SUSTAINABLE DEVELOPMENT AND DESIGN OPTIMIZATION OF HYBRID PLASTIC ROOFING TILE COMPOSITES FOR ENHANCED REDUCTION OF THERMAL LOAD

PROJECT REPORT

Submitted by

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of

Master Of Technology

In

Computer Integrated Manufacturing

DEPARTMENT OF MECHANICAL ENGINEERING

T.K.M. College of Engineering

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DECLARATION

I Kasthoori Nath A J, hereby declare that the project report entitled “Sustainable development and design optimization of hybrid plastic roofing tile composites for enhanced reduction of thermal load", submitted for partial fulfillment of the requirements for the award of degree of Master of Technology of the APJ Abdul Kalam Technological University, Kerala is a bonafide work done by me under supervision of Dr. K.E. Reby Roy, Professor, Department of Mechanical Engineering, TKMCE Kollam. This submission represents my ideas in my own words and where ideas or words of others have been included. I have adequately and accurately cited and referenced the original sources. I also declare that I have adhered to ethics of academic honesty and integrity and have not misrepresented or fabricated any data or idea or fact or source in my submission. I understand that any violation of the above will be a cause for disciplinary action by the institute and/or the University and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been obtained. This report has not been previously formed the basis for the award of any degree, diploma or similar title of any other University.

Kollam

12/09/2022 KASTHOORI NATH A J

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CERTIFICATE

This is to certify that the project report entitled **'SUSTAINABLE DEVELOPMENT AND DESIGN OPTIMIZATION OF HYBRID PLASTIC ROOFING TILE COMPOSITES FOR ENHANCED REDUCTION OF THERMAL LOAD'** submitted by **KASTHOORI NATH A J, TKM20MECI06** to the APJ Abdul Kalam Technological University in partial fulfillment of the requirements for the award of the Degree of Master of Technology in Computer Integrated Manufacturing, Department of Mechanical Engineering is a bonafide record of the project work carried out by her under our guidance and supervision. This report in any form has not been submitted to any other University or institute for any purpose.

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ABSTRACT

The novel ‘plastile’ composite roofing tiles (8 × 8 × 1.3 cm3) are prepared using a three-step-controlled compression process. The developed tiles are having an inner core section of metal oxide layer encased by the hybrid plastic material. The metal oxides collected were analysed and treated and the properties of the powder samples were managed. The prepared tiles have a bulk thermal conductivity value of 0.25W/mK and minimum to zero water absorption making it a highly suitable material for roofing applications on residential buildings. The thermal performance test of hybrid ‘plastile’ roofing tiles is conducted using a guarded hot plate experiment, plotting the performance values. The study is expected to provide insight into the potential areas of developed hybrid ‘plastile’ roofing tiles for various insulation/air conditioning applications. This will help further research activities in this aspect to reduce the final cost of the product thereby adding value to society.

Keywords— *metal oxide, hybrid plastic material, hybrid plastile roofing tiles*

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ABBREVIATIONS

ABS	Poly (acrylonitrile butadiene styrene)
DSC	Differential Scanning Calorimetry
PC	Polycarbonate
PE	Polyethylene
PET	Polyethylene Terephthalate
PP	Polypropylene
PS	Polystyrene

CHAPTER 1

INTRODUCTION

1.1 PLASTIC WASTE ACCUMULATION

It is estimated that 9 to 23 million tonnes of plastic garbage are spilled into rivers, lakes, and oceans annually on a global scale. 0.13 million to 0.25 million tonnes were released into the terrestrial environment in 2016. Consequently, the significance of treating plastic trash is growing. However, because plastic waste typically consists of a variety of plastic kinds, it might be challenging to recycle these materials due to their proximity to incompatible polymers. Therefore, sorting plastic garbage using the plastic separation process is essential for successfully recycling it. Take a look at a car's polypropylene bumper, for instance. This might have been on the same automobile for more than ten years. A fresh chicken's plastic wrapping, on the other hand, might only be used for a few days before being thrown. Similar to how a grocery store carrier bag can be thrown away once it has carried the groceries home. The lifespan of plastics used in the packaging industry is often substantially shorter. When a product enters the waste stream depends on how long it lasts.

1.1.1 Different types of plastics

Almost all plastic will have a sign on it that looks like three arrows racing toward one another. This symbol contains a number that corresponds to the kind of plastic used to make the product. This may fall between one and seven:

1. PET or Polyethylene Terephthalate

This kind of plastic is used in drinks, water bottles, beverage containers, and packaging for perishable foods. Although the odour from any foods or beverages placed in it can be absorbed by the plastic, it is believed to be a safe material. The majority of facilities recycle plastics, including PET bottles.

Fig 1.1: PET plastic bottles

2. HDPE or High-Density Polyethylene

This kind of plastic is also seen in kids' toys. HDPE may also be found in outdoor furniture and trash cans since it doesn't break down or lose its form in the sun. We may use it to make furniture, pens, plastic lumber, and bottles after it is recycled. Most facilities will take HDPE for recycling since it is reasonably simple to do.

Fig 1.2: HDPE bottles

3. PVC or Polyvinyl Chloride

This kind of plastic may be used for windows, pipelines, and various pieces of medical equipment. It is frequently used in applications where flexible plastic is needed, such as cables and plastic wrap. Given that it does contain hazardous compounds, this form of plastic, often known as poison plastic, should not be used for food or beverages. These substances have been linked to both children's developmental issues and liver illness. This plastic will be recycled through certain procedures and converted into guttering or flooring. Only 1% of PVC plastic gets recycled, nevertheless.

Fig 1.3: PVC pipes

4. LDPE or Low-Density Polyethylene

Many household goods use this hygienic and reliable plastic. Squeezable bottles, frozen food bags, and plastic shopping bags might all fall under this category. Thankfully, there are more recycling services now that will take this kind of plastic. After recycling, we may utilise it to make furniture and other products like bubble wrap.

Fig 1.4: LDPE bubble wrap

5. PP or Polypropylene

This plastic is safe to use in products like plastic Tupperware containers, hot food containers, plastic straws, and even prescription bottles because of its long-lasting qualities. Plastic manufacturers may utilise recycled plastic to create pallets, battery cables, and even rakes because of its durability and toughness. Once again, a lot of recycling programmes are glad to recycle this kind of plastic garbage.

Fig 1.5: PP bottle caps

6. PS or Polystyrene

The majority of people are familiar with polystyrene as a plastic. In addition to serving as insulation as a protective barrier surrounding packed goods, we utilise it in egg cartons and cups. Since it is difficult to recycle, it is renowned for leaching. s plastic is fragile; therefore, it crumbles extremely readily. Additionally, it is quite light. As a result, once fragmented, it quickly disperses across the ecosystem. While much of it makes its way into the oceans, we may see polystyrene on numerous beaches. Additionally, marine creatures are consuming it, which causes health issues and even death.

Fig 1.6: PS food trays

7. Others

A variety of plastics that are unrelated to one another have their own category. These are products that are challenging to recycle. Sunglasses, infant bottles, and even CDs fall into this category. They are namely polycarbonate, polylactide, acrylic, acrylonitrile butadiene, styrene, fiberglass, and nylon.

1.1.2. Impacts of plastic waste accumulation

The impact of plastic garbage on land, the oceans, animals, and people are substantial. Only a limited portion of plastics may be recycled, and more than 50% of plastics are not biodegradable. So, until they are removed, they will stay undamaged where they are thrown.

Impact on land: Due to the discharge of dangerous chemicals, when chlorinated plastics are dumped in the soil, it affects not only the soil but also the nearby water sources and ecology.

Impact on oceans: According to experts, the oceans across the world are home to more than 165 million tonnes of plastic trash. Because certain marine species are eaten by humans and are then devoured by other animals through the food chain, these plastics have an impact on plankton, fish, and eventually the human race. Cancer, immunological problems, and birth deformities may all rise as a result of eating seafood that contains these poisons.

1.1.3 Plastic recycling techniques

Plastics come in a variety of varieties. Additionally, this prevents the uniform recycling of all plastics. There are two ways to recycle plastic, though.

1. Traditional recycling

This recycling technique is the most common. Mechanical recycling is another term for conventional recycling. Thermoplastic materials can be recycled using this technology. Melting plastics and turning them into new plastic goods is the classic recycling process. Recycling companies first melt the plastic before using an injection moulding technique to turn it into new items.

a. Injection Moulding: The most popular production method for creating plastic parts is injection moulding. Injection moulding is used to create a vast range of items, each with a unique size, level of intricacy, and use. A mould, raw plastic material, and an injection moulding machine are required for the injection moulding process. To create the finished product, the plastic is first melted in the injection moulding machine and then injected into the mould.

2. Advanced recycling

The breakdown of plastic material by chemicals occurs during advanced recycling. Three more procedures make up this method. Pyrolysis, chemical recycling, and gasification are some of these methods. Plastic trash is recycled using the pyrolysis method to produce crude oil. Reducing a polymer into a monomer that can produce new goods is the process of chemical recycling. For instance, producers use chemical recycling to create nylons. Gasification, on the other hand, turns plastic into gas. Gas obtained through this procedure is used by producers to produce energy.

a. **Pyrolysis:** Plastic waste is frequently converted into solid, liquid, and gaseous fuels through the process of pyrolysis. When plastic trash is thermally degraded at different temperatures (300-900°C) without oxygen, liquid oil is generated.
b. **Chemical recycling:** Chemical recycling technologies can break down plastics into its building blocks and transform them into valuable secondary raw materials. These materials can then be used to produce new chemicals and plastics. There are various chemical recycling technologies available that follow three recycling techniques to treat plastic waste:
    i. Dissolution: Plastic trash is first sorted and prepared for subsequent processing as part of the dissolving recycling process. Plastic is dissolved into a mixture of polymers and additives it was originally manufactured from heat and solvents. Before recovering the polymers from the solution, the additives and polymers

are separated in the next step. The polymer's structure is not changed throughout the course of dissolution. New additives are combined with polymers in the final stage to create the new recycled plastic.

ii. Depolymerisation: Plastic debris is first sorted and prepared for further processing as part of the depolymerization recycling process. Different combinations of chemistry, solvents, and heat are used in the depolymerization process, also known as chemolysis or solvolysis, to convert polymers into monomers. The constituent parts of polymers are called monomers. The next stage involves separating any contaminants from the monomers in order to get rid of them. The monomers are then used as a secondary raw material in the regular plastic manufacturing operations. The polymers generated in this manner are of comparable quality to those made using conventional fossil fuels.

iii. Conversion: Screening and preparing mixed plastic garbage for subsequent processing is the first step in the conversion recycling process. The waste plastic is then converted using heat and chemistry in a reactor to transform it into a liquid, an oil-like feedstock (pyrolysis), or a gaseous feedstock (gasification). To assure high-quality products, the process either occurs in the presence of oxygen (gasification) or the absence of oxygen (pyrolysis). Potential pollutants are isolated and eliminated in the next phase. At the refinery or cracker stage, the generated oil or gaseous feedstock (re)enters the chemical production chain as a secondary raw material in place of freshly extracted fossil feedstock. Chemicals, including polymers of comparable grade to those created from conventional fossil fuels, are produced from the by-products.

c. **Gasification:** Plastic waste is frequently gasified or partially oxidised at temperatures between >600°C and 800°C. The gasification agent is air (or oxygen in some applications), and the air factor ranges from 20% to 40% of the air required for PSW combustion. To produce the endothermic depolymerization heat, the technique essentially controls the oxidation of the hydrocarbon feedstock. With tiny amounts of gaseous hydrocarbons also produced, the main byproduct is a gaseous combination of carbon monoxide and hydrogen. This gas combination, known as syngas, can be utilised as a natural gas alternative or as a feedstock in the chemical industry to produce a variety of chemicals.

1.2 METAL OXIDE ACCUMULATION

Due to their widespread usage in household items including antifouling paints, construction materials, sunscreen, cosmetics, and bottle coatings, metal oxides pose a special threat to human and environmental health as well as the ability to accumulate in aquatic ecosystems. Particularly in soft sediments, which make up a sizable amount of the bottom habitat in estuaries and seas, species that dwell on the seabed are likely to be at the highest risk of biological effects from exposure to and toxicity from metal oxides in marine settings. In saltwater, many ENPs, and particularly metal oxides, rapidly aggregate to the micron scale and settle from the water column where they might build up in sediments. After being buried in sediments, they may be bound by particulate organic matter (POM), decomposed by bacteria, bioturbated, or digested, or otherwise changed by physical and biological processes. If ZnO metal oxides are introduced to marine habitats, for instance, they will quickly settle and dissolve, exposing faunal species to hazardous Zn ions in pore water or epibenthic animals to dissolved ions at the sediment-water interface.

1.3. INCREASED THERMAL LOAD ON RESIDENTIAL BUILDINGS

One of the most pressing problems confronting humanity today is the threat posed by global warming. Almost every industry is impacted by climate change and climatic variability, including forestry, energy, tourism, and leisure. These wide-ranging effects have sparked study in a variety of sectors. Particularly, there is a significant and expanding body of economics work that focuses on how climate change may affect global home power demand. People's capacity to function efficiently, job satisfaction, probability of continued business, and other factors are all impacted when they are not content with their thermal environment. This is in addition to the possible health risks that might result. Current environment conditions are increasing the thermal load on building and thereby reducing the comfort levels of occupants. In order to offer comfort levels, HVAC systems have become standard equipment for both residential and non-residential buildings. This forced air-conditioning techniques utilises more energy. Energy usage for space cooling is increasing more quickly than any other energy service in buildings. Global demand for "cooling" energy more than quadrupled between 1990 and 2016. Building cooling now makes for around 20% of all power used globally (IEA, 2018). The yearly sales of air conditioners nearly doubled to 135 million units from 1990 to 2016. As everyone cannot such expensive cooling solutions and the scarcity of energy demands people to switch to alternative cooling solution which involves roofing tile applications that promote thermal reduction in tropical climates.

1.3.1 Different types of roofing solutions

The different types of roofing applications that currently exist are:

1. Slate roof tiles

Natural stone called slate has a distinct, lovely look. Only time and Mother Nature can create the amazing colour changes found in slate. Slate is a resilient, long-lasting, and fire-resistant roofing material. It could be among the most elegant roofing materials available. Slate's disadvantage is that it weighs a tonne and needs to be supported by a stronger framework because of this. Repairs might be a concern because it is also challenging to handle and quite expensive to install.

Fig 1.7: Slate roof tiles

2. Metal roof tiles

Copper, aluminium, zinc, and steel are the materials that are most frequently used to make metal roof tiles. The most widely used of these materials are steel and aluminium. In order to replicate items like barrel tiles (Spanish roofs), slate tiles, wood shake tiles, and even standard shingle patterns, metal tiles are offered in a variety of designs and forms. Due to their low weight and simplicity of installation, metal roof tiles have gained a lot of popularity; yet, these same advantages also pose certain drawbacks.

i. Metal is raucous.
ii. Metal is readily dented, which makes repairs challenging.
iii. When its wet, metal is quite unsafe to tread on.
iv. Metal does not offer considerable insulating value and conducts heat away from it.

Fig 1.8: Metal roof tiles

3. Concrete roof tiles

These were created in Bavaria in the middle of the 19th century; the fundamental elements of concrete were affordable and accessible. Concrete roof tiles were first created by hand, but as time went on, modern manufacturing techniques made them one of the most affordable roof tile solutions available. Concrete tiles may be beautifully crafted to resemble wood shakes, clay tiles, and slate tiles. Because stone roofs add weight and concrete is so heavy, a reinforced roof structure is needed to support the extra weight. Additionally, they require roofing teams who are knowledgeable about the equipment and methods needed to correctly install concrete roof tiles. They require many of the same upkeep procedures as clay.

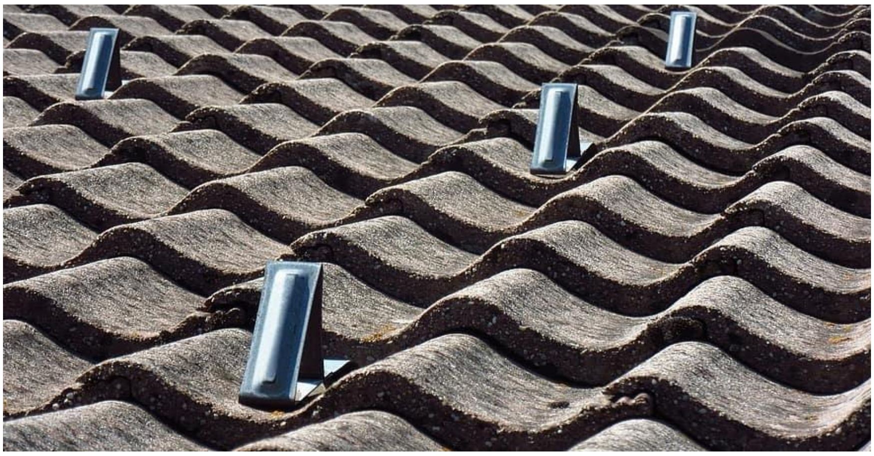


Fig 1.9: Concrete roof tiles

4. Composite roof tiles

The advantages of composite slate roof tiles over natural stone, wood, clay, metal, or concrete are numerous. Composite slate roof tiles are created from a combination of natural and man-made components. They effortlessly mimic the appearance of any tile roofing product and have the benefit of providing unique colour combinations for the majority of designs. They are more portable, have solid guarantees, and can typically be installed by the most seasoned roofing experts.

