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JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF CHEMICAL ENGINEERING

Development and Performance Evaluation of HDPE Waste Plastic-Diatomite and Sawdust Based Composite Material for Thermal Insulation in Buildings

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By

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ABSTRACT

*Applying thermal insulation material in the wall is a major means of improving building energy conservation. However, traditional building insulation materials have defects in varying degrees, including, water absorption, low strength and not environment-friendly. To solve this problem, a novel thermal insulation bio-composite composed of spent brewery diatomite earth, sawdust and HDPE waste plastic-based composite materials were manufactured by the melt-mixing method followed by compression molding. The effect of HDPE, DE and, SW weight proportion and mold compression load (CL) on composite properties were investigated to evaluate their physical (water absorption, density, morphological properties), thermal (thermal conductivity, thermal diffusivity, specific heat capacity and thermal stability) and mechanical (compressive and flexural strength) tests. A D-optimality design was employed to determine the optimum preparation condition of the thermal insulation bio-composites, to obtain the lowest thermal conductivity and water absorption value and the highest compressive strength. It was found that composites were best fit by a linear * quadratic regression model with high coefficient of determination (R^2) value (0.9995, 0.9988, and 0.9998)* for *WA, CS, and TC respectively. The selected optimum condition was 72.13 wt.% HDPE, 25wt.% DE, 2.87 wt.% SW, and 10 MPa mold compression load (CL), leading to a desirability of 75.6 %. Under the optimum condition, the thermal conductivity, water absorption, and compressive strength of the bio-composites were 0.023 W/(m.k), 0.603 %, and 87.579 MPa, respectively. Those selected optimum parameter formulation was also gave the maximum flexural strength ~94.2 MPa. The thermal conductivity, thermal diffusivity and bulk density of the samples decreased as filler (DE/SW) contents were increased and mold compression load (CL) decreased. In addition, the thermal stability of the samples increase with DE weight proportion and mold compression load (CL). The compressive and flexural strength of the TIDSPCs were higher than those the commonly used insulating materials and comparable to those of construction materials (52.47 - 87.579 MPa) and (50.8 - 94.2 MPa), respectively. The characteristic of the TIDSPCs indicate that they are stable composites with promising insulation and construction capacity. The developed materials may be used in the handle of kitchen utensils and other materials that required thermal insulation.*

Keywords: *Building energy conservation; Wastes; Thermal conductivity; Water absorption; Spent brewery diatomite earth; Mechanical strength*

Table of Contents

List of tables

List of figures

Acronyms

ANOVA	Analysis of variance
ANSI	American National Standard Institute
ASTM	American Society for Testing and Materials
ATDM	Avizheh Technology Development of Middle East
C.V%	Coefficient of Variation
DS	Diatomite earth-Sawdust
EN	European standard
FRs	Flame retardants
HDPE	High density polyethylene
L	Linear
LDPE	Low density poly ethylene
PP	Polypropylene
Q	Quadratic
RSM	Response Surface Methodology
SC	Special Cubic
SEM	Scanning Electron Microscope
TGA	Thermogravimetric analysis
TIDSPCs	Thermal insulation diatomite sawdust plastic composites
WPC	Wood plastic composite
WPTICs	Wood-plastic thermal insulation composites
WA	Water Absorptions
CS	Compressive Strength
TC	Thermal Conductivity

1 INTRODUCTION

1.1 Background of the study

The main challenge of the 21st century is to maintain sustainability in all levels of energy resources and environmental context (plamer, 2012). There is a tremendously increasing concern in the energy and environmental sectors (wazna et al., 2018). In the energy sector, the concern is mainly due to the imbalance between the consumption and limited resources of energy (Ruttinger and Feil, 2010). In the environmental sector, the concern is due to the rapid increase of world population with their consumption rate, and gradual increase in the tendency to discard materials to landfills as waste before the end of lifetime of the products (Bergstrom and Randall, 2016). Building and automobile sectors are considered as main consuming sectors of global energy. The residential and commercial sectors accounted for about 40% of the total energy consumption in Africa in 2018 (Gigli et al., 2018). This percentage is likely to be higher in countries with hot climates, including in Ethiopia, hence refrigerators and ventilators con sumpti on rates increased in such type climate condition areas. By the 2018 electricity consumption in Ethiopia, had reached a value of 143 MWh/capita (Zealand et al., 2018). Moreover, the electricit y power demand has been reported to increase by 30 % (WHO, 2018) annually, which placing Ethiopia has among the highest energy consumption per annum. But the other issue in this country is that in certain areas fire wood is used in space heating in high-latitude rural areas, where the temperature can drop to freezing-point at night and during the rainy season, in addition to this charcoal is commonly used for heating indoor in urban and semi urban households (Zealand et al., 2018). Logging and consumption of wood is the second main driver of forest degradation in Ethiopia, emissions from burning wood are expected to be increased from about 25 Mt CO_2 equivalent in 2010 to more than 40 Mt in 2030 as a result of unsustainable use of fuel (Zealand et al., 2018)Therefore, reducing energy consumption in buildings is becoming a major concern, and is challenging policies in the present world (Iwaro and Mwasha, 2010) .This is because of the low efficiency thermal insulation properties associated with many existing building materials (Jelle et al., 2011; Calteral et al., 2018). Using efficient insulation materials can help to save energy by minimizing the losses and gains of heat during heating and cooling of building (Al-Homoud, 2005). Reducing energy consumption is vital to reduce CO_2 emissions and the gradual depletion of fossil fuels and mitigate the high energy costs. In this scenario, the

reduction of energy losses due to the use of inefficient or insufficient thermal insulation systems is crucial, and novel technologies having a low environmental footprint are expected to play a decisive role.

Currently, many different classes of insulation materials are commercialized and can be categorized as inorganic, petroleum-derived and natural organic materials. Inorganic thermal insulators, such as mineral wools, together with petroleum-derived polymeric foams (such as expanded polystyrene and polyurethane) are the major one, sharing together more than 90 % of the world market (Pavel & Blagoeva, 2018). Unfortunately, these conventional insulation materials are either obtained from oil-derived chemical substances, or high temperatures are needed to process the raw materials (Asdrubali, D'Alessandro, & Schiavoni, 2015). Moreover, some concerns about health risks related with the handling and storage of mineral wools are under discussion (Harrison et al., 201). For these reasons there is a real interest in developing replacement materials (Caniato, Sbaizero, Schmid, & Bettarello, 2015).

Natural materials are now getting attention due to their minimum environmental impact and their low cost: cotton, cork and wood fiber-based bio-composite insulation materials are already commercialized (Muthuraj, Lacoste, Lacroix, & Bergeret, 2019: Erkmen, Yavuz, Kavci, & Sari, 2020) and better biodegradability brace the research interest in plants-derived materials: A great advantage of the insulation based on bio-composite insulating material is not only a low value of thermal conductivity but also the natural character of input fibers. Another benefit is that it is a renewable material which does not place any significant strain on the environment. For example, when compared with mineral wool, the insulation based on natural fibers have comparable and sometimes even better thermal characteristics (e.g., heat capacity or the afore-mentioned thermal conductivity) (Hroudova et al., 2012). However, the practical application of these natural fiber-based bio-composite thermal insulation materials are limited due to unsatisfactory mechanical pe rformance and high water absorptivity of the manufactured sample (Zou et al., 2020; Cibinel et al., 2021). Because most bio-composite insulating materials are made with easily aging organic binder and lack thermal retardant additives and water proof agent adhesive materials, they have poor bonding strength, are prone to mildew owing to moisture absorption, and have poor thermal resistance of the final products. Another reflection is the need to protect natural materials against biological attacks (e.g. against fungi and parasites) (Jiří et al., 2013).

Therefore, in this study for encouraging the adaption of these type of problem, using spent brewery diatomite earth and sawdust blend with HDPE waste plastic binding, will be a critical technical way to improve, the mechanical (flexural, compressive) and physical (fire resistance, m oisture protection, and thermal insulation) property of building composite materials. The beer industry has to find a sustainable solution to prevent the environment impact of spent diatomite gahh waste deposition, which carries sanitary and economical elimination of this by-product is ei ther its deposition on a landfill or its spread over agricultural fields (Eduardo et al., 2011). The p rocedures referred are not satisfactory with regard to sustainable development and environmental care. In the other way, Since diatomite has special characteristics of low density, high thermal in sulation capacity, little volumetric weight, strong surface absorptivity, stable chemical performan ce and strong fire retardancy property, other uses include sound insulation and vehicles for herbicides and fungicides (Taylor et al., 2011). Thus properties of the material will be important for improving the mechanical, thermal stability, thermal insulation and diffusivity properties of this bio-based thermal insulation composite materials.

Therefore this study employing to manufacture high-value-added thermal insulation goods, using spent brewery diatomite earth, sawdust and high density polyethylene (HDPE) waste materials, which are easily locally available and abundant resources. This development of commercial building insulating materials have multiple benefits, including energy consumption reduction, environmental protection, and maximum exploitation of our resources in energy supply systems. These benefits are also the sustainable development goals of Ethiopia (to be achieved by 2030) (Worku, 2014).

1.2 Statement of the problem

Heating and cooling includes a wide range of end-use applications and technologies. In the buildings sector, it includes cooking, water heating, ambient heating, ambient cooling, and refrigeration. In industry, besides ambient heating and cooling, it also includes process heating-from low temperature applications(e.g. in the food industry) to high temperature applications (e.g. in the cement, iron and steel industries). Heating and cooling for residential, commercial and industrial purposes accounts for a large share of total final energy demand. This is because of the use of inefficient or insufficient thermal insulation systems associated with many existing building materials (Cibinel et al., 2021).

Numerous different classes of insulation materials have been developing (Durakovic et al., 2020). Among them currently, natural fiber based bio-composite insulating materials (Muthuraj, Lacoste, Lacroix, & Bergeret, 2019; Erkmen, Yavuz, Kavci, & Sari, 2020), have been become the most persuasive technology. Bio-composite insulation materials has many advantages, mainly biological origin, preferably requiring very little processing, morever they are renewable, recyclable and environmentally friendly unlike some traditional thermal insulators such as mineral wool which have poor environmental performance (Cibinel et al., 2021). However, these studies mainly focused on clear preparation methodology, sustainability, cost and thermal and sound insulation capacity of these natural fiber-based bio-composite insulation materials (Limam et al.,2016), but have significant physical (water resistance, thermal resistance) and mechanical (flexural, compressive strength) issues with the aforementioned insulation materials, which are also crucial for field application. The challenge in the literature in natural fiber-based bio-composite materials with easily aging organic binders is that they have poor bonding strength and are always made without a thermal retardant additive or a water proof agent adhesive (Amar a et al., 2017). It should be noted that bio-based composite materials without thermal retardant ingredient and water proof agent adhesive have poor thermal stability and are also water vapor permeable, allowing moisture to final products by adsorption from the air. Excessive humidity can lead to biological corrosion, which is the breakdown of materials by microorganisms (Binici et al., 2016). Thermal insulation characteristics diminish and mechanical strength is reduced as a result of the humidity and moisture. Thus characteristics limit the supply of these materials on the market (Shao et al., 2020; Zou et al., 2020; Cibinel et al., 2021). This, study is conducted to

improve the tail back based on physical (moisture resistance, thermal stability, and thermal insulation and diffusivity capacity) and mechanical (flexural and compressive strength) features inherent in natural fiber-based bio-composite thermal insulation materials.

The purpose of this research is on the preparation, thermo-physical and mechanical performance analysis of spent brewery diatomite earth, sawdust and HDPE waste plastic-based composite materials that can be used for thermal insulation and in construction applications.

1.3 Objectives

1.3.1 General objective

The main focus of this research is on Preparation, Thermo-Physical and Mechanical Performance Investigation of spent brewery diatomite earth, Sawdust and HDPE Waste Plastic-Based Composite Material for Thermal Insulation in Buildings

1.3.2 Specific objectives

- ✓ Production of thermal insulation composite materials from spent brewery diatomite earth and sawdust blended with waste high density poly ethylene
- ✓ Quality optimization TIDSPCs properties of (thermal conductivity, compressive strength and water absorption) by using D-optimality (design expert software).
- ✓ Characterization of (Flexural strength, Bulk density, Specific heat capacity,Thermal diffusivity,Thermal stability, and Surface morphological) properties of TIDSPCs.

1.4 The Scope of the study

The current study is covered production and characterization of thermal insulation composite materials based on spent diatomite earth and sawdust used as reinforcements and HDPE waste plastics as a matric. Physicomechanical and thermal properties of the produced thermal insulatio n composites materials are characterized by SEM using (JEOL JSM-IT300SEM), TGA by Q50 thermogravimetric analyzer, water absorption testing as per ASTM D570-98, Mechanical testing Machine (DTRX), and thermal conductivity testing on the concept of steady state condition acco rding to ISO 8302. The physical, thermal and mechanical properties of the composites, were investigated by considering the parameters of raw materials (high density polyethylene, diatomit e earth, and sawdust) weight% proportion contents and mold compression load. Factor affecting the thermal conductivity, water absorption and compressive strength of the composites were studied and optimization through a D-optimality of optimal (Combined) design methodology.

1.5 Significant of the study

The advancement, production, and characterization of thermal insulation composite materials based on spent brewery diatomite earth and sawdust reinforcement, as well as high density polyethylene waste plastic matrices, is the focus of this research. The physical (thermal resistance, water resistance, and thermal insulation capacity) and mechanical (flexural and compressive strength) qualities of natural fiber based bio-composite thermal insulation materials, which are critical for field use, are improved using this approach. For providing an alternative and the cost-effective insulation composite materilas, for the present ecological and commercial insulation materials, which are specially, poor water vapor permeable and allowing moisture to final products by adsorption from the air. In addition, most of these materials are hazardous to the environment, and need a large amount of energy during the manufacturing process.

This help to overcome the current research gap in the physical and mechanical properties of biomas-based thermal insulation composite materials, as well as providing communities with the most cost-effective, clear-cut production, sustainable, and high efficiency insulation materials.

The study also aimed for converting forest biomass waste (sawdust), waste plastics and spent brewery diatomite earth waste into valuable materials that can combat for environmental purpose . This will add the comfort to the building, create a healthier home environmental impact.

Adding home insulation to an existing home regulate the temperature, making the living environ ment more enjoyable, especially in place of extreme weather. With insulation the home become more energy efficient. The benefit of home insulation is not related to the occupants inside the house only but it is also extended to keep the environment out of pollutants. The insulation building materials contribute to use less energy for air-conditioning. This reduce the carbon footprint. Moreover, the following indicates the outcome of the study:

- Save way production and characterization of thermal insulation composite materials based on spent brewery diatomite earth, sawdust and waste plastics.
- The study makes it easier to manufacture thermal insulation composite materials with less energy and resource consumption, which is the main problem with traditional thermal insulation composite materials in meeting the energy and resource conservation requirements of modern buildings, as their manufacture requires a lot of energy and resources.
- Producing insulation composite materials from the waste is very crucial technical way for improving energy efficiency and effectively consuming our resources.
- It enhance the economic value of the waste raw materials in particular waste plastics, spent brewery diatomite earth and sawdust.
- It could create a job for the community

2 LITERATURE REVIEW

2.1 Historical Development of bio based Building Insulator

Understanding the requirements of various characterizations for building insulation necessitates a study of historical development perspectives. Wooden buildings were employed for living purposes in ancient culture. However, the general public was unaware that the insulation was provided by a wood-based construction. Concrete and cement materials were widely used in the early 1900s to improve structural stability and mechanical qualities. At the same time, energy consumption and environmental pollution were raised by the building sector. Just then, the researchers and scientist have shown their interest to save the earth. There are few reports based on thermal insulation in early 1970. The bio based building insulation was a new area intended to wards research. In the mid-nineties, some researchers had worked on building insulation. Previously, the building's goal was solely to provide a place to live and stay, and no one was concerned with environmental performance or energy conservation. Following that, due to sever al rules in the field of energy conservation and pollution, a storm descended on this specific inquiry site. As a result, both renewable and conventional insulating materials were given consid eration. Due to the economic downturn, research interest in biomaterial-based building insulation has increased since 2010. Environmental protection and energy conservation legislatio n has been enacted all over the world. On the other hand, there has been a rapid increase in demand for indoor air quality, which leads to the use of an air conditioner and increased energy usage (Park et al., 2017). As a result, the demand for energy saving has shifted to the quest for an environmentally acceptable solution to install a heat flow barrier. As a result, bio-based insulation materials were brought to light as a way to keep heat flowing from space to surrounds or vice versa. People nowadays prefer to be tranquil at work and at home, thus noise reduction or soundproof insulation systems are also used as acoustic insulation systems. The goal of building insulation is to save energy and protect the environment, which leads to the research of characterization of bio-insulation materials for building use.

