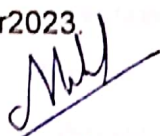
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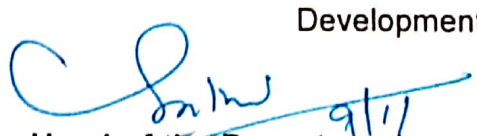
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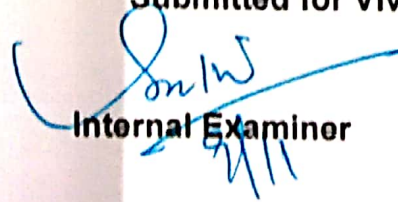
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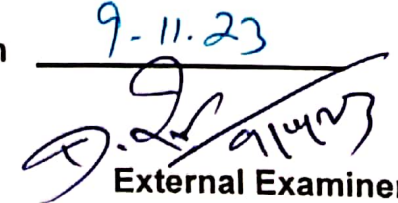

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ABSTRACT

This research thoroughly evaluates roof metal sheet that have been coated with alumina, titania, and zirconia, three separate ceramics. Finite element analysis (FEA) is used to evaluate thermal performance, while other tests, including as Vicker hardness testing, corrosion resistance analysis using the salt spray method, and a light optical microscope study of the microstructure, round out the investigation. To determine whether or not coated roof metal sheet are suitable for use in high-temperature applications, we can use the information gained from the FEA step. Furthermore, we determine the best option for thermal insulation and protection by evaluating the efficiency of these three ceramic coatings. Vicker hardness testing provides empirical evidence of the affects of coatings on the steel sheets' hardness and surface qualities.

From the FEA analysis it shows that zirconia is the best one among others (alumina and titania). And the experimental results indicate that hardness test shows these coatings can provide increased wear resistance and durability, making them suitable for applications where mechanical stress is a concern, The microstructural results show only minor defects were observed and the corrosion test results indicate that these coatings can provide increased corrosion resistance, making them suitable for applications where corrosive environments is a concern.

These findings facilitate informed decision-making for industries seeking optimal solutions for applications that demand high-temperature insulation, hardness improvement, and protection against corrosion. Future research may focus on refining manufacturing processes to minimize defects and enhance the overall performance of these ceramic coatings, further expanding their practical applications.

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CHAPTER – 1

1.1 INTRODUCTION

Asbestos roof sheet has been excavated and used monetarily around the world afterward the early 1900s. Asbestos roof sheets the common name for several fibrous materials found in nature. The commercial success of asbestos may be traced back to the material's many useful properties, such as its inflammability, lofty tensile strength, corrosion aversion, and poor electrical conductivity in few groups of asbestos fibers. There are many types of asbestos fibers found around the world, but only three are commonly used to make AC sheets. The other two main types of asbestos fibers (crocidolite and amosite) have been banned due to their high toxicity, leaving only chrysotile as legal. Because of their low toxicity, chrysotile fibers are used to make asbestos cement sheets.

Because of their longevity, low maintenance requirements, and low overall cost, metal roofs are frequently employed on commercial and industrial buildings. Metal roofs, on the other hand, have a high thermal conductivity, which can result in an excessive amount of heat transfer into buildings when hot weather conditions are present. Because of thermal expansion and contraction, this can lead to discomfort for those living in the building, an increase in the amount of energy needed for air conditioning, and even damage to the roof itself.

There is a dearth of information regarding the efficiency of thermal coatings in reducing heat stress on the roof metal sheet itself, despite the fact that these coatings have several benefits. High values of the heat index, which is a measurement of the thermal load on a surface, can lead to thermal fatigue and deformation of the roof metal sheet. The heat index measures the thermal load on a surface. As a result, it is essential to conduct research into the efficiency of various thermal coatings in lowering the heat index on roof metal sheets.

Several procedures were performed on these fibers in order to create Asbestos Cement Sheets. Some waste occurs during the manufacturing process of these Cement sheets. The aforementioned wastes are the most frequently reported issues (drum sticking, shrinkages during the curing stage, etc.). Superplasticizer and kaolin were used as additives to cut down on these losses

and maintain steady cure times. Binding green sheets perfectly on a Hatschek machine requires very few modifications. The temperature of the cured asbestos sheet was measured and compared to that of the Paraffin Wax mixed green sheets. Paraffin Wax is an excellent Phase Change Material for decreasing heat; however, because of its binding property, its addition should take place in the green sheet. The aforementioned information on garbage was compiled by RAMCO Industries Limited. The purposes of this paper are to reduce the shrinkage that occurs during curing, the amount of heat that an asbestos sheet absorbs, and the quantity of waste that is produced by drum sticking during the fabrication of green sheets. The remaining parts of the paper are as follows. Part II displays the literature review, while Section III details the approach taken to manage trash and temperature. The thermal analysis of the sheets is discussed in Section IV, and the work is concluded with some suggestions for further research in Section V.

Coatings have been made for centuries to protect against corrosion and erosion by isolating the substance from the chemical and physical effects of its surroundings. Because of their impact on the operation and manufacturing industries and the amenity life of many components, corrosion and wear problems remain critically essential in a broad range of industrial applications and products. This is because deterioration and in time failure of element and systems are the end result of corrosion and wear issues. Several techniques exist for depositing the appropriate surface protection that can withstand specific environments. Typically, the thickness of the deposited coating which can be anywhere from 10 to 20 micrometers to several micrometers is used to classify them into several categories. These latter coatings, often manufactured at ambient pressure, can have a thickness of several millimeters and are typically thicker than 30 micrometers. When the functional performance and longevity of a component are directly tied to the thickness of the protective layer, these are used. Wet coating methods and dry coating methods are two classifications that can be used to both coating technologies. The medium utilized to handle the deposited material is the primary dividing line between the two processes. The ability to maintain high temperatures has been essential to the growth of civilization in many locations throughout human history. Structural materials utilized in many cutting-edge high-

tech industries must be able to work under extreme conditions, such as high heat, high pressures, and corroding environments. High-heat material degradation is, thus, a major problem for many sectors of the modern industry. Gas turbines in aero planes, petrified remain fuel petrochemical, refineries, and power plant industries, and heating components for high temperature furnaces and construction sites are all situations where corrosion and thermal limitation their usage or shortens in life. The improved heat conduction via asbestos sheet has major effects on efficiency and human health.

CHAPTER – 2

2.1 LITERATURE REVIEW

Due to the remarkable thermal, chemical, and mechanical properties of ceramic coatings, they are widely used as a protective layer on metal sheets along with other functional purposes. In addition to increasing the thermal stability of the metal sheets, the coatings may also increase the sheets' resistance to wear and corrosion. The use of ceramic coatings for efficient in terms of energy purposes, like reducing heat transmission into buildings, has gained popularity in recent years. Cutting back on the quantity of sunlight that goes into buildings is one example of this kind of application.

A unique ceramic coating was produced by Wang and colleagues (2020) in their research. The raw elements for this coating were silica aerogel and polyurethane. After applying the coating to the metal sheet, the thermal performance was analyzed under a range of temperature settings. The findings indicated that the ceramic coating has the potential to efficiently limit the quantity of heat that is goes through the roof metal sheet. As a consequence, the temperature within the building was found to be lower.

In a separate piece of research, Xu et al. (2019) explored how the application of ceramic coatings might affect the thermal performance of metal roofs. The researchers covered a roof metal sheet with a ceramic coating that contained silicon dioxide and titanium dioxide. The coating was applied using a spray gun. Measurements of the coated sheet's thermal conductivity and thermal resistance showed that the ceramic coating has the ability to greatly reduce the heat transfer through the metal sheet. As a consequence, the amount of energy needed to cool the building is reduced.

For the purposes of solar energy applications, a ceramic coating was applied to a metal sheet in a study that was conducted by Kim et al. (2018). The coating, which had a top layer that was transparent and a bottom layer that was black and made of ceramic, was analyzed for the solar absorption and thermal emittance capabilities it possessed. The investigation revealed that the ceramic coating is

capable of successfully absorbing solar radiation and radiating thermal energy; as a consequence, the rate at which heat was transferred through the metal sheet was found to be significantly reduced.

In a study that was conducted by Song et al. (2021), a ceramic coating was produced by the use of an aqueous sol-gel technique, and it was then applied to a sheet of stainless steel. High levels of hardness and resistance to wear were displayed by the coating, which was made up of nanoparticles of zirconia. According to the findings, applying a ceramic coating to a metal sheet can greatly increase both its resistance to corrosion and its resistance to wear, thereby rendering the sheet ideal for a variety of uses in the industrial sector.

In a separate piece of research, Zhang et al. (2019) looked at the impact that ceramic coatings have on the oxidation resistance of metal sheets when exposed to high temperatures. Ceramic coating made of yttria-stabilized zirconia was utilized by the researchers, and it was applied to a sheet of nickel-based superalloy. The ceramic coating was evaluated for its thermal stability as well as its resistance to oxidation, and the outcomes demonstrated that the metal sheet can be successfully shielded from high-temperature oxidation by the ceramic coating., which results in improved durability and reliability. Additionally, the coated sheet's thermal stability was assessed.

A ceramic coating was put to an Aluminum alloy sheet for use in aerospace applications in a study that was conducted by Liu and colleagues (2018). Titanium dioxide and silicon dioxide were used to create the coating, which was then tested for its ability to insulate against heat and prevent corrosion. According to the findings, the ceramic coating has the ability to significantly cut down on the quantity of heat that is goes through the metal sheet. This leads to an increase in energy efficiency. Furthermore, the coating exhibited excellent anti-corrosion properties, which makes it suitable for use in aerospace applications.

Ravi Kumar looked examined the feasibility of using phase change material as a means of passively cooling structures. In his article, he contrasts numerous roofs,

some of which have Phase Change Material, with others that do not. Overall, heat transfer was cut by about 45% compared to when using WC sheets. Heat-reflective paints were evaluated by John Pockett and Marti Belusko, who found that pigments that match visible colors that naturally reflect more infrared radiations were the most effective. You may read about their findings in Heat Reflective Paints. The discussion was successfully wrapped up when it was decided that painting house roofs white would be an efficient solution to the problem of overheating caused by direct sunshine.

A.T.Pise (2013) utilized using alumina nanoparticles as a phase-changing substance in paraffin, studied the melting characteristics of paraffin wax, and predicted the impact on thermal performance brought on by the wax's improved thermal conductivity. To see how the improved thermal conductivity of the wax influenced its thermal performance, this was done.

A study that Pawan R. Ingole and Tushar R. Mohod research discussed here focuses on using phase change materials in the building trade. In this article, the writers categories and review the widely used PCM variations according to their distinct chemical properties.

In their study, **Qiu et al. (2012)** a PCM heat transport model was developed and the melting and solidification of PCMs were explored. Numerical simulations are performed with the help of CFD software, taking into account natural convection in the liquid phase.

Mario A. Medina and colleagues (2013) discussed the potential for using phase change materials in building walls to increase the building's thermal efficiency. The PCM that was covered with reflective foil sheets on the frame walls resulted in the highest reductions, with a maximum reduction of 52.4% and an average reduction of 35.6% at a PCM concentration of around 15%. The result was more consistent temperature in the vicinity of the walls.

2.2 CONCLUSION REMARKS

When the prior research was evaluated for this study, it was discovered that a number of other studies had examined the application of ceramic coatings on

roof metal sheets to provide thermal insulation. The use of ceramic coatings on roof metal sheets over energy-effective building applications is sadly understudied, especially when compared to asbestos metal sheets. There is a big research void in this area.

Therefore, the goal of this study is to close the research gap by analyzing the heat transfer characteristics of roof metal sheets coated with different thermal materials through a numerical investigation made possible by the Ansys program. And research has been done on zirconia coating on a few materials other than roof metal sheets. This will make it possible for the study to offer insightful data about the behavior of roof metal sheets with thermal coatings, that will aid in enhancing building comfort, lowering energy costs, and advancing environmental sustainability.

2.3 PROBLEM IN ROOF METAL SHEET

Asbestos roof sheet is a type of building material that has been utilized to a significant extent in the past owing to the fact that it is long-lasting, economical, and resistant to fire. On the other hand, due to the presence of asbestos fibers, asbestos sheet presents a significant danger to the health of human beings. Asbestos fibers, when inhaled, can lead to a variety of serious respiratory diseases and cancers, including lung cancer, mesothelioma, and others.

As a direct consequence of this, the use of asbestos sheet and other materials that contain asbestos has been limited or outright prohibited in numerous nations across the globe. If it is not disposed of in the correct manner, asbestos sheet can create problems for the environment in addition to the health dangers it already poses. It is possible for asbestos fibers to go airborne and contaminate the environment if the items that contain asbestos are not handled and disposed of in the appropriate manner.