Fig 1.10: Composite roof tiles

5. Clay roof tiles

The history of clay roof tiles is extensive. The starting point has always been easily available. The roof was covered with hand-formed, sun-dried tiles. Although the procedure is now mostly automated, the final result is still stunning. The majority of us are accustomed to seeing clay roofs with flat or barrel-shaped tiles. They are sealed to prevent water absorption and are available in a range of colours. Clay tiles are quite heavy, prone to shattering if not handled carefully, and demand experienced installers. A roof with clay tiles will require significant reinforcing to sustain the additional weight of the clay, just as concrete and slate.

Fig 1.11: Clay roof tiles

6. Corrugated roofing sheets

Corrugated roofing sheets have a pattern of repeated folds on its surface and are mostly employed in agricultural structures. They provide greater strength and years of dependable utility due to their distinctive design. They are stronger than previously thanks to their corrugated design with ridges and grooves. The wavy design makes it possible to distribute higher strength across a smaller surface area.

Fig 1.12: Corrugated roofing sheet

7. Polycarbonate roofing sheets

In India, large-scale commercial and industrial structures frequently utilise polycarbonate roofing sheets. They are suited for such applications due to their high strength quotient and insulating qualities. Polycarbonate sheets come in a wide variety of textures and patterns and are completely weather-resistant, simple to install, and incredibly durable. They may be employed as excellent roofing solutions in locations like walkways, sky lighting, and swimming pool areas because of their minimal maintenance costs.

Fig 1.13: Polycarbonate roofing sheets

8. Metal roofing sheets

Metal roofing sheets often contain copper, tin, aluminium, and zinc. They may be altered to produce roofs that differ in terms of their cost, toughness, fashion, energy efficiency, lifespan, and aesthetic value. They are less curved than corrugated roofing sheets and are offered in a vast array of designs, textures, and colours.

Fig 1.14: Metal roofing sheets

9. Galvanized steel sheets

Continuous hot dipping is used to manufacture carbon steel that has been zinc coated. Typically, raw, coated, or painted sheets are chosen based on the amount of weathering they must resist. The primary foundation material for corrugated and plain roofing sheets is galvanised steel sheeting. Coated polyester paint or PVC plastisol paints can be used to protect them.

Fig 1.15: Galvanized roofing sheets

10. Asbestos cement roofing sheets

Fibrous cement that is used to strengthen thin, stiff cement sheets is known as asbestos cement. These offer a reliable and cost-effective fire protection solution. These are corrugated-sectioned moulded sheets. Due to its fibrous makeup, asbestos might be susceptible to airborne infections when exposed to weather and erosion factors. To prevent the suspension of fibres in the air, they are cleaned using pressure washers.

Fig 1.16: Asbetos cement roofing sheets

CHAPTER 2

LITERATURE REVIEW

Vanessa Goodship [1] provided a brief review of the key difficulties related to disposing of plastic trash and methods for recycling plastic garbage. It gave an overview of the types and amounts of plastics in the trash stream as well as the key effects recycling has on plastics. The applications of each of the four forms of recycling—primary, secondary, tertiary, and quarternary as well as the requirements each sets on the feed material were provided. The study explained that the plastic garbage was entering the waste stream at an increasing rate. It is increasing at a rate of 4% per year across Western Europe. Plastics only make up around 7% of residential garbage, but because of their light weight, they might appear to be contributing a considerably greater percentage of the bulk and are more noticeable in the waste stream than heavier elements like metals. Every year, plastics provided around 3 million tonnes, with packaging materials accounting for 56% of total.

K. Pivnenko et al [2] looked at the aspects that influence quality in plastics recycling. According to early findings, the elements most impacting the quality of plastics recycling include polymer cross contamination, the presence of additives, non-polymer contaminants, and polymer deterioration. Plastics quality deprivation has been demonstrated to occur across the plastics value chain, however preliminary phases where improvements may occur have been identified. The analysis of Cr in plastic samples revealed the possibility for chemical dispersion and build-up, resulting in waste plastics. Transparency in data on plastic quality and improved monitoring are required to provide a viable recycling plan and preserve consumer and market acceptability of recovered plastics.

Setyo Budi Kurniawan and Muhammad Fauzul Imron [3] investigated the impact of tides on the buildup of plastic waste in the Wonorejo River Estuary in Surabaya, Indonesia. This study focuses on the deposition of visible plastic trash on the shoreline of Madura Strait during high and low tide levels. Three sampling locations (SLs) were chosen throughout the 500 m coastal transect. The Kolmogorov-Smirnov test was performed to assess the data distribution, which revealed that it follows the normal distribution. The link between tide level and plastic buildup was determined using metric analysis of one-way ANOVA. Tukey's Significance Honest Test (Tukey' HSD) was used to determine the importance of the number of plastic debris on each SL. The amount of plastic trash was found to be significantly significant during the high-tide level of Madura Strait (p0.05). SL2 accumulated substantially more plastic trash than the other SLs (p0.05). Low-density polyethylene (LDPE) was shown to be the most prevalent plastic type in the study area. To improve cleaning effectiveness, it was suggested that the Wonorejo River Estuary be cleaned manually on a regular basis during high tide in Madura Strait.

Teresa Randazzo et al [4] analysed how families adopt and utilise air conditioning to adapt to climate change and rising temperatures, which endanger vulnerable groups' health. The study looks at eight temperate, industrialised nations (Australia, Canada, France, Japan, the Netherlands, Spain, Sweden, and Switzerland). By connecting geocoded homes with climate data, the identification technique takes use of cross-country and cross-household variability. According to our findings, homes respond to excessive heat by purchasing and running air conditioners, resulting in higher power usage. When households use air conditioning, they pay 35%-42% more on power. We demonstrate that climate change and rising demand for air conditioning are expected to increase energy poverty using an example analysis. The number of energy poor people who spend a large portion of their income on electricity grows, and those in the lowest income quantile suffer the most.

Johnghun Lim et al. [5] offered a method for sorting plastic garbage in order to increase recycling effectiveness while taking into account economic viability. They created a unique optimization model that takes into account the total cost, which is the sorting cost minus the money from selling the recycled plastic from the sorting cost, in order to determine the best sorting approach. The best method for sorting plastic garbage using mixed-integer programming was then determined using the created model, with the goal of reducing the overall cost of plastic waste sorting equipment. They also performed a sensitivity study to see how much the findings may vary depending on the situation. The optimization findings showed that there were four different types of plastics in the best sorting strategy: LDPE, HDPE, PP, and PVC. In comparison to the usual example, the overall sorting cost was greatly reduced by 69.28% thanks to the optimum sorting approach, which also marginally increased sorting efficiency overall by 4 weight percent. The created model decides how to categorise plastic garbage in the most advantageous way for the economy. In order to improve plastic recycling while lowering the total cost of the sorting system.

N. Miskolczi et al. [6] investigated the pyrolysis of mixed plastic waste made up of high-density polyethylene, polypropylene, polystyrene, and polyvinyl chloride utilising a horizontal tube reactor with a lengthy residence period (25 min). The pyrolysis products from the reactor's atmospheric and vacuum distillation columns were divided into heavy oil, light oil, gasoline, and gases. The impact of polyvinyl chloride (PVC) concentration on product characteristics was studied. Gas chromatography, infrared spectroscopy, and energy-dispersive X-ray spectroscopy were utilised to characterise products, while other standardised techniques were employed to ascertain the primary characteristics of hydrocarbons. The yields of gases, gasoline, and light oil from the mixed plastic waste samples ranged from 36.9 to 59.6%. The conversion of decomposition was greatly accelerated by increasing PVC content.

Reginald Umunakwe et al. [7] showed that currently, recycling accounts for 15% of the 400 million tonnes of plastic generated yearly. Despite the fact that recycling rates have been rising gradually over the past 30 years, the rate at which plastic is produced globally far outpaces this, which means that an increasing amount of plastic is ending up in landfills, dumps, and ultimately the environment, where it harms the ecosystem. Better solutions for plastic trash's final disposition are required to aid existing recycling efforts and stem the flood of plastic garbage. Plastic pyrolysis, a chemical procedure that reduces polymers to their constituent parts, is a potential developing technology. Key outputs include a crude oil-like liquid that may be burnt as fuel and other feedstock that can be employed in a wide variety of new chemical reactions, enabling a closed-loop process. Pyrolysis is a different process from combustion and incineration that, if the conditions are right, is known to create less hazardous byproducts while recovering fuel and a variety of other valuable raw materials. Additionally, the significance of pyrolysis as a comprehensive strategy is highlighted by the rising levels of plastic waste and the rising proportion of thermosetting polymers. Although the hazardous byproducts produced by the pyrolysis of some polymers, such as polyvinyl chloride, are understandably problematic, they may be avoided by making the right feedstock choices. The high sulphur content of liquid fuel produced by plastic pyrolysis may prevent it from being used in the majority of designed applications. This could be avoided by additional processing and blending with the gasoline of a higher quality.

Chao Li et al. [8] investigated on catalytic pyrolysis of PET granules in the presence of A4 zeolite. The results showed that zeolite might significantly alter product yields, characteristics, and compositions through influencing secondary and primary reactions. The faster rate of dehydrogenation and cracking processes mediated by the zeolite catalyst boosted the yields of H_2 and light hydrocarbons in the gaseous product. Furthermore, the zeolite catalyst may break down wax and char, boosting the yields of gas and tar while decreasing the yields of acids and aromatics within the tar. The char produced by catalytic pyrolysis was more aliphatic and less aromatic, although the production of graphite-type structures was boosted. The coke, which contained oxygen-rich aliphatic and aromatic molecules, accumulated on the catalyst, clogged pores, and drastically decreased the catalyst's activity. Furthermore, due to the migration of inorganics from PET, the metal content of the zeolite catalyst surface increased.

R. Miandad et al. [9] investigated the development, difficulties, and prospects for the catalytic pyrolysis of plastic waste in contrast to thermal pyrolysis. We discovered the variables influencing the catalytic pyrolysis process, including temperature, retention time, feedstock content, and catalyst application. Thermodynamic or catalytic processes can be used to pyrolyze materials. Low-quality liquid oil is produced through thermal pyrolysis, which necessitates a high temperature and a long retention period. Catalytic pyrolysis of plastic waste has been developed with the use of a catalyst to address these problems. It has the ability to transform between 70 and 80 percent of plastic trash into a liquid oil with properties akin to those of regular diesel fuel.

P. O. Awoyera et al. [10] studied the prospects of the usage of plastic wastes in construction products. Demonstrated how plastic bags, which frequently cause soil and water pollution, may be transformed into extremely strong and light items. Researchers looked at the initial characteristics of self-consolidating concrete (SCC) that used plastic trash as the fine aggregate. The study found that adding plastic to SCC at 12.5% of the weight of fine aggregate enhanced its fresh qualities, including its capacity for passing and filling. When PW is shredded, it may also be used as fibres in cementitious composites, however, the characteristics of the resultant composite are different than when it is used as aggregate. For instance, it has been discovered that using PW as fibre reduces the slump of the cementitious mixture, whilst using it as aggregate results in an increase in a slump.

Rinku Verma et al. [11] studied that burning municipal solid waste, which contains roughly 12% plastics, releases hazardous chemicals into the environment, including polychlorinated biphenyls, dioxins, and furans. Burning poly vinyl chloride also releases dangerous halogens into the air, which pollutes it and has a negative impact on climate change. The ecosystem as a whole, vegetation, and the health of people and animals are all at risk due to the harmful compounds that have been discharged. Toxic to the central nervous system is polystyrene. The dangerous brominated substances are mutagenic and can cause cancer. Dioxins accumulate on the crops and in our rivers, ultimately making their way into our food and then our bodies. The most dangerous component of these Dioxins, 2,3,7,8 tetrachlorodibenzo-p-dioxin (TCDD), also known as agent orange, is a toxic substance that damages the nervous and reproductive systems, disrupts the thyroid and respiratory systems, and causes cancer. These Dioxins are the deadliest persistent organic pollutants (POPs).

Samuel Kofi Tulashie et al. [12] in Ghana, looked at the recycling of plastic trash into pavement blocks. Pit sand, sea sand, plastic garbage, and pavement block physical and chemical qualities were evaluated. The FTIR analysis revealed that the primary components of the sand samples were quartz and kaoline minerals, whereas the main components of the plastic wastes were polyethylene and polypropylene. The SEM revealed that the fibrous surface of the plastic-pit sand pavement block (PPPB) had a lower pore volume and grain size than the plastic-sea sand pavement block (PSPB). The water absorptivity of PPPB and PSPB was highest at 20% plastic content, at 3.98% and 4.60%, respectively. A greater amount of plastic reduced the block's water absorption but increased its compressive strength. The PPPB and PSPB have maximum compressive strengths of 36.96 N/mm2 and 27.81 N/mm^2, respectively. The maximum tensile strength of PPPB (8.2 N/mm^2) was greater than that of PSPB (6.1 N/mm^2). Furthermore, increasing the plastic composition enhanced both paving blocks' average penetration resistance. The findings indicate that turning plastic trash into pavement blocks is viable and can help minimise Ghana's fast accumulation of plastic garbage.

J. Xaman et al. [13] with the consideration of environmental factors from a city in Mexico with hot weather, the thermal analysis of a hollow block with/without insulation and reflecting materials for the roofing was investigated over 24 hours (the warmest and coldest days). The typical Mexican roof blocks with two and three hollows were taken into consideration. The four different roof arrangements that were examined are (C1) Reference or traditional block (hollow block + concrete slab), (C2) Traditional block with a reflective coating on the exterior of the slab, (C3) Traditional block with an insulating material between the exterior of the block and the slab, and (C4) Traditional block with an insulation material and a with a reflective coating. Gray, Black, and White are the 2 coating options that are being explored. According to the results, the configuration C4 with a white reflective coating requires a lower thermal load for the block with two hollows (B2-Wins-RW) and three hollows (B3-Wins-RW), with values of 1045.3 and 975.9 Wh/m^2, respectively. In comparison to the conventional roof, these data show a 32.4 and a 46.3% reduction in the heat load (C1). This outcome demonstrated the benefit of utilising an insulating substance and reflecting coating in combination on roofs in hot areas.

E. Arunraj et al. [14] studied that in comparison to ordinary roof tiles, cooling roof tile technology offers reduced heat absorption and sunlight reflection. In hot climates, just using light colours can minimise heat gain; the cooling effect of roof tile material also works on this principle. Due to the crucial role that roofing features play in a building's energy efficiency and interior thermal conditions, finding creative ways to increase the thermal energy output of this dispersed roofing feature has emerged as a key development challenge. Also studied 13 different cooling roof materials and their properties. Solar power sheet insulation roof tiles are an intelligent approach to reduce the amount of fossil fuels used to generate energy for buildings, and they frequently have a favourable heat loss of up to 50%. The ideal solution is metakaolin with an EPS sheet covering since the structure has a wide surface area.

Dr. Naseer M A et al [15] in the warm, humid environment of Kerala, this study set out to examine the thermal performance of RCC roofs that were both uncovered, that is, without any covering material, and roofs that were covered with the two most popular types of roofing materials. A specially built gadget dubbed the "Architectural Evaluation System" was used to continuously evaluate the inside comfort state and the equivalent exterior environment. For the study, residential structures with exposed RCC roof slabs and RCC roofs covered with typical roofing materials were chosen. The roof with the Mangalore pattern tile was determined to be thermally performing best among the three roofs evaluated.

Shanshan Tong et al [16] studied to predict the transient roof temperature and transmitted heat flux via the multilayer roofs of naturally ventilated rooms, an analytical Complex Fast Fourier Transform (CFFT) approach is employed in this study and modified. Two full-scale roofs are used in a field experiment to verify the CFFT model. When employing the CFFT model to estimate the ceiling temperature, the mean bias error (MBE) and cumulative variation of root mean square error (CVRMBE) are shown to be less than 4% on both sunny and rainy days. Following validation, a parameter study is carried out to determine the effects of rooftop surface solar reflectivity (between 0.1 and 0.9) and thermal resistance (between 0.1 and 2.5 m2 K/W) on the thermal performance of two different types of concrete-based roofs, namely the unventilated and ventilated roofs. On average, during a Singaporean weather day, increasing the solar reflectivity of a roof by 0.1 results in an 11% reduction in the day heat gain on both ventilated and unventilated rooftops. While used alone, roof ventilation and 2.5-cm expanded polystyrene (EPS) foam insulation reduce daily roof heat gain by 42% and 68%, respectively, when combined, ventilated roofs with 2.5-cm EPS foam and radiant barrier reduce daily roof heat gain by 73% and 84%, respectively.