2.2 The importance of thermal insulator materials in Building Sector

With the increasing growth of population and urbanization, energy scarcity and environmental challenges are two key worldwide issues that must be addressed immediately (Ouakarrouch et al., 2020). In today's world, energy consumption is steadily increasing in all fields. At the same

time, the cost of energy has risen due to depletion of energy sources and the negative impact on the environment (ozone layer depletion, global warming, climate change, etc.). Building energy usage accounts for almost one-third of global yearly energy consumption (Zhao et al., 2020). In engineering systems, energy conservation in buildings is crucial. Developing extreme wall thermal insulation technology and materials is critical for achieving energy efficiency in buildings. Conduction, convection, and radiation are the three primary techniques for transferring heat energy out of your home. External walls that aren't insulated account for 35% of your home's heat loss. With a 25 percent heat loss, air leakage is a regular occurrence in un-insulated roofs. In Ethiopia, especially in rural and semi-urban areas, biomass energy (such as wood and charcoal) was widely utilized for cooking and heating, especially during the summer season. This is due to the fact that kitchens and living quarters are uninsulated structures that are easily exposed to outside temperatures. This results in energy waste and deforestation, and contributes significantly to environmental damage. In the other way most of the area, like Afar, Semera, Adama, Gamebela and Deredwa have very hot air conditions, the house which made using tradit ional building materials in this area, are easily affected by the external hot temperature and not comfortable for the occupants, the food in the house easily contaminated by bacterial due to hot air condition in the house, as well as the water distributing through pipe are affected, due to the factor of external temperature on the pipe, such problem forcing the people to use refrigerator as well as ventilator. Beside of the cost, using refrigerator or ventilator in each house is impossible in our country context, because of cost issue, and as well as electric power is not available for each houses. Therefor thermal insulator materials very important to improve such kind of problems. Building insulation is a low-cost, high-efficiency energy-saving strategy that can be used in the residential, industrial, and commercial sectors. Thermal insulation minimizes energy consumption and so protects the environment, while also extending the life of a structure by protecting it from the elements. Figure 2 shows a building with seamless insulation. The graphic clearly shows that throughout the summer, insulation keeps the area warm and prevents heat from dissipating to the surroundings. In the winter, however, because outside heat cannot enter through the insulation, air conditioning is used to provide thermal comfort without wasting energy. Here are some of the most important characteristics of building insulation.

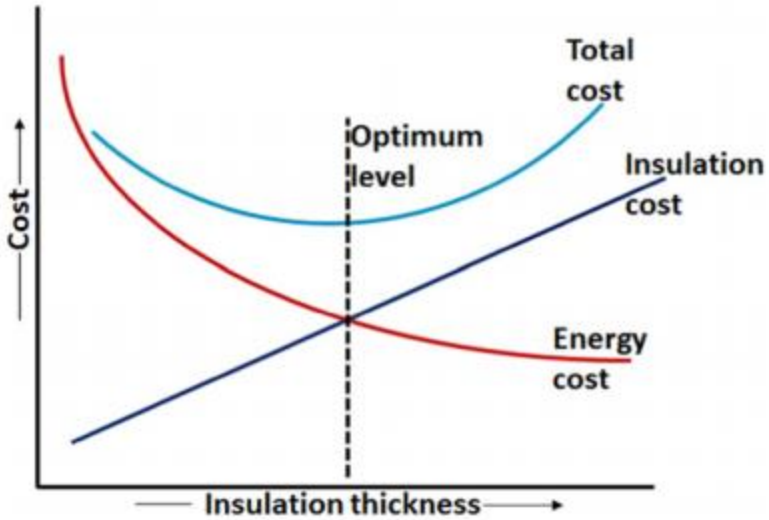


Figure 1. Optimum thickness of insulation. Reproduced from (Kaynakli et al., 2012). A review of the economical and optimum thermal insulation thickness for building applications. Renewab le and Sustainable Energy Reviews.

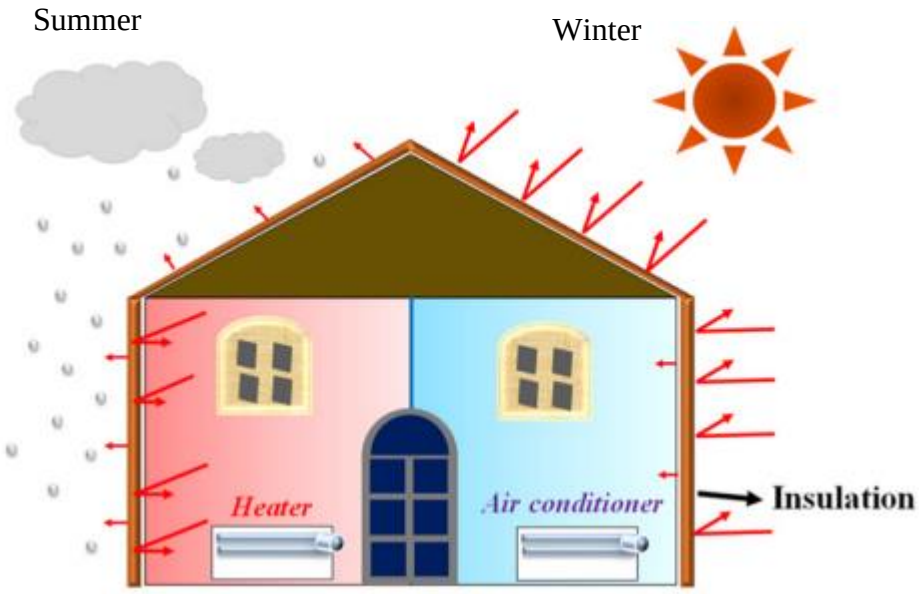


Figure 2. thermally comfort building from (Kaynakli et al., 2012)

2.2.1 Thermal Comfort

The temperature of the space air and the temperature of the surrounding surface have a significant impact on thermal comfort. Due to large temperature variations, a draft is formed between the interior and the surroundings in an uninsulated space. As a result, creating a thermall y comfortable zone necessitates a tremendous amount of energy. By insulating the walls, roof, and floor of the building, a modest temperature difference in the air is maintained between the system and its surroundings. This helps to lessen reliance on energy usage while also extending the time when temperatures are pleasant (Gupta & Maji, 2019).

2.2.2 Environment Protection

Building insulation saves money by lowering fuel usage, which is also linked to lower CO_2 emissions. Less energy usage means less pollution in the environment. In comparison to non-insulated building panels, insulated building panels lowered environmental pollutants by 45 percent, according to a report (Gupta & Maji, 2019).

2.2.3 Acoustic Insulation

Insulation materials should be able to absorb entering sound waves and contrast sound transmission, in addition to providing heat insulation. Acoustic insulation refers to a material's ability to dissipate sound energy caused by resonance, thermal, or friction loss (Schiavoni et al., 2016). In general, sound-absorbing materials are good thermal insulators, but this is not always the case. Because open cell porous structure is required for sound absorption, and the open porous cell collects warm air molecules, it is also an ideal condition for thermal insulation. Closed cell porous structure is good for thermal insulation but not for acoustic insulation since acoustic insulation requires air movement within the insulation material (Gupta & Maji, 2019).

2.3 Thermal Insulation

"The time rate of steady state heat flow through a body of per unit area (1 m^2) by inducing per unit (1 K) thermal gradient in the perpendicular direction of isotropic substance," according to thermal conductivity. Density, porosity, extractive content, moisture content, grain orientation, structural imperfections, and temperature all affect the thermal conductivity of wood and cork. Thermal conductivity is proportional to density, moisture content, and temperature in general. Thermal insulation refers to a material's or a system's ability to resist heat passage from the

system to the environment or vice versa. The heat flow by conduction, convection, and radiation is slowed by thermal insulation. The study concentrated on the thermal conductivity of building insulation materials (Gupta & Maji, 2019).

2.4 Working Principle of Building Thermal Insulator

Insulation is used to maintain a sanitary environment and a suitable temperature in a space by reducing heat exchange between the building and its surroundings. The essential idea behind all insulating materials is that heat constantly travels from a warmer to a colder location. As a result, building insulation limits heat transmission from inside to exterior regions in the summer and vice versa in the winter. The goal of thermal insulation is to reduce thermal conductivity as much as possible. The capacity to use a thin building envelope is demonstrated by the low thermally conductive material. High thermal resistance (R value) and low thermal transmittance are requir ed of the insulation material (U-value). The thermal conductivity of a system depends on several factors (Eq. (1)), which is follows:

$$\lambda_{\text{total}} = \lambda_{\text{conduction}} + \lambda_{\text{convection}} + \lambda_{\text{radiation}}. \quad (1)$$

Each contribution should be as low as possible in order to obtain a low total thermal conductivity (total) of insulation material. A material's thermal conduction is determined by two factors: solid conduction and gaseous conduction. Solid conduction is devoted to the phonon phenomenon in the situation of insulation. Thermal energy is transferred through solids via lattice vibration and chemical interactions between atoms. Gaseous conduction occurs when gas molecules collide with each other and thermal energy is transferred from one molecule to another (Jelle, 2011). Thermodynamic mass transfer of air or moisture between the pores produces thermal convection. Reducing the pore size of insulating material is one of the most effective techniques to limit heat convection. As a result, the air molecules are trapped within the pores and interact with the walls of the pores. The effect is known as the Knudsen effect. Thermal radiation is based on the infrared region's emittance of electromagnetic energy. The temperature differential determines all of these thermal contributions. Building insulation materials must meet a number of criteria. Other requirements, including as low density, high porosity, fire resistance, and low thermal conductivity, limit the materials and solutions available for building insulation

2.5 Common thermal insulation materials

Developing external wall thermal insulation technology and materials is a critical component of achieving energy efficiency in buildings (Orlik et al., 208; Fang et al., 2014). Thermal insulation materials are those with a thermal conductivity of less than 0.25 W/(m.k) at room temperature (RT=25°C) (Pasztory et al., 2018; Zhou et al., 2010). Insulation materials can be divided into three groups. These classifications are based on the chemical makeup of the underlying components used to make insulating materials

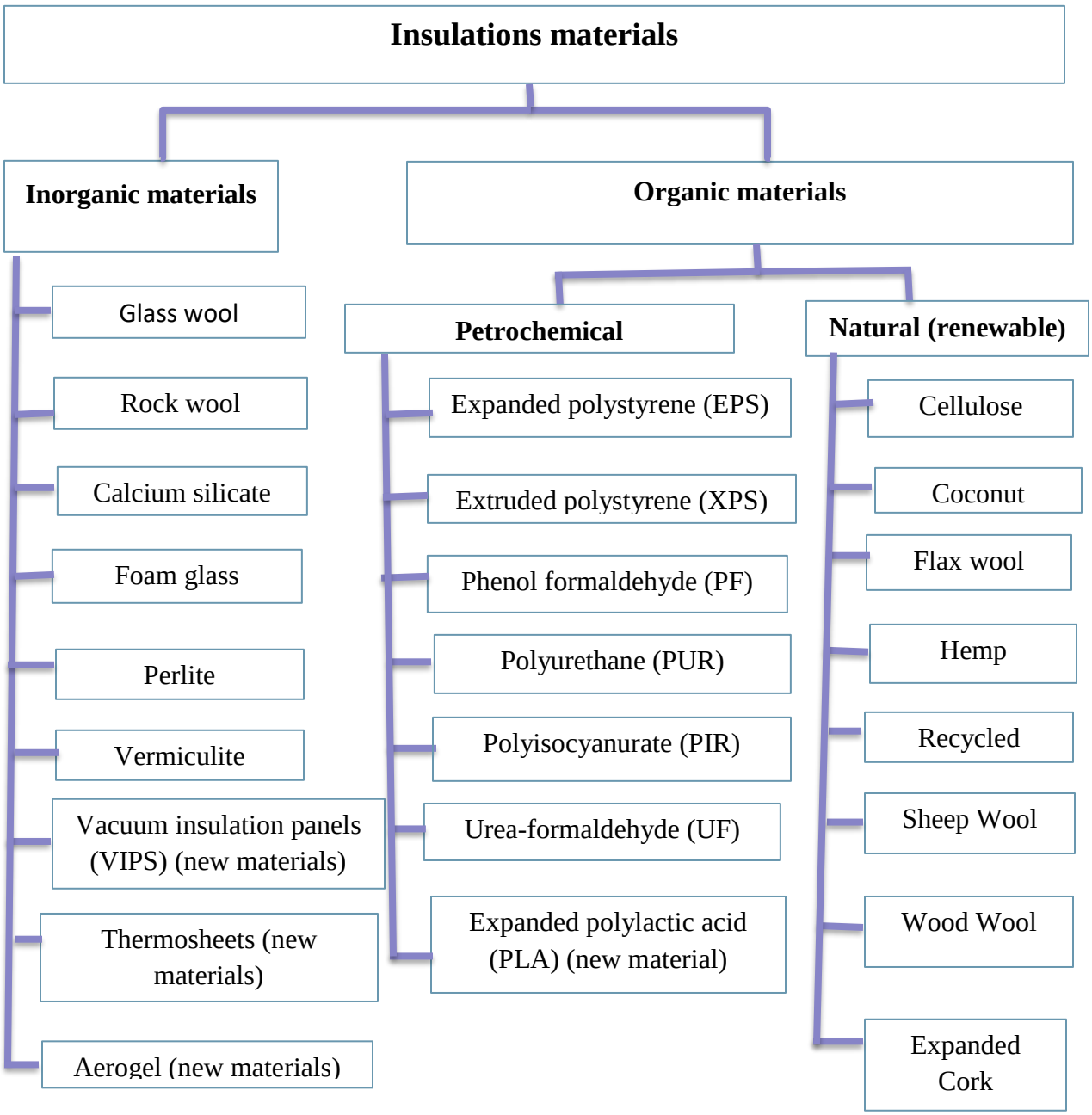


Figure 3. Classification of insulation materials (Durakovic et al., 2020)

In comparison to inorganic and petrochemical insulation materials, natural/renewable insulating materials offer much lower global warming potentials (Durakovic et al., 2020). A comparison analysis of global warming potential between natural/renewable, petrochemical, and inorganic insulating materials was described as follows by (Durakovic et al., 2020) and the results are displayed in Figure 4.