Asbestos sheeting has a number of issues, one of which is that it is a brittle and weak substance that is prone to cracking and breaking readily. This could result in

damage to the roofing or other buildings constructed of asbestos sheet, which could then lead to leaks and other structural issues.

Because of the dangers to one's health that come with asbestos exposure and the possibility that asbestos sheet would contaminate the surrounding environment, the utilization of asbestos sheet is a serious issue in the field of building. In order to reduce the likelihood of being exposed to asbestos fibers, it is critical to practice safe handling and disposal procedures whenever asbestos-containing items are being handled or disposed of.

Asbestos roof sheet is a type of building material that has been widely utilized in the past due to the fact that it is reasonably priced, lasts for a long time, and is resistant to fire. On the other hand, due to the presence of asbestos fibers, asbestos roof sheet presents a significant danger to the health of human beings. Asbestos fibers, when inhaled, can lead to a variety of serious respiratory diseases and cancers, including lung cancer, mesothelioma, and others.

Another issue that can arise with asbestos roof sheeting is that, over a period of time, it can become brittle and weak, which can result in cracking and breaking. This can lead to leaks as well as other structural difficulties in the roof, which can ultimately result in water damage as well as possible safety hazards. Additionally, asbestos roof sheet is not an environmentally conscious material because it is hard to recycle and, if not properly disposed of, can contaminate the area around it. This may lead to multiple issues with the environment, such as the polluting of soil and water.

The use of asbestos roof sheeting is a substantial challenge for the building and construction industry because of the dangers to human health that are posed by asbestos exposure and the possibility of contaminating the surrounding environment. In order to lessen the likelihood of being exposed to asbestos fibers, it is essential to practice safe handling and disposal procedures when working with materials that contain asbestos. Additionally, it is critical to identify and use roofing materials that are less harmful to the environment in place of asbestos.

CHAPTER – 3

3.1 AIM & OBJECTIVES

- Study the properties and effects of Asbestos roof sheet
- To identify and select the suitable coating powder
- To design the asbestos sheet with SolidWorks software
- To investigate the numerical analysis of asbestos sheets with different ceramic powders like Titania, Alumina and Zirconia
- To compare the results and identify the suitable ceramic powder
- Prepared the sample for coating
- Coat the sample with the identified best ceramic powder
- Conducted the mechanical (hardness), corrosion, and Microstructural characterization with coated and un-coated substrate.

3.2 NEED AND IMPORTANCE

In summary, the following can be used to summarize the importance and requirement of experimental studies, investigation of the heat index using multiple thermal coatings on the metal roof sheet

Applications for energy-efficient buildings Metal roofs are a typical component in the construction of buildings; nevertheless, they can also contribute to an increase in the building's internal temperature when the weather is hot. It is possible to apply thermal coatings to the metal roof in order to limit the amount of heat that is transferred into the structure; as a result, the amount of energy needed to cool the building will be reduced. Hence, it is essential to conduct research into the influence that various thermal coatings have on the roof metal sheet's heat index to ascertain which coating is best suited for uses including energy efficiency in buildings.

Financial savings: Buildings that are more energy efficient can lead to significant cost savings on energy bills, in addition to reducing the carbon footprint of the structure. Building owners can reduce their monthly energy costs and make a

contribution to the preservation of the environment if they choose the thermal coating for a roof metal sheet that is shown to be the most efficient. Structures that have a high rate of heat transmission via the roof are more likely to become unpleasant during hot weather, which can lead to decreased productivity as well as health problems for the people who live or work in those buildings. Building occupants can have a more comfortable indoor climate if the building's roof is coated with thermally efficient materials, as this will reduce the amount of heat that is transferred through the roof.

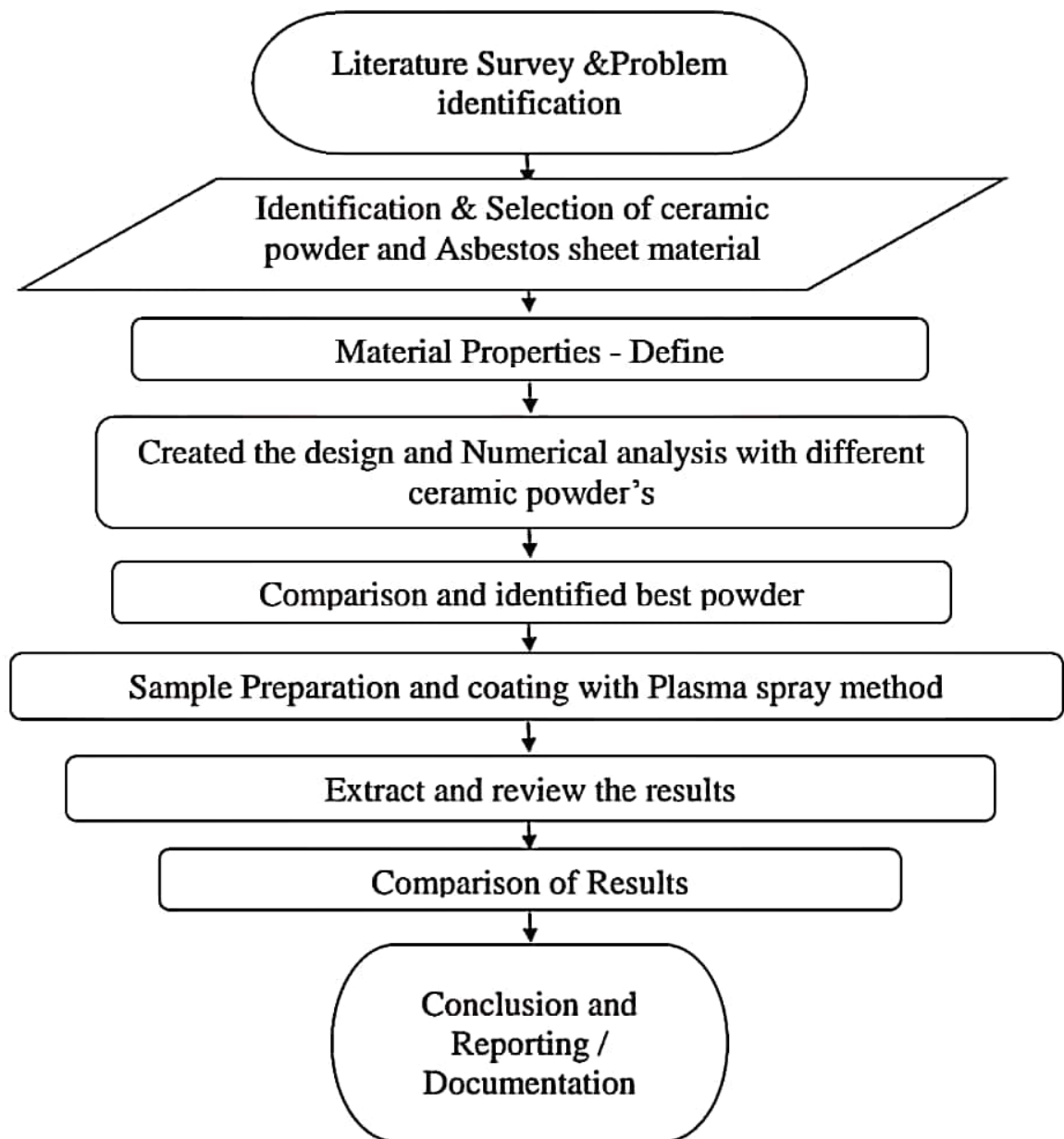
Material selection: The computational analysis can shed light on the characteristics of the various roofing materials and show how varying coating thicknesses affect the roof metal sheet's heat index. Finally, applying this knowledge to select the ideal coating materials for given applications may lead to improved material economy and efficacy.

Numerical simulation: By using Ansys for numerical modelling, it is possible to produce precise and practical predictions for the roof metal sheet's heat transfer properties with different thermal coatings. When compared to a physical inspection, this can save time and money while also providing a better understanding of how the roof metal sheet reacts to temperature variations.

CHAPTER – 4

4.1 METHODOLOGY

The methodology includes the Material selection, Design and numerical analysis.



4.2 MATERIAL'S: AN OVERVIEW

4.2.1 PROPERTIES OF ALUMINA

The chemical formula for Aluminium oxide, which is an alloy of Aluminium and oxygen, is Al_2O_3 . It is known as Aluminium oxide and is the most common kind among the different kinds of Aluminium oxides. Though depending on the form or application, it can also be known to as alkoxide, alkoxide, or alundum, alumina is the most commonly used term. Ruby and sapphire are two valuable gemstones that are formed from corundum, a mineral that is mostly found in the crystalline polymorphic phase Al_2O_3 . Al_2O_3 is an important material because it is used to produce Aluminium metal, and because of its hardness and high melting point, it can be used as an abrasive and as a refractory material.

Al_2O_3 is a ceramic with a high thermal conductivity (30 $\text{Wm}^{-1}\text{K}^{-1}$ [3]) despite being an electrical insulator. Water does not dissolve aluminium oxide. Corundum, also known as beta-aluminium oxide, is the most prevalent crystalline form of aluminium oxide and is used as an abrasive and cutting tool component due to its high hardness.

Aluminium oxide is what gives Aluminium metal its resistance to corrosion. Aluminium oxide produces a thin passivation layer on any exposed aluminium surface (4 nm thick) due to its high reactivity with ambient oxygen. This coating prevents further oxidation of the metal below. Anodizing is a technique that improves the thickness and characteristics of this oxide coating. Some alloys, such aluminium bronzes, use this feature to their advantage by incorporating some aluminium into the mix. In contrast to the amorphous aluminium oxide generally produced by anodizing, the crystalline aluminium oxide produced by discharge assisted oxidation techniques like plasma electrolytic oxidation significantly increases the hardness of the coating.

4.2.2 PROPERTIES OF TITANIA

TiO_2 , also referred to as titania or titanium oxide, is a naturally existing oxide of titanium. When used as a pigment, this material is known as titanium white. It is frequently produced using the minerals anatase, rutile, and ilmenite. It can be used

for anything, including food colouring, painting, and sun protection. At the Ries crater in Bavaria, two high-pressure forms of titanium dioxide were recently found, in addition to the well-known mineral's rutile, anatase, and brookite. These are the orthorhombic like form and the monoclinic baddeleyite-like form. Ilmenite ore is a significant source. The concentration of titanium dioxide in this particular type of ore is higher than in any other. Rutile, which has a titanium dioxide content of roughly 98%, is the second most common ore. The metastable anatase and brookite phases permanently change to the equilibrium rutile phase at temperatures above 600 °C to 800 °C.

It is possible to synthesize three metastable phases of titanium dioxide (monoclinic, tetragonal, and orthorhombic), in addition to the naturally occurring rutile, anatase, and brookite, and five high-pressure forms of titanium dioxide. also exist:

Titanium dioxide

Chemical Compound.

1. **Molar mass:** 79.866 g/mol
2. **Melting point:** 1,843 °C
3. **Density:** 4.23 g/cm³
4. **Boiling point:** 2,972 °C
5. **IUPAC ID:** Titanium dioxide, Titanium (IV) oxide

4.2.3 ZIRCONIA

There are three distinct zirconia crystal structures. Structures can be either monolithic (m) or tetragonal (t) or cubic (c). Between 0 and 1170 °C, the monolithic structure is stable, whereas above that temperature, the tetragonal structure takes over. Above 2379 degrees Celsius, the tetragonal structure changes to the cubic structure. Ceramic zirconia (ZrO₂) has sufficient mechanical qualities for use in the creation of medical equipment. The optimum characteristics for these uses can be found in zirconia stabilized with Y₂O₃. When ZrO₂ is stressed, a crystallographic alteration prevents cracks from spreading across the surface. ZrO₂ has a rather high compression resistance, around 2000 MPa. Zirconia is a zirconium dioxide

crystal. It looks like tooth enamel and has mechanical qualities very close to metals.

4.3 TYPES OF ZIRCONIA'S

The family of zirconia is broad and varied. These came about as researchers and manufacturers looked for fresh approaches to profit from the phases' distinct characteristics. Some phases benefit from toughening mechanisms specific to these and a small number of other materials, while others are only stable at high temperatures and must be "frozen" in to be used at room temperature. The common abbreviations for a number of these resources are listed underneath.

TZP - Tetragonal Zirconia Polycrystals

PSZ - Partially Stabilised Zirconia

FSZ - Fully Stabilised Zirconia

TTC - Transformation Toughened Ceramics

ZTA - Zirconia Toughened Alumina

TTZ - Transformation Toughened Zirconia

Prefixes will also be added to the abbreviations in table 1 to indicate whether or not the zirconia has had materials (oxides) added to it to stabilize or toughen it. Sometimes they'll be employed with a certain quantity of them, which stands for the amount of stabilizing agent. Yttria, ceria, magnesia, and alumina are all common examples of such elements. The addition of 3mol% Y_2O_3 as a stabilizer to tetragonal zirconia polycrystal results in the material designated as 3Y-TZP.