Darsana P Ruby Abraham et al [17] studied on the production of cost-effective roofing tiles without sacrificing quality by utilising coir fibre to replace cement up to 15%. Based on the findings, a composite with a 10% fibre volume was deemed to be the ideal composite. Cost comparisons revealed that this composite tile was significantly less expensive than regular cement concrete tiles. Different test was conducted on the prepared samples including water absorption test, breaking load test and permeability test. It was noted that properties like breaking load and ductility were improved by the integration of fibres.

R. Alavez-Ramirez et al [18] developed a real-scale prototype home created at CIIDIR facilities in Oaxaca, Mexico, coconut fibre filled precast ferrocement roofing channel components were produced, their thermal behaviour was evaluated, and their performance was compared to precast ferrocement-only roofing channel components. This study's experimental analysis was based on dynamic climatology. To detect the solar radiation strength operating on the home, a solar orientation map of the location was created. Temperature damping and temperature wave lag were determined by measuring roof surface temperatures. The site's monthly average temperature and direct sun radiation statistics were taken into account. The performance of coconut fibre packed precast ferrocement roofing was compared to that of ferrocement-only roofing and typical concrete slab roofing. The results show that coconut fibre filled precast ferrocement roofing channel components encounter increased solar radiation intensity, yet have a 40% thermal damping and a three-and-a-half-hour thermal lag. Traditional concrete slab roofing has a thermal damping of just 13% and a thermal lag of zero, while precast ferrocement-only roofing channels have no thermal lag or damping. As a result, it is determined that coconut fibre filled precast ferrocement roofing channel components are an environmentally friendly option for energy savings and thermal comfort.

2.2 PROBLEM STATEMENT

Higher energy demand and plastic waste accumulation is major concern to looked into. The accumulation of plastic and metal oxide waste in the environment leads many health problems to living and aquatic beings in the long run. Current plastic recycling techniques are costlier and requires huge manpower. Many industries do not opt for such recycling techniques as it cost as much as the production of virgin quality plastics itself. High thermal load on buildings forces many people to rely on alternative cooling solution which are not affordable by everyone in the society. The existing cooling materials in the market have lower life and also exploit the usage of natural resources for their production which puts a heavy toll on the environment.

2.2 SCOPE OF PROJECT

A lot of plastic and metal oxide waste is accumulated in the environment. This causes many health issues to living beings. Also, the increased thermal load on residential buildings forces people to turn into external cooling solutions which demands more energy. Practical methodology promoting reusability of plastic and metal oxide waste might be the eco-sustainable solution. Usage of hybrid composite materials from waste resources as better building materials. Many industries do not opt for recycling techniques as it cost as much as production of virgin quality plastics. This technique provides a value addition concept to the industries. Currently used roofing applications has lower life and exploits the natural resources which puts a huge toll on the environment. This technique a provides a better alternative by incorporating hybrid mix of plastic and metal oxide waste as better roofing solution with longer life. This majorly reduces the accumulation of plastic and metal oxide waste and also the energy demand due to thermal load on buildings. Its also reduces the toll on environment due to exploitation of natural resources.

2.3 OBJECTIVES

The following are the objectives of this experimental study:

- To determine a method for the reutilization of metal oxide waste.
- To characterize the converted metal oxide additive for thermal application.
- To optimize the process parameters of the proposed design of hybrid roofing tile 'Plastile'
- To find the thermal performance of plastile

CHAPTER 3

METHODOLOGY

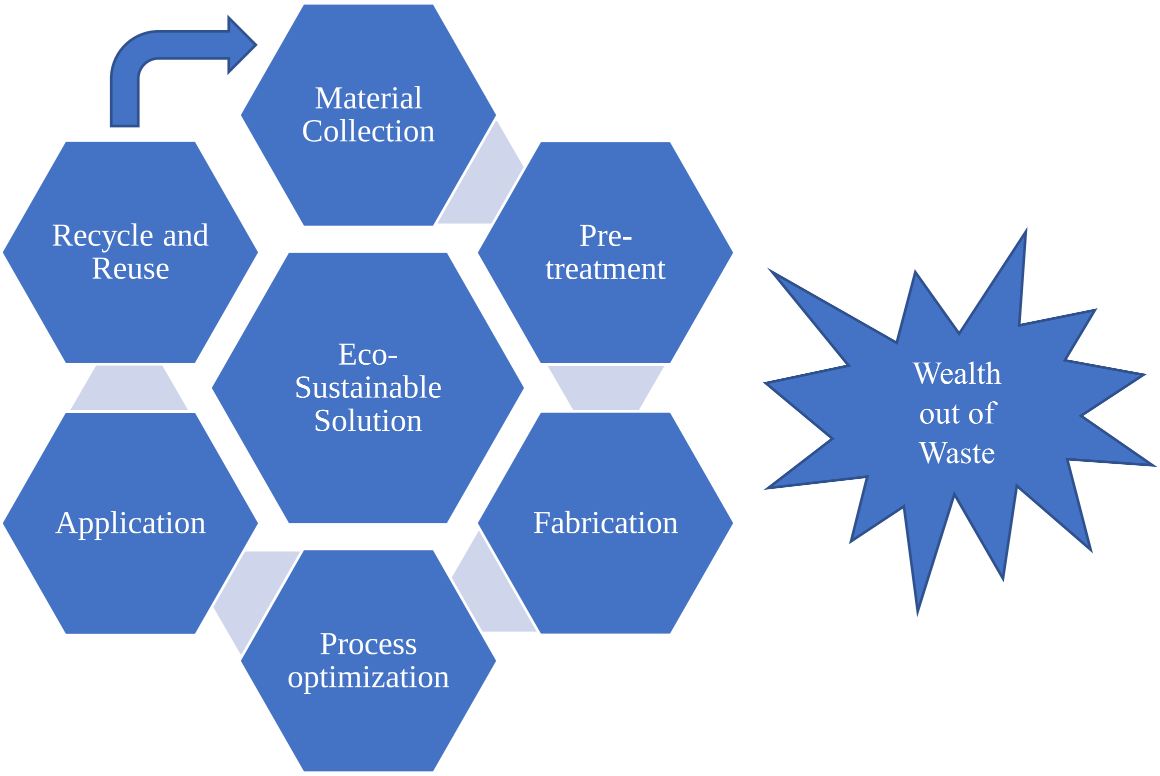


Fig.3.1 Circular flowchart of methodology

The approach starts with the collection of materials. Materials are identified from the industrial wastes that are being eliminated into the environment. After material collection phase involves the pre-treatment of the collected waste samples. Since these are waste samples, pre-treatment is required to identify and remove unwanted contaminants in the collected samples. The next phase involves the characterisation of samples based on their properties identified. The next stage, process optimization involves the fabrication of novel roofing tile composites and optimizing the processing techniques using the process parameters identified. After fabrication next step involves the application of novel roofing tile composites. The result values are collected in this stage and compared with other conventional roofing applications in the market.

After the life cycle of the product, it can again be recycled and reused which involves the next phase of the circular methodology which makes this product an eco-sustainable solution.

3.1 MATERIAL COLLECTION

The material collection involves the process of selecting waste plastics and metal oxides from different industries which is compatible with the fabrication of proposed novel roofing tile composites. Polycarbonate and ABS are selected as the waste plastic samples and are collected from Covestro, Germany and Sabic, Saudi Arabia respectively and metal oxides such as iron oxide and silicon dioxide are collected from Kerala Minerals and Metals Ltd. (KMML), Kollam and HLL Life Care Limited. (HLL), Trivandrum respectively.

Fig 3.2: ABS collected from

Acrylonitrile Butadiene Styrene (ABS) is a common thermoplastic polymer. the glass transition temperature of ABS is 105 °C. Styrene and acrylonitrile are polymerized with polybutadiene to create ABS, a terpolymer. The ratios might range from 5% to 30% butadiene, 40% to 60% styrene, and 15% to 35% acrylonitrile. As a result, a lengthy polybutadiene chain is crisscrossed by shorter poly chains (styrene-co-acrylonitrile). Since polar nitrile groups from nearby chains are attracted to one another and bind the chains together, ABS is more durable than pure polystyrene. The heat deflection temperature is raised while the acrylonitrile also contributes to chemical resistance, fatigue resistance, hardness, and stiffness. The styrene imparts plastic hardness, rigidity, and better processing ease in addition to a lustrous, impervious surface. The rubber-like material polybutadiene offers heat resistance and rigidity at the expense of toughness and flexibility at low temperatures. ABS has good mechanical properties such as impact resistance, toughness, and rigidity when compared with other common polymers.

Table 3.1: Typical mechanical properties of ABS

Property	Value
Youngs Modulus	2.28
Tensile Strength	43
Flexural modulus	2.48
Flexural strength	77
Notched Izod	0.203
Heat deflection temperature	81

Fig 3.3: Polycarbonate pellets collected from

Polycarbonate is another group of thermoplastic polymers which contains carbonate groups in their chemical structures. They are strong tough materials having different grades and some grades are optically transparent. Polycarbonate is a long-lasting material. Although it has good impact resistance, it has low scratch resistance. Therefore, polycarbonate eyewear lenses and polycarbonate external automotive components are given a strong coating. Polymethyl methacrylate (PMMA, acrylic) and polycarbonate have similar properties, although polycarbonate is tougher and more resistant to high temperatures. Since thermally treated material is typically completely amorphous, it transmits visible light more effectively than many types of glass. With a glass transition temperature of roughly 147 °C, polycarbonate gradually softens and flows above 155 °C. Polycarbonate can withstand significant plastic deformations without breaking or cracking, unlike the majority of thermoplastics

Table 3.2: Typical properties of polycarbonate

Property	Value
Youngs Modulus	2 GPa
Tensile Strength	55 MPa
Glass transition temperature	147 °C
Specific heat capacity	1.2 KJ/KgK
Thermal conductivity	0.12 W/mK
Heat deflection temperature	0.45 MPa

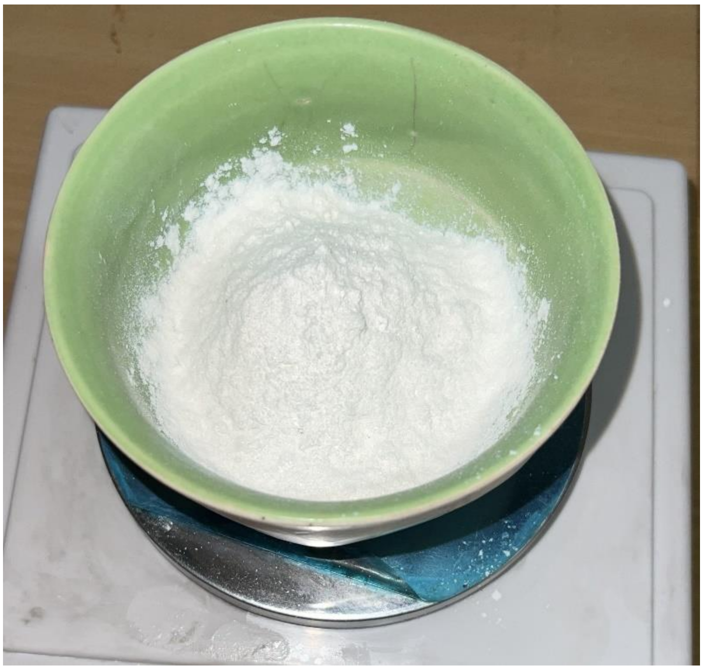


Fig 3.4: Silicon dioxide powder collected from HLL Trivandrum

Silicon dioxide, often known as silica, is a silicon oxide with the chemical formula SiO_2 that is most typically found in nature as quartz and a variety of living species. Silica makes up the majority of sand in various regions of the world. One of the most diverse and common groups of materials is silica, which may be found naturally as well as in synthesised form. Fused quartz, fumed silica, silica gel, opal, and aerogels are a few notable examples. It is utilised as an electrical insulator in microelectronics, structural materials, as well as pharmaceutical and food sectors. Most glass is produced using silica as the main component. The principle of freezing point depression reduces the mixture's melting point when additional minerals are melted with silica, increasing fluidity. Pure SiO_2 has a glass transition temperature of approximately 1475 K. Rapid cooling of molten silicon dioxide SiO_2 results in a glassy solidification rather than crystallisation. Because of this, silica is a common element in pottery glazes.

Fig 3.5: Iron oxide powder collected from KMML Kollam

Iron oxide, often known as ferric oxide, is an inorganic substance with the formula Fe_2O_3. It is one of the three primary iron oxides, the other two being the uncommon iron (II, and III) oxide (Fe3O4) and iron (II) oxide (FeO), which occurs naturally as the mineral magnetite. Hematite, often known as the mineral Fe_2O_3, is the main source of iron for the steel industry and is easily affected by acids. Iron oxide is frequently referred to as rust. Due to the same composition and shared features of rust, this term has some limited utility. Rust, which is hydrous ferric oxide, is classified as an ill-defined substance in chemistry.

3.2 PRE-TREATMENT

Since the samples collected were waste materials a preliminary analysis and treatment were done to ensure the safety of the materials and also to determine the properties of the samples.

3.2.1 XRF Analysis of waste metal oxide from HLL and KMML

XRF analysis was done to identify the percentage composition of other components in the collected metal oxide samples.

Table 3.3: Percentage composition of metal oxide from XRF analysis of metal oxide from HLL

Sample	**Weight composition (%)**
SiO_2	**94.4**
K_2O	0.275
Al_2O_3	0.268
ZnO	2.03
Na_2O	1.47

Cl	0.387
SO_3	1.20

Table 3.4: Percentage composition of metal oxide from XRF analysis of metal oxide from KMML

Sample	**Weight composition (%)**
SiO_2	0.21
TiO_2	0.07
Al_2O_3	1.88
MnO	1.22
Fe_2O_3	**85.96**
CaO	0.33
MgO	2.33
Na_2O	0.32
Cl	5.87
SO_3	1.01
V_2O_5	0.35
Cr_2O_3	0.19
Total	99.74

Table 3.5: Results of XRF

Sample	MMO-T	MMO-U
Date	2/20/2019 10:02	2/20/2019 9:50
SiO_2 (%)	0.20	0.14
TiO_2	0.07	0.07
Al_2O_3	1.98	2.30
MnO	1.24	1.28
Fe_2O_3	91.15	84.13
MgO	2.59	2.64
CaO	0.33	0.33
Na_2O_3	ND	ND
K_2O	0.02	ND
P_2O_5	ND	ND
Cl	0.52	7.37
SO_3	0.97	0.91
TOTAL	**99.06**	**99.16**

The metal oxide powder collected from HLL Ltd was subjected to heat treatment and the treated and untreated samples were analysed using XRF analysis. The results indicate that the weight percentage of chlorine in the sample was considerably reduced upon heat treatment. The weight percentage of chlorine dropped from 7.37% (untreated sample) to 0.52% (treated sample). Contents of other elements almost remained the same without any change.