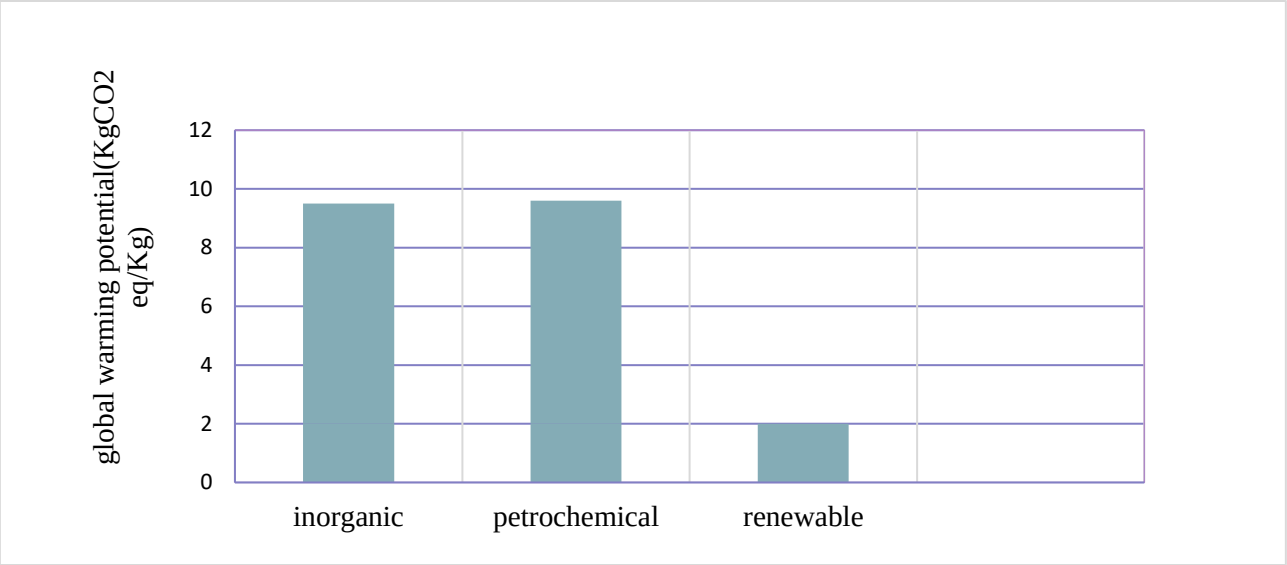


Figure 4. Mean values of global warming potential according to (Durakovic et al., 2020)

In general, there are three categories of thermal insulation materials: inorganic, organic, and thermal insulation mortals (Jiang et al., 2020). Thermal insulation Materials, such as vitrified microspheres and sticky polystyrene particles, provide excellent thermal insulation and flame resistance (Gong et. al., 2016; Dong et al., 2014). Thermal insulating mortal, on the other hand, is not frequently utilized due to its poor water resistance and high cost, as these flaws severely limit the practical application of these materials (Gong et al., 2016). Jiang et al. recently evaluated the physical, mechanical, and thermal performance of mortar when popular leaf fibers, Wheat straw fibers, and rice straw fibers were added to the vitrified bead + expanded perlite mixture. The research shows that increasing the amount of plant fibers results in enhanced thermal insulation performance, but that due to its low water resistance feature, it also results in a decline in thermal and mechanical performance, making it impossible to acquire long-term service from this product. Jia et al. Have successfully prepared Aerogel/expanded perlite (AEP)

thermal insulation materials by putting aerogels into the porous structure of EP, which exhibit better hydrophobicity and lower heat conductivity than EP. Nonetheless, large-scale industrial AEP manufacturing is now impossible due to the complicated AEP preparation method and weak water resistance feature (Xu et al., 2020). Nonrenewable materials are used to make inorganic insulating materials, yet there are enough of them available. Mineral wool, perlite, aerated concrete blocks, composite silicate, and foamy glass are examples of inorganic insulating materials (Lin et al., 2021). Also, the existing thermal insulators are primarily inorganic materials, which, despite their high thermal performance, but have a considerable negative environmental impact and poor water resistance are very significant. From a sustainability standpoint, cement uses more water, and recent studies show that cement produces a substantial amount of CO_2, which has an unfavorable impact on climate change. Concrete and concrete-related products exhale about 5% of annual anthropogenic CO_2 (Kour et al., 2016). Many researchers have attracted the interest of developing new sustainable materials by mixing organic insulation materials with inorganic insulation materials to provide hydrophobicity, improved mechanical strength, fire retardant and thermal comfort without using heating and cooling systems. One of the most important technical ways to improve building energy efficiency is to combine inorganic and organic thermal insulation materials (Fakih et al., 2019). Lin et al. (2021) combined EP with organic plant fiber and inorganic adhesive to create a unique thermal insulation material. Despite the fact that this EP composite has a thermal conductivity of 0.0869 Wm-1K-1, a density of 180 kg/m3, hydrophobicity of 98 percent, and ameets the class A1 fire protection standard GB/T8624-2012 (China), the strength of EP composites still has needs to be improved (Yan et al., 2019). By combining sawdust and inorganic clay, Sghiouri et al. (2020) have created a novel thermal insulating material. Although sawdust-clay insulating materials are good flame resistant, they readily absorb water and their heat insulating properties quickly deteriorate. Cement, gypsum, lime, and other inorganic minerals are currently being employed as adhesives for biomass-based insulating products. Plastics, on the other hand, are rarely used as a binder for biomass-based composites by researchers (Dalhat et al., 2016).

2. 6 Inorganic insulation materials

Nonrenewable materials are used to make inorganic insulation, mineral wool, expanded perlite, expanded vermiculite, rock wool, aerated concrete blocks, composite silicate, and foamy glass

are some of the most often used inorganic insulating materials (Lin et al., 2021). As can be seen from the figure, inorganic materials can be classified accordingly:

Fibrous materials

-glass wool

-rock wool

Cellular materials

-calcium silicate

-cellular glass

Mineral wools, such as glass wool and stone wool, are made from mineral fibers and are commonly referred to as mineral wool. Thus materials are very common for commercial insulation purposes because they have the following properties: non-flammability, high durability, and resistance to moisture and noise, but they are a furnace product of molten glass at a temperature of about 1450 °C, and thus cannot meet the energy saving requirements of modern buildings because their manufacture requires a lot of energy and resources (Schiavoni et al., 2016; Status et al., 2010). And if you come into direct contact with it, it is highly irritating to your skin and lungs, as well as more expansive. Thermal insulation for buildings is always applied as the inner or exterior coatings, which puts it in direct contact with people. As a result, not only during the manufacturing process but also during their lifetime, their environmental performance is receiving a lot of attention. Thermal insulations constructed of rocks (e.g., rock wool, perlite, vermiculite, etc.) have generally poor environmental performance due to the emissions of different pollutants (COx, NOx, SOx, volatile organic compounds, and particulates matter) during their energy-intensive manufacturing process (Liu et al., 2017). Inorganic insulating materials have a significant impact on global warming during their manufacture and life cycle, and so play a significant part in environmental pollution. Or the raw materials must be processed at high temperatures (Asdrubali, Alessandro, & Schiavoni, 2015). Inorganic thermal insulation materials are non-combustible and long-lasting, but they cannot match the energy-saving demands of modern buildings because their production needs a lot of energy and resources (Schiavoni et al., 2016; Status et al., 2010). Wang et al. (2020) can employ pitchstone to make expanded and vitrified small balls (EVSBS) for thermal insulation materials, but the EVSBS production needs a lot of energy and results in a lot of unique tailings.

Some emerging thermal insulation materials have extremely low thermal conductivity such as Nano insulation materials (~4 mw/ (m.k)), vacuum insulation panels (~0.004w/ (m.k)), gas-filled panels (~0.04 w/ (m.k)), and phase change materials are examples of new thermal insulation materials with exceptionally low thermal conductivity (Mehrali et al., 2013; Mofijur et al., 2019). There are some materials that are seen to be the most promising for future applications, namely silica aerogel (~4-14 mw/ (m.k)). However, these materials' needs high production costs and difficult preparation processes limit their use as building insulation materials (Jelle et al., 2011).

Geopolymer (GPs) are alkali activated materials having a three-dimensional oxide network structure, and depending on the SiO_2 to AL_2O_3 molar ratio, they usually have excellent thermal stability, reasonably high strength, great fire resistance, and extended service life (Zhu et al., 2020). Porous GPS offer a lot of potential in the field of thermal insulation. The majority of porous GPs, on the other hand, have a high thermal conductivity (>0.65w/m.k), a high bulk density (>600kg/m3), and a low strength (Samso et al., 2017). Thermal conductivity was found to be outstanding (0.03-0.04 w/(m.k)) by Duan et al. (2017) and Vaou et al. (2010). Which is similar to the performance of organic thermal insulating materials. Duan et al., on the other hand, used inorganic particles (polystyrene) in the preparation process, which represent a risk to the environment and human health when used for thermal insulation in buildings. Vaou et al. also describe a porous pelite Geopolymer that performs well in terms of thermal insulation but has a high density and low strength. Aerogel is a novel nanoporous thermal insulation material with an extremely low thermal conductivity of about 0.014 W/ (m.K) (Huakun et al., 2020). However, because it is significantly more expensive than typical insulating materials, and because it has poor thermal insulation and mechanical qualities when exposed to high temperatures, its use in actual construction projects is limited (Jiangming et al., 2019). From a sustainability standpoint, cement uses more water, and recent studies show that cement produces a substantial amount of CO_2, which has negative effects on climate change. Concrete and concrete-related products exhale about 5% of annual anthropogenic CO_2 (Krishna et al., 2016). In addition, contemporary thermal insulators are mostly inorganic materials, which, despite their high thermal performance, have a considerable negative impact on the environment and low water resistance. Therefore, for improving such difficulty, currently many scholars have been developing an alternative bio- based thermal insulation composite materials on the market.

2.7 Petrochemical insulation materials

Insulation materials made of petrochemicals: Thermal insulation materials generated from petrochemicals, such as polyurethane, polyethylene, and polystyrene, are widely utilized due to their superior thermal insulation properties and inexpensive cost (Aditya et al., 2017). However, they burn easily, and their mechanical strength is insufficient for widespread use in the construction process. As a result, widespread use of these materials increases the chance of a building catching fire and is not environmentally friendly (Yang et al., 2018).

2.8 The effect of water concentration on the thermal conductivity coefficient of inorganic and petrochemical insulating materials

All three stages of moisture (solid, liquid, and gas) can be detrimental to building materials in normal ambient circumstances around buildings. Excessive moisture leads to five issues: decreased habitation quality, decreased temperature resistance, increased mechanical stress or mechanical strength is reduced as a result of the humidity and moisture, salt movement, and material deterioration. Moisture infiltration into the building interior as a result of contact with liquid water, moisture deposition on the building surface as a result of contact with water vapor, moisture intrusion into the building as a result of contact with contact water vapor, and built-in moisture (Pinteric et al., 2017). Moisture can reduce the effective thermal characteristics of building envelopes, insulated walls, and roofs. Furthermore, moisture migration via building envelopes can result in poor interior air quality since high ambient moisture levels promote microbial development, which can be harmful to human health, reduce the composite service life and induce allergies and respiratory complaints (Qin et al., 2006). Water absorption is always associated with an increase in thermal conductivity since the thermal conductivity of water is approximately 20 times larger than that of stationary air (Schritt et al., 2021). Experiments on building insulation materials such as mineral wool, fiberglass, and polystyrene have discovered that higher moisture content is always associated with increased thermal conductivity (Troppovia et al., 2015). With increasing moisture content from 0 to 100%, Lakatos reported a modest rise of up to 0.2 W (m.k) for mineral wool and fiberglass samples (Lakatos et al., 2016). His prior research using extruded polystyrene (XPS) found that moisture content had an impact on thermal conductivity (Lakatos et al., 2014). Thermal conductivity of mineral wool rises quickly from 0.041 W/ (m.k) to about 0.9 W/ (m.k) as moisture content rises, according to Jerman et al.(2012).

Another study found that when the moisture level of mineral wool was increased from 0% to 10% by volume, the thermal conductivity increased from 0.037 to 0.055 W/(m.k) (Jelle et al., 2011). In contrast, a rise in moisture content has only a minor effect on expanded polystyrene (EPS). It had a dry value of 0.037 W/ (m.k) and a saturated value of 0.051 W/ (m.k). Another study looked at thermal performance by cooling polystyrene insulating materials and found that when moisture content increased, so did thermal conductivity (Khoukhi, et al., 2018). Thermal conductivity of mineral wool can increase by up to 446 percent when moisture content is increased by 15% (Abdou et al., 2013), whereas thermal conductivity of rock wool can increase by up to 312.8 percent when moisture content is increased by 13.6 percent (Gusyachkin et al., 2019), and thermal conductivity of fiberglass increases by nearly 300 percent when moisture content is increased by 3 percent. The original moisture content can explain this, the percentage change in thermal conductivity is always higher in samples with a higher initial moisture content. Most of these building insulation materials are porous, with thermal conductivity coefficients ranging from 0.02 to 0.08 W/(m.K) (Wang et al., 2018). Porous materials can absorb substantial amounts of moisture under high humidity circumstances due to their high porosity, resulting in an increase in the thermal conductivity coefficient (Ochs et al., 2009). According to Liu et al. (Liu et al., 2016), thermal conductivity of foam concrete increased rapidly in the low volumetric fraction of moisture content and gradually increased as moisture content increased. The effect of water content on the thermo-acoustic performance of building insulation materials was later measured by the authors (Alessandro et al., 2018). Samples of high porosity insulation materials were heat treated in a series of steps before being measured with the transient plane method to see how water content affects thermal conductivity. For four different types of specimens, including mineral wool, melamine foam, polyurethane, and cork, there was a linear rise. Wet insulation can improve the maximum ratio of heat conductivity between the dry and wet samples by 3.51 with a maximum moisture content of 15.1 percent in the ambient temperature ranging from 24.9 to 38.6 ℃ after 55 days when the building materials are moistened (Zhu et al., 2015). When the moisture content in foam concrete exceeds 10%, the thermal conductivity increases by about 200 percent (Liu et al., 2016). In contrast to the aforementioned findings, another study using spruce-pine-fire wood frame insulating walls found no discernible influence on thermal conductivity since moisture content was less than 19 percent (Liu et al., 2018). Gawin et al. (2004) used a heat flow meter to measure the impact of initial moisture content on the thermal

conductivity of wood-concrete and EPS-concrete materials. The results showed that increasing the water content in the range of 70%–85% relative humidity increased thermal conductivity. Taoukil et al. (2013) confirmed the influence of relative humidity on thermal characteristics using the same lightweight specimens but with various densities. Thermal conductivity increased fast as water content increased, and the relationship was represented as an exponential equation. The next laboratory work, by Nguyen et al. (2017), added to the premise that heat conductivity of lightweight concretes are moisture dependent. The result in this situation revealed a linear relationship.