4.3.1 PROPERTY COMPARISON

The information in Table 4.1 describes the features was acquired from a range of sources and included different grades of zirconia. On the other hand, a number of variables, such as initial powder composition and manufacturing processes, can impact the properties of ceramic materials. Almost all of the ceramic fabrication techniques have been used to create zirconia. Injection moulding, extrusion are examples of this. By adding impurities, processing can also cause a material to deteriorate or have flaws.

TABLE 4.1 Typical properties of various types of zirconia.

Property	Y-TZP	Ce-TZP	ZTA	Mg-PSZ	3Y20A
Density (g.cm^{-3})	6.05	6.15	4.15	5.75	5.51
Hardness (HV_{30})	1350	900	1600	1020	1470
Bend Str. (MPa)	1000	350	500	800	2400
Compressive Str. (MPa)	2000	-	-	2000	-
Young's Modulus (GPa)	205	215	380	205	260
Poisson's Ratio	0.3	-	-	0.23	-
Fracture Toughness ($\text{MPa.m}^{-1/2}$)	9.5	15-20	4-5	8-15	6
Thermal Exp. Co-Eff ($\times 10^{-6} \text{ }^{\circ}\text{C}^{-1}$)	10	8	8	10	9.4
Thermal Conductivity ($\text{W.m}^{-1} \cdot \text{K}^{-1}$)	2	2	23	1.8	3

4.3.2 YTTRIA (Y_2O_3)

Yttria has a melting point of 2410 $^{\circ}\text{C}$. It floats steadily and cannot be easily compressed. It dissolves in acid and stores carbon dioxide. Small amounts are alloyed with zirconia and thorium and used as filament in Nerst lamps. It helps keep zirconia's cubic structure stable when added to the substance. Gadolinite, xenotime, and fergusonite are all primary yttria minerals. Its cubic structure makes it extremely refractory.

4.4 COATING: AN OVERVIEW

4.4.1 PLASMA SPRAY TECHNIQUE

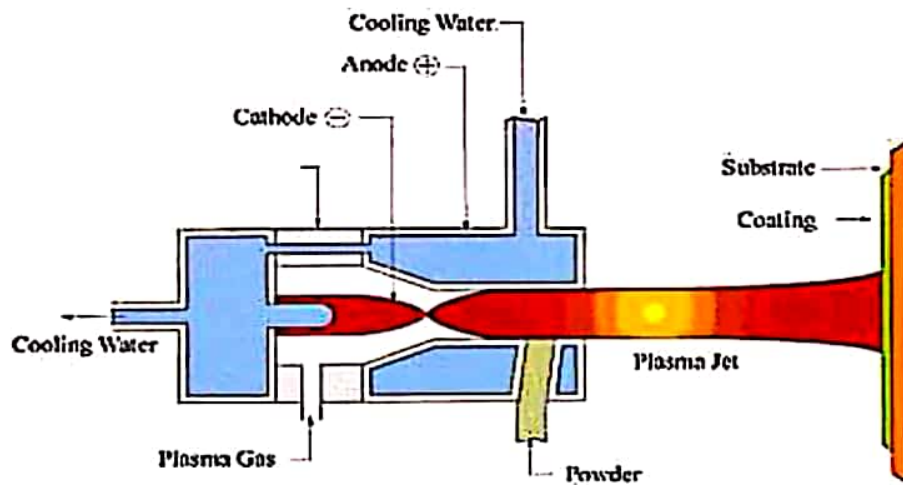


Figure 1 PLASMA SPRAY TECHNIQUE

The thermal spraying technique coats the substrate's surface with a thin, homogeneous layer of molten metal or non-metallic coating material, like wire or powder. The material must first be made plastic or molten in order to use thermal spray. The impact with the substrate surface deforms the particles, creating a layered sheet that adheres to the surface. Over time, they progressively thicken into a film. Different coating materials can be used to achieve different properties, such as resistance to abrasion and erosion, heat insulation, ceramic insulation, and so forth.

Thermal spray is a cutting-edge technology that has found applications in numerous industries, including aviation, automobiles, energy, metallurgy, paper production, machinery maintenance, and municipal building.

When it comes to improving surface functions and characteristics in the fields of engineering and mechanical engineering, thermal spray technology is the most efficient, cost-effective, and straight-forward technique. Equipment and spare parts can have longer lives, better surface performances, and lower production and maintenance costs when the thermal spray technology is used. The properties of

thermal spray include resistance to abrasion and heat, as well as anti-erosion, gap control, size restoration, and electrical conductivity modification, among others.

4.5.2 A PROCESS FOR PLASMA COATING

The most flexible thermal spray method is plasma spray because it can heat or melt any material, increasing the range of potential coating materials. A plasma spray pistol consists of a tiny chamber housing an electrode (the cathode) and a nozzle (the anode). Gas passing through the chamber is ionized by a high-intensity arc, creating a plasma material and releasing a great deal of heat (up to 16000 degrees Celsius). Coating materials are melted when they strike the surface of the substrate after being rapidly pumped into a gas flame.

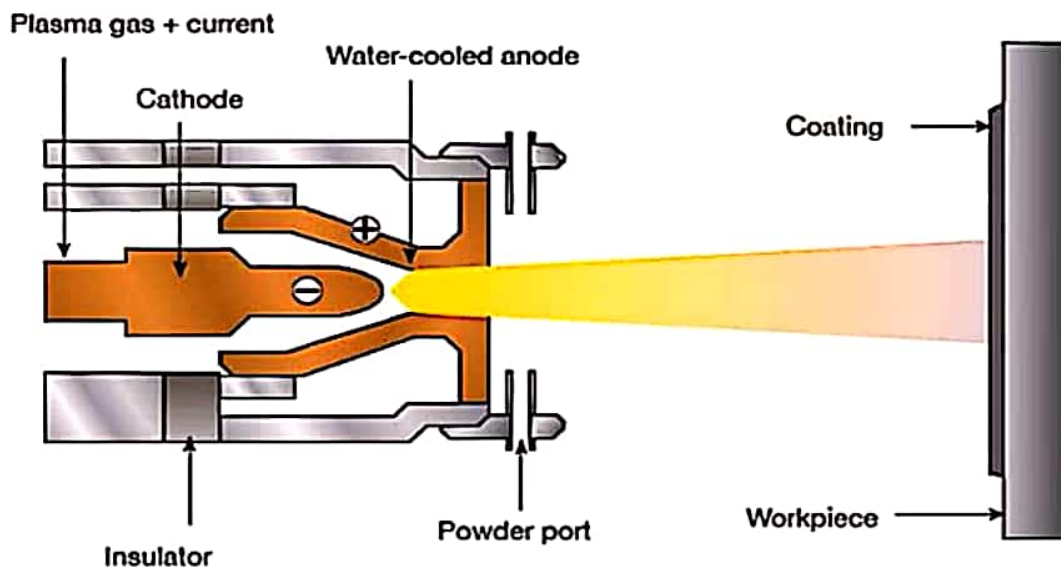


Figure 2 PROCESS FOR PLASMA COATING

Ceramic, zirconium, yttrium, chrome carbide, and tungsten carbide coatings are just some of the many that can be applied to seal diameters, machine spindles, and print rollers.

4.4.3 OVERVIEW OF PLASMA COATING PROCESS

An anode and tungsten cathode are connected by a high frequency arc to form a plasma coating. A several-centimetre-long plasma plume forms when the gas (He, H₂, N₂, or mixes) that is moving between the electrodes becomes ionized. Within the plume, temperatures can get as high as 16,000° K. powdered material Injecting into the plasma plume causes it to melt, and as it accelerates to the substrate surface, it forms a coating that quickly cools.

The warmer particles transfer their heat to the colder ground substance. The particles adhere to the roughened foundation as they contract and solidify. The coating's adhesion relies on mechanical "hooking" to hold objects together. Since plasma spraying is a cold process, the wide variety of substrates we can cover are protected against damage and distortion, among other potential problems.

4.6 DESIGN AND ANALYSIS

4.6.1 DESIGN

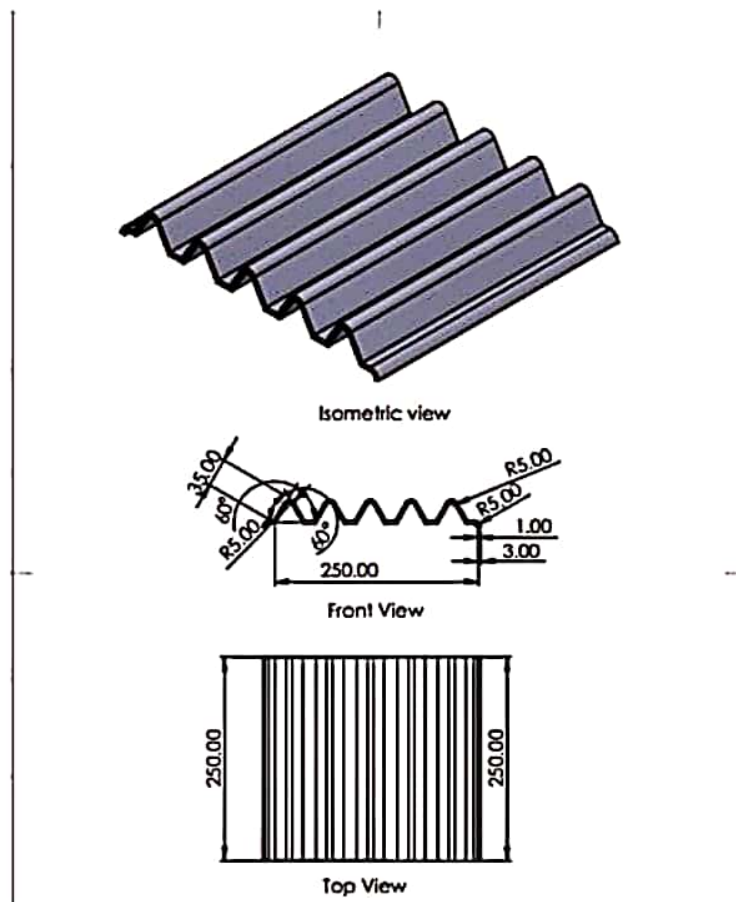


Figure 3 Design

4.6.2 ANALYSIS

Outline of Schematic A2: Engineering Data				
	A	B	C	D
1	Contents of Engineering Data			Source
2	Material			Description
3	Alumina			C:\Users\user\Desktop\Engi
4	Polycarbonate			C:\Users\user\Desktop\Engi
5	Structural Steel			General_Materials.xml

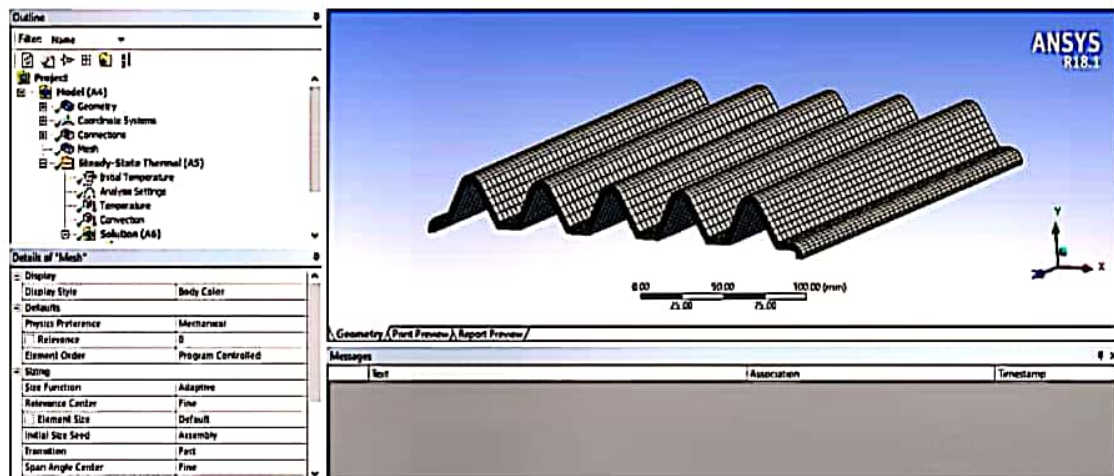
Properties of Outline Row 4: Polycarbonate				
	A	B	C	D
1	Property	Value	Unit	
2	Material Field Variables	Table		
3	Isotropic Thermal Conductivity	0.22	W m ⁻¹ C ⁻¹	