3.2.2 SEM micrographs of metal oxides collected from HLL and KMML

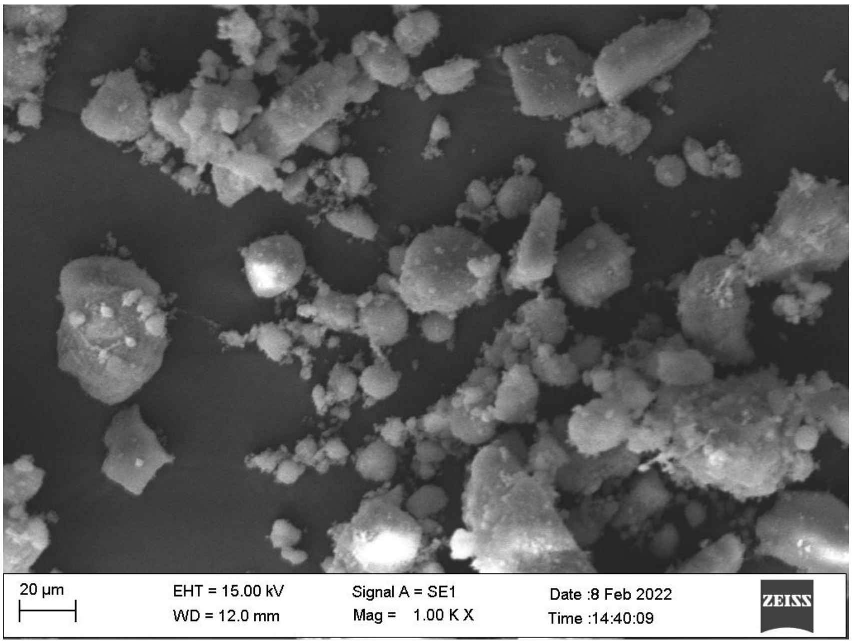


Fig 3.6: SEM micrograph of metal oxide sample collected from HLL Ltd

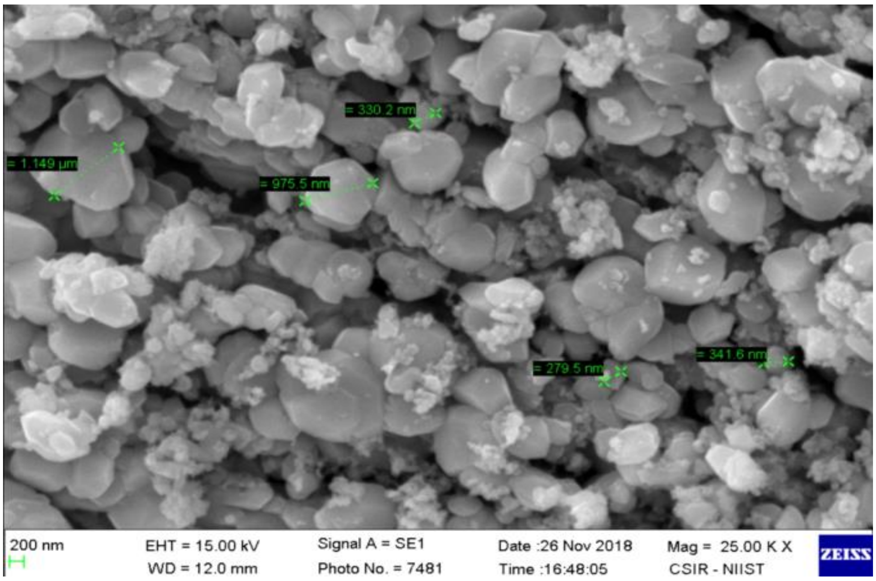
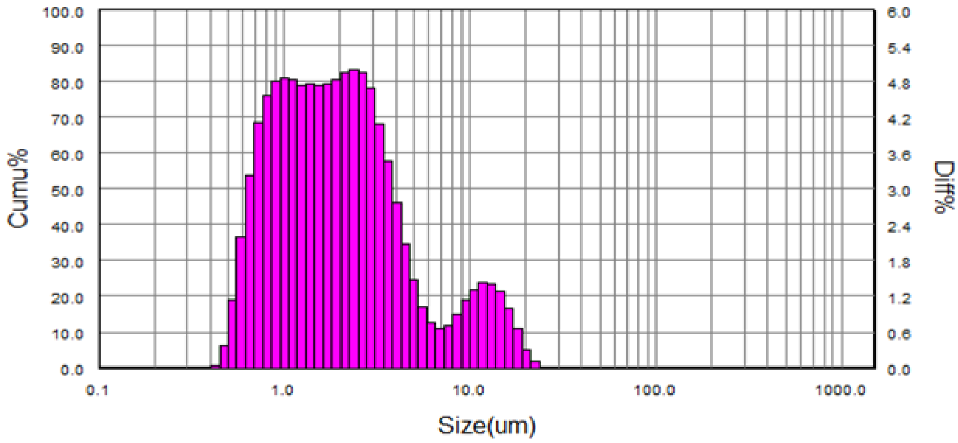
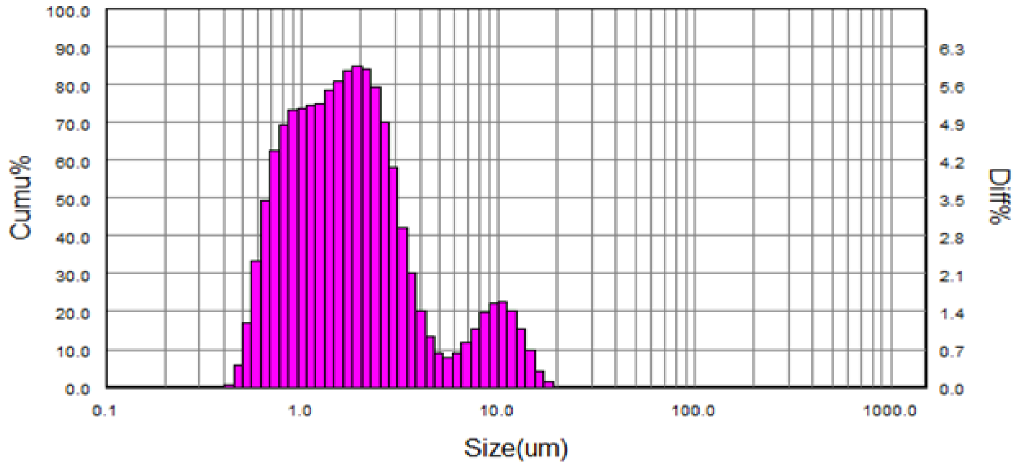


Fig 3.7: SEM micrograph of metal oxide sample collected from KMML



Size	Percent
0.000-0.300	0.00
0.300-0.510	0.55
0.510-1.350	35.81
1.350-2.500	27.84
2.500-32.00	35.80
32.00-38.00	0.00
38.00-40.00	0.00
40.00-114.5	0.00
114.5-115.0	0.00
115.0-116.0	0.00

Fig 3.8: Particle size analysis of untreated metal oxide from KMML



Size	Percent
0.000-0.300	0.00
0.300-0.510	0.59
0.510-1.350	38.52
1.350-2.500	32.99
2.500-32.00	27.90
32.00-38.00	0.00
38.00-40.00	0.00
40.00-114.5	0.00
114.5-115.0	0.00
115.0-116.0	0.00

Fig 3.9: Particle size analysis of treated metal oxide from KMML

The particle size of the untreated sample ranges from 0.361-32.41 µm and the majority of particles lie in the range of 0.686-3.422 µm. Whereas the particle size of the treated sample ranges from 0.361-18.97 µm and the majority of particles lie in the range of 0.617-3.075 µm. The metal oxide samples from KMML had a higher packing fraction compared to the metal oxide sample from HLL Ltd due to the lower size of particles which is evident from the SEM micrographs. The lower the size of the particles, the higher will be the packing fraction. This in turn leads to a higher bulk density of particles and also has low porosity values.

3.2.3 DSC analysis of metal oxides collected

DSC analysis was done in the Sophisticated Instrumentation Facility, NIT Trichy to determine the specific heat values of the collected metal oxide samples from HLL Ltd and KMML respectively. Since applications of the fabricated plastile involved thermal applications, it was a necessity to determine the specific heat values of the samples.

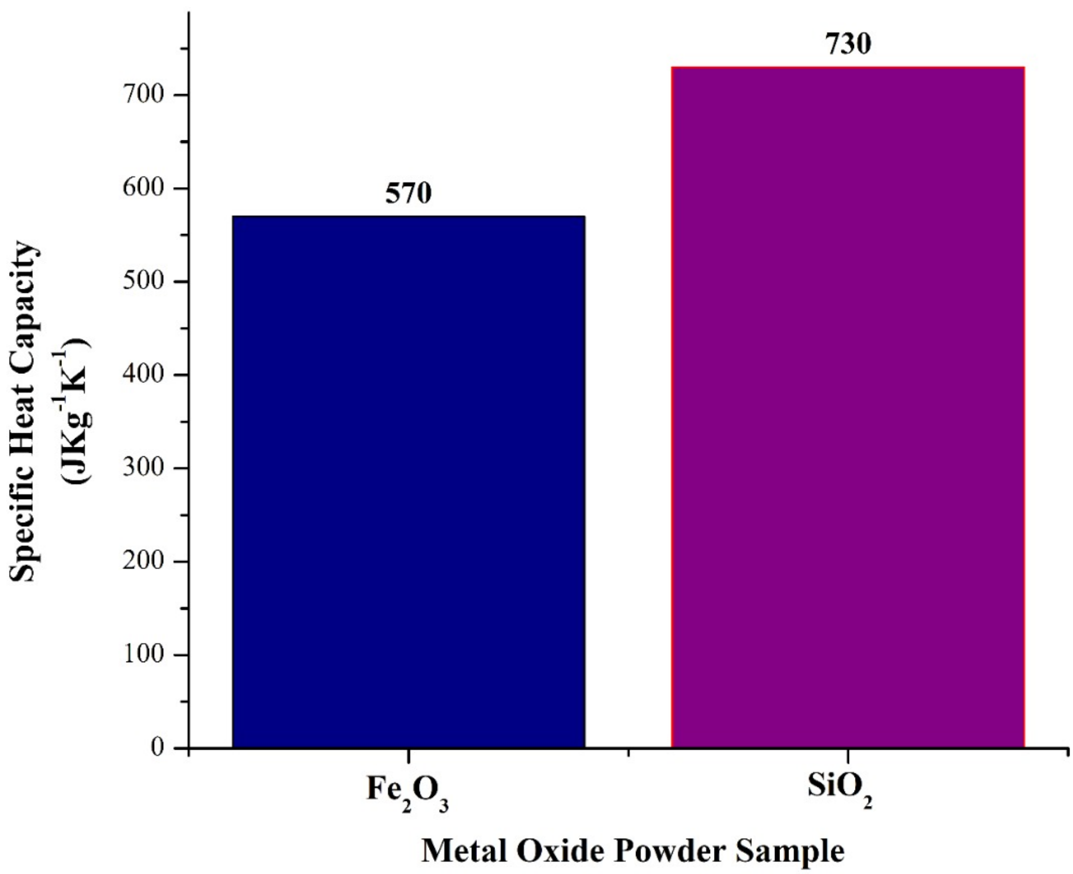


Fig 3.10: Specific heat values of metal oxides collected from HLL Ltd and KMML

3.2.5. Bulk thermal conductivity of metal oxides from HLL Ltd and KMML using KD2Pro

The bulk thermal conductivities of metal oxides from HLL Ltd and KMML were determined using KD2Pro with maximum compaction. For the metal oxide samples from HLL Ltd whose majority of particles lay in the range of 0.617-3.075 µm, the bulk thermal conductivity was measured to be K= 0.035 W/mK and for the metal oxide samples from KMML whose majority of particles lay in the range of 0.686-3.422 µm the bulk thermal conductivity was measured to be K= 0.162 W/mK. The thermal conductivity of metal oxide samples was measured at maximum compaction by filling the metal oxides into a test tube and by compacting the maximum. The thermal conductivity values were measured with full compaction and loosely packed and it was found that the thermal conductivity values are not much affected with or without compaction. The percentage change in values of thermal conductivity with and without compaction measured was within 1%.

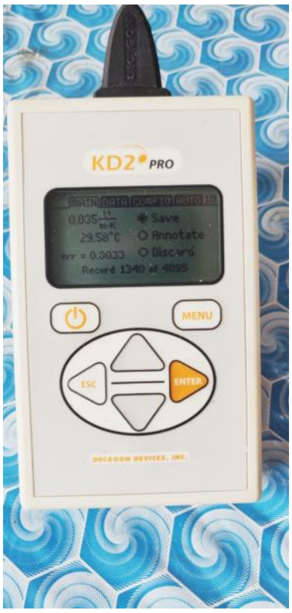


Fig 3.11: Thermal conductivity of metal oxide from HLL Ltd

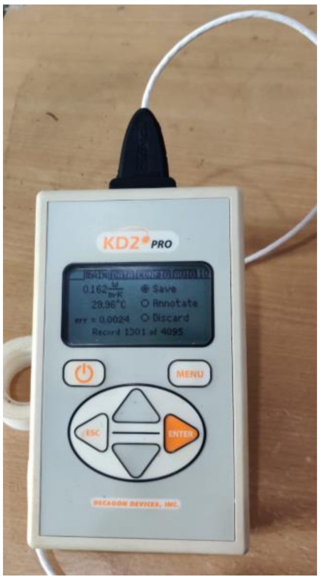


Fig 3.12: Thermal conductivity of metal oxide from KMML

3.2.6. pH analysis of metal oxides from HLL Ltd and KMML

Since the metal oxides collected from HLL Ltd and KMML were mainly industrial wastes it was required to determine the pH value of the metal oxides to determine whether they are in the usable range and to determine the treatments to bring the pH values to the neutral range. A pH analyser was used to determine the pH values of the samples and it was found that the pH value of metal oxide from HLL Ltd was 7.535 and after stirring the pH value dropped to 7.229, therefore, the pH value of the samples was in the neutral range. The pH values value of metal oxide collected from KMML was found to be 3.91 which was in the acidic range therefore the sample was heat treated and after treatment, it was found that the pH shifted to 5.32. It was concluded that the pH value of the metal oxide sample from KMML shifts to the neutral range upon heating and the acidity of the sample drastically reduces upon heating.

Fig 3.13: pH of metal oxide from HLL Ltd before stirring

Fig 3.14: pH of metal oxide from HLL Ltd after stirring

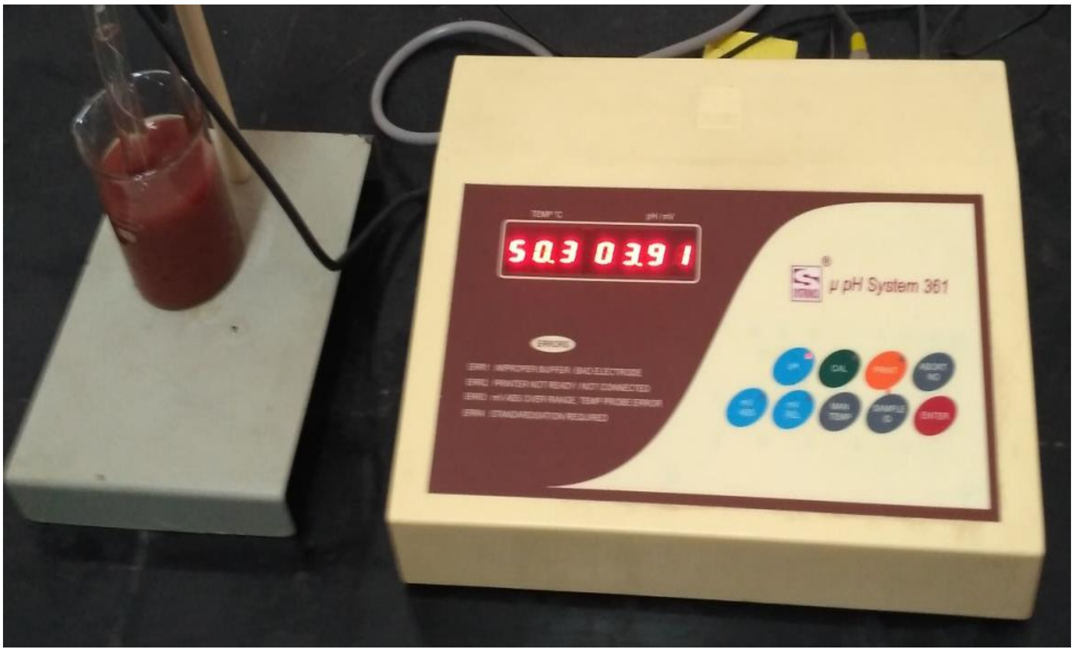


Fig 3.15: pH of metal oxide from KMML before heat treatment

Fig 3.16: pH of metal oxide from KMML after heat treatment

The pH for the samples for mixed proportions was also measured by hybrid mixing of two the two metal oxides (SiO_2/Fe_2O_3) in the composition of 0/100%, 25/75%, 50/50%, 75/25% and

100/0% respectively. The pH of each composition was measured 3 to 4 times to ensure repeatability in the values.

Table 3.6: pH value of different compositions of metal oxide from HLL Ltd and KMML

Composition		**pH before stirring**	**pH after stirring (after 1 hour)**
SiO_2	**Fe_2O_3**		
0%	100%	2.079	1.931
25%	75%	2.978	2.936
50%	50%	4.295	4.541
75%	25%	7.683	5.873
100%	0%	7.535	7.229

3.2.7. Bulk density and other properties

The bulk density of the metal oxides from HLL Ltd and KMML was calculated by compacting the powder into a test tube. The volume of the test tube was measured by calculating the volume of the water occupied in the test tube. The mass of the compacted metal oxide powder was measured using a weighing machine. And by using the following calculation the bulk density of the metal oxides was calculated.

Mass of SiO_2 powder = 9g

Volume of test tube = 84.78 cm^3

Density of SiO_2 powder = $\rho = \frac{m}{V}$

$$\rho = \frac{0.9}{84.78}$$

$$\rho = 0.106 \text{ g/cm}^3$$

Mass of Fe_2O_3 powder = 9g

Volume of test tube = 84.78 cm^3

Density of Fe_2O_3 powder = $\rho = \frac{m}{V}$

$$\rho = \frac{25.6}{84.78}$$

ρ = 0.301 g/cm^3

The bulk density of the hybrid mixing of metal oxides was calculated in a similar method and the values were validated using the Rule of Mixtures. The rule of mixtures in general is a method used to predict the various properties of a composite material.

Rule of mixtures = (property of A x % of A) + (property of B x % of B)

The bulk density of hybrid mixes metal oxides (SiO_2/Fe_2O_3) for compositions 10/90, 30/70, 50/50, 70/30 and 90/10 are respectively calculated experimentally.