2.9 Organic insulation materials

Natural materials are gaining popularity as a result of their low cost and low environmental impact: cotton, cork, and wood fiber-based panels are currently available. Furthermore, the added value of a negative CO_2 balance (Asdrubali, Schiavoni, & Horoshenkov, 2012) and better biodegradability support the research interest in plant-derived materials: hemp (Nguyen et al., 2016), kenaf (Ardente, Beccali, Cellura, & Mistretta, 2008; Erkmen, Yavuz, Kavci, & Sari, 2020), rice and wheat husk (Muthuraj, Lacoste, Lacroix, & Bergeret, 2019) are just a few examples of raw materials from which thermal insulation panels can be obtained. Natural fiber materials, agricultural wastes, and forest product wastes have all been employed as source natural organic materials in thermal insulation products in recent years. As a result, the amount of toxic waste gas released into the atmosphere by petrochemical and inorganic insulating materials have been decreased. They're renewable, recyclable, non-toxic, and environmentally friendly, and require very low resource production techniques (Barkhad et al., 2020, Aditya et al., 2017). The energy required to make organic insulation materials is lower than that necessary to manufacture standard insulation materials. The most significant disadvantage of organic thermal insulation materials is their low fire resistance and proclivity for absorbing water; as a result, these materials are more susceptible to moisture. On the previous study, the moisture dependence of thermal conductivity values of various insulating materials made from hemp, jute, and flax was investigated (Korjenic et al., 2011). With increasing moisture content, the results revealed a significant rise in thermal conductivity. The effect of water content on thermal conductivity of three bio-based concretes derived from hemp, jute, and flax revealed a linear increase in -values as the moisture content increases, with the effect becoming more important

due to the increase in thermal conductivity of air and water at high temperatures (Rahim et al., 2016). The influence of humidity on the thermal conductivity of a binderless board made from date palm fibers was investigated by Boukhattem et al. (2017) in an experiment. The link was described as a polynomial function, and it demonstrated a significant rise with volumetric water content ranges from 0 to 40%. As a result of its low thermal conductivity of 0.033 W/ (m.K) in a dry state, date palm fiberboard can be employed as an insulation material in structures. The impact of moisture content on thermal performance of wood-based fiberboards as a result of variations in relative humidity was investigated. With increasing moisture content, thermal cond uctivity increases approximately linearly (Troppov et al., 2015). Thermal conductivity increases linearly with increasing moisture content, according to studies conducted on twenty-four soft fiberboards manufactured from wood fibers (Sonderegger et al., 2012). Abdou and Budaiwi (201 3) studied the thermal properties of eleven different fibrous materials at various moisture content percentages. Higher moisture content is always associated with higher thermal conductivity for different densities, according to the findings. Except for mineral wool, which was expressed by a non-linear function, the results fit a linear relationship for practically all of the specimens. Natural insulators have a lower thermal conductivity value and better thermal technical propertie s than conventional materials. However, because of the open structure of natural fiber, they have a high wettability and absorbability, which can negatively impair mechanical and thermal qualities. To efficiently counteract hydrophilicity and prevent rotting, natural fiber can be activat ed with silane surfactant (Erkmen et al., 2020). To cope with the water absorption and hygroscop icity of hemp fibers in the investigation, a variety of hydrophobic treatment products were employed. When compared to untreated fibers, hydrophobic-treated fibers showed poorer short-term absorbability (Zach et al., 2013). The following graph depicts the effect of plant fiber moisture content and mass ratio on the thermal insulation capabilities of plant fiber-cement composite materials.

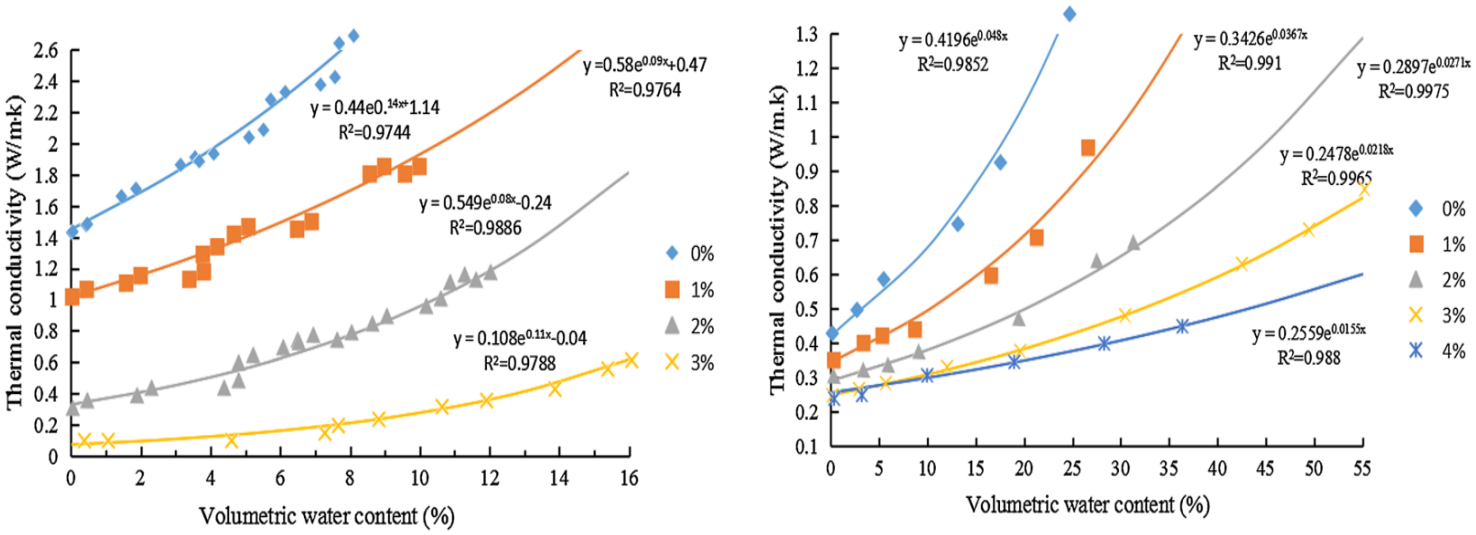


Figure 5. Composite material thermal conductivity curve with the change of moisture content (diamonds, squares, triangles, cross express the mass ratio of fiber content to cement (Zhao et al., 2020; Belkharchouche et al 2016).

Therefore, it is urgent to improve the hydrophilic properties these insulation materials. Wang et al. (2021) successfully prepared agricultural and forestry waste with post-consumer polymers that are more hydrophobic and thermally insulating. Nonetheless, it is obvious that large-scale industrial production of these composite materials cannot be realized at this time due to the complex preparation method, weak mechanical strength property, and strong flame ability (Brito et al., 2019).

2.10 Combined(inorganic-organic) insulation materials

According to research, the materials usually utilized in building construction have low thermal insulation qualities (Laaroussi et al., 2017, Ouakarrouch et al., 2019, Mohamed et al., 2019). Similarly, modern thermal insulators are mostly inorganic materials, which, despite their superior thermal performance, have a considerable negative influence on the environment. Many researchers are interested in developing new sustainable materials that can give thermal comfort without the need of heating or cooling systems. As a result, organic-inorganic thermal insulation materials have received more attention in recent years. Many scientists are interested in developing new sustainable materials by combining organic and inorganic insulating materials to give hydrophobicity, increased mechanical strength, fire resistance, and thermal comfort without

the use of heating and cooling systems. Combining inorganic and organic thermal insulation materials is one of the most important scientific solutions for improving the drawbacks of traditional insulation materials (Muhammad et al., 2019). Lin et al. (2021) combined EP with organic plant fiber and inorganic adhesive to create a unique thermal insulation material. Despite the fact that this EP composite has a thermal conductivity of 0.0869 Wm-1K-1, a density of 180 kg/m^3, and a hydrophobicity of 98 percent, and meets the GB/T8624-2012 (China) class A1 fire protection standard, the mechanical strength of EP composites need has to be improved (Ding et al., 2014). By combining sawdust and inorganic clay, Charai et al. (2020) produced a unique thermal insulation material. Although sawdust-clay insulating materials are flame resistant, they readily absorb water and their heat insulating properties quickly deteriorate. Cement, gypsum, lime, and other inorganic minerals are currently being employed as adhesives for biomass-based insulating products. Plastics, on the other hand, are rarely used as a binder in biomass-based composites by researchers. Dalhat and Wahhab. (2016) used plastic waste to replace 100% of the cement and asphalt while leaving the aggregate intact. They compared the outcomes of two different plastic concretes, one containing (polypropylene) and the other including (HDPE) at 22 percent of total weight, to two traditional concretes containing portland cement and asphalt. The samples were baked for "2 hours" at 90°C. Plastic concrete outperformed asphalt concrete in terms of compressive strength, water resistance, and thermal sensitivity. Furthermore, as compared to Portland cement concrete, PP concrete has superior stiffness and flexural strength. As a result, replacing plastic for concrete as a binding agent offers up new research possibilities for incorporating more plastic waste into concrete without reducing compressive strength. It goes without saying that substituting cement for aggregates is more environmentally beneficial, as cement production produces a lot of CO_2 and requires a lot of energy. However, because concrete is non-renewable, it has become quite expansive in recent years. For these reasons there is a real interest in developing replacement materials.

Table 1 summery of a few currently developed bio-based thermal insulation composite materials and their drawback.

No.	Reference	Study parameter	Focus	Gap	Finding
1	High-added-value biomass-derived composites by chemically coupling post-consumer plastics with agricultural and forestry wastes(Wang et al., 2021)	Analysis the effects of raw material ratio such as pine nutshell /polypropylene(pp) and corn straw /pp composite as well as dosage of compatibilizer on mechanical and physical properties of the prepared samples.	-Achieving high – level waste resource re-utilization as well as preparing high quality biomass – waste/plastic composites.	- Complex and costly compatibilizer preparation method. The effect of filler-matrix raw material ratio on tensile and flexural strength was high lighting, needs to further investigate.	-The highest tensile strength of forestry pine nutshell/PP composite is 25.44 MPa and the flexural strength is 47.84 MPa with the assistance of 5.0 wt% compatibilizer. If agricultural corn straw is used as the raw materials, the highest flexural strength of corn straw/PP composite is 42.94 MPa and the tensile strength is 22.60 MPa under the same experimental conditions
2	Preparation and characterization of expanded perlite/wood-magnesium composites (EPWMC) as building insulation materials(Lin et al., 2021)	By making the other parameters are constant, Evaluate the influence of EP mesh number or size on the performance of EPWMC composites	For improving the water absorption, flexural strength and fire retardant properties of EPWMC composites.	flexural strength and water absorption properties of the composites needs to further improve, flexural strength value blew minimum standard (<16 MPa) value according to ANSI for mechanical strength value of building materials	The results revealed that, for EPWMC composites filled with 60–70 mesh EP, the maximum flexural strength value 9.6 MPa, 24-hr minimum water absorption value 3.5 % and thermal conductivity obtained was 0.0869 $W\,m^{-1}k^{-1}$

3	Effect of thermal insulation components on physical and mechanical properties of plant fiber composite thermal insulation mortar (Jiang et al., 2020)	By varying the type and content of thermal insulation components (TICs) such as: Poplar leaf fiber, Wheat straw fibers ,and Rice straw fibers in vitrified bead + expanded perlite, were studied on physical and mechanical properties of thermal insulation mortal (TIM)	For Improving the mechanical and water absorption properties of plant fibres based insulation mater ials, as well as the resource level of agricultural and forestry waste materials.	Even though, the used resource materials were environmentally frien dly, abundant and cost effective, the reported physical and mechanical properties of the composites not sufficient, needs further improve.	The optimum experimental result of thermal conductivity, water absorption ,flexural and compres sive strength reported value was 0.15 w/(m.k), 8 %, 4MPa and 13 MPa respectively
4.	Thermal insulation using bio degradable poly (lactic acid)/date pit (PLA-DPP) composites (Barkhad et al., 2020)	By altering the weight % content of date pit powder (DPP) in PLA-DPP composites, analysis the effects on the water absorption, thermal conductivity, and mechanical (compressive strength) properties of the composites	-producing environmentally friendly insulator materials -improving the mechanical and water absorption problem relating with bio-based insulation materials	The produced PLA-DPP thermal insula tion composite mater ials no Fire retardant fillers. Even though, the compressive strength of the PLA-DPP composites was higher than those of the commonly used thermal insulation materials, water abso rption and thermal stability properties of the composites needs further improvement.	The experimental result indicate that: thermal conductivity value Between (0.0794 to 0.0682 w/m.k , 24-hr cold water immersion between (1 to 8 %), and compressive strength value between (84.3 to 64.4 MPa)
5.	Thermal Performance and Characterization of a Sawdust-Clay Compos ite Material(Charai et al., 2020)	Samples Were prepared by hand-mixing clay with different percentages of sawdust (2%, 4%, 6%, 8% and 10%) to evaluate its effect on the thermal performance of unfired	The objective is to evaluate the impact of sawdust on the thermal insulation improve ement of unfired clay bricks	The author focuses only thermal property of sawdust-clay composite. Thermal impact of sawdust on different soil-based materials in order to determine the optimal	Experimental results show that sawdust affects positively the thermal insulation quality of building materials and other thermal transport properties Adding 10%

		bricks.		blend of ingredients ensuring the best possible thermos mechanical performa nce evaluated are needed.	of sawdust decreases the thermal conductivity around 30% of an earthen-building block, the thermal diffusivity of 20.1% and the density of 22.7%.
6.	Fabrication and inter facial modification of wood/recycled plastic composite materials (Cui et al., 2008)	-The effect of maleic-anhydride polypropylene (MAPP) as a coupling agent together with fiber surface treatments (an alkaline method, a silane method and an alkaline followed by a silane method) were investiga ted for WRPC's	To improve the compatibility between HDPE matrix and wood sawdust and to develop WRPC materials for structural applications	High flame ability property and low mechanical strength ability of these compo site materials difficult to manuf acture in the real world.	Test results indicate that WRPC material with wood fiber treated by the alkaline followed by silane treatment method together with the MAPP coupling agent possesses good mechanical properties. The content of wood fiber affects the flexural strength, flexural modulus, and impact strength of these WRPC materials.
7	Thermal performances and environmental analysis of a new composite building material based on gypsum plaster and chicken feathers waste(Ouakarrouch et al., 2020)	- Depending on incorporating of different mass fractions of chicken feathers waste, observe performance of gypsum plaster materials.	- The main objective of this paper is the improvement of the thermal properties of gypsum plaster through mixing it with chicken feather waste	- The author only studied and characterized the thermal properties of the developed compo site materials. However, the mechan ical strength, water absorption properties of the composite, which are also crucial for the field of application was not studied.	The obtained results show that the increase in the mass fraction of chicken feathers resulted in a signify cant improvement thermal insulation properties. The obtained thermal conductivity value (0.3 to 0.4 W/(m.k))

8	Utilization of devulcanized waste rubber tire in development of heat insulation composite (Hittini et al., 2020)	The physical, thermal, and mechanical properties of the composite were characterized; The effects of alkaline treatment on the composite were also investigated.	The effect of variation of filler percentages on the physical and thermal properties of the composites is investigated. Moreover, data for DVR–PS density, thermal, conductivity and thermal stability are presented.	-Thermal resistance and water absorption properties of the composites which are curial for the field application were not study. The reported mechanical strength properties of the composites were under the minimum value of (< 16 MPa by the standard of ANSI for commercial building insulation material. .	With less than 40 wt.% devulcanized rubber tire content thermal conductivity ranging from 0.0502 to 0.07084 w/(m · k), density from 462.8 to 482.32 kg/m^3, compressive strength from 11.66 to 7.47 MPa, and flexural strength from 40.4 and 19.26 MPa.

As a result, in this work we present an alternative thermal insulation composite materials using HDPE waste plastic as a matric and diatomite/sawdust as reinforcements. The development of new eco-sustainable materials and technologies to be implemented in the near future society. The selecting of Spent Brewery Diatomite earth aiming for improving the mechanical, thermal resistance, and thermal insulation qualities of the prepared composite materials, due to its unique properties such as low density, low thermal conductivity and volumetric weight, high surface absorptivity, stable chemical performance, and strong fire retardancy properties (Munir et al., 2018).