Material of sheet

Outline of Schematic A2: Engineering Data				
	A	B	C	D
1	Contents of Engineering Data			Source
2	Material			Description
3	Alumina			C:\Users\user\Desktop\Engi
4	Polycarbonate			C:\Users\user\Desktop\Engi
5	Structural Steel			General_Materials.xml

Properties of Outline Row 3: Alumina				
	A	B	C	D
1	Property	Value	Unit	
2	Material Field Variables	Table		
3	Isotropic Thermal Conductivity	38.5	W m ⁻¹ C ⁻¹	

Material Property of Alumina



Titania

Outline of Schematic A2: Engineering Data

	A	B	C	D	E
1	Contents of Engineering Data			Source	Description
5	Structural Steel			General_Materials.xml	1998 ASME BPV Code, Section 8, Div 2, Table 5-110.1
6	Titania			C:\Users\user\Desktop\Engi	
7	Zirconia			C:\Users\user\Desktop\Engi	
*	Click here to add a new material				

Properties of Outline Row 6: Titania

	A	B	C	D	E
1	Property	Value	Unit		
2	Material Field Variables	Table			
3	Isotropic Thermal Conductivity	4.8	W m^-1 C^-1		

Outline of Schematic A2: Engineering Data

	A	B	C	D	E
1	Contents of Engineering Data			Source	Description
5	Structural Steel			General_Materials.xml	1998 ASME BPV Code, Section 8, Div 2, Table 5-110.1
6	Titania			C:\Users\user\Desktop\Engi	
7	Zirconia			C:\Users\user\Desktop\Engi	
	Click here to add a new material				

Properties of Outline Row 7: Zirconia

	A	B	C	D	E
1	Property	Value	Unit		
2	Material Field Variables	Table			
3	Isotropic Thermal Conductivity	5	W m ⁻¹ C ⁻¹		

Material property

Analysis of Roof sheet

Outline of Schematic A2: Engineering Data					
	A	B	C	D	E
1	Contents of Engineering Data			Source	Description
2	Material				
3	 Alumina			C:\Users\user\Desktop\Engi	
4	 Polycarbonate			C:\Users\user\Desktop\Engi	
5	 Structural Steel			General_Materials.xml	Fatigue Data at zero mean stress comes from 1998 ASME

Properties of Outline Row 4: Polycarbonate					
	A	B	C	D	E
1	Property	Value	Unit		
2	 Material Field Variables	Table			
3	 Isotropic Thermal Conductivity	0.22	W m ⁻¹ C ⁻¹		

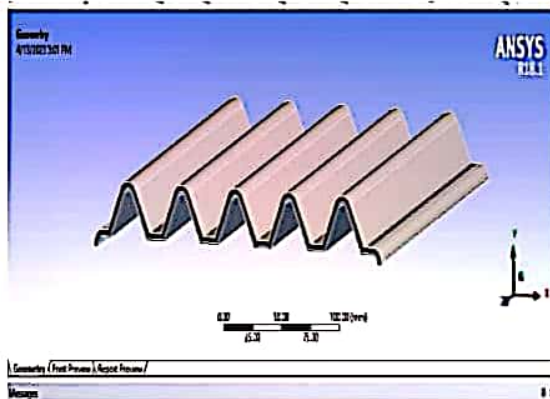
Material Property of Alumina

Outline of Schematic A2: Engineering Data				
	A	B	C	D
1	Contents of Engineering Data			Source
2	Material			Description
3	Alumina			C:\Users\user\Desktop\Engi
4	Polycarbonate			C:\Users\user\Desktop\Engi
5	Structural Steel			General_Materials.xml

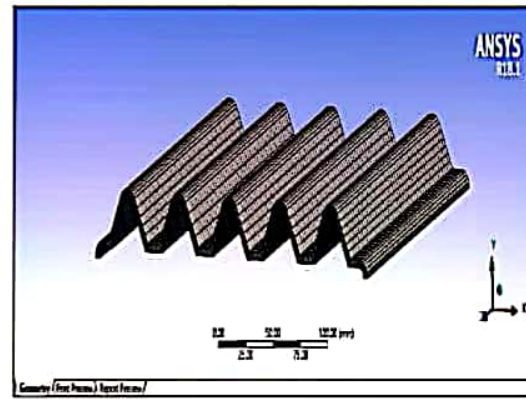
Properties of Outline Row 3: Alumina				
	A	B	C	D
1	Property	Value	Unit	
2	Material Field Variables	Table		
3	Isotropic Thermal Conductivity	38.5	W m ⁻¹ C ⁻¹	