Experimental calculation for 10/90 (SiO_2/Fe_2O_3) composition,

Mass of SiO_2 = 0.9g

Mass of Fe_2O_3 = 23.04 g

Volume of test tube = 84.78 cm^3

Density, $\rho = \frac{m1+m2}{V}$

$$= \frac{0.9+23.04}{84.78}$$

= 0.282 g/cm^3

Calculation using rule of mixtures for 10/90 (SiO_2/Fe_2O_3) composition,

ρ_{SiO2} = 0.106 g/cm^3

$\rho_{Fe2O3} = 0.301$ g/cm^3

$\rho_{bulk} = (0.1 \times 0.106) + (0.9 \times 0.301)$

$\rho_{bulk} = 0.2815$ g/cm^3

The experimental value and rule of mixture for the same composition are approximately equal which further validates the value. Similarly, the bulk density values for the remaining compositions are in table 3.6

Table 3.7: Bulk density of different compositions of metal oxides from HLL Ltd and KMML

Composition (SiO_2/Fe_2O_3)	**Density (g/cm^3)**	**Rule of mixture (g/cm^3)**
10/90	0.282	0.2815
30/70	0.2432	0.2425
50/50	0.204	0.2035
70/30	0.1648	0.1645
90/10	0.1257	0.1255

Similarly, the thermal conductivity of the hybrid mixes of different compositions of metal oxides from HLL Ltd and KMML was calculated experimentally using KD2Pro and the same was validated using the rule of mixtures. The thermal conductivity values for the different compositions of metal oxides from HLL Ltd and KMML are in table 3.7 below,

Table 3.8: Thermal conductivity of different compositions of metal oxides from HLL Ltd and KMML

Composition (SiO_2/Fe_2O_3)	**KD2Pro**	**Rule of mixture (g/cm^3)**
10/90	0.141	0.1483
30/70	0.119	0.1209
50/50	0.098	0.0935
70/30	0.062	0.0661
90/10	0.037	0.0387

3.3 FABRICATION

The fabrication phase involves a 3-step production technique using ∆T-comp (*Patent No. 202141008715*). A total of 6 tiles were fabricated starting from neat tiles of polycarbonate and ABS (8mm &13mm), ABS tile with iron oxide as core (8mm &13mm) and ABS tile with silicon dioxide as core (13mm). But polycarbonate tiles did not provide sufficient strength when compared to ABS tile therefore it was discarded for further studies. A 3-D model was drawn using Solidworks 2020 a better understanding of the model of the novel plastile to be fabricated. The model shows three different layers of the plastile named Layers 1,2 and 3 respectively. Layer 1 and layer3 are made of entirely plastic material and layer 2 which is the core of the tile comprises of a frame made of plastic and the metal oxide powder is entrapped inside the frame. The neat plastic tile model comprises layers 1,2 and 3 as plastic material itself.

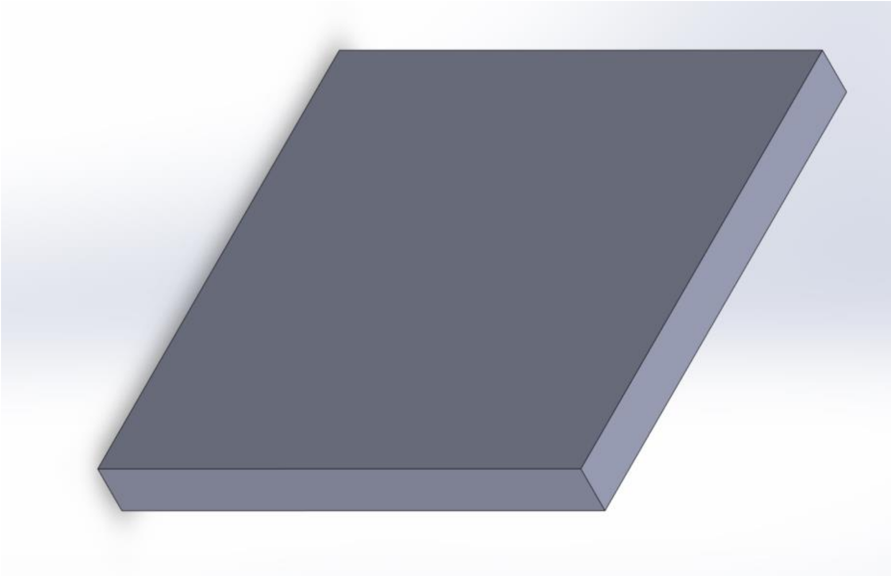


Fig 3.17: Solid model of ABS neat tile

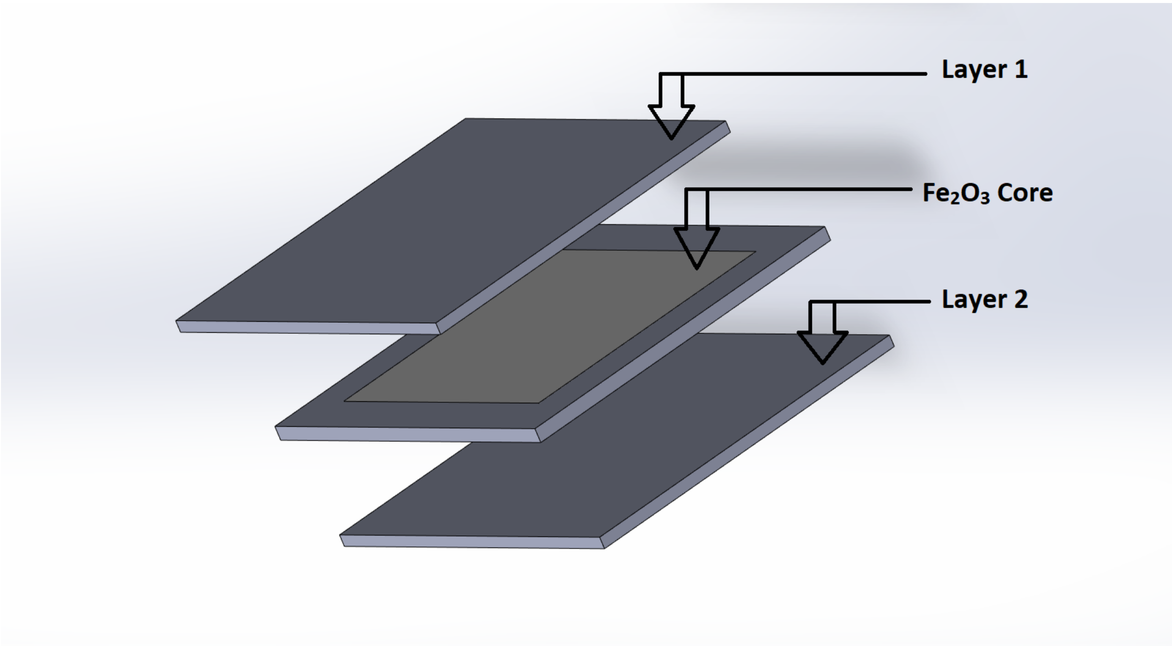


Fig 3.18: Solid model of ABS tile with Fe_2O_3 core

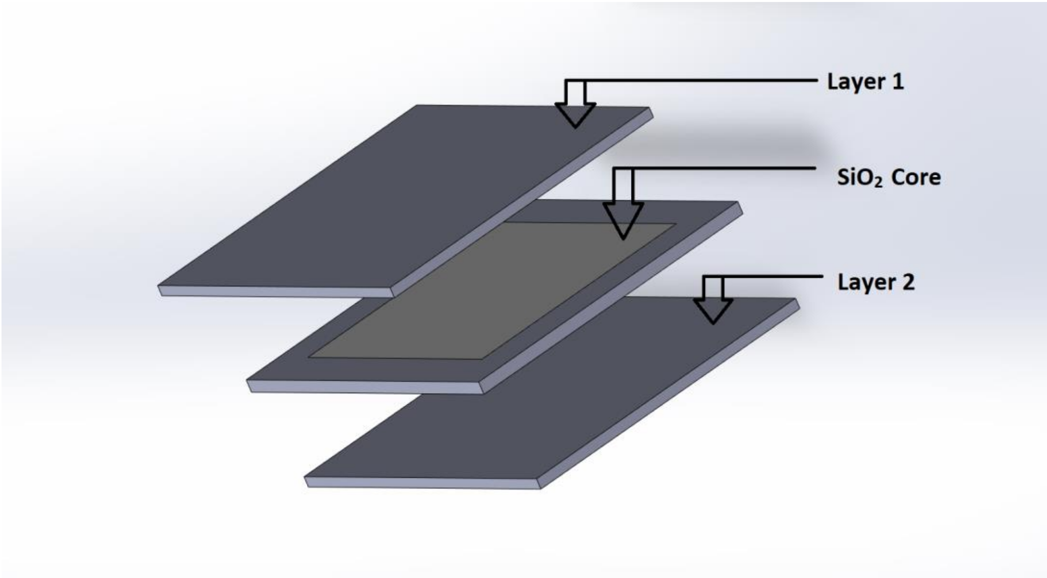


Fig 3.19: Solid model of ABS tile with SiO_2 core

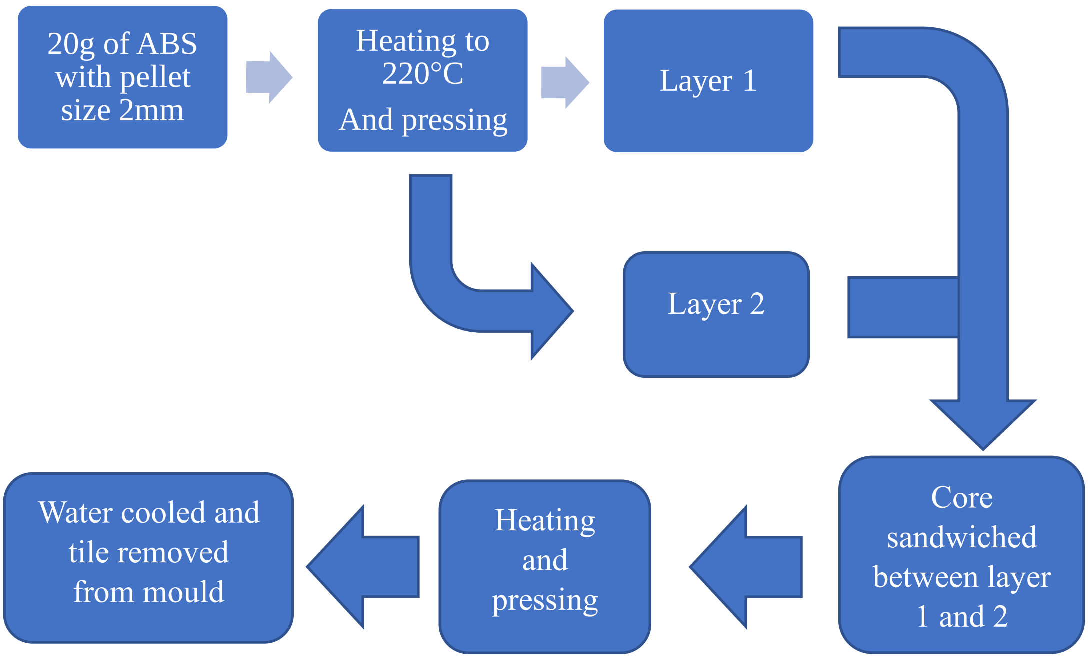


Fig 3.20: Process flow chart of fabrication

The novel plastile is of dimension 8cmx8cm and thickness varies from 8mm to 13mm and the core dimension is 6cmx6cm with a thickness of 3mm. After continuous trial fabrication, it was found that 8g of ABS pellets having 2mm pellet size were heated and fully compacted in the mould to fabricate tile of 1mm thickness. Therefore, firstly for the fabrication of layer 1 20g of ABS pellets having 2mm pellet size was laid up even inside the mould. Similarly, layer 3 was also fabricated. And for layer 2, the metal oxide powder which is the core and the remaining ABS pellets for the frame were placed evenly between layers 1 and 2 and was fully compressed in the ΔT-comp 21 at 220°C for 20min and later cooled for 15min and placed into a water bath and finally, the cooled plastile was removed from the mould. Using this 3-layer technique plastile with ABS neat (8mm and 13mm) and ABS tile with Fe_2O_3 core (8mm and 13mm) and ABS tile with SiO_2 core (13mm) was fabricated. This 3-layer technique ensures the geometrical accuracy of the tile was maintained. Also, the spillage of molten plastic from mould and leakage of metal oxide powder was avoided. This technique also reduced the fabrication time drastically.

Fig 3.21: ΔT-comp 21

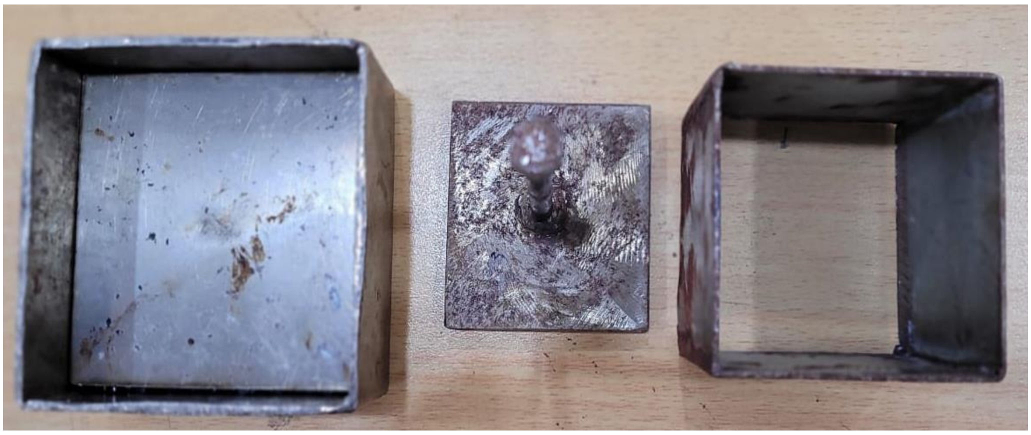


Fig 3.22: Custom-made mould design used for the fabrication of plastile

Fig 3.23: Fabricated ABS neat tile

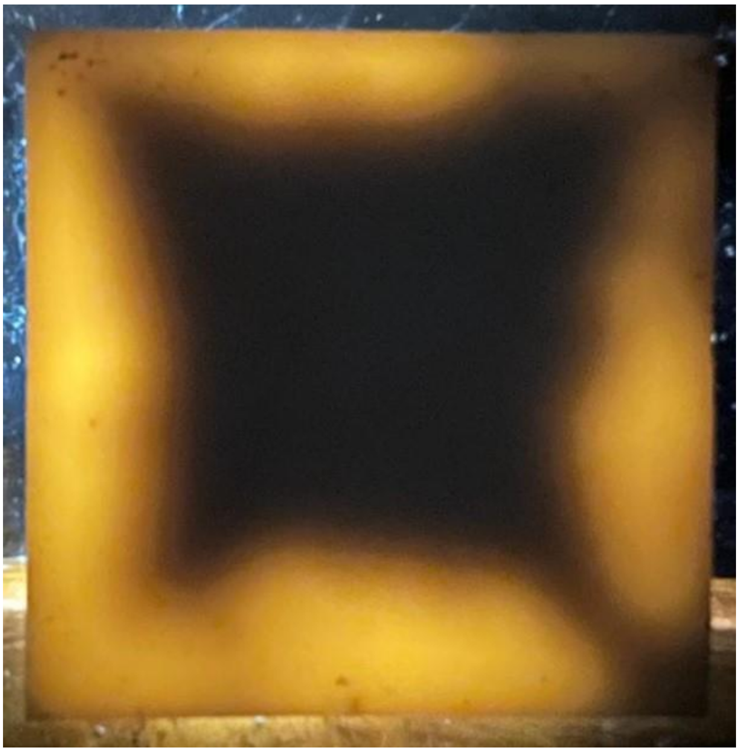


Fig 3.24: Fabricated ABS tile with Fe_2O_3 core

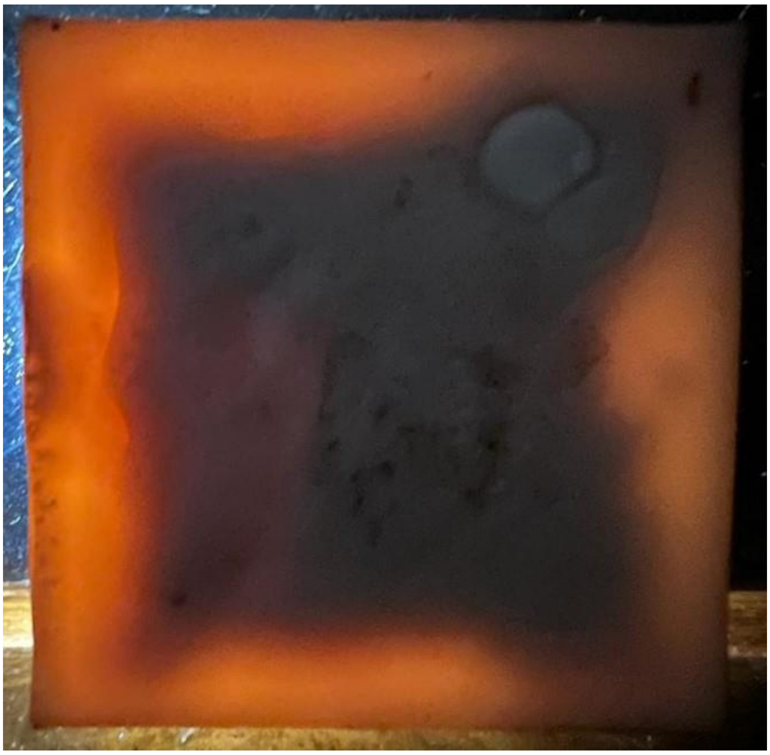


Fig 3.25: Fabricated ABS tile with SiO_2 core

3.4 PROCESS OPTIMIZATION

In this phase, the processing technique is optimized to provide better results. This involves optimization of both temperature and time in fabrication by continuous trial and run method. This ensures that the novel plastile was fabricated in the least time using the least energy expenditure. The melting temperature of ABS tile was found to be 200 °C and by continuous trial and the run method, it was found that the optimum temperature for this fabrication technique was 220 °C. The heating time and cooling time were also optimized to get better results.