2.11 Post-consumer HDPE, spent brewery diatomite earth (DE), and sawdust (SW) environmental behavior

Another important environmental problem is pollution caused by the usage of plastics. Plastic use worldwide grew from 299 million metric tons in 2013 to 355 million metric tons in 2016. (Statista, 2018). Because of their high manufacturing, low recycling rate, and long natural degradation time, polymers used to manufacture plastics are becoming a severe environmental

hazard (Hu et al., 2020). On the one hand, HDPE materials are the fourth most manufactured plastics materials in the world, with 51.33 million metric tons produced in 2017 and predicted to reach 66.69 million metric tons by 2020 (Aeslina et al., 2018). Furthermore, HDPE trash accounts for 13% of all global plastic waste, with a recycling rate of less than 35% (Limami et al., 2020). HDPE is employed in a wide range of industrial applications due to its outstanding thermal and physical qualities. Diatomaceous earth is used to filter the beer, which is subsequently carbonated, pasteurized, and packed. After being utilized for filtering in the beer sector for seven days in a row, the companies are simply dumped as waste on public property. Even yet, diatomite earth isn't recycled in the beer business for filtering (Kuzina et al., 2021). Diatomite, on the other hand, has a low density and porous structure with sufficient hardness for thermal performance, fire resistance, and sound absorption, making it a desirable light weight construction material. They are mostly amorphous, hydrated, or opaline silica ($SiO_2.nH_2O$), with some clay minerals, calcite, and organic components thrown in for good measure (Mateo et al., 2016). Diatomite can be utilized as a component of concrete and plasters due to its low density (Mateo et al., 2016). Throughout the years, there has been a significant increase in the problem of wood waste, which is regarded as a troublesome byproduct, with disposal and disposal in land filling or in cineration thought to be viable solutions to this environmental issue. A related issue is that sawdust, a byproduct of wood exploitation and processing, can be a significant source of pollution when stored in uncontrolled settings (Chaudemanche et al., 2018). The most serious effect of this pollution is on human health, which is caused by NO_2 emissions, which harm the respiratory system. NO concentrations more than 3ppm are harmful to the lungs, causing irritation and the development of asthma. The CO_2 produced in the wood burning process, which is considered part of nature's carbon cycle, is also an air pollutant. In this process, more than 80% of the particles are in the form of ash (fly ash), of which 40% have a diameter of less than 10ppm, 20% reaches the ground, and the rest is released into the atmosphere, causing health problems (Deac et al., 2016). New recycling methods for sustainable bio-composites thermal insulation and cleaner production criteria are therefore urgently needed. Several studies on various waste recycling methods have been published. Omran et al. (2016), for example, employ ed glass powder as a concreate filler, whereas, Hashemina et al. (2012) concentrated on diopsid-based glass-ceramic foam; Gong et al. (2016), on the other hand, constructed a foam out of recycled amber glass. Valverde et al. (2013) employed textile industry offcuts such as thermos

formed polyester and polyurethane. Wood, on the other hand, is a well-studied waste product. Souza et al. (2018) demonstrate that it can be reused in conjunction with ink wastes, whereas, Fongang et al. (2015) presented a clear manufacture of hardwood composites, and Morris (2017) examined a variety of recycling, landfill, and fire possibilities. Plastic recycling, too, has been the subject of numerous studies. Curlee (1986) began discussing this topic in his book and came to the conclusion that it is linked to a favorable economic balance. As a result, Einaga and Ragab suggested PET waste as a filler for asphalt mixtures, while Humeidawi and Qadisiyah. (2018) discussed the use of plastic in hot-mix asphalt. Accordingly, adaptive reuse systems are good techniques to follow in plastic recycling (Brown et al., 2003); nonetheless, it is usual to burn plastic wastes or utilize them as a filler for something completely different from their original application (Chandni et al., 2018). Recycled PET, nylon/spandex fibers, wool, alginate, cotton, and other materials might be added to the list, and Asdrubali et al. (2015) wrote a complete review on the subject. All of the above-mentioned solutions contribute to the reduction of the use of virgin feedstock and the initial disposal of waste in the landfills.

Combining these sustainable resources to make thermal insulation composite materials offers a new, cleaner material with thermal, physical (such water absorptivity), and mechanical qualities that could be useful in a variety of applications. As a result, the development of readily available, renewable, recyclable, and low-cost commercial building insulating materials will have several advantages, including reduced energy consumption, environmental protection, and maximum use of renewable resources in energy supply systems.

2.12 Bio fillers-polymer insulation composite materials development

A double net positive effect can be obtained by developing building insulating materials from renewable resources: the environment will not be harmed as a result of their production, and an insulated buildings are consume the least amount of energy, resulting in increased energy efficiency and reduced use of fossil-fuel based energy supply. As a result, the development of renewable-source commercial building insulating materials have a number of advantages, including reduced energy consumption, environmental protection, and the most efficient use of renewable resources in energy supply systems. Ethiopia's sustainable development goals (to be achieved by 2030) are likewise based on these benefits (Wennersten, 2018). Researchers and the general public have recently become interested in ecofriendly materials that are renewable,

recyclable, sustainable, and biodegradable. People have just recently become aware of such materials, notably bio-based composites, despite the fact that they are not new materials. Bio-based composites, which incorporate natural fillers as reinforcements and polymers as the matrix, are replacing traditional inorganic and petrochemical thermal insulation composite materials, which are very expansive and generate environmental concerns, due to their promising characteristics (Satyanarayana et al., 2017, Bayart et al., 2017). Despite the benefits of inorganic or synthetic fillers, the related health risks and expensive prices are adequate motivations to investigate the use of natural fillers (Salman et al., 2018, Khan et al., 2018). Manufacturers and researchers have been interested in polymer-plant fiber based thermal insulation composites because of their low cost and superior efficiency, which includes high sustainability, lower water uptake, durability against environmental impacts such as fungi and insects compared to wood, high dimensional stability over their lifetime and high relative stiffness, low thermal conductivity and strength (Salman et al., 2018). Many recent research projects have focused on the creation of biomass-polymer-based thermal insulation composites. Jdayil et al. (2019) and Medina et al. (2018) present an outstanding overview on banana fiber polystyrene thermal insulation composites for building applications. The acquired thermal conductivity values of the produced banana fiber-polystyrene composites ranged from 0.100 W/ (m k) to 0.14 W/ (m k). In other words, the concept of cleaner production is utilized in the development of sawdust waste plastics composites, where waste recycling is targeted at conserving the environment and enhancing resource use efficiency. Saeed et al. (2020) developed and characterized a thermal insulation poly (lactic acid)/sawdust composite. They claimed that the composite outperformed currently available thermal insulators. However, the composites' compressive strength qualities and thermogravimetric results show that they fall below the minimal required value for commercial building insulation materials (Krehula et al., 2015). HDPE, which is a thermoplastic polymer derived from monomer ethylene raw materials. It has excellent toughness and cut and wear resistance, and also has very good chemical resistance and good temperature impact resistance, its mechanical properties are comparable to those of the commonly used petroleum-based polymers (Mokhena et al., 2018). These features have allowed the usage of HDPE in various applications, including the production of packaging materials and medical devices and in the automotive industry(Bayart et al., 2017). Brewery Diatomite earth is one of the conventional, highly effective and widely used environment-friendly flame retardants and high thermal

resistance materials used for the amelioration of the flame retardant and contain 90% silica ($SiO_2.nH_2O$), it is better chose for improving thermal stability and mechanical strength capacity of the bio-based thermal insulation composites. Besides diatomite earth, several kinds of inorganic additives including aluminum hydroxide (Sain et al., 2014) and magnesium hydroxide (Umemura et al, 2014) were reported as flame retardants an reinforcement fillers for polymer matric composites. Furthermore, some organic flame retardants were also developed to improve the mechanical and thermal stability properties the plant fiber-polymer composite through increasing the char yield (Seefeldt., 2012,Guan et al., 2015). However, to achieve a satisfactory thermal resistance level, high loading of either inorganic or organic thermal resistance reinforcement mentioned above is usually required, which leads Poor compatibility between these the reinforcements and polymer matrix resulted in deterioration of both compressive and flexural strength and the elongation at break of the developed composites (Wang et al., 2015).

Table 2 properties of different plastics

Kind of plastic	LDPE	HDPE	LLDPE	PP	PET
Density (g/cm^3	0.92	0.94 to 9.6	0.92	0.905	1.37
Melting point (°C)	105-115	125-136	130	160	255
Maximum service temperature(°C)	80	80	50	80	70
Tensile strength(MPa)	0.20-0.40	0.2-0.40	0.20-0.40	0.95-1.3	2.5
Notched impact strength(KJ/m^2)	No break	No break	No break	3.0-30.0	1.5-3.5

Source:((Mohan et al., 2021)

2.13 Alkaline (NaOH) treatment

Wood plastic composites (WPC), a type of new functional composite material made primarily of polymers and natural fibers, have been used in a wide range of applications, including decking, construction, furniture, and a variety of outdoor products (Gwon et al., 2010, won et al., 2010, Kamdem et al., 2004, Peltola et al., 2014). Incompatible interfaces between hydrophilic hydroxyl-rich natural fibers and hydrophobic polymer matrix, on the other hand, frequently result in mechanical, physical, and thermal qualities that are unsatisfactory (Liikanen et al., 2019,

Liu et al., 2019, Xu et al., 2019). Various successful ways have been developed to improve the interfacial compatibility between natural fibers and polymers (Wechsler et al., 2019; Rocha et al., 2019; Luedtke et al., 2019; Hosseinaei et al., 2012). Chemical alteration of polar hydroxyl groups in natural fibers is a popular approach. Hosseinaei (2012) described the extraction of hemicelluloses from wood flour (WF) to increase mechanical qualities by obtaining good interfacial bonding and low-level hydrophilic characteristics. Wei (2013) used esterification to endow good hydrophobicity and compatibility with the high-density polyethylene (HDPE) plastic matrix, and they concluded that the esterified fibers could improve the stress-transfer between the plastic matrix and the fiber, resulting in increased tensile and flexural strength of the resulting WPC. Dominkovics (2017) stated that benzylation of wood fibers in a 20 wt percent sodium hydroxide solution at 105°C resulted in a significant reduction in water absorption of the produced fibers/PP WPC. These findings suggest that chemical treatment of natural fibers can alter their surface hydrophilic properties and improve interfacial compatibility when combined with various types of plastic matrix. The reaction between the two stages is aided by chemical treatment of the plastic or filler. Plastic fibers treated with bleach alkaline treatment (NaOH) or reactive material for pozzolanic reactions (Silica flume, iron slag, metakaolin) increased the flexural strength of concrete composites, according to Sharma et al. (2016). As a result, the concrete and plastic's durability has enhanced. Organic fibers are also given an alkali treatment to increase the surface roughness, which improves adhesion and mechanical interlocking between the fiber and the polymer matrix (Chen et al., 2015). To achieve good adhesion with other materials, wax, lignin, and pectin on the surface of the fibre must be removed (Sharma et al., 2016). The product's elongation and impact strength have improved, but its water absorption has reduced. Silane treatment (SiH_4) makes coir fibers more stiff, giving them a high tensile strength, whereas NaOH makes them more flexible, allowing them to withstand torsion better (Arrakhiz et al., 2012). In comparison to other more sophisticated chemical agents, these two therapies are readily available, environmentally acceptable, and inexpensive (Ichaze et al., 2017).

2.13 Mechanical property of plastic composite with different bio fillers

Table 3 Mechanical property of plastic composite with different bio filler

Filler	Plastic	Ratio plastic/ filler	Coupling agent or compatibilizer (%wt)	Flexural strength (MPa)	Compressive strength (MPa)	Tensile strength (MPa)	Reference
Sawdust	PET	60:40	-	27	-	-	Srivast et al., 2015
Wood waste	HDPE	70:30	NaOH (5)	20	-	-	Quaranta et al., 2010
Sawdust	LDPE	50:50	Coconut oil (10)	6.1	-	-	Kimetal, 2016
Sawdust	LDPE	50:50	Fusabond (2)	22.7	43	611.8	Guzman, 2015
Sawdust	LLDPE	50:50	EVAL (3)	-	11.5	-	Kim et al., 2016
Bamboo powder	PP	66:33	MAPP (3)	47	-	25	Zhou et al., 2013
Wood flour	LDPE	70:30	MAPE (3)	-	-	22	Yang et al., 2007
pineapple leaf fibers	LDPE	70:30	NaOH (5)	454.9	-	1562	Gebremedhin & Rotich, 2020
sawdust	PP	60:40	NaOH (5)	46.1	35.56	18.36	Ferede, 2020

Sawdust and wood chips are byproducts of the woodworking industry that can be utilized as fillers. They are made up of cellulose, lignin, and hemicellulose-based fine and coarse wood particles. It is very combustible and can be utilized as briquettes, mulch, or particleboard as a fuel. The qualities of sawdust are determined by the type of wood used and its size. It is a widely available waste at a low cost all around the world, with the added benefits of renewability, lightweight, and high rigidity. Outdoor terrace flooring is one of the many applications for wood dust plastic composite. All popular plastics (LDPE, HDPE, LLDPE, PP) and sawdust can be recycled into a composite material. According to the study (Krehula et al., 2015), the compressive strength of plastic-sawdust composite bricks built of an equal proportion of LDPE to sawdust with 2% Fusabond got a strength of 4.3 MPa, which is higher than clay bricks (3.5 MPa) (Krehula et al., 2015). Compressive strength experiments of such blocks were conducted

based on application and a long and thin plate form structure, with an emphasis on the horizontal rather than the vertical direction. Chen et al. (2017) have well established the bending strength. Zhang et al. (2012) focused their research on HDPE plastic in a 70:30 sawdust ratio using NaOH as a coupling agent at 5% of the weight. They achieved a bending strength of 20 MPa by applying hot press to the mix, which exceeded the ANSI (American National Standard Institute) minimum value of 16 MPa for conventional thermal insulation materials.

2.14 Treatment of plastics waste

Waste plastic materials can be treated in a variety of ways. The first phase in the treatment is to shred the material to the proper size, after which advanced technologies is take over. After melting the LDPE to a semi-liquid state at 120°C, Dharmaraj and Iyyappan (Dharmaraj, 2016) ground it with a metallic mortar and pestle. The particles that are kept are then sieved at a size of 4.75 mm. The garbage was shredded using a rotary grinder (Rahman et al., 2013; Jarusombuti, 2011). It can be shredded into fine aggregate of less than 500 mm (Estil, 2019) or between two sieves ranging from 300 mm to a few millimeters (Estil, 2019). A plastic shredding machine, on the other hand, is more expensive than a rotary grinder (more than 1600 US dollars in the Indian market). Simpler options, such as Chen et al. (2015)'s utilization of plastic waste in a screw extruder to convert into pellets without any mechanical size reduction, are available. The pellets, along with the filler and coupling agent, are re-extruded in the extruder machine. The size of the plastic particles does not matter in this process because as the plastic melts, the varied segments bond together to make a homogenous substance.

2.15 Production method

The technique is similar for sawdust, with a few small differences (Chen et al., 2015, Hamid et al., 2011, Chen et al., 2016). Using a shredding machine, the plastic is first ground to the required size. If several types of polymers are employed, a compatibilizer is used to extrude them into pellets (Chen et al., 2016). Second, the plastic and filler are melted with the coupling agent in a screw extruder (single or twin screw) at temperatures ranging from 160 to 215 degrees Celsius. They are either extruded into pellets (Chen et al., 2015), or directly injected into the mold to prepare intermediate products (Hamid et al., 2015). (Zhou et al, 2013, Yang et al., 2017). The pellet or liquid stage is then combined and placed into the mold, where it is hot-pressed and

cold-pressed twice to obtain the final composite shape (Chen et al., 2015, Chen et al, 2016, Li et al, 2015). This is a pricey procedure that necessitates the use of three expensive machines: a grinder, a screw extruder, and a hot press mold. Because the screw extruder is a costly machine, the studies were conducted without it. Along with a hot press, mixers and rotary drums are used as alternate solutions. Plastic particles can be combined in a container at a 30 rpm speed before being fed a mixture of wood dust and a coupling agent. Heating (Zhou et al., 2013) and cooling (Srivastava, 2015) were used to finish the procedure. Finally, a pre-press, hot press, and cold press process are used (Srivastava et al., 2015, Zhou et al., 2015). However, this method of manufacture necessitates a lengthy procedure. Koranteng (2015) employed a simplified method that involved mixing the shredded plastic, coupling agent, and sawdust in a mixer, then pouring the material into the mold for a cold process (Koranteng, 2015). He found thermal insulation and mechanical qualities that were equivalent to prior studies. The melt compounding approach, as proposed in this paper, is a novel way for preparing samples. This method involves blending and combining waste HDPE plastics with diatomite earth and sawdust (DE/SW) in a molten condition while maintaining constant agitation at higher temperatures (160°C and 215°C). The advantages of this technique are that it ensures adequate additive dispersion in the composite matrix due to constant agitation, and that it maximizes polymerization intensity and HDPE-(DE/SW) interactions of the prepared mixture without the need for any high-class stabilizing techniques because the polymeric additives' fibrous structure serves as a conditioning agent.