BOUNDARY CONDITION

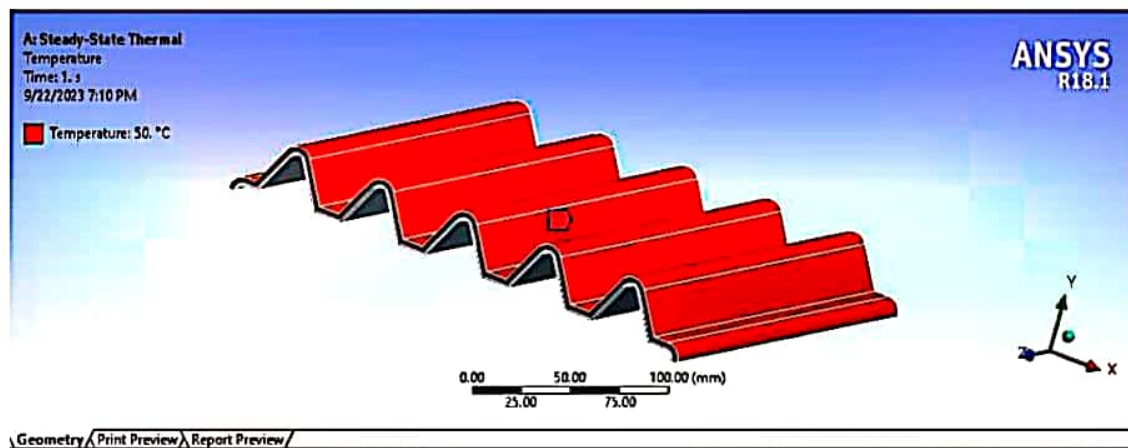
GEOMETRY



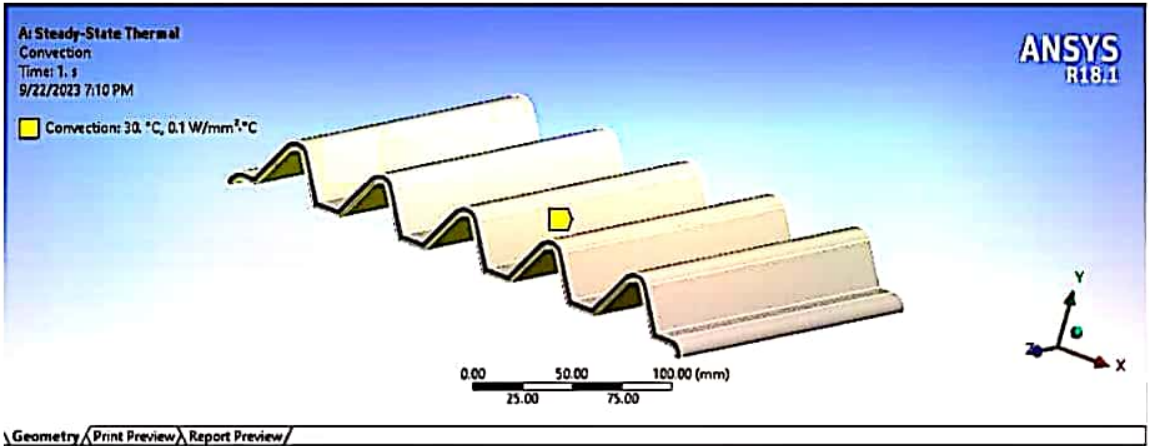
MESH



Temperature

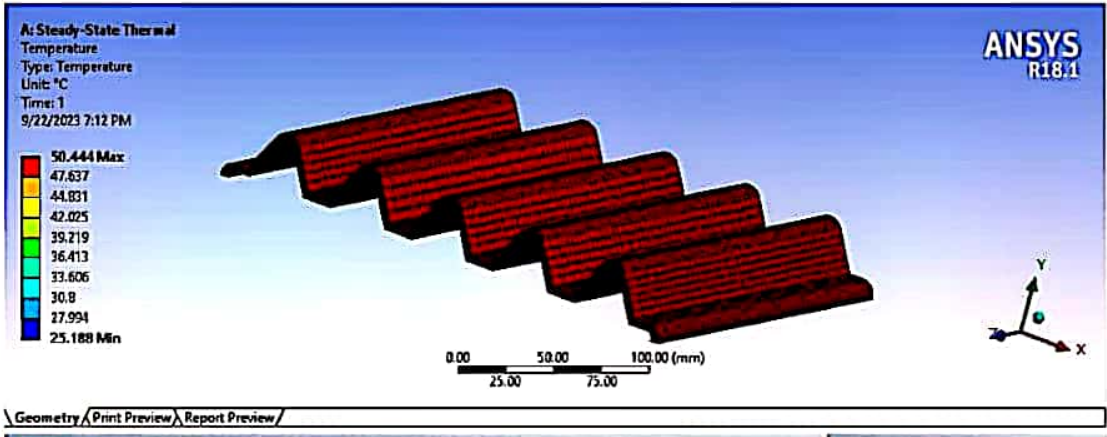


Convection

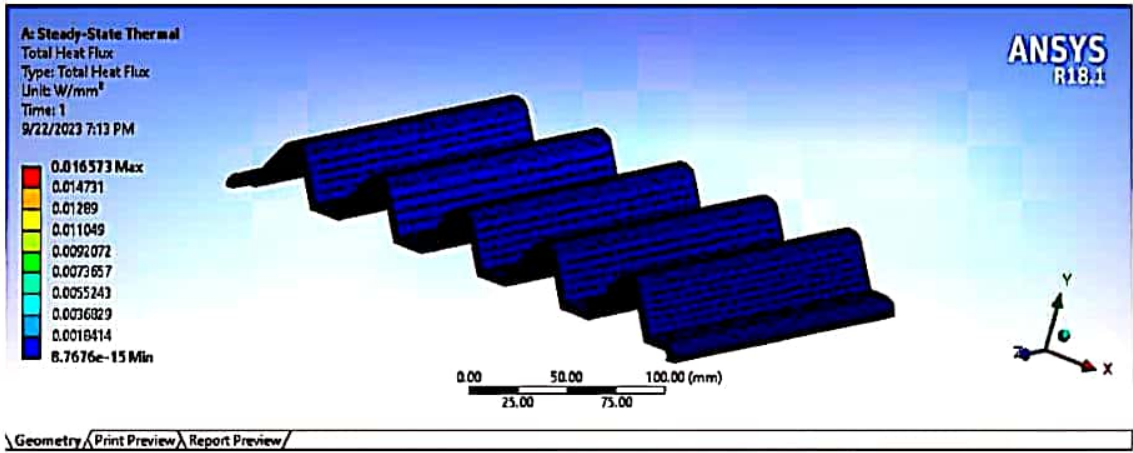


RESULT FOR STRUCTURAL STEEL

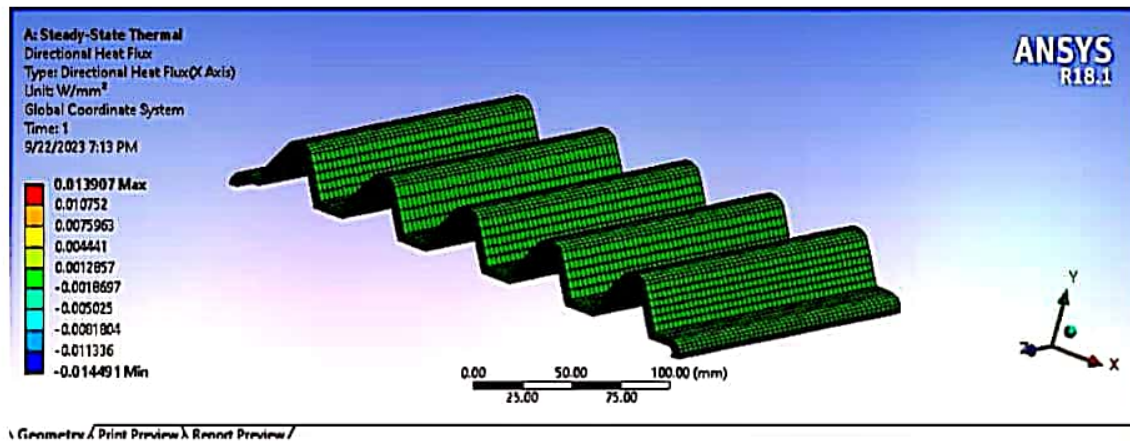
Temperature



Total Heat Flux

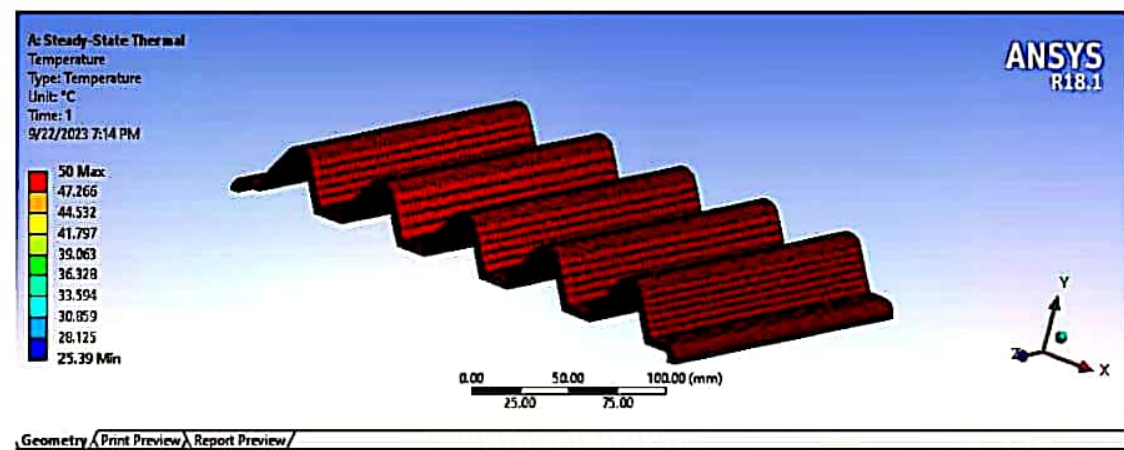


Directional Heat Flux

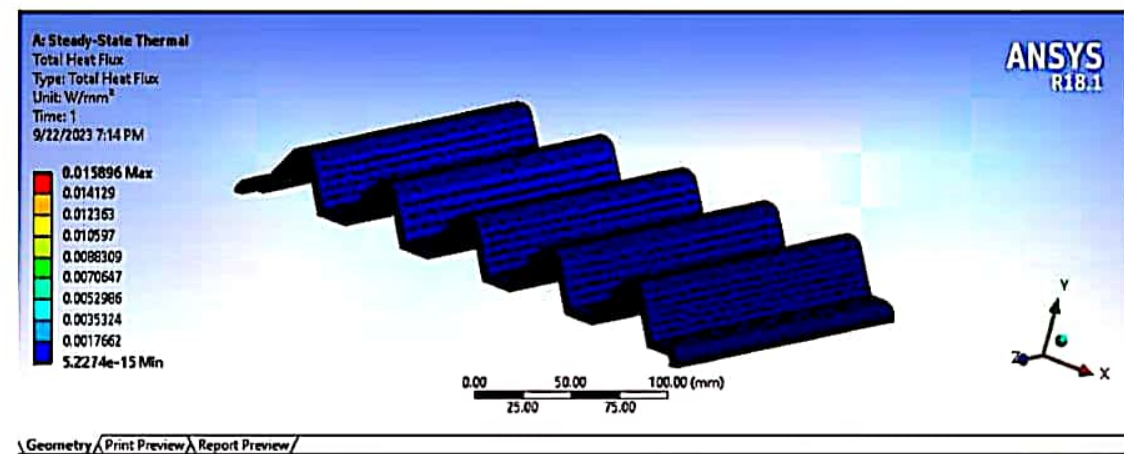


RESULT FOR ALUMINA

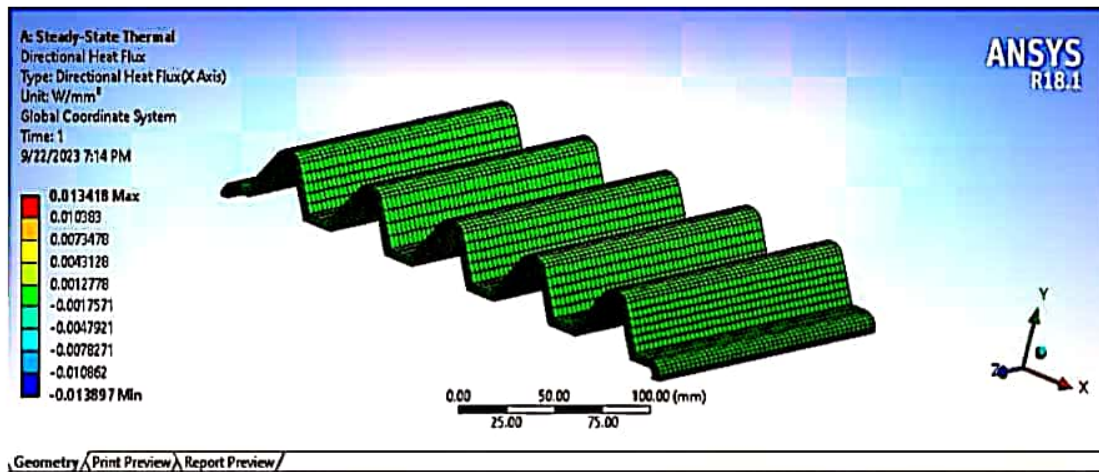
Temperature



Total Heat Flux

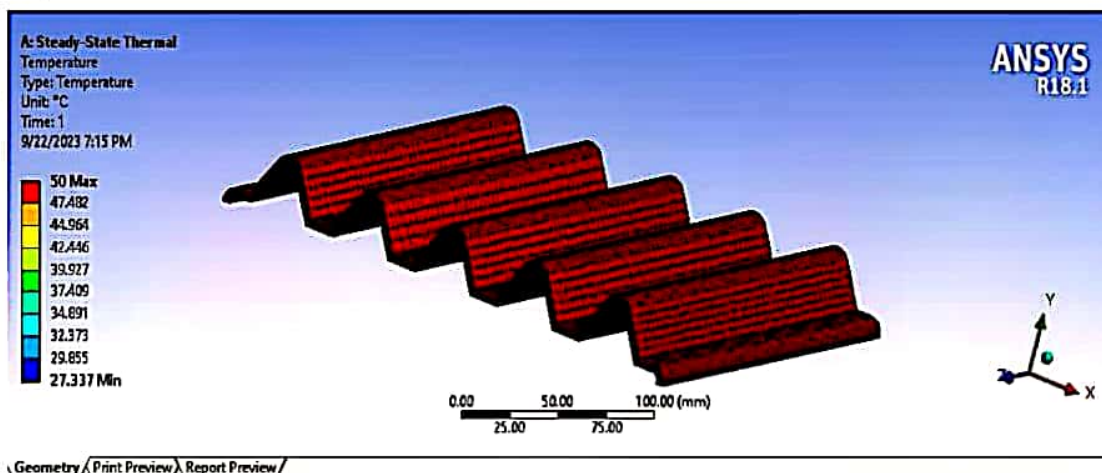


Directional Heat Flux

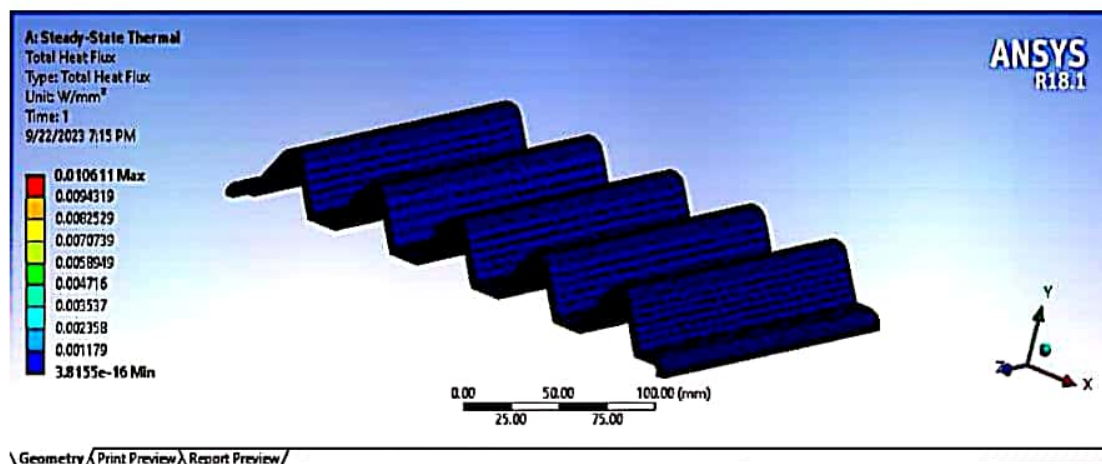


RESULT FOR TITANIA

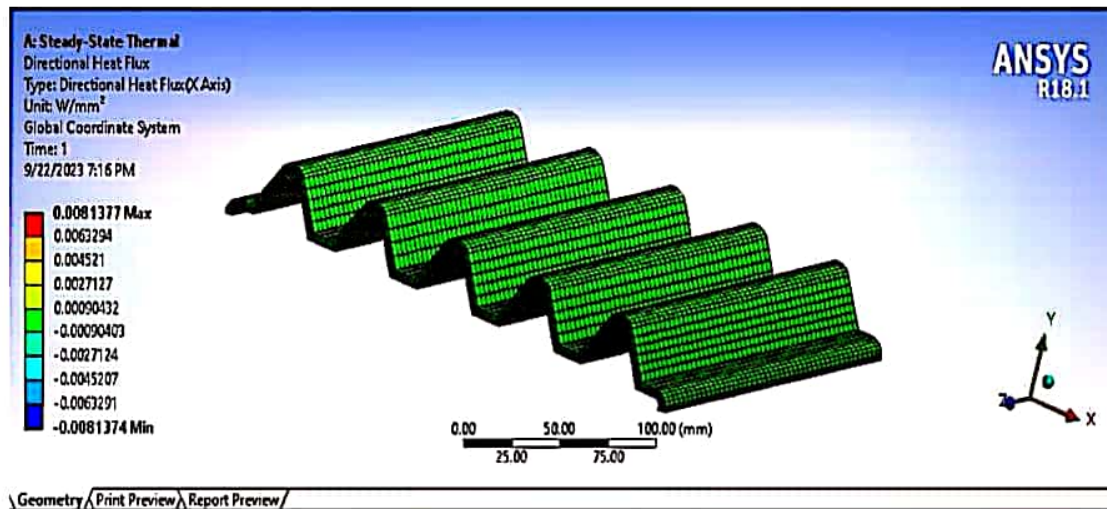
Temperature



Total Heat Flux

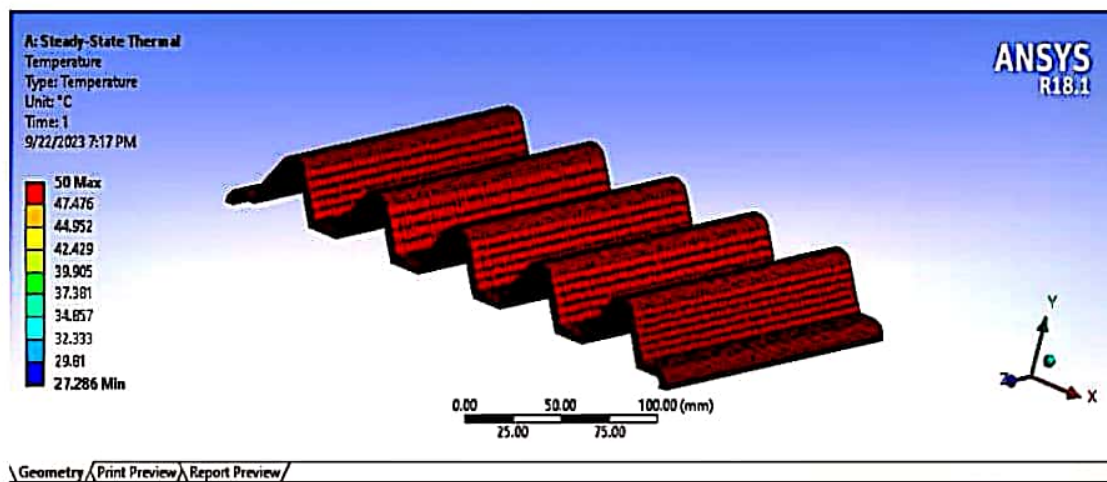


Directional Heat Flux

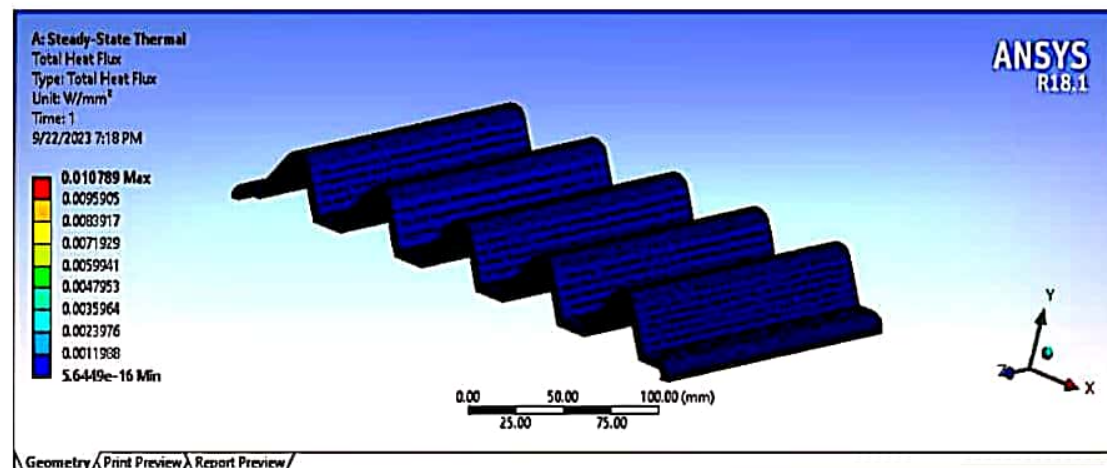


RESULT FOR ZIRCONIA

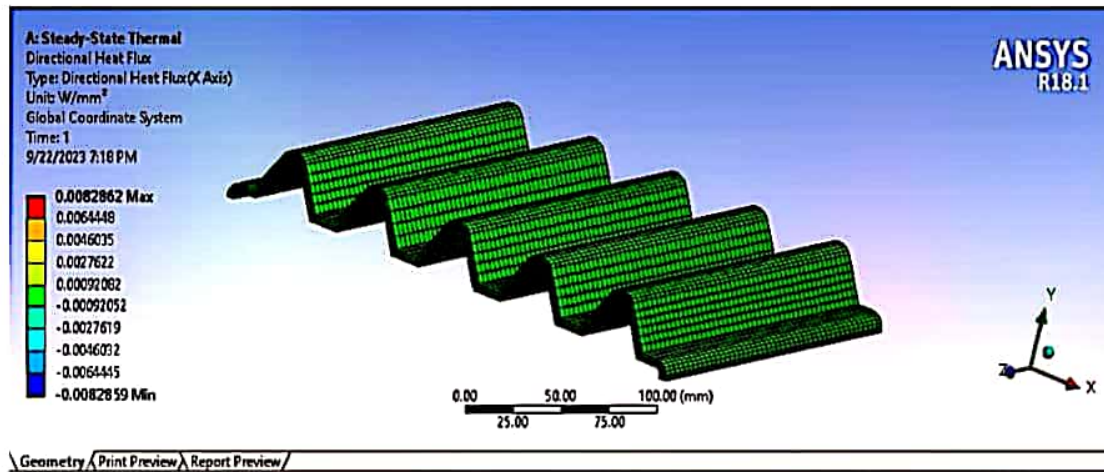
Temperature



Total Heat Flux



Directional Heat Flux



4.7 COMPARISON OF ASBESTOS SHEET ANALYSIS RESULTS

Table 4.2 Total Temperature

	Total Temperature	
	Max	Min
Structural Steel	50	25.188
Alumina	50	25.39
Titania	50	27.337
Zirconia	50	27.286

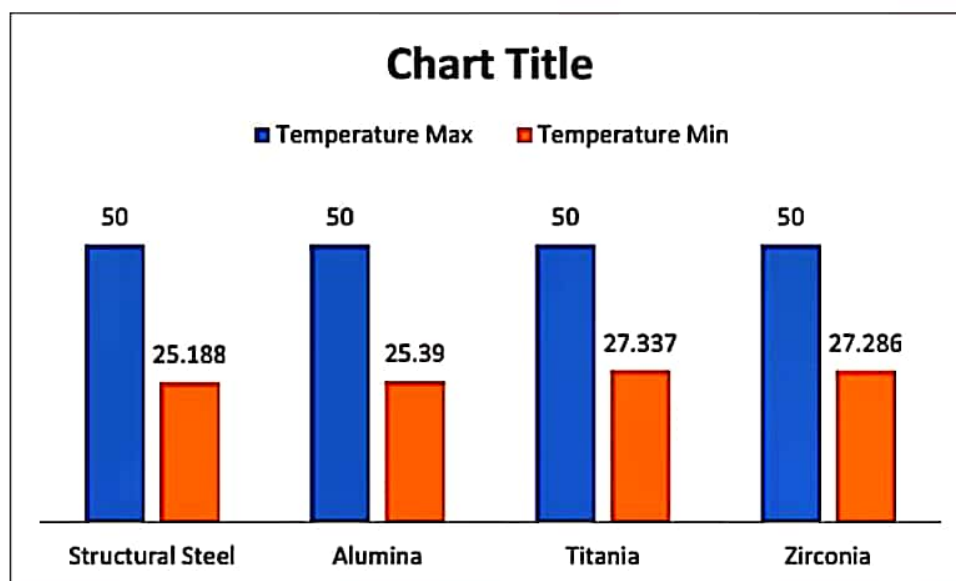


Table 4.3 Total heat flux

	Total Heat flux W/mm2
Structural Steel	0.016573
Alumina	0.015896
Titania	0.010611
Zirconia	0.010789

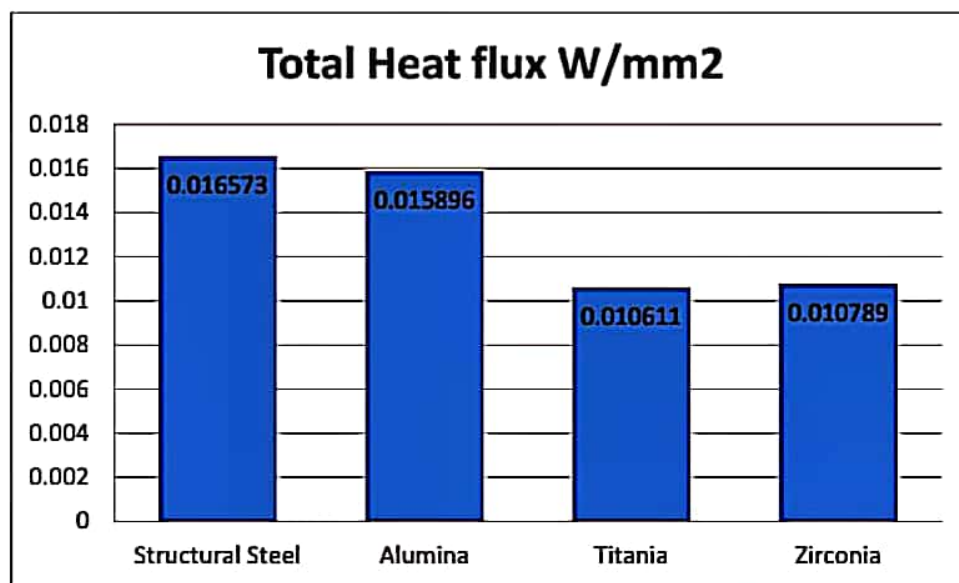
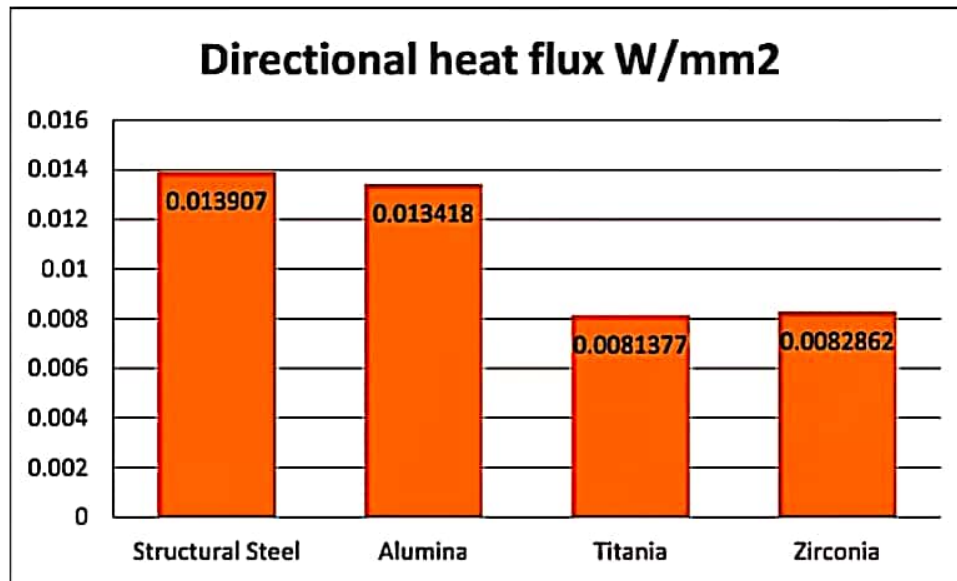


Table 4.4 Directional heat flux

	Directional heat flux W/mm2
Structural Steel	0.013907
Alumina	0.013418
Titania	0.0081377
Zirconia	0.0082862



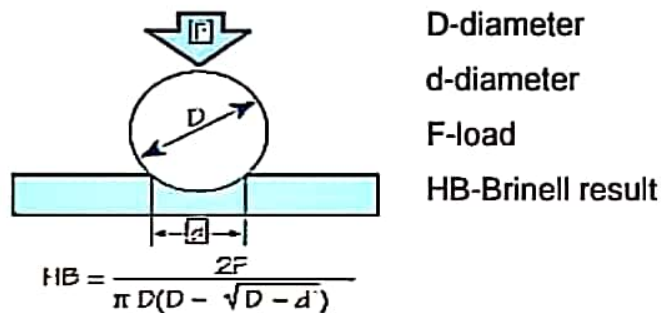
4.8 EXPERIMENTAL WORKS

4.8.1 BRINELL HARDNESS

Contrary to popular belief, hardness is not an intrinsic physical feature of any substance. It is defined as the resistance to indentation and is measured as the depth to which an indentation remains after repeated attempts to remove it.

ASTM E10 specifies the procedure to be followed when measuring Brinell hardness. Common applications include testing castings and forgings, both of which have structures and surfaces that are too rough for other types of testing. With a 3000 kgf test load and a 10mm indenter diameter, Brinell testing can smooth out most surface and sub-surface irregularities.