Table 3.9: Overall processing time of plastile

Tile	Processing time (min)	Cooling time (min)	Overall processing time (min)
Neat (ABS) tile	10	10	20
Plastile with Fe_2O_3 core	20	15	35
Plastile with SiO_2 core	20	15	35

3.4 APPLICATIONS

The major application of this novel plastile involves thermal load reduction materials in concrete surfaces. They are used as roofing materials alternatives. They can also be used as indoor ceiling and wall decorations.

3.5 RECYCLE AND REUSE

The 3-layer design of this plastile ensures that this product can be recycled and reused easily. After the life-cycle completion of the plastile the 3- layers can be cut separately and washed off to remove the metal oxide from the core and the plastic can be melted again and reused to make plastile or any other product. The washed-off metal oxide can be collected using a filter and dried up and used again in the reusing of plastile. This design ensures very less complexity in recycling and reusing. And also recycling and reusing ensures the decrease of plastic and metal oxide accumulation in the environment.

CHAPTER 4

TESTING AND CHARACTERIZATION

Material testing provides great information regarding fabricated samples, product samples or prototypes for a variety of applications. The information acquired during testing and the test results themselves can be very useful to the engineering industry. For the novel roofing plastile composite the main study involves the thermal performance analysis of the same. Guarded hot plate experiment was conducted in order to evaluate the thermal performance of the fabricated samples. It works on the principles of Fourier law of conduction. For this testing an experimental setup was designed. Samples of ABS neat tile (8mm and 14mm), ABS tile with Fe_2O_3 core (8mm and 13mm) and ABS tile with SiO_2 core (13mm) was used to evaluate the thermal performance.

4.1. MATERIALS AND EQUIPMENT USED

4.1.1. Wooden box

A wooden box was used as an isolated chamber where the study is to be performed. Details of the stainless-steel plates used in this study are listed in table 4.1.

Table 4.1: Specification of wooden box

Sl No.	Parameters	Specification
1	Dimension	35cm x10cm x20 cm
2	Material	Wood
3	Make	Custom made

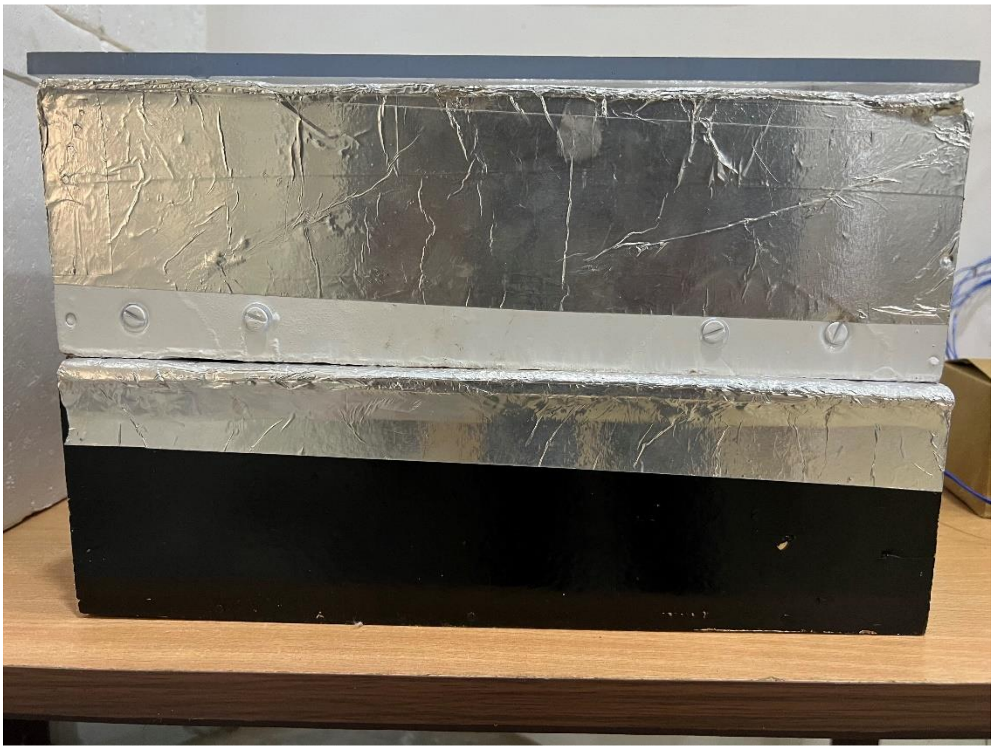


Fig 4.1: Wooden box

4.1.2. Stainless Steel Plate

Two stainless steel plates were used to sandwich the specimen in between. Details of the stainless-steel plates used in this study are listed in table 4.2.

Table 4.2: Specification of Stainless-steel plates

Sl No.	Parameters	Specification
1	Dimension	5cm x 5cm x 5mm
2	Material	Stainless Steel
3	Provider	SIDCO Tools, Kollam

Fig 4.2: Stainless steel plate

4.1.3. Thermocouple

T-type thermocouples were used for this study in order to monitor the temperature in layers. Details of the thermocouple used in this study are listed in table 4.3.

Table 4.3: Properties of Thermocouple

Sl No.	Parameters	Specification
1	Type	T type
2	Temperature range	-270°C to 370°C
3	Provider	WorldCare
4	Length	1metre

Fig 4.3: T- Type thermocouple

4.1.4. Polyurethane tape

Polyurethane tapes were used to fully insulate the sides of the specimen in order to maintain heat flow in only one direction. Details of the polyurethane tape used in this study are listed in table 4.4.

Table 4.4: Properties of polyurethane tape

Sl No.	Parameters	Specification
1	Thickness	6mm
2	Thermal conductivity	0.034 W/mK
3	Foam density	20 kg/m^3
4	Provider	3M
5	Temperature range	-40°C to 80°C

Fig 4.4: Polyurethane Foam Tape

4.1.5. PTC Heater plate

A PTC heater unit is connected to a bottom plate in the wooden box which is in contact with one of the stainless-steel plates. Details of the PTC heater unit used in this study are listed in table 4.5.

Table 4.5: Properties of PTC heater plate

Sl No.	Parameters	Specification
1	Heater total size	15cm x 10cm x 7 cm
2	Voltage	220V
3	Provider	WorldCare
4	Temperature range	150°C

Fig 4.5: PTC Heater Plate

4.1.6. Glass slab

A glass slab is placed above the wooden box to cover the exposed top portion and to maintain an isolated system inside the wooden box. Details of the glass slab used in this study are listed in table 4.6

Table 4.6: Properties of glass slab

Sl No.	Parameters	Specification
1	Material	Glass
2	Size	35cm x 10cm x 1cm
3	Thickness	1cm
4	Make	Custom made

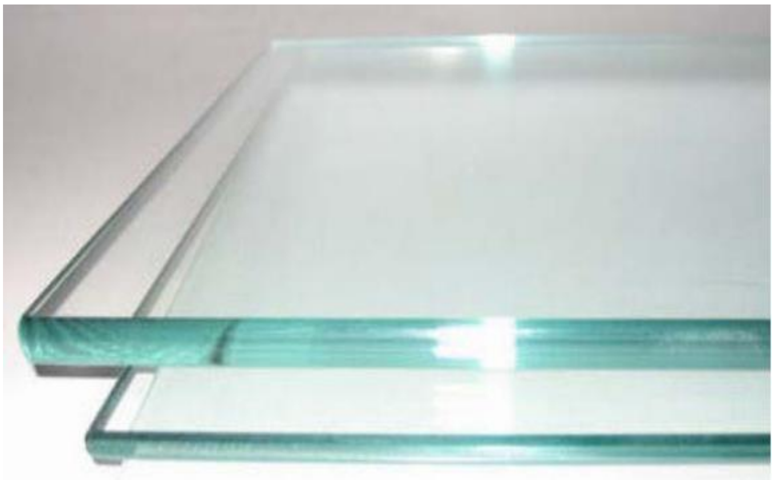


Fig 4.6: Glass slab

4.1.7. Thermal Imaging Camera

A thermal imaging camera was used to monitor the heat distribution during the experimental setup. Thermal imaging is the technique of employing a thermal camera to collect and produce a picture of an item using the infrared light that the object emits. The temperature of the item is depicted in the produced picture. Details of the thermal imaging camera used in this study are listed in table 4.7

Table 4.7: Properties of thermal imaging camera

Sl No.	Parameters	Specification
1	Digital camera	2MP, 83° FOV
2	Display Type	QVGA (320 × 240 pixels)
3	Image Modes	Thermal, Visual, MSX®
4	Sensitivity	<150 mK
5	Thermal image minimum focus distance	10 cm

Fig 4.7: Thermal Imaging Camera

4.1.8. Data Acquisition Unit

The process of measuring an electrical or physical phenomena, such as voltage, current, temperature, pressure, or sound, is known as data acquisition (DAQ). Sensors, DAQ measuring gear, and a computer with programmable software make up a DAQ system. The data collected from the isolated chamber using thermocouple is measured through each scan using a DAQ system.

Fig 4.8: Data Acquisition Unit

4.2 GUARDED HOT PLATE EXPERIMENT

This experiment is based on the principle of Fourier's law of conduction. The guarded hot plate experiment was conducted for the samples ABS neat tile (8mm and 13mm), ABS tile with Fe2O3 core (8mm and 13mm) and ABS tile with SiO2 core (13mm) respectively. The experimental setup involves a wooden box with a PTC heater at the bottom coupled to a copper plate. The sample to be tested is sandwiched between two stainless steel plates and one stainless steel plate comes in contact with the copper plate and thermocouples are placed in the order T1, T2, T3 and T4 respectively. T1 is the thermocouple placed in the interface between the bottom copper plate and the stainless-steel plate. T2 is on the interface between the top face of the bottom SS plate and the bottom face of the sample. Similarly, T3 is on the interface between the top face of the specimen and the bottom face of the top SS plate. T4 is on the top face of the top SS plate. The side faces of the specimen are insulated using polyurethane foam tape to maintain heat transfer only from one direction (bottom to top). The top surface of the wooden box is closed using a glass slab to maintain an isolated system inside. The thermocouple wires are connected to the respective channels in the DAQ unit which was connected to a laptop and the experiment is started in an air-conditioned space. Keysight Data Logger software was used to monitor the readings from the DAQ unit. The initial temperature readings from the DAQ unit were noted to check for any error in configuration. All temperature reading from DAQ giving the same reading as room temperature shows the configuration is correct. The PTC heater is turned ON and the heating cycle begins and the readings of all interface temperatures are measured every 10 seconds in the DAQ unit. The heating cycle is continued till a steady state is achieved (i.e.; negligible temperature change in all interfaces after each scan). After steady is reached the heating cycle is stopped by turning OFF the PTC heater and the specimen is allowed to gradually which initiates the cooling cycle. The cooling cycle is continued till all the interface temperature reaches room temperature. After the cooling cycle, the scanning is stopped and the file is saved in Excel format. The graph of the heating and cooling curve for the specimen is plotted using Origin software.