3 MATERIALS AND METHODS

3.1 Materials

3.1.1 Reinforcements

Sawdust was obtained from the local wood house in jimma, Ethiopia. At particle size (0.25-0.5mm) and Waste spent brewery diatomite earth was kindly supplied by the beddele Brewery industries. The obtained diatomite was then transferred an oven for drying at a temperature of 110 ^{0}C for 24 hours to obtain constant mass. Subsequently the sample was grounded to small granules and sieved by using (0.25-0.5mm) mesh size (Figure 6). Finally, the well-sieved sample was stored in a desiccator to prevent moisture uptake until the onset of the experiments.

A B C

Figure 6.The raw A), the grounded B), and the sieving C) process of spent brewery diatomite earth material

3.1.2 Polymer matrix

High density polyethylene (HDPE) was obtained from waste plastic in Jimma University. The collected sample was milled using electric grinder, sticker and labels were removed from the waste HDPE after which it was washed to remove grease or any impurities. It was then sun dried for 48 hours to obtain constant mass (Dorothy et al., 2015). The physical properties of the HDPE used in this study was given in Table 4. HDPE, which is a thermoplastic polymer derived from monomer ethylene raw materials. The major technical impact considering for the selection of HDPE is that, HDPE has excellent toughness and cut and wear resistance, and also has very

good chemical resistance and good temperature impact resistance, its mechanical properties are better than those of the commonly used petroleum-based polymers (Mokhena et al., 2018).

A B

Figure 7.Washing A), and drying B) of HDPE waste plastics

3.1.3. Chemicals

Sodium hydroxide(NaOH) (99.8%) (ATDM, Turkey) and acetic acid (CH_3COOH) (99.7%) (Merck,Germany) were purchased from chemical product suppliers in Addis Ababa, Ethiopia.

3.2. Method

3.2.1. Preparation of Sawdust

The sawdust samples were sun-dried for two days to remove excess moisture, after that, the wood sawdust was sieved out by using (0.25-0.5mm) sieve (Figure 8) to remove some unwanted materials such as pieces of plastic, pieces of metals, and wood particles. Wood sawdust serves as filler and reinforcement in the matrices. In this study the main porpuse of sawdust fillers incorporated in DHPE:DE composites as pore–forming agent. Such combined products give the composite materilas more porous microstructure. This would result in decrease the thermal insulation composite sample density and improve the composite thermal insulation capacity (Souza et al., 2018). Most of the time, sawdust residue can be used in polymer technologhy to create lightweight and more porous products (Souza et al., 2018).

Table 4. Properties of composite raw materials

Materials	Properties	
Spent brewery diatomite earth	Particle size	0.25-0.5mm
	Density	0.22 g/cm^3
	Moisture content	7.24%
Sawdust	Particle size	0.25-0.5mm
	Density	0.124g/cm^3
	Moisture content	9.45%
High density polyethylene	Density	0.97g/cm^3

Moisture content and density of the raw materials were evaluated according to ASTM D1909-13 test standard (Ferede, 2020, Gebremedhin et al., 2020).

3.2.2. Chemical treatment of wood sawdust

Prior to composite manufacture, the sawdust was treated with sodium hydroxide solution in order to improve the filler–matrix interface. The dried, cleaned, and sieved wood sawdust was soaked in NaOH solution with 5% concentration at room temperature for 2 hours. After that the reinforcement was washed several times with distilled water to remove any NaOH solution sticking to the reinforcement surface, neutralized with acetic acid, and again washed with distille d water. Finally, wood sawdust reinforcement was dried in sunlight for 3 days before continuing manufacturing the composites (Basalp et al., 2020).

A B C

Figure 8. Cleaned, dried, and sieved sawdust A), soaked in NaOH solution B), and drying using sunlight C) process of sawdust material.

3.2.3. Preparation of the sample

HDPE:DE:SW composite preparation. Randomly oriented HDPE:DE:SW thermal insulation composites with varying reinforcements (DE and SW) and matrix (HDPE) weight % proportion and mold compression load were manufactured by the melt-mixing process following by compre ssion molding. The parameters used were a mixing time of 10min, rotor speed of approximate 60 rpm, and mixing temperature of 130℃ based on an early work by Dean et al. (2017). The temperature of 130℃ was used because it does not affect the sawdust filler properties. Thermal insulation composite samples of size 200 x 150 x 20mm were prepared using a closed mold. The mold was polished with a release agent to avoid HDPE from sticking to it. The process involved melting of the shredded and predetermined weight proportion HDPE, adding predeterm ined weight proportion of fillers (DE and SW), melt-mixing thoroughly to form a homogeneous viscous solution, and placing it into the prepared mold. Finally, the mold was closed and the samples were cooled down to room temperature under different mold compression load between 2 and 10MPa, using weight compression machine (Figure 10) according to design expert software combination run order (Table 6) for 30 min. This preparation technique is known as the melt compounding technique, which is achieved in dry conditions for maximum polymerization intensity (Theng et al., 2012), since wood-polymer blending is maximized in dry conditions (Cui et al., 2015). The benefits of this technique is; first, ensuring an adequate additives dispersion in the composite sample matrix due to the steady agitation, and second, the molten state blending maximizes the polymerization intensity and the reinforcement-polymer interactions of the prepa red mixture (Theng et al .2012), without the need to using any stabilizing technique, as the polymeric additives' fibrous structure play the conditioning role. The specimens of TIDSPCs produced were labeled according to design expert software run order and stored in dry environm ent and used for testing as shown in Figure 10.

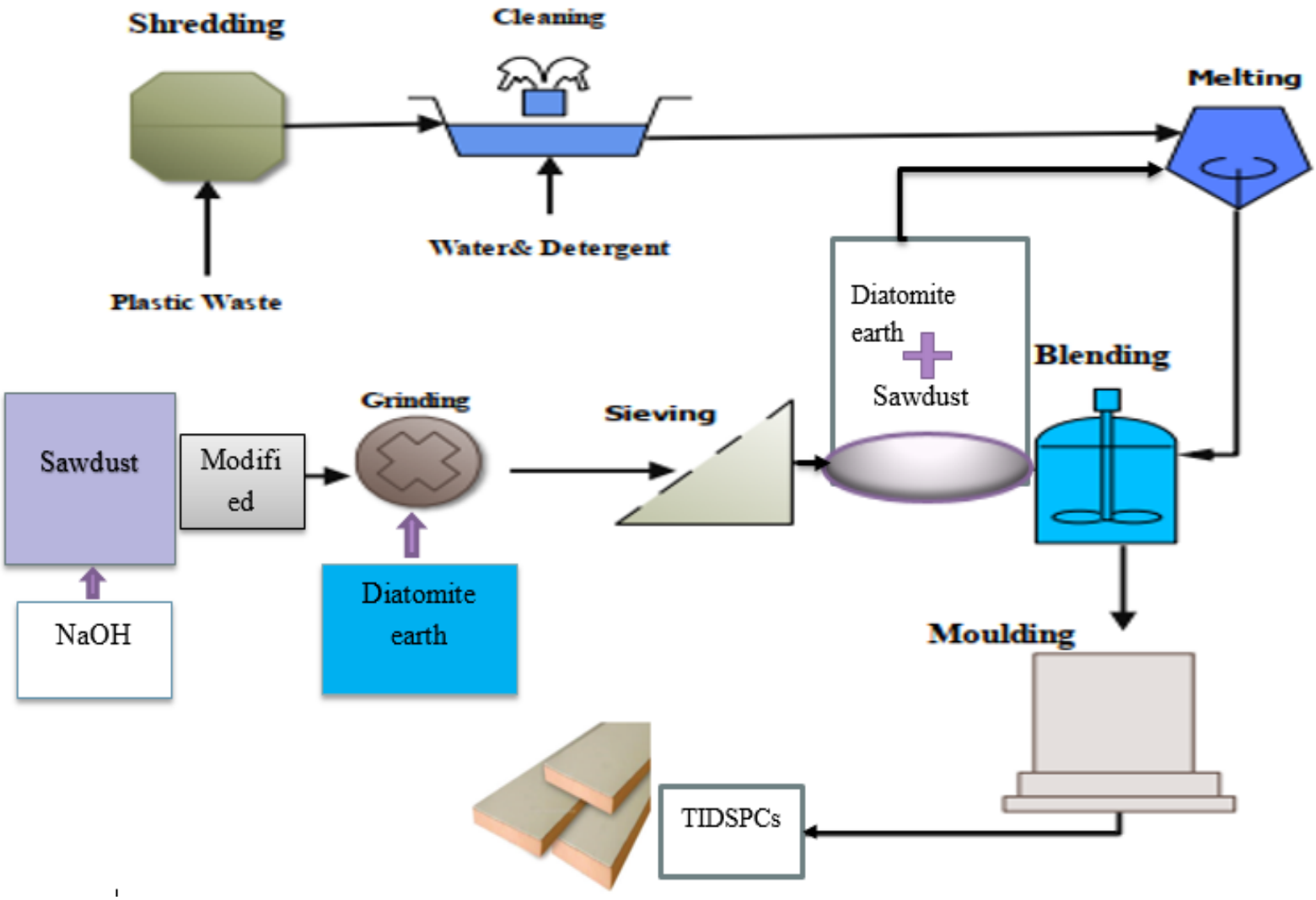


Figure 9. Process block diagram for production of (TIDSPCs) materials

Raw materials

Size reduced HDPE waste plastic by cutting in to small peace, for easily and uniformly melting.

Grinder

Grinded HDPE plastic waste

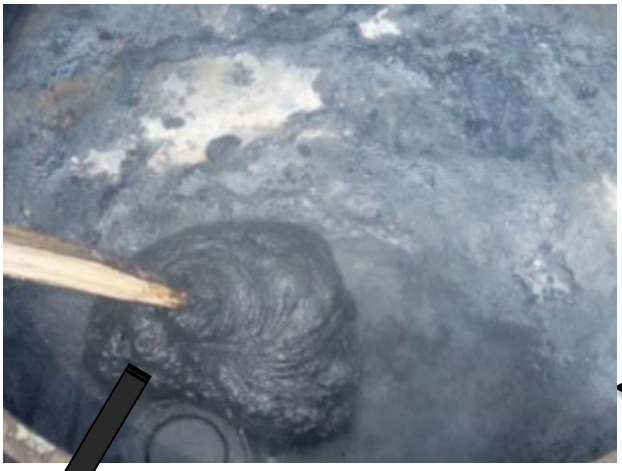
DE and SW prepared in 0.25-0.5mm particl size

Sieving

Sawdust powder

Diatomite earth powder

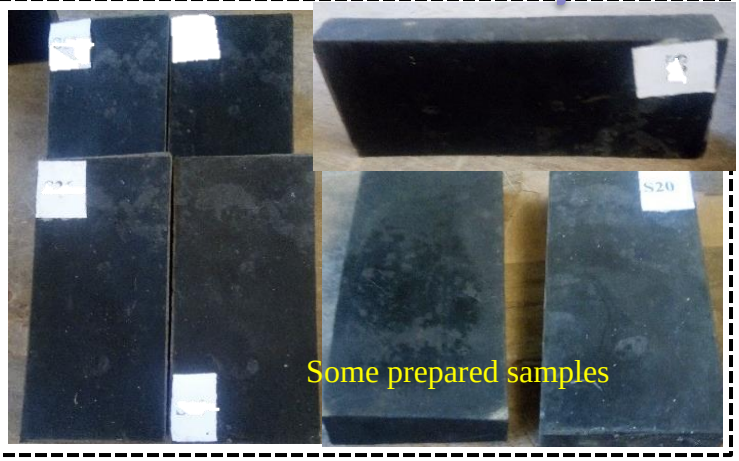
Melting the Plastic at 130℃ and added SW and DE, then Mix vigorously up to homogenize



Weight Ratio

Molding

Mold compression



Some prepared samples

Figure 10. The main laboratory production processes of (TIDSPCs) based on high density polyethylene waste plastic, diatomite earth and sawdust.

3.3 Characterization and quality optimization of thermal insulation composite samples

3.3.1 Compressive Strength Test

Compressive strength indicate the force applied to the top and bottom of a test sample until the sample fractures or is deformed or the resistance of a material breaks under compression. The composite properties of the composite specimens were measured with a Deepak universal testing machine (DTRX) according to ASTM D6641/d6641M 16e1 (ASTM International, West Consho hocken, PA, USA, 2016) test standard with sample dimension of 40x50x20 mm.

3.3.2 Water absorption test

Mechanical, thermal insulation properties and moisture absorption behavior are related to each other. (Thermal insulation composite materials) which absorb less water will show better mechanical and thermal insulation properties. The standard methods for water absorption are mostly short-term tests (Murillo et al., 2015); hence the results obtained are limited only to surface diffusion phenomena and not equilibrium throughout the thickness of the test specimen. In this study water absorption tests were carried out as per ASTM D570-98 (ASTM International, PA, USA, 2018) test method. Sample of each composite type were oven-dried before its weight was recorded as the initials weight of the composite. The sample were then placed in distilled water and maintained at room temperature (25℃) for 72 hours. The samples were then removed from the water, dried, and weighed. The amount of water absorbed by the composites (in percentage) was calculated using the following equation:

$$\%W=\frac{(W_t-W_o)}{W_o}*100 \qquad (2)$$

Where W_t is the weight of the samples after water immersion and W_o is the weight of the samples before water immersion

3.3.3 Thermal Conductivity Test

Thermal conductivity test is performed based on the concept of steady state condition according to ISO 8302(.N. ISO, 8302 Stand.Geneva, Switz., 1991). In this test a heater coil is placed in between two identical (TIDSPCs) samples with dimensions 18mm dimeter and 12 mm thickness and two (TIDSPCs) are tied together to ensure that all the heat come out through the slab only. The temperature are measured by calibrated temperature sensors which were attached to the specimens at the hot and cold faces. The heat transfer assumed to be unidirectional, to eliminate the distribution caused by edge losses in unidirectional heat flow, the central plate is surrounded by a guard ring plate, which is separately heated. The latter plate is slightly overheated to avoid lateral heat loss. The whole assembly except 2 sides is insulated with a highly insulating material named glass wool to avoid heat loss from other directions and to allow heat flow in one direction. The heater coil is connected to electric circuit through ammeter, volt meter and dimmer stat. Then switch on the power to start the experiment and power input is adjusted by dimmer stat. The central heat plate was set at 60℃ and ring guard plate was set at 65℃ and the cold plate at ambient temperature (at 23℃). The whole arrangement is kept in a closed room to avoid air flow which causes delay in formation of steady state condition. Once the steady state regime is established and note down the reading temperature sensors, the thermal conductivity can be measured from the heating power(Q), the sample thickness (e),the measuring surface area of the specimen (S), and the temperature difference between the two plates(ΔT).

$$\lambda = \frac{Q * e}{s * \Delta T} \tag{3}$$

The thermal conductivity test of TIDSPCs specimen is shown in Figure 11.