The Brinell method involves holding a carbide ball of a known diameter (D) under a known test load (F) for a given amount of time (t). With a Brinell microscope or optical system, the resulting impression is measured along at least two diameters, often at right angles to one another, and the average is calculated (d). Although the Brinell number can be calculated, most people just use a chart to convert the mean diameter into a hardness rating. In general, 500 kgf is used for testing non-ferrous materials and 3000 kgf is used for testing steels and cast iron. Other Brinell hardness testers exist, with loads as low as 1kgf and indenters as small as 1mm in diameter, but these are rarely utilized.



The measurement of the indentation is typically the largest contributor to error in Brinell testing. Even under ideal settings, the findings will vary due to the differences between the people taking the measurements. When conditions aren't ideal, there can be a noticeable increase in dispersion. In order to eliminate surface conditions, a grinder is frequently used to prepare the test surface.

Because of the indentation's jagged edge, it's hard to read. In addition, when operators are aware of the requirements limitations for rejects, they are more likely to interpret the data in a way that maximizes the proportion of "good" tests and minimizes the need for re-testing.

Over time, two distinct technological solutions to Brinell measurement error issues have emerged. The B.O.S.S. system is just one example of an automatic optical Brinell scope that employs computers and image analysis to reliably read the indentations. This uniformity reduces the likelihood that operators may mistakenly interpret within-tolerance results when the sample's result may be outside of tolerance.

Brinell units, which measure in accordance with ASTM E103, use Brinell hardness parameters in conjunction with a Rockwell hardness method to determine the hardness of the samples. Since an autonomous mechanical depth measurement eliminates the room for error introduced by human interpretation of optical data, this approach yields the most reliable findings (with increased speed).

In some cases, an offset to the results may be necessary for specific materials, as the results may not be strictly compatible with Brinell results due to the differing test procedures. In situations when this can be an issue, it is simple to determine the appropriate values.