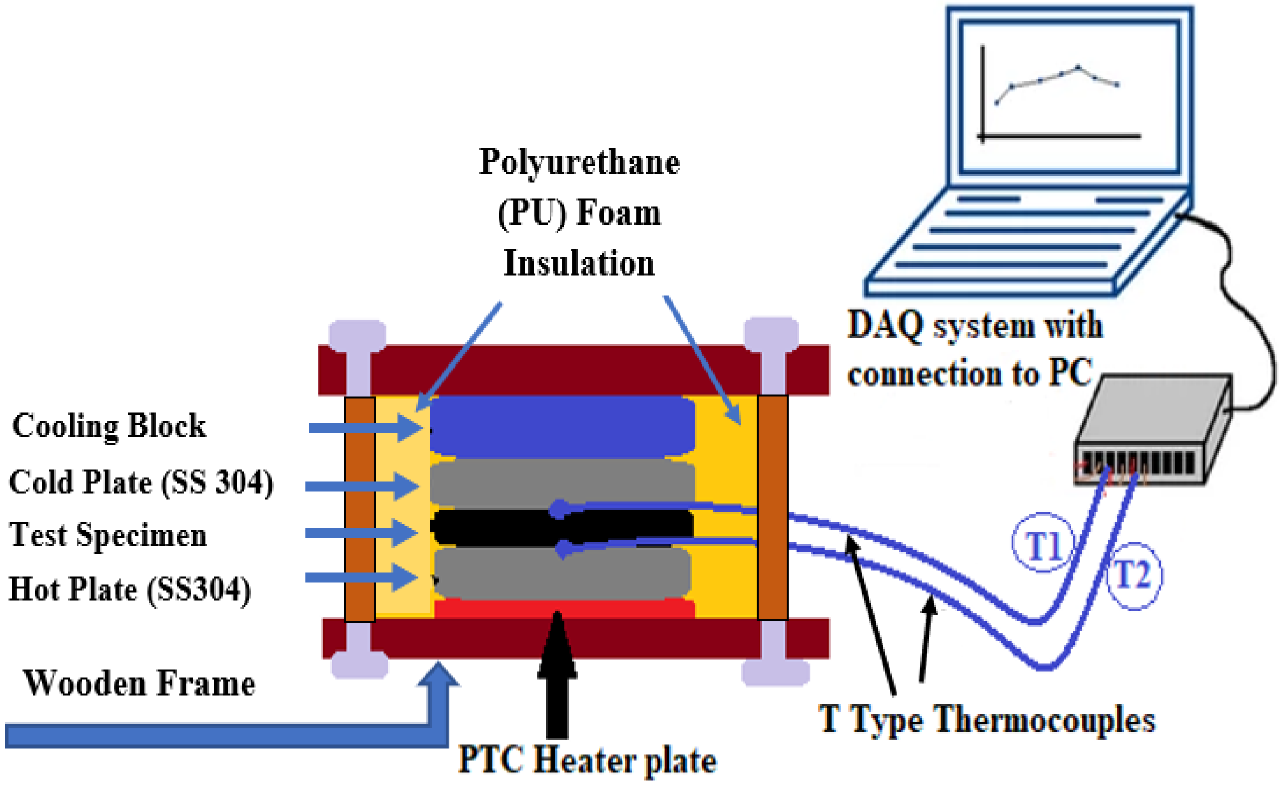


Fig 4.9: Model of Experimental setup

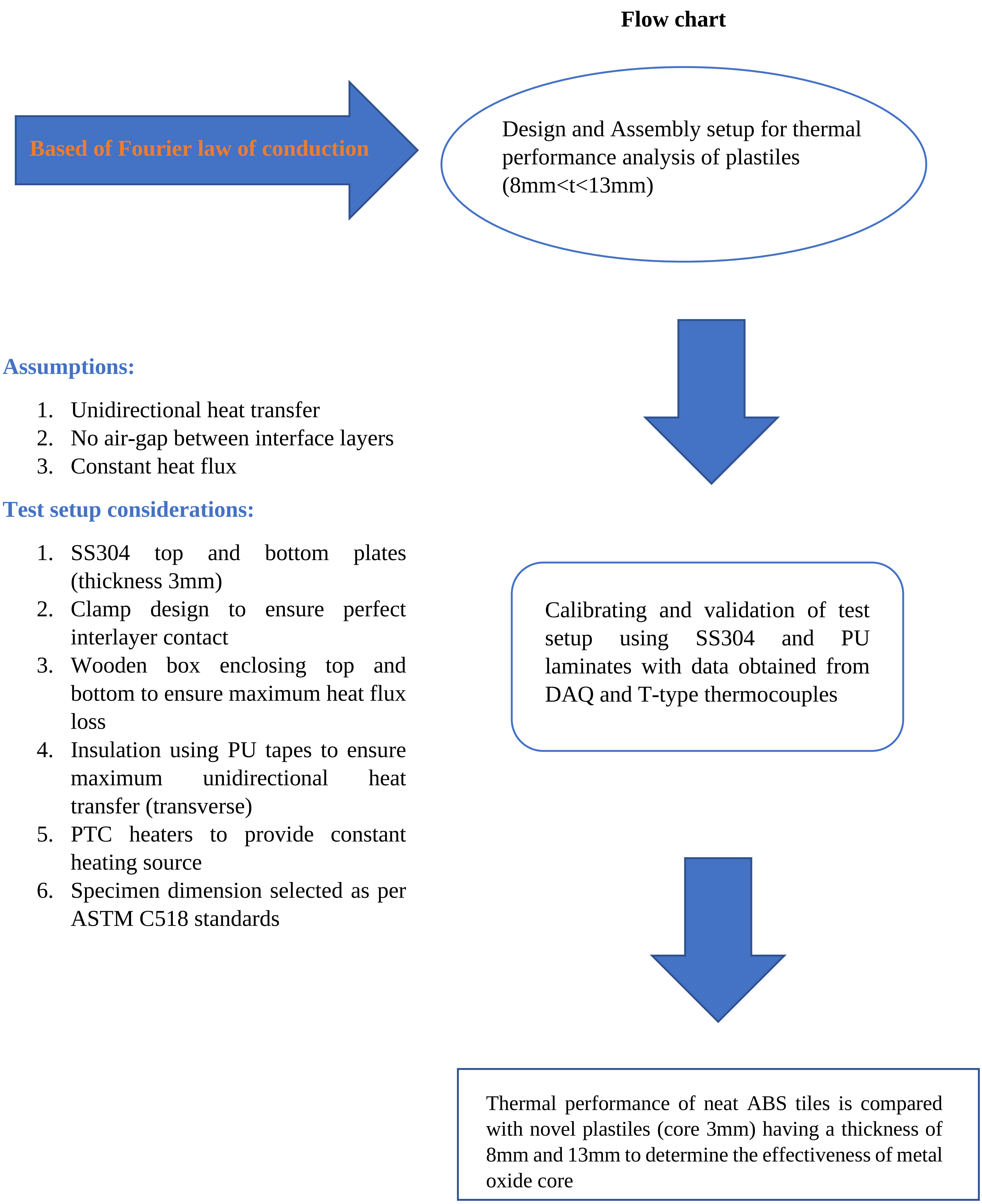


Fig 4.10: Process chart of guarded hot plate experiment

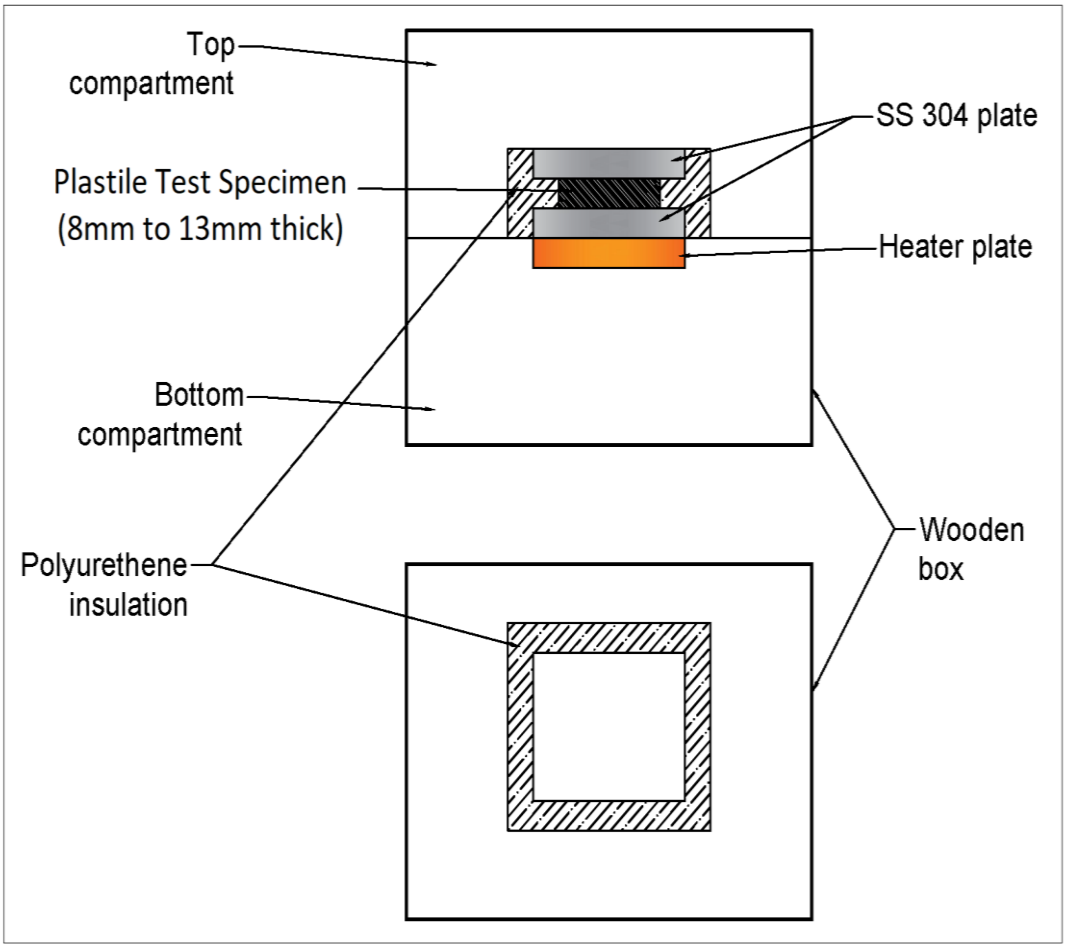


Fig 4.11: Model of the sample inside wooden box

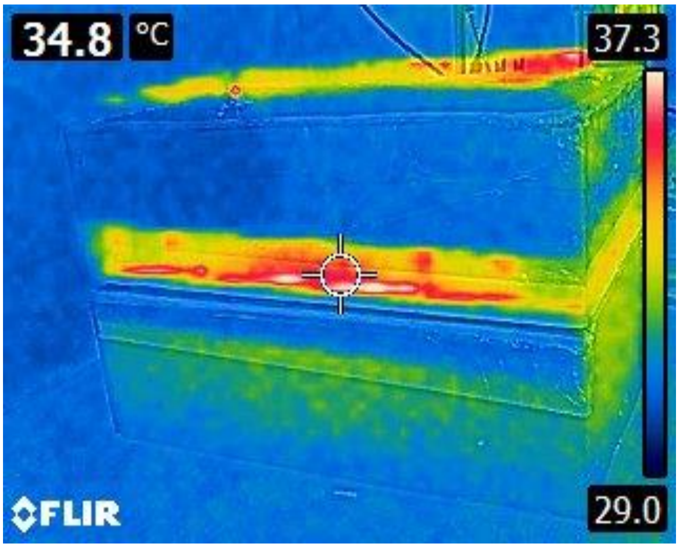


Fig 4.12: Thermal image of experiment using thermal imaging camera

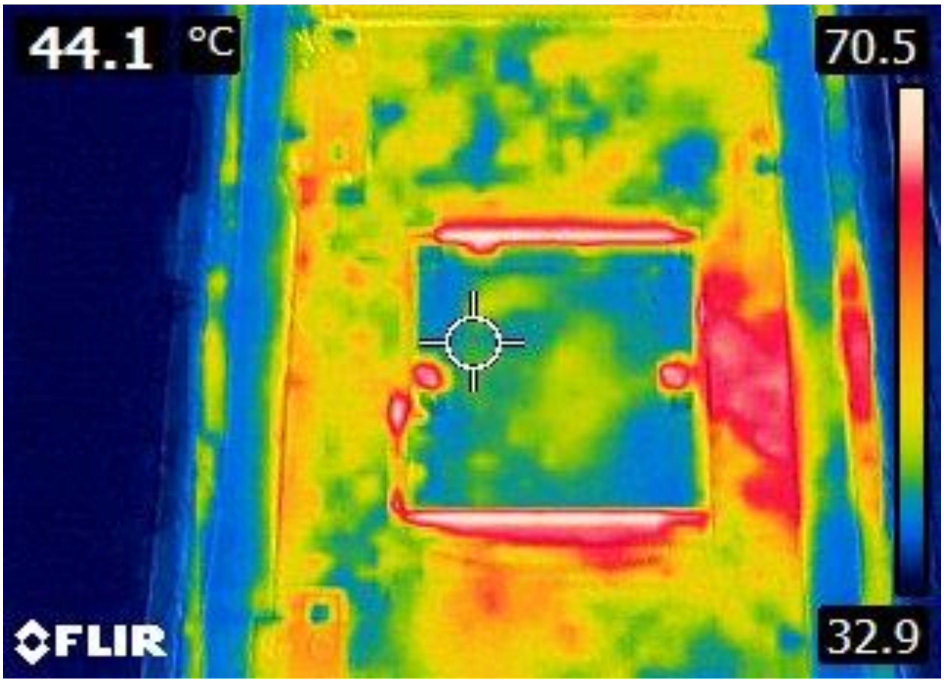


Fig 4.13: Thermal image of the sample inside wooden box

Fig 4.14: Experimental setup for thermal performance analysis

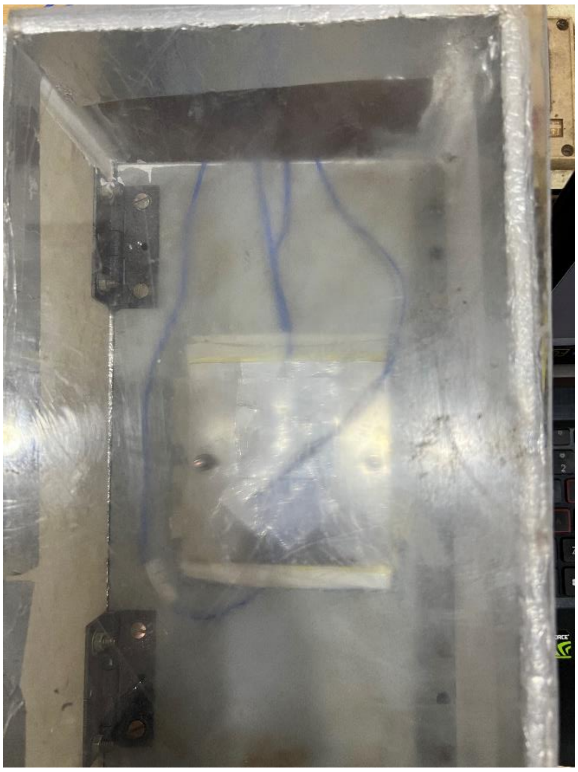


Fig 4.15: Sample placed in the experimental setup

CHAPTER 5

RESULTS AND DISCUSSION

5.1 THERMAL PERFORMANCE EVALUATION OF NOVEL PLASTILE

The results of the guarded hot plate experiment were collected in an excel format using the Data Acquisition System (DAQ) and the heating and cooling curve for the bottom and top surface of the tile was modelled using Origin software. The varying parameter of tile was the core material and the tile thickness. The study involved 5 samples namely ABS neat tile of thickness 8mm and 13mm, ABS tile with Fe2O3 core of 3mm and thickness of 8mm and 13mm, and ABS tile with SiO2 core of 3mm and thickness of 13mm respectively.

Table 5.1: Different case studies conducted

Cases	Sample	core				Tile thickness (mm)
		Material	Thickness (mm)	Thermal conductivity (W/mK)	Bulk density (g/cc)	
1	Neat ABS tile	ABS	3mm	0.24	1.05	8mm
2	ABS tile with SiO_2 core	SiO_2		0.03	0.106	
3	ABS tile with Fe_2O_3 core	Fe_2O_3		0.16	0.301	
4	Neat ABS tile	ABS		0.24	1.05	13mm
5	ABS tile with SiO_2 core	SiO_2		0.03	0.106	
6	ABS tile with Fe_2O_3 core	Fe_2O_3		0.16	0.301	

The study was conducted in two different case studies to to identify the effect of core material on the thermal performance of the plastile and also to determine the effect of the overall thickness on the thermal performance of the plastile.

5.1.1. Case 1: Effect of thickness of tile and core material on thermal performance

The thermal performance study was performed on samples namely ABS tile (8mm), ABS tile (8mm) with Fe_2O_3 core (3mm) and ABS tile (13mm) with SiO_2 core (3mm). The core thickness of all the tiles remained the same but the core material was changed. The overall thickness of the tile was also different. The data obtained from the thermocouples on each interface layer with Data Acquisition Unit (DAQ) was used to plot the heating and cycle on the bottom and top faces of the tile using Origin software.

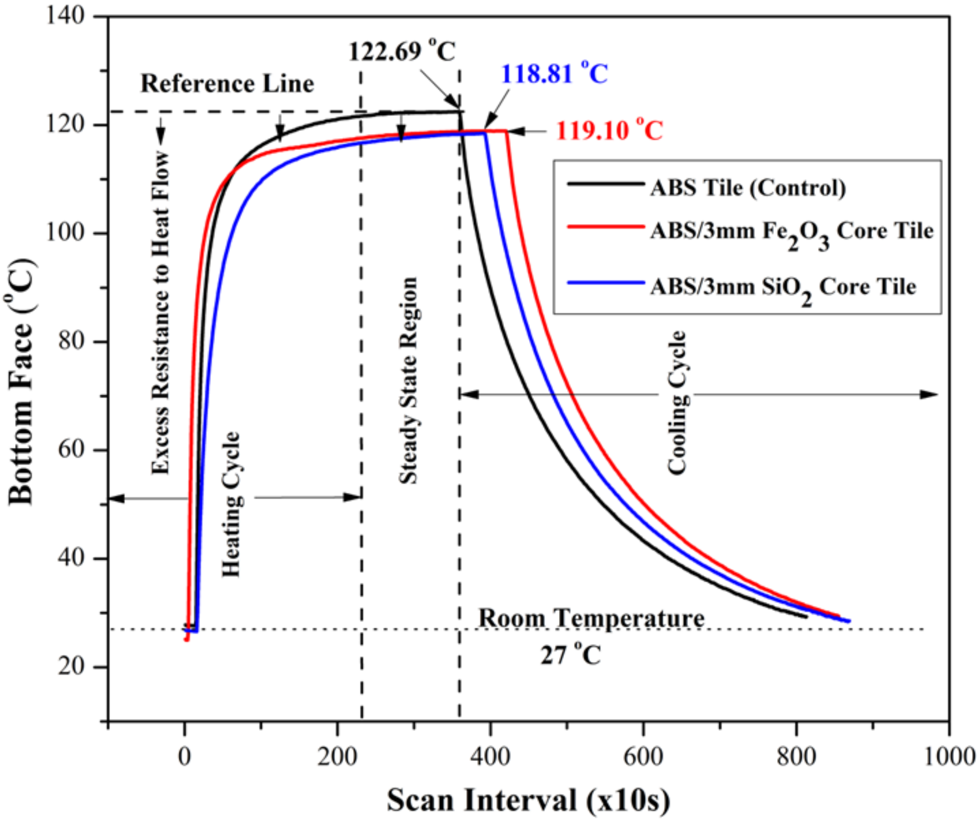


Fig 5.1: Heating and cooling cycle of bottom face of fabricated tiles

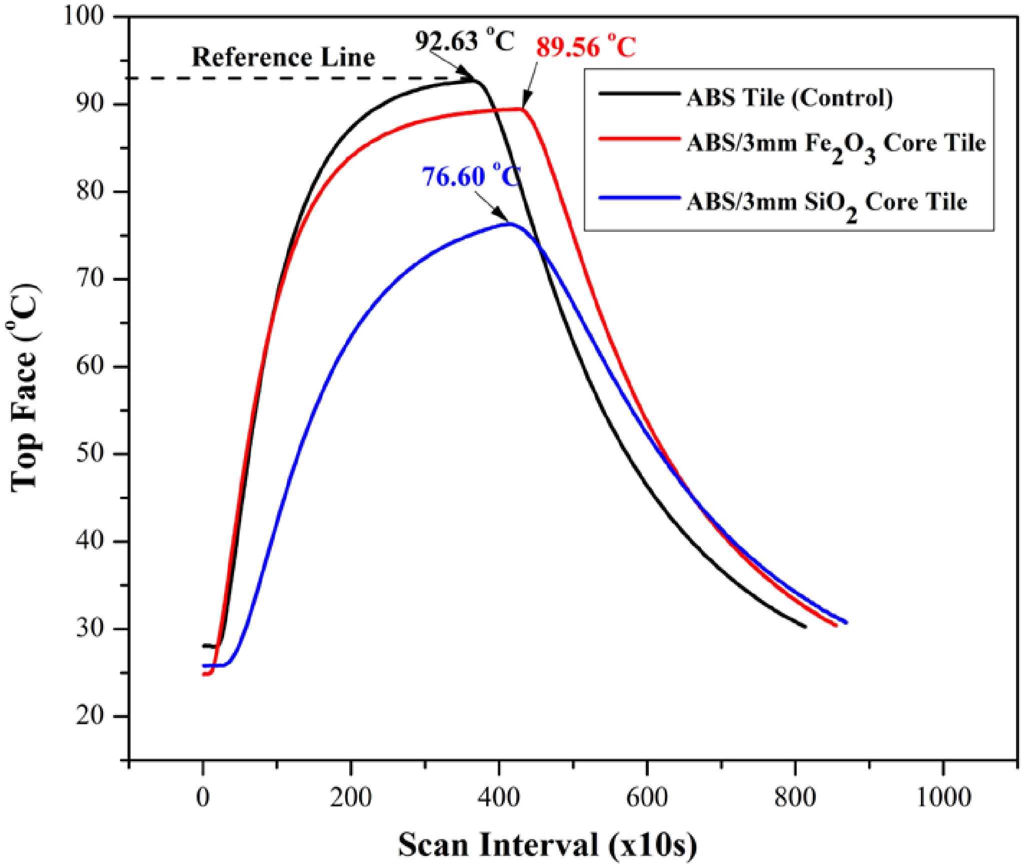


Fig 5.2: Heating and cooling cycle of top face of fabricated tiles

Table 5.2: Table: Evaluation of temperature drop in case 1

Sample	**Bottom surface temperature (°C)**	**Top surface temperature (°C)**	**Overall temperature reduction in %**
ABS neat 13mm	122.69	92.63	24.5 %
ABS tile (13mm) with Fe_2O_3 (3mm)	119.10	89.56	25%
ABS tile (13mm) with SiO_2 (3mm)	118.81	76.60	35.5%

The black curve shown in the heating and cycle represents the ABS neat tile with 8mm thickness, similarly, the red and blue curve shows the ABS tile (8mm) with Fe_2O_3 core (3mm) and ABS tile (8mm) with SiO_2 core (3mm) respectively. The ABS tile with SiO_2 core showed a much greater thermal drop compared to the other two due to its low thermal conductivity and increased thickness. As the thickness of the tile increases the thermal resistance increases. On the bottom face, the heating takes at a much rather slow pace in the tile with SiO_2 when compared to the other two due to the due to the higher specific heat capacity of SiO_2 the heat from the bottom surface gets stored faster in the core region and also due to the low thermal conductivity it does not allow much heat to transfer from the core to the other side of the tile. A temperature drop of about 17.3% was observed in the top face of the tile with SiO_2 core when compared to ABS neat tile with 8mm. This temperature drop was observed due to the increased thickness of the core and also the low bulk thermal conductivity.