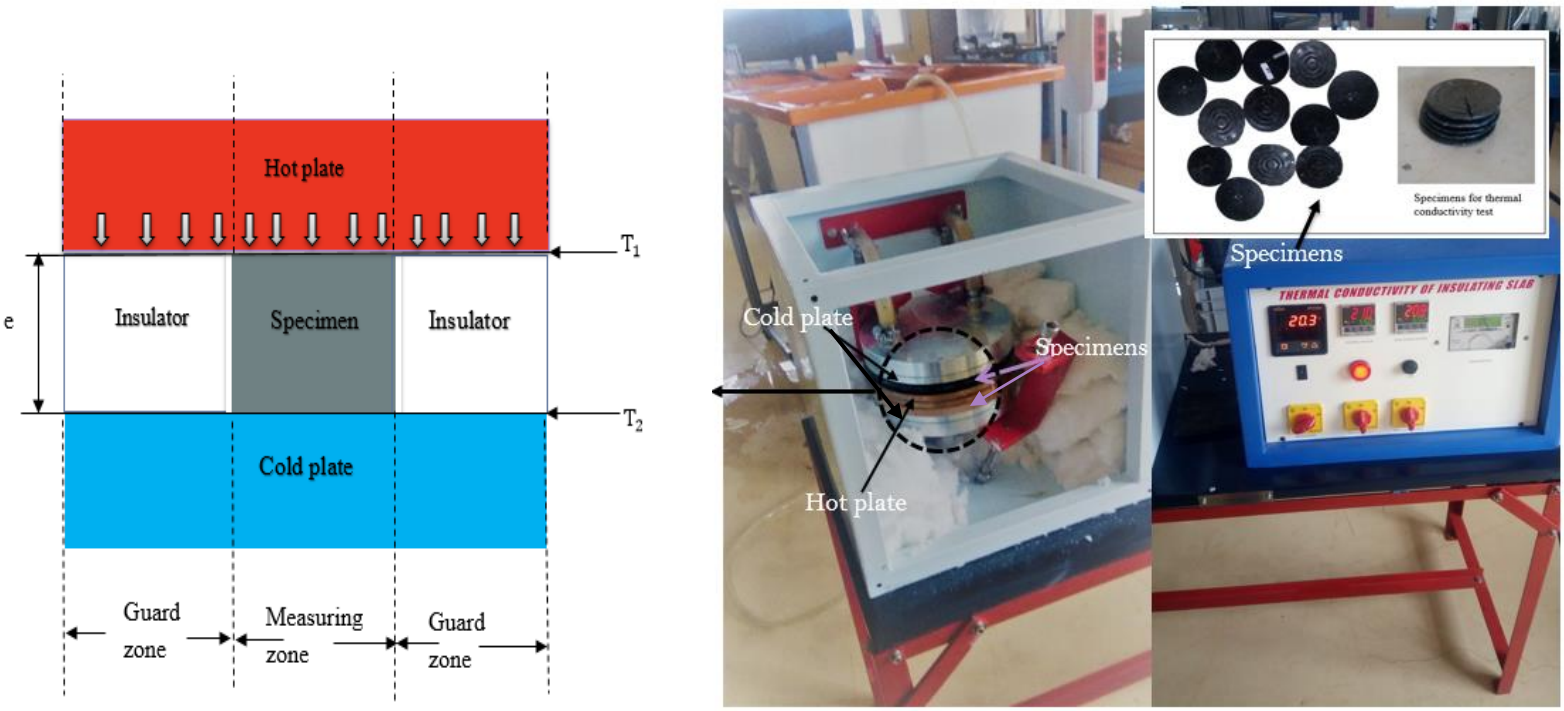


Figure 11.Thermal conductivity test of TIDSPCs specimens

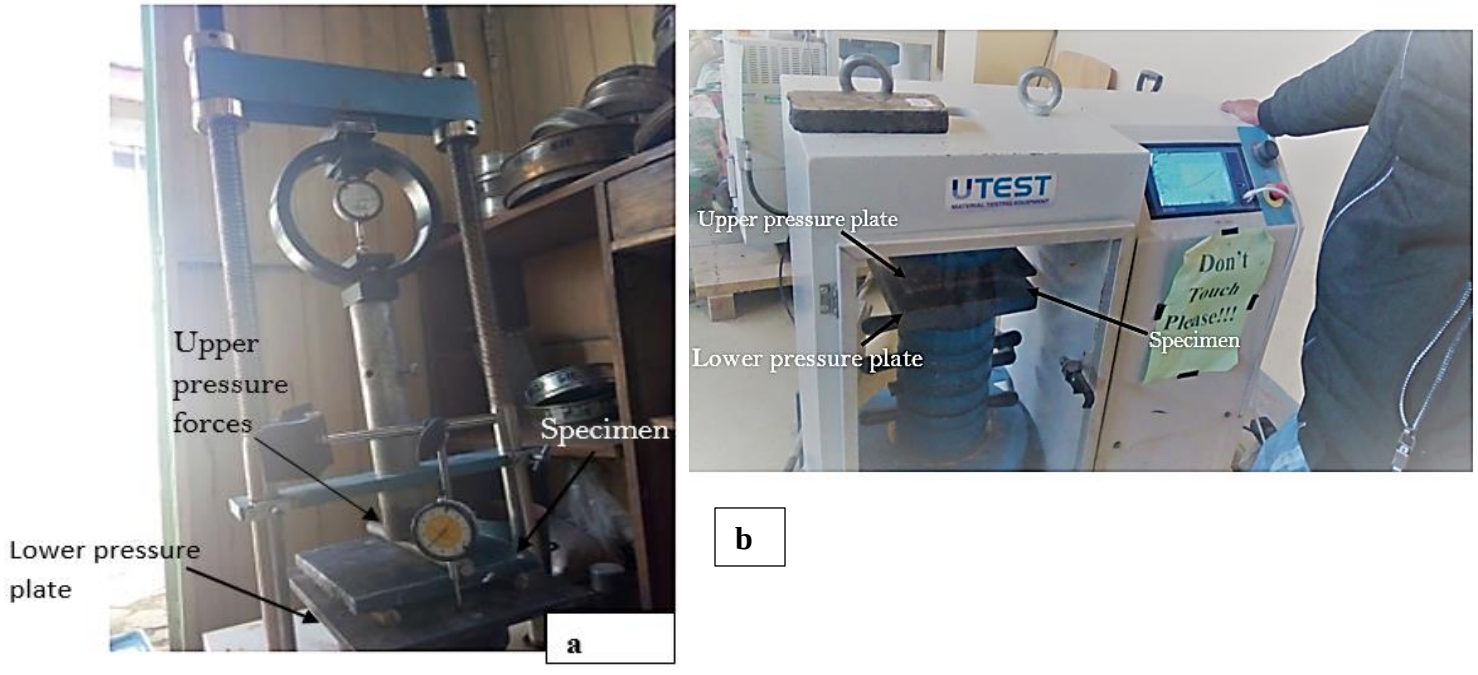


Figure 12. Mechanical properties test of TIDSPCs: (a) flexural strength; (b) compressive strength

Figure 13. Water absorption properties test of TIDSPCs

3.4 Experimental design

Optimal (combined) design methodology was used to optimize the condition for the preparation of TIDSPCS materials. The Design of experiment was done using Design Expert 11 (DX) (Stat-Ease Inc. USA). Four independent variables were employed by (D-optimality). The variables used were weight% proportion of (HDPE), weight% proportion of (DE), and weight% proportion of (SW) in the mixture, and mold compression load for the process. The design consisted of 22 runs including, six vertices experiments, four center of edge experiments, six third edge experiments, and six replicate in overall centroid point. The level of factors and their coding are present in Table 5. The design matrix present in Table 6. The selected level of factors were designated based on the previous researchers (Binici et al., 2016; Saeed et al., 2020). The responses function measured were thermal conductivity (w/m.k) (Y_1), compressive strength

(MPa) (Y_2), and water absorption (%) (Y_3). The D-optimal method selects design points from a set of candidate points aiming to minimize $|(X'X)^{-1}|$ (identity matrix) (Habib & Aboughaly, 2016). Candidate points were vertices, centers of edges, and centroid for MCs. PVs candidate point was vertices as shown in Figure 14.

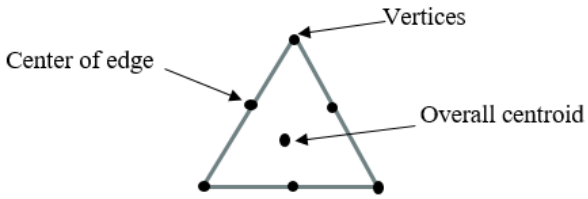


Figure 14. The optimal (combined) design model candidate points for optimize the mixtures-process variables interactions (Habib & Aboughaly, 2016)

For mixture-process factors interaction of optimal (combined) design, a quadratic x linear polynomial equation, a quadratic polynomial equation as function of X for mixture factors, a linear polynomial equation as function of Z for process factor, was a well fitted model for each Mixture-Process factor interactions according to Schiff model (Kowalski et al., 2010) as follows:

$$\breve{y}_m = f(alpha, z) * g(beta, x) \quad (4)$$

Where $\breve{y}_m$ the observed value of the m^{th} response, in this case thermal conductivity, compressive strength, and water absorption properties of the prepared samples. The function g (beta, x) is a polynomial Model representing the factor of mixture components (MCs) in this case weight % proportions of (HDPE, DE and SW). **f(alpha,z)** is a polynomial model representing the factor of process variables (pvs z) in this case mold compression load (Zafrillaa et al., 2013, Cornell et al., 2012).

The most frequently used models for one PVs is:

Linear $$\breve{y}_m = \alpha_0 + \alpha_{CL} Z_{CL} \quad (5)$$

The subscript CL denotes compressive load

The most frequently used models for three MCs are

Quadratic

$$\breve{Y}_m = \beta_{HDPE} X_{HDPE} + \beta_{DE} X_{DE} + \beta_{SW} X_{SW} + \beta_{HDPExDE} X_{HDPE} X_{DE} + \beta_{HDPExSW} X_{HDPE} X_{SW} + \beta_{DExSW} X_{DE} X_{SW} \quad (6)$$

Where the β_i and β_{ij} are the coefficients representing, respectively, the linear and quadratic blending properties of the three (MCS) (X_i). The subscript HDPE denotes high density polyethylene waste plastics, DE denotes spent brewery diatomite earth, and SW sawdust. Thus, **a *Quadratic x linear*** combined MPV is:

$$\breve{Y}_M = \gamma_1{}^0 X_1 + \gamma_2{}^0 X_2 + \gamma_3{}^0 X_3 + \gamma_{12}{}^0 X_1 X_2 + \gamma_{13}{}^0 X_1 X_3 + \gamma_{23}{}^0 X_2 X_3 + \gamma_1{}^1 X_1 Z_1 + \gamma_2{}^1 X_2 Z_1 + \gamma_3{}^1 X_3 Z_1 + \gamma_{12}{}^1 X_1 X_2 Z_1 + \gamma_{13}{}^1 X_1 X_3 Z_1 + \gamma_{23}{}^1 X_2 X_3 Z_1 \quad (7)$$

Where $\breve{Y}_m$ is the value of response M predicted by the regression model and the $\gamma_j{}^i$ are the combinations of α_i and β_j coefficients (Vieira et al., 2010; Piepel et al., 2012). The first line of the equation (set of gamma coefficients with zero superscript) quantify the effect of the blending properties of the MCs on responses of $\breve{Y}_M$. The gamma coefficients with 1superscript quantify the combination effects of MPV on the responses of $\breve{Y}_M$. The variance for each factor was partitioned in to linear, quadratic, and interactive terms. The lack-of-fit and error components were used in determining the significance of these variables and the suitability the quadratic* linear polynomial function.

Table 5.MCs and PVs with their constraints.

Mixture components	Levels investigated (wt.%)		L-pseudo values	
	Lower bound	upper bound	Lower bound	Upper bound
A:High density polyethylene(HDPE)	65	80	0	1
B:Spent brewery diatomite earth(DE)	15	25	0	1
C:Sawdust(SW)	0	10	0	1
Process variables	**Level investigated(MPa)**			
	Lower bound		Upper bound	
D:Compressive load	2		10	

***Total amount of sample forming components was fixed at 700(gm)**

3.5 Thermal insulation composite test

3.5.1 Flexural strength test.

Flexural strength is a material or structure's ability to withstand bending. The flexural properties of the composite specimens were measured with a Deepak. Universal testing machine (DTRX) according to ASTM D790-00 (ASTM International, West Conshohocken, PA, USA, 2002). The dimension of the test specimen were 10x 5x 20 mm. Then, they were pressed until either the load value was reduced by 10% of the maximum load or fracture occurred. All the tests were conducted at an overhead speed of 1.3 mm/min at room temperature.

3.5.2 Micro Structural (Morphology) analysis of (TIDSPCs)

To observe how uniformly the reinforced diatomite earth and sawdust are distributed in the plastic matrix, the Scanning Electron Microscopy (SEM) is employed. This helps to analyze the homogeneity and compatibility of diatomite earth and sawdust fillers with the plastic matrix. Scanning Electron Microscopy (SEM) has been extensively used to characterized the microstruct

ure of (TIDSPCs). The surface morphology, such as the surface shape, pattern, and feature of the selected (TIDSPCs) is observed using JEOL JSM-IT300SEM attached with Energy Dispersi ve X-ray (EDX).

3.5.3 Thermogravimetric analysis

A Q50 thermogravimetric (TGA) analyzer from TA Instruments was used to perform the thermal analysis. A heating rate of 10°C/min was used to increase the temperature from 30 to 850°C under the nitrogen flowing at 20 ml/min. Nitrogen flow rate is set to Thermo Gravimetric Analysis (TGA) is an instrumental techniques applied to measure the amount and rate of change in weight as a function of time and temperature in a controlled atmosphere. For the thermo gravimetric analysis to be carried out, the developed (TIDSPCs) samples which is placed in a vial, which is present in the TGA analyzer. This vial is connected to sensors which detects the weight of the sample at all times. Testing is carried out under inert atmosphere (N_2) with a flow rate of 2 ml/min to remove all corrosive gases and avoid thermoxidative degradation and the retention time of the sample at the maximum temperature. These values are used as basis for the analysis.

3.5.4 Bulk density

The building sector is inserting in lightweight materials representing also an economic incentive. Therefore the identification of the density becomes an important process for each study. To determine the bulk density, it is necessary to measure the weight of the sample and its dimensions (Ouakarrouch et al., 2019). The mass of the studded samples was weighed in dry state using an electronic mass balance and the dimension of each samples were measured using a high precision caliper. The bulk density is calculated based on the following equation.

$$\rho_B = \frac{M_B}{V_B} \tag{8}$$

Where: ρ_B bulk density (kg/m^3), M_B mass (kg), and V_B volume (m^3) of the samples

3.5.5 Specific Heat capacity and thermal diffusivity (α)

Thermal properties of the composites were analysis using differential scanning calorimetry (DSC25, TA instruments). 5 mg of each sample was heated to 200℃ at 40 $℃/min$ and isothermally heated at a 200℃ for 5 min to eliminate any thermal history. Then the specific heat capacity (C_P) of the composite was measured as a function of the temperature ranging from 10℃ to 70℃ at 3 ℃/min; according to instructed by apparatus developed (lasercomp,inc.FOX50110 ℃ Instrument manual.2002-2013). And then the average result of specific heat capacity values at 25 ℃ were reported.

Thermal diffusivity (α) indicates the rate of heat transfer in materials from the hotter extremity to the cooler end. Thermal diffusivity is obtained, as described in equation (9), by dividing thermal conductivity (λ) with density (ρ) and specific heat capacity (C_P) of the prepared samples.

$$\alpha = \frac{\lambda}{C_P * \rho} \tag{9}$$

4. Results and Discussions

4.1 Preparation of raw materials (DE, HDPE, and SW).

Preparation process of raw materials (DE, HDPE, and SW) are shown in the Figure (6, 7 and 8) respectively, and their physical properties are shown in Table 4.