4.9.2 SALT SPRAY TEST

The salt spray test is a popular technique to assess a coating's resistance to corrosion. Metal components composed of steel, zinc, or brass benefit from coatings that prevent corrosion. It is important to verify corrosion resistance in various ways since coatings can give strong corrosion resistance during the expected lifetime of the part in use. A salt spray test, an accelerated corrosion test that creates a corrosive attack on the coated samples, is used to assess the coating's potential as a protective finish. After a certain amount of time has passed, the presence of corrosion byproducts (oxides) is analyzed. The amount of time that passes during testing without any evidence of corrosion is directly proportional to the corrosion resistance of the coating.

Salt spray testing has become widely used due to its low cost, short duration, high level of standardization, and moderate repeatability. However, The duration of the salt spray test has little bearing on the expected life of a coating due to corrosion is a complicated process that is susceptible to numerous outside influences. Nonetheless, the business world frequently uses the salt spray test to ascertain how well a surface or component will withstand corrosion.

The salt spray test is widely used as a standard procedure to evaluate a material's or coating's resistance to corrosion. Typically, the materials being tested are metallic and have a surface coating applied to them in an effort to prevent corrosion.

In order to determine whether or not a coating is suitable as a protective finish, it can be subjected to salt spray testing, an accelerated corrosion test that simulates

the effects of corrosion on coated samples. After a certain amount of time, the corrosion byproducts (rust) are assessed. The coating's ability to prevent corrosion or rust during testing will determine how long the coating will last under controlled conditions.

The salt spray test has been around for a long time and is widely used as a corrosion test. In 1939, ASTM B117 was published as the first standard for salt spray protection. ISO9227, JIS Z 2371, and ASTM G85 are also relevant and important standards.

Test equipment



Figure 5 Salt spray chamber for Corrosion test

4.9.3 SALT SPRAY CABINET

The testing apparatus includes a sealed testing chamber with a nozzle for atomizing a salty solution (often a 5% sodium chloride solution). This causes the chamber to fill with corrosive dense saline fog, putting any exposed parts at risk of severe corrosion. Due to the minimum volume recognized by International Standards on Salt Spray Tests For chamber volumes under 400 liters, maintaining uniform corrosivity across all test conditions has proven extremely challenging. There is a wide range of chamber sizes available, from 120 liters (4.3 cu ft) up to 58,300 liters (2,058 cu ft). The typical range for home washing machines is 15–160 cubic feet (420–4,530 L).

The term "neutral salt spray" (abbreviated "NSS") describes experiments carried out with a 5% NaCl solution. The number of non-corrosion-product-appearing NSS testing hours (720 h in NSS, for example, as per ISO 9227) is usually used to display the results. Alternative options for testing decorative coatings include the

acetic acid (ASS test) or the acetic acid with copper chloride (CASS test). These coatings include electroplated copper-nickel-chromium, electroplated copper-nickel, and anodized aluminium.

Some sources advise against using either type of cabinet for NSS tests because it is said to be very difficult to thoroughly clean the cabinet after an ASS or CASS test. While ASTM does not address this, ISO 9227 opposes it and suggests a thorough cleaning if it is necessary. Standards at the national and international levels, such as ISO 9227 and ASTM B 117, standardize testing parameters, testing technique, and chamber structure. The standards specify the requirements for this test, including temperature, concentration, pH, air pressure of the sprayed solution, and spraying solution preparation. To show that testing parameters are being followed, they must be checked every day, and appropriate documentation must be maintained. Benchmarks commonly used are the international standards ISO 9227 and ASTM B 117. Testing cabinets are custom-built here in compliance with the standards. Nevertheless, these criteria do not specify the length of testing or the appearance of corrosion products in the form of salts. The specs must be approved by the customer and the manufacturer. The standards for production in the auto industry are outlined in material specifications. The length of time required for each test varies because different coatings react differently to a salt spray test. For example, in a salt spray test, a typical electroplated zinc and yellow passivated steel component may withstand white rust for 96 hours. Electroplated zinc-nickel steel parts are resistant to rusting red even after passing the NSS test for over 720 hours or the CASS test for 48 hours. Coatings must adhere to the hourly minimum test times that are specified.

ASTM International is where you may get the synthetic saltwater needed for salt spray testing. Standard Practice for the Preparation of Artificial Seawater, as defined by ASTM D1141-98, is the gold standard for Artificial Seawater.

The salt spray test (ISO 1461 or ISO 10684) is not often performed on hot-dip galvanized surfaces. Hot-dip galvanizing protects the coated metal and slows the rate of corrosion by producing zinc carbonates when exposed to natural environments. Since hot-dip galvanized samples do not form zinc carbonates

when exposed to salt spray fog, this technique of testing cannot be relied upon to provide a reliable determination of corrosion resistance. Corrosion resistance testing protocols for hot-dip galvanized specimens are outlined in ISO 9223.

The procedure can be used to examine painted surfaces that have been hot-dip galvanized below. For further reading, refer to ISO 12944-6. From under a day (e.g., 8 or 24 hours for phosphate steel) to over a month (e.g., 720 hours for zinc-nickel coatings, 1000 hours for some zinc flake coatings), testing durations can vary widely.

4.9.4 MICROSTRUCTURE

The microscopic structure of a material's prepared surface or thin foil can be seen by using a microscope with a magnification greater than 25x. The microstructure of a material, which can be broadly categorized into metallic, polymeric, ceramic, and composite, governs physical properties such as strength, toughness, ductility, hardness, corrosion resistance, high/low temperature behaviour, wear resistance, etc.

Macrostructural characteristics of everyday things may help the layperson understand the notion of microstructure. Galvanized steel, such as that used for lamppost and traffic divider casings, has a surface pattern that resembles a patchwork of interlocking polygons in various colours of grey or silver. Each of the hexagons or other regular polygons is a single zinc crystal stuck to the surface of the underlying steel. Large crystals of zinc and lead can be seen with the naked eye. There are seven different crystal lattice systems for metals, and each one ensures that the crystal's metallic atoms are neatly aligned like points in a three-dimensional matrix: cubic, tetrahedral, hexagonal, monoclinic, triclinic, rhombohedral, and orthorhombic.

But because the matrices aren't aligned consistently from crystal to crystal, the reflectivity of the galvanized surface is different from crystal to crystal. Crystals with perfect symmetry are often unaltered or unworked. They have uniform growth in all directions and display no deforming stresses during or after their development. For large crystals, the inter-crystal boundary (or, more precisely, the

intergranular boundary) to crystal mass ratio is large. A proper analysis would take into account the intercrystallite bonding strength and the relative strengths of the crystal quantitatively; this one only suggests a proportionately reduced strength but excellent ductility (see Hall-Petch Strengthening).

4.9.5 MICROSCOPY

Optical It is common practice to use macrophotography when a flat, polished sample shows evidence of its microstructure. Optical microscopy, electron microscopy, X-ray diffraction, and other similar techniques require sample preparation (cutting, microtomy, polishing, etching, vapor-deposition, etc.) before they can examine the microstructure of a material. Alloys and metals are the focus of metallography, but the techniques can be adapted for application with ceramics, glasses, composites, and polymers.

Flat, polished, and etched objects are often examined using either a reflection microscope or an inverted microscope, both types of optical microscopes. A digital camera inserted inside the eyepiece captures the image.

4.9.6 X-RAY MICROTOMOGRAPHIC

Computer microtomography is the current solution to the problem of non-destructive examination of microstructure for biological materials. The microstructure of a wide variety of different materials can also be evaluated with CMT. However, CMT is sometimes prohibitively expensive for research projects that require a three-dimensional microstructure to be generated from two-dimensional cross-sectional pictures. Many researchers are focusing their efforts here.

4.9.7 Electron Microscopy

Copper precipitation inside the aluminium matrix of an aluminium-copper (4 at% Cu) alloy. This is a projection through the metal, with the dark areas representing copper precipitates in the shape of plates.

Electron microscopic techniques can be used to obtain such detailed data on metallurgical microstructures. This can make it possible to see minute details like dislocations, grain boundaries, and very tiny precipitation processes. Methods like

these may be essential when trying to calculate values like the diffusivities of solids.

4.9.8 OPTICAL MICROSCOPY

The optical microscope, also known as a "light microscope" due to its reliance on visible light and a lens system, is a device used to examine and magnify microscopic specimens. The optical microscope is the oldest type of microscope, with its modern form potentially being established in the 17th century. In spite of the complexity of certain designs, basic optical microscopes can be quite straightforward.

Normal light-sensitive cameras can record the image from an optical microscope, resulting in a micrograph. Digital images may now be captured thanks to advancements in CMOS and charge-coupled device (CCD) cameras; formerly, images were captured on photographic film. These days, you can buy a microscope that doesn't even have eyepieces—it's a pure digital model that uses a CCD camera to inspect a sample and displays the findings on a computer screen. Scanning electron microscopy and transmission electron microscopy are two alternatives to optical microscopy that do not rely on visible light.

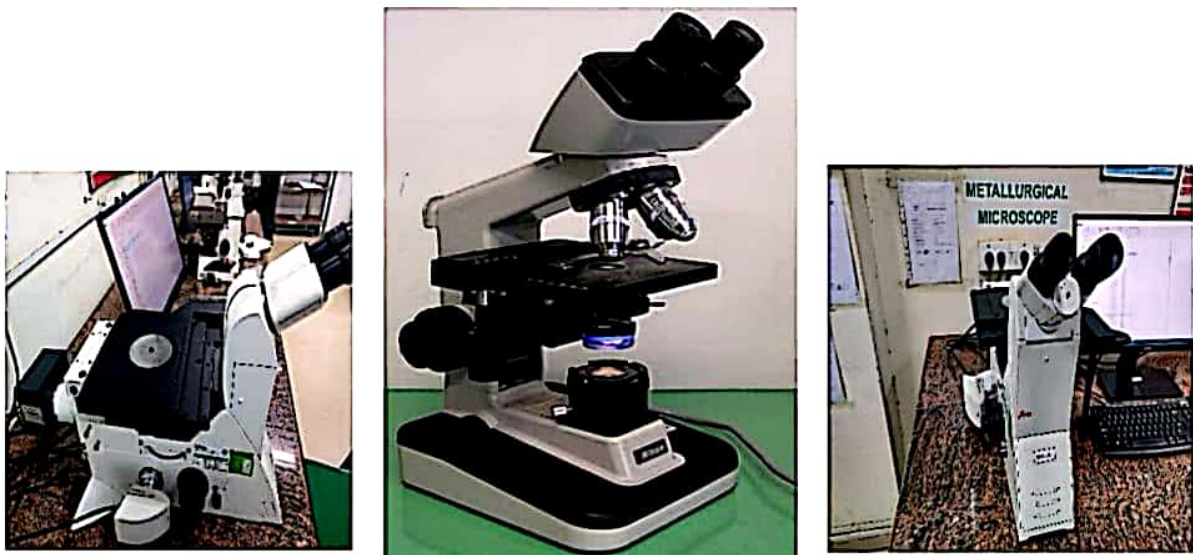


Figure 6 Optical configuration

CHAPTER - 5

5.1 TEST RESULTS

5.1.1 Vickers Hardness Test: (ASTM E92-2017)

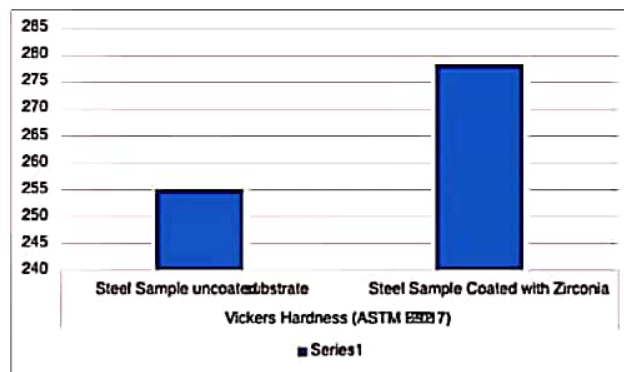
Vickers hardness test

Table 5.1 Vickers hardness test

Test parameters (HV 10kg)	Observed values
Zirconia Coated Substrate	276 , 278 , 281
Uncoated Substrate	253 , 255 , 257 Table

Table 1.2 Vickers hardness test avg

Vickers Hardness (ASTM E92-2017)			
Steel Sample uncoated substrate		Steel Sample Coated with Zirconia	
255		278.3	



Comparison graph of Vickers hardness

The results indicate that these coatings can provide increased wear resistance and durability, making them suitable for applications where mechanical stress is a concern.