In the cooling cycle, the ABS tile with Fe_2O_3 core showed better cooling performance compared to the other two. This is due to the specific heat values and thermal conductivity of the core region. The specific heat value (520 J/kgK) of the Fe_2O_3 core allows the temperature from the bottom surface to be stored in the core. But the higher thermal conductivity value of the Fe_2O_3 (0.162 W/mK) core compared to the SiO_2 core (0.032 W/mK) allows the temperature stored in the core region to be released back at a much higher rate allowing it to give more cooling performance when compared to the other two.

5.1.2. Case 2: Effect of core material on the thermal performance of fabricated tiles

To identify the effect of core material alone on the thermal performance of the fabricated tiles all other parameters were set to fix and only changed the core material of the tile. The core thickness of all tiles was set to 3mm and the thickness of the overall tile was set to 13mm. the study was conducted on three fabricated tiles namely ABS neat tile (13mm) thickness, ABS tile (13mm) with Fe_2O_3 core (3mm) and ABS tile (13mm) with SiO_2 core (3mm) respectively. The thermal performance was conducted in the same method and the temperature data of the interface layers from the thermocouple was obtained using Data Acquisition System (DAQ) and the heating and cooling cycle of the bottom and the top faces of the samples were plotted using Origin software.

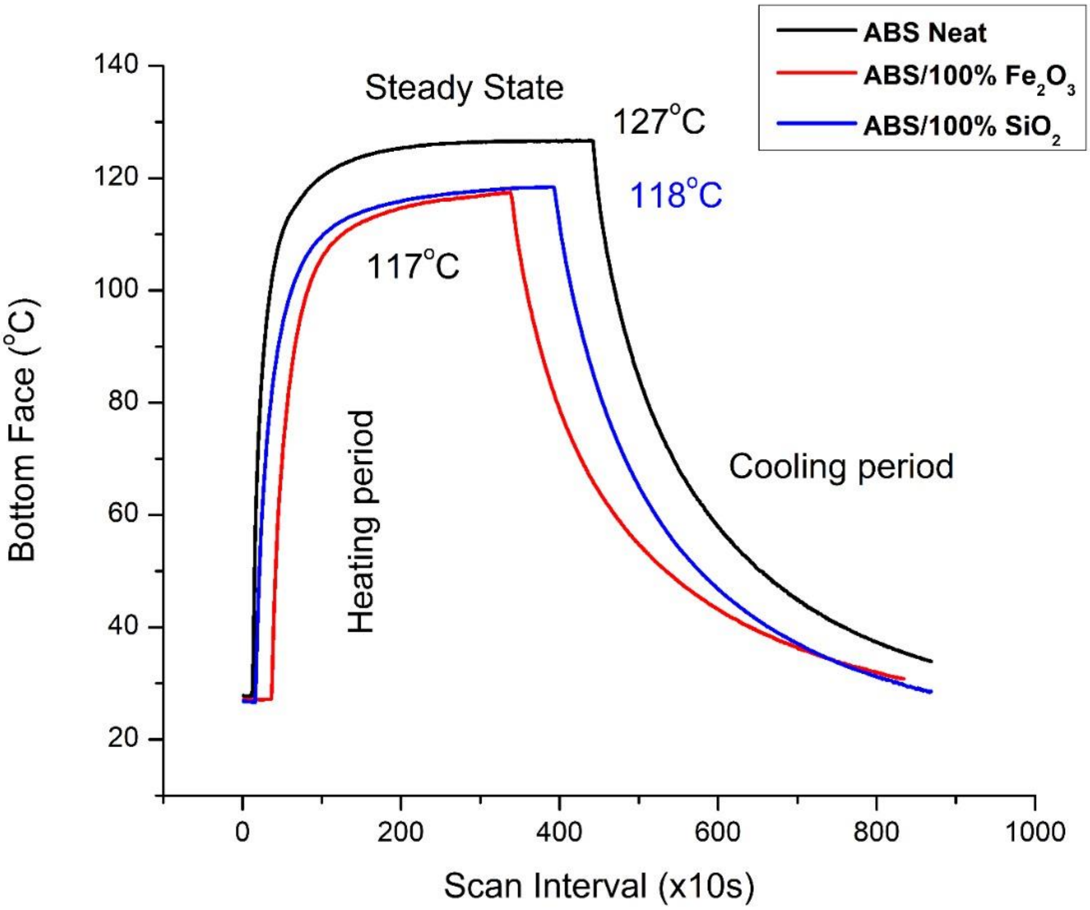


Fig 5.3: Heating and cooling cycle of bottom face of fabricated tiles

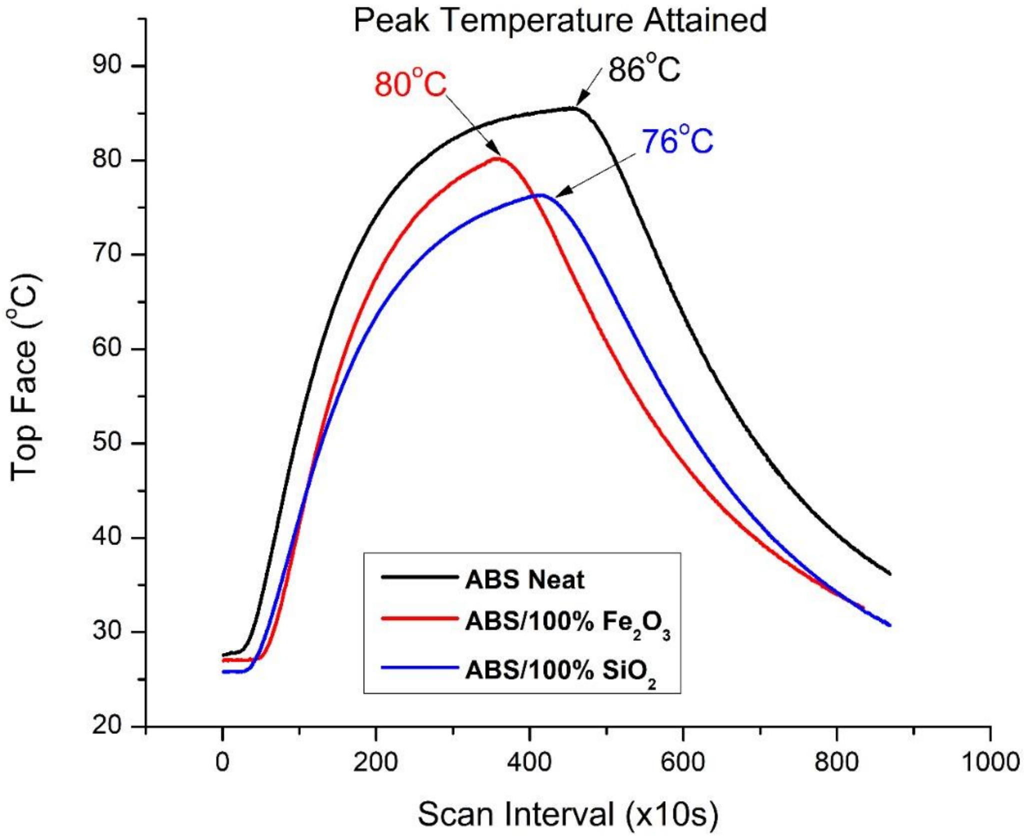


Fig 5.4: Heating and cooling cycle of top face of fabricated tiles

Table 5.3: Evaluation of temperature drop in case 2

Sample	Bottom surface temperature (°C)	Top surface temperature (°C)	Overall temperature reduction in %
ABS neat 13mm	127	86	30 %
ABS tile (13mm) with Fe_2O_3 (3mm)	117	80	32 %
ABS tile (13mm) with SiO_2 (3mm)	118	76	35.5%

The black curve shows the heating and cooling cycle of ABS neat tile (13mm) thickness. Similarly, the red and blue curve shows the heating and cooling cycle of ABS tile (13mm) with Fe_2O_3 core (3mm) and ABS tile (13mm) with SiO_2 core (3mm) respectively. Since all other parameters are fixed and the core material is only being varied this shows the effect of the core material on the thermal performance of the fabricated tiles. It is evident that the bottom surface of the ABS neat tile heats up more and a steady state is achieved faster compared to the other two. The bottom face of the ABS tile with SiO_2 core remained almost 8% cooler compared to the ABS neat tile because of the higher specific heat capacity of the SiO_2 metal oxide (720 J/kgK) it absorbs heat from the bottom face of the tile faster and stores it in the core region. While the bottom face of the ABS tile with Fe_2O_3 core only remained almost 7% cooler compared to the ABS neat tile because of the slightly lower value of specific heat value (590 J/kgK) compared to the SiO_2 metal oxide.

Also, it was evident that the top face of the ABS tile with SiO_2 core showed almost a temperature drop of 11.5% compared to the ABS neat tile. While ABS tile with Fe_2O_3 core showed only a 7% drop. This was due to the huge difference in the bulk thermal conductivity values of SiO_2 (0.035 W/mK) and Fe_2O_3 (0.162 W/mK). The lower thermal conductivity of the SiO_2 metal oxide did not allow much heat transfer from the core to the top face.

Further moving on to the cooling cycle it is evident that the ABS tile with Fe_2O_3 showed much better cooling performance compared to the other two. This is due to the higher thermal conductivity value of Fe_2O_3 metal oxide compared to the SiO_2 metal oxide. It tends to release heat at a much faster pace to the low-temperature region. Therefore, it is noticeable that comparing the plastiles the ABS tile with SiO_2 provides much better performance during the heating cycle but the ABS tile Fe_2O_3 core showed even though not very large but a noticeable better performance in the cooling cycle. This opens up a wide research opportunity for the hybrid mixing of the metal oxides as the core region.

CHAPTER 6

COST ANALYSIS AND GANTT CHART

6.1 COST ANALYSIS

Table 6.1: Cost analysis

Type of expenditure	Specification/Items	Estimate amount (Rs)	Actual amount (Rs)
ABS and Polycarbonate	10kg	0	0
Metal Oxide powders	10kg	0	0
Transportation	N/A	2000	1800
Testing	Guarded hot plate	0	0
Miscellaneous	N/A	2000	1500
Total		4000	3300

The table shows the estimated budget for the experimental investigation and the overall expenses of the study. The overall expense of the work does not exceed the estimated budget even though some miscellaneous expense occurs and was budget friendly.

6.2 GANTT CHART

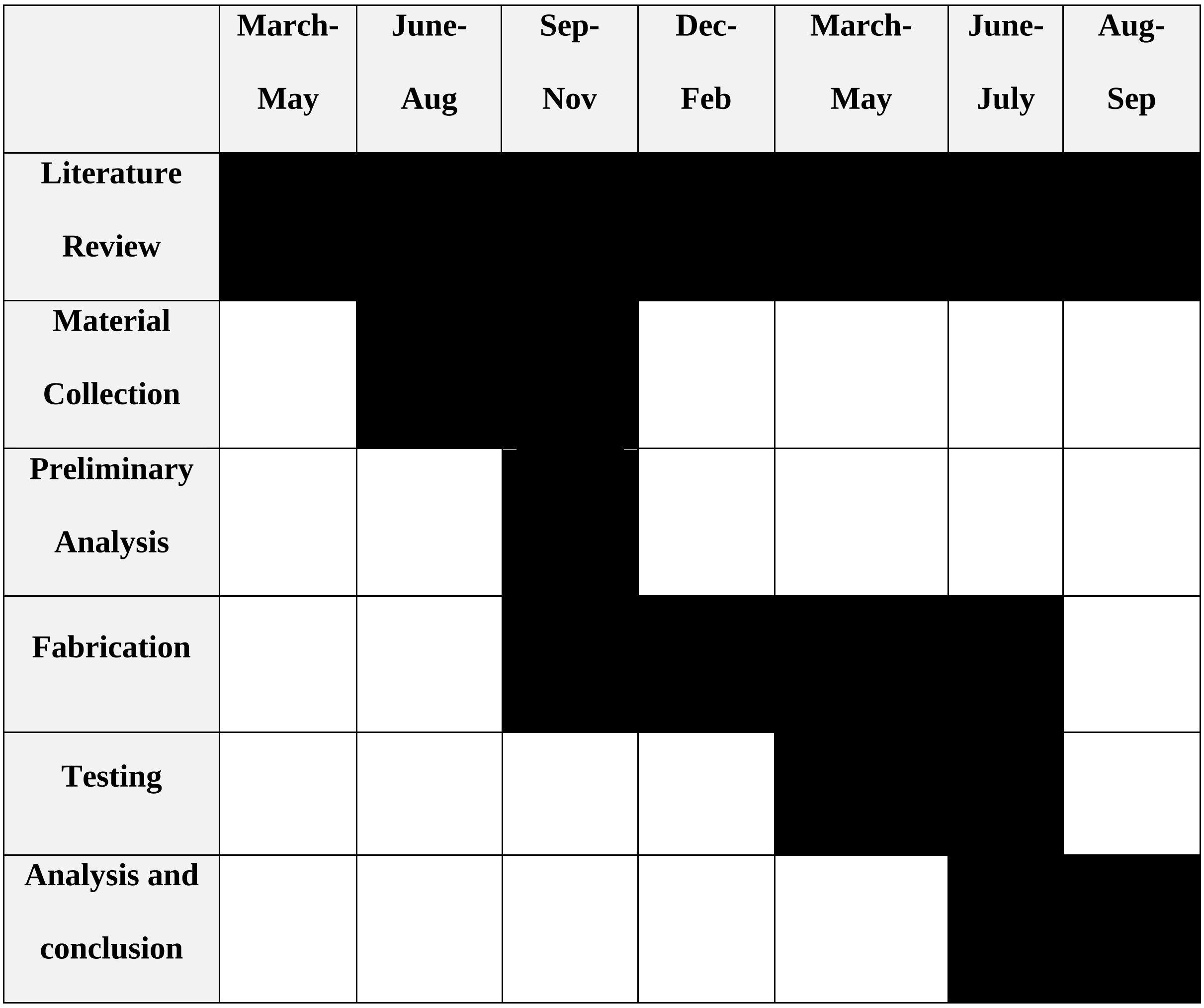


Fig 6.1: Gantt chart

Fig6.1 shows the Gantt chart form, which represents the total timeline indicating the time of beginning and ending of each stage in the experimental investigation study. It takes around 16 months to complete the entire investigation.

CHAPTER 7

CONCLUSION

The disposal and accumulation of plastic and metal oxide waste is a major issue to be considered. It affects drastically the health of every living being. Recent techniques do not provide a better eco-sustainable solution for this. Higher energy utilisation due to high thermal load on buildings is another major concern to look at. The proposed technique provides an eco-sustainable solution and thereby providing a solution to the two major aforementioned issues. Currently, used products have very low life and also exploit natural resources.

The following conclusions were drawn from the work:

1. The proposed product can be used as a better alternative to existing roofing tile materials
2. While inferring the results the proposed design showed a promising value in thermal reduction
3. Materials collected were waste which was available as free cost thereby substantial reduction in the cost of manufacturing. This makes this a cost-effective material as well.
4. Also provides value addition to the industries as well

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1. **Aravind J, K E Reby Roy, Kasthoori M S** and **Kasthoori Nath A J** (2022) Enhancement of fracture toughness and reduced brittle characteristics of modified CFRP composites by incorporating synergism effect between PC/ABS blend with DGEBA resin systems, *Polymer-Plastics Technology and Materials*, DOI: 10.1080/25740881.2022.2084414
2. **Aravind J et al.** (2022) Numerical Analysis to optimise the Effective Thermal resistance of novel waste plastic/SiO2 composite roofing tiles for Residential buildings, *SSRN*