4.2 Manufacturing of the TIDSPCs materials .

The main manufacturing processes of the TIDSPCs are shown in Figure 11, based on previous study Dean et al. (2017), melt compounding technique which is achieved in dry conditions for maximum polymerization intensity (Theng et al., 2012), since wood-polymer blending is ma ximized in dry conditions (Cui et al., 2015). The benefits of this technique is; first, ensuring an adequate additives dispersion in the composite sample matrix due to the steady agitation, and second,the molten state blending maximizes the polymerization intensity and the reinforcements, in this case (diatomite earth and sawdust)-polymer(HDPE) interactions of the composite (Theng et al., 2012) without the need to using any stabilizing technique, as the polymeric (HDPE) additives, (DE and SW)' fibrous structure play the conditioning role.

4.3 Characterization of the manufactured TIDSPCs materials.

From the experiments, the thermal conductivity, compressive strength, and water absorption properties of the manufactured TIDSPCs are shown in Table 6.

4.4 Experimental result and statistical analysis of the experimental result

A batch of preparation of thermal insulation composite material experiments and randomization were designed using design expert 11 software (Table 6). The prepared samples based on each variable run order of the designed experiment software were labeled and used for characterizatio n of the physical, thermal and mechanical properties of the composites. The tested result of the TIDSPCs (water absorptivity, thermal conductivity, and compressive strength) properties were analyzed by the software, and the well fitted regression model were determined from statistical analysis of the optimal (combined) methodology (Table 7-14).

Table 6.The response of the parameter used in combined (Optimal) design

Input variables					**Output (Responses)**		
Runs	A: waste HDPE weight proportion (wt. %)	B: DE weight proportion (wt. %)	C: SW weight proportion (wt. %)	D:CL compression load (MPa)	Thermal conductivity (W/m.k)	Compressive strength(MPa)	Water absorption (%)
PS1	77.5	22.5	0	8	0.0321	78.998	0.32
PS2	75	25	0	10	0.0262	84.86	0.4247
PS3	75	15	10	4.66667	0.025	79.999	0.42
PS4	72.5	22.5	5	2	0.0245	87.62	0.766
PS5	72.5	22.5	5	10	0.02476	87.75	0.68
PS6	80	18.3333	1.6667	2	0.037	68.57	0.19
PS7	77.5	22.5	0	4	0.0302	78.65	0.313
PS8	72.5	22.5	5	10	0.02469	87.85	0.675
PS9	75	15	10	7.33333	0.026	80	0.4
PS10	80	18.3333	1.6667	10	0.0406	68.85	0.1399
PS11	72.5	22.5	5	2	0.0243	87.5	0.77
PS12	65	25	10	4	0.0115	52.47	1.81
PS13	70	20	10	10	0.0187	76.98	0.856
PS14	71.6667	18.3333	10	2	0.0181	81.11	0.8334
PS15	68.3333	25	6.6667	7.33333	0.0182	76	1.01
PS16	78.3333	15	6.6667	2	0.0354	74.889	0.2283
PS17	72.5	22.5	5	10	0.02478	87.998	0.679
PS18	75	25	0	2	0.0256	84.6	0.5

PS19	65	25	10	10	0.0122	52.73	0.9772
PS20	70	20	10	10	0.0186	77.14	0.8715
PS21	78.3333	15	6.6667	10	0.0368	75.556	0.149
PS22	72.5	22.5	5	2	0.02415	87.35	0.769

Factors affecting the quality of the prepared TIDSPCs samples were highlighting in Figure 15. The main problems observed were the reinforcements (DE/SW) - polymer (HDPE) interaction effects, specially the weight proportionality of thus fillers and matrix, as the fillers (DE/SW) weight% proportions increase beyond 27.5 wt.% in HDPE matrix, an agglomeration happened, which directly relating to mechanical and water absorption properties of the composite materials. (Gebremedhin et al., 2020). The amorphous liquid of HDPE was not enough to follow thoroughl y in DE/SW powder. The mixing time and applying mold compression loads also an important control able factors for preparing a high quality TIDSPCs materials.

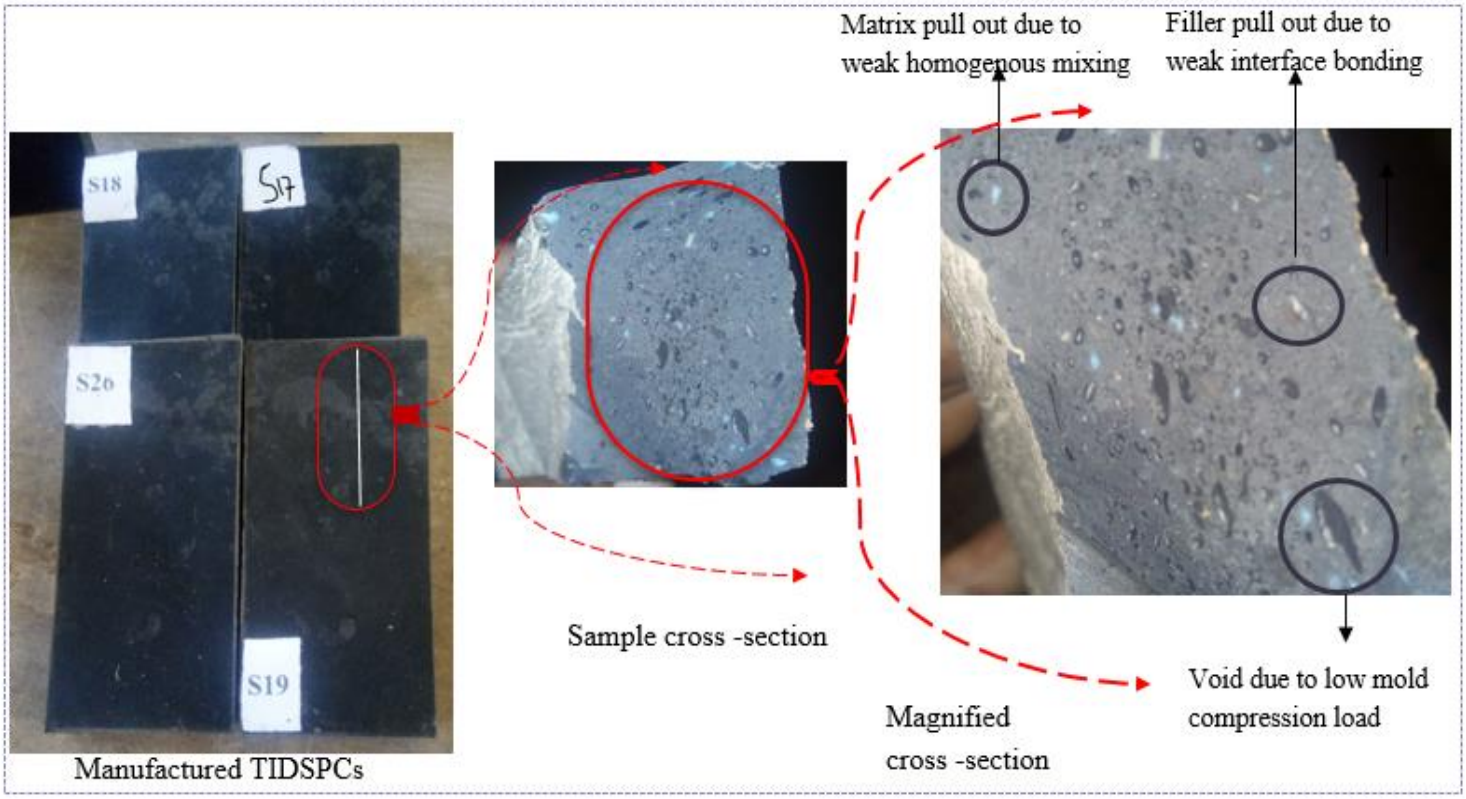


Figure 15. Sample cross-sectional area

4.5 Water Absorption

4.5.1 Effect of Matrices and Fillers Weight Proportion as a Function of Mold Compression Load on Water Absorption. The results of the 22 runs to determine the water absorption, compressive strength, and thermal conductivity of composites based on the corresponding independent variable are tabulated in Table 6. The four factors tested in this study were high density polyethylene (HDPE) % weight proportion, diatomite earth (DE) % weight proportion, and sawdust (SW) % weight proportion in the composition and mold compression load in production processes. The water absorption of the samples ranged from 0.1399 to 1.81%. The maximum water absorption value was 1.81% under the test condition of HDPE:DE:SW (65:25:10) (wt.%) weight proportion and 4 MPa mold compression load; meanwhile, the minimum water absorptio n value was 0.1399 % under the test conditions of HDPE:DE:SW (80:18.3333:1.6667) (wt. %) weight proportion and 10 MPa mold compression. As indicated in figure 16, the water absorption of composite increases with increases in sawdust and diatomite earth weight %proportion contents. This could be due to the formation of less surface interaction between the matrixes (HDPE) and the reinforcements of (SW and DE) when mixed giving higher water absorption (Gebremedhin et al., 2020). This is due to the presence of higher contents of reinforcement loading in the composites that can absorb more water. When the wood sawdust content increase in the composite, the presence of free –OH groups in the cellulose and hemicellulose structure increases, then these hydrophilic wood particles absorb water through hydrogen bonding between water molecule and –OH groups on the surface of wood particles (Idrus et al., 2020; Paul et al., 2018; Turku et al., 2017; Kaewkuk et al., 2013). Similarly the skeleton of the diatomite contains a multitude of pores causing it to have a sponge-like structure so that good-quality diatomaceous earth can absorb water (Abu et al., 2019). The statistical comparative study on water absorption of these composite was examined using combined (D-optimal) method and the effects of the independent variables to the responses are discussed in the next section.

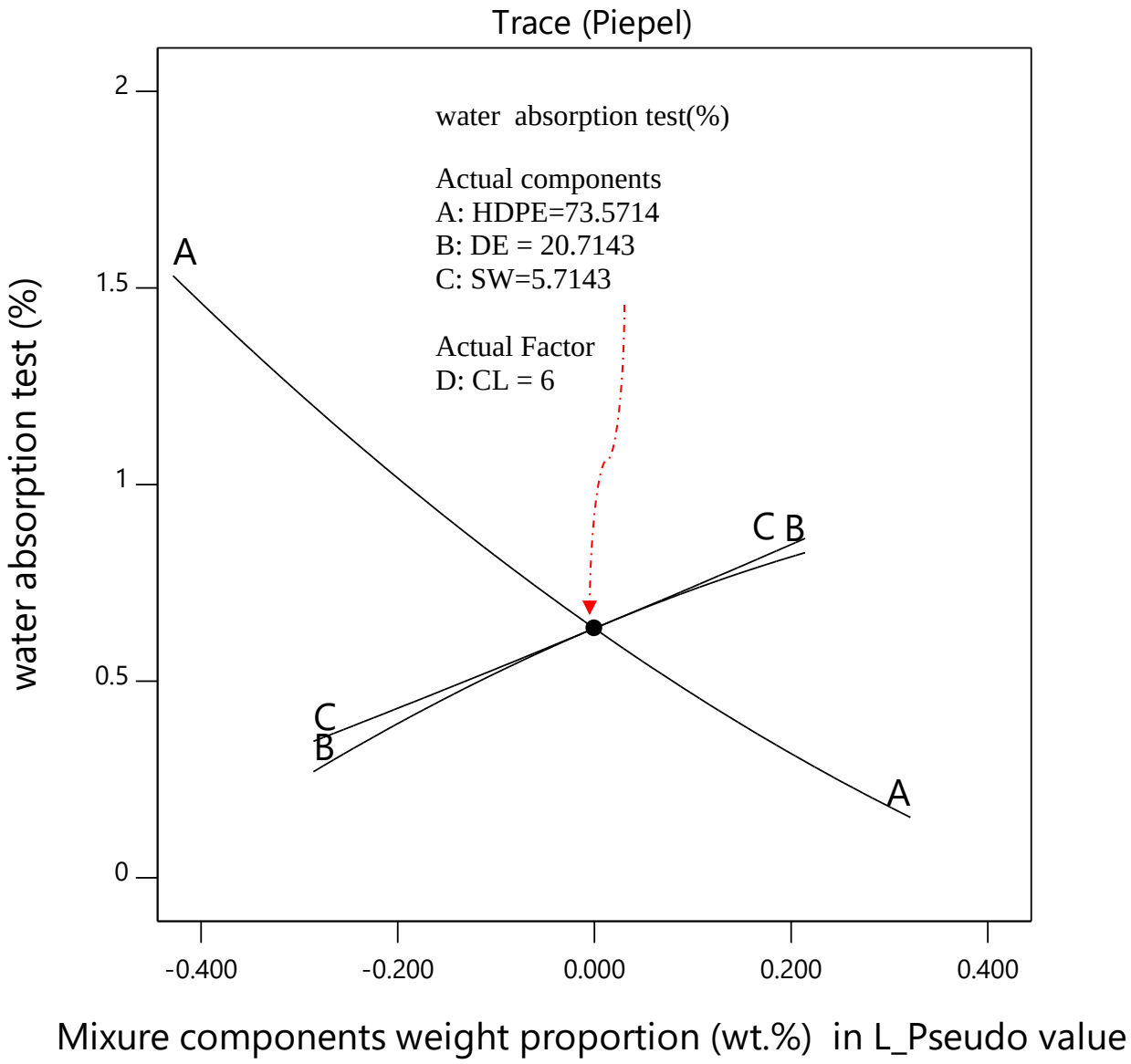


Figure 16. Piepel's response trace plot for water absorption on changing HDPE, DE, and SW weight % proportion L-pseudo value over its range (low level to high level) at (6 MPa) CL keeping constant.

4.6 Compressive Strength

4.6.1 Effect of Matrices and Fillers Weight Proportion as a Function of Mold Compression Load on Compressive Strength.

The result of the 22 runs to determine the compressive strength and other response variables of the composites are tabulated in Table 6. The four factors tested in this study were, the three materials weight proportion i.e. HDPE Weight% proportion, DE weight% proportion, and SW Weight% proportion in composite, and the corresponding mold compression load. The compressive strength of the TIDSPCs composites range from 52.47 to 87.99 MPa. The highest compressive strength value was 87.99MPa under the test conditions of HDPE:DE:SW (72.5:22.5:5) (wt.%) weight proportion and 10 MPa mold compression load. Meanwhile the lowest compressive strength value was 52.47 MPa under the test conditions of HDPE:DE:SW (65:25:10) (wt.%) Weight proportion and 4 MPa mold compression load. As seen from the Figure 17, the compressive strength of the composite increased with the increase polymer matrix (HDPE) weight proportion from 65 to 72.5wt.%, DE weight proportion from 15 to 22.5 wt.%, SW weight proportion from 0 to 5 wt.% and mold compression load increased from 2 to 10 MPa. In fact, there was a decrease in compressive strength for composites of higher weight% proportion of reinforcements (DE+SW) (i.e., > 27.5 wt.%), the fillers (SW+DE) was excessive above this level, that the matrix (HDPE) was not enough to follow through and wet each and every fillers, wich leads the composite leaving voids and the fillers were easily expose to environ mental degradation (Figure 15 and figure 30 B). The interfacial adhesion between fillers and HDPE was not good at this levels of weight proportion (Figure 17). Filler agglomerations occurs thus casing both fillers (DE and SW) dispersion problems in HDPE, which leads to decreased in mechanical strength (Gebremedhin & Rotich, 2020). In the other word, the optimum addition of (22.5 wt.% DE and 5 wt.% SW) weight content of fillers in 72.5 wt.% weigh content HDPE matrix under 10 MPa mold compression load, could increase the strength of the composite by almost 40% as compare with HDPE:DE:SW (65:25:10) (wt.%) and 2 MPa mold compression load made composite. This increase of strength means that the reinforced DHPE became stiff and could withstand higher load. The fillers of DE and SW served as reinforcement, because the major share of load was taken up by thus fillers (Mukherjee et al., 2011). The increase in compressive strength was