5.1.2 MICROSTRUCTURE RESULTS

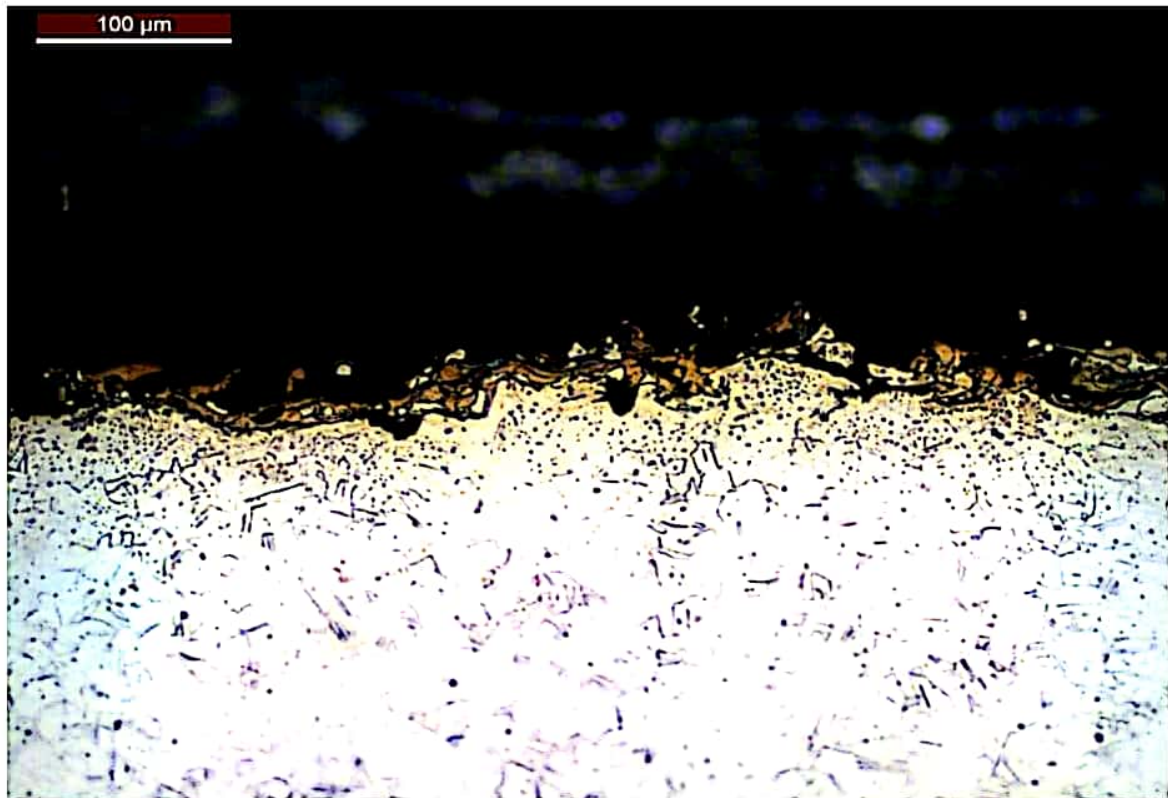


Figure 7 Coated 100X Sampe Microstructure results



Figure 8 Coated 200X Sampe Microstructure results

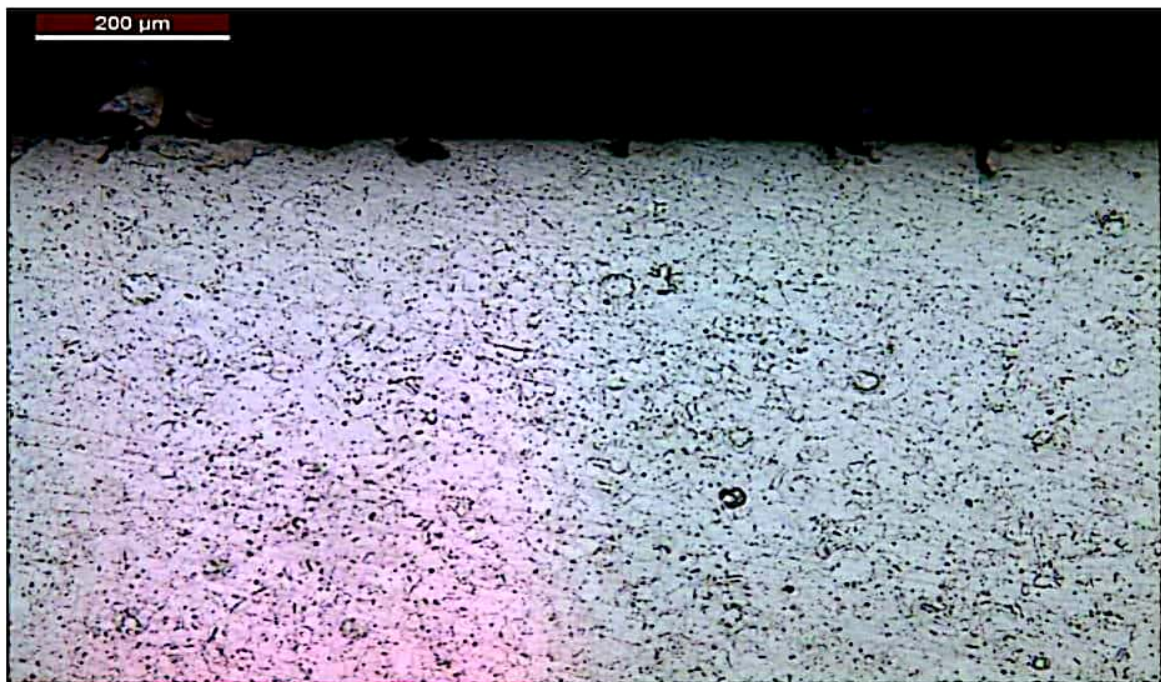


Figure 9 Non-Coated 100X Sampe Microstructure results

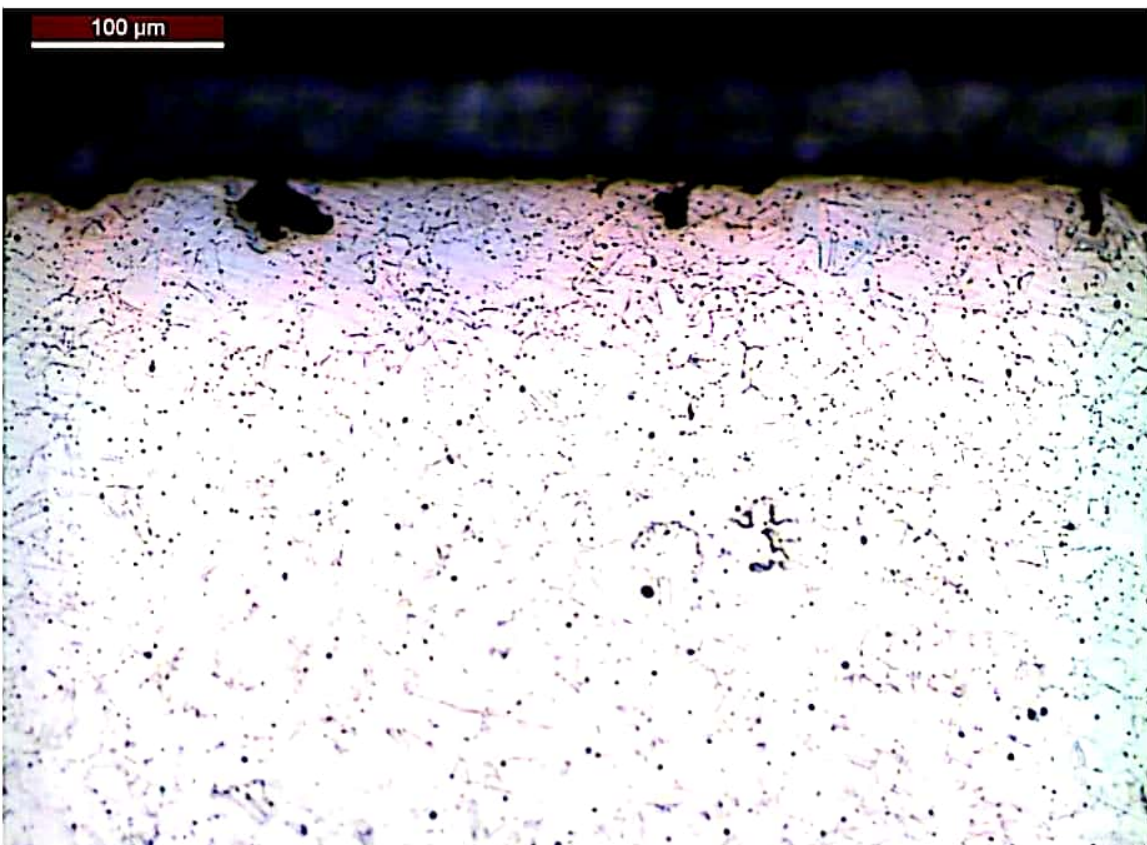


Figure 10 Non-Coated 200X Sampe Microstructure results

The above microstructural results show only minor defects were observed

5.1.3 CORROSION TEST RESULTS

Corrosion Test : un-coated sample

Table 5.3 Corrosion Test : un-coated sample

Netural Salt spray	ASTM-B-117-2019	
Test parameter	Specified value	Observation
Test Duration (Hours)	24 H	24 H
Test starting date (DD/MM/YY)		23/03/23
Test ending date (DD/MM/YY)		24/03/23
Tower Temperature (*C)		47.5-48.5
Air Pressure (Psi)		14-18
Chamber Temperature(*C)		Chamber temperature(*C)
Components Loading in Chamber Position (Degree Angle)		15-30 Degree from vertical
Concentration of Solution (%)		4.80-5.30% of Nacl
pH value		6.65-6.85
Volume of salt solution collected (ml/hr)		1.00-1.50
Test Observation		Red Rust formation noticed at 24 Hrs.

STEEL Sample Coated with Zirconia

Table 5.4 STEEL Sample Coated with Zirconia

Netural Salt Spray		ASTM-B-117-2019
Test parameter	Specified value	Observation
Test Duration (Hours)	24Hrs	24Hrs
Test starting date (DD/MM/YY)		23/03/23
Test ending date (DD/MM/YY)		24/03/23
Tower temperature (*C)		47.5-48.5
Air pressure (Psi)		14-18
Chamber Temperature (*C)		Chamber temperature (*C)
Components loading in Chamber		15-30 Degree from vertical
Position (Degree Angle)		4.80-5.30% of NaCl
Concentration of Solution (%)		6.65-6.85
pH value		1.00-1.50
Volume of salt solution collected (ml/hr)		No Rust formation noticed up to 24 Hrs.
Test observation		

The results indicate that these coatings can provide increased corrosion resistance, making them suitable for applications where corrosive environments is a concern.

5.2 DISCUSSION & PERFORMANCE ANALYSIS

5.2.1 THERMAL ANALYSIS (FEA):

The FEA revealed that all three ceramic coatings offer significant thermal protection to the underlying asbestos steel sheets. They effectively mitigate heat transfer, making them suitable for applications requiring insulation from high temperatures.

Alumina, titania, and zirconia ceramics demonstrated their respective strengths in thermal insulation, allowing for informed choices based on specific temperature requirements. From the obtained numerical investigation, the zirconia was the best one. Zirconia was chosen for further experimental investigation and obtained below research findings

5.2.2 VICKER HARDNESS TESTING:

Vicker hardness testing demonstrated that each ceramic coating significantly enhances the hardness and surface properties of the asbestos steel sheets.

The results indicate that these coatings can provide increased wear resistance and durability, making them suitable for applications where mechanical stress is a concern.

5.2.3 CORROSION RESISTANCE (SALT SPRAY METHOD):

The corrosion resistance evaluation using the salt spray method highlighted the protective qualities of the ceramic coatings against corrosive environments.

Alumina, titania, and zirconia ceramics exhibited varying degrees of resistance, with zirconia showing exceptional performance in preventing corrosion.

5.2.3 MICROSTRUCTURE ANALYSIS (LIGHT OPTICAL MICROSCOPY):

Microstructural analysis using light optical microscopy revealed that the coatings generally maintained their structural integrity under thermal and corrosive conditions.

Some minor defects were observed, which can be addressed through improved manufacturing processes.

CHAPTER – 6

6.1 CONCLUSION

The comprehensive analysis of roof metal sheets coated with alumina, titania, and zirconia ceramics, combining Finite Element Analysis (FEA) for thermal performance evaluation with experimental investigations, has yielded valuable insights into the suitability and performance of these coatings in high-temperature and corrosive environments.

In conclusion, this study provides a comprehensive understanding of the thermal and protective characteristics of alumina, titania, and zirconia ceramic coatings on asbestos steel sheets. The selection of the most suitable coating material depends on the specific application requirements. Zirconia and titania gives the best result but cost comparability zirconia is the best of all.

These findings facilitate informed decision-making for industries seeking optimal solutions for applications that demand high-temperature insulation, hardness improvement, and protection against corrosion. Future research may focus on refining manufacturing processes to minimize defects and enhance the overall performance of these ceramic coatings, further expanding their practical applications.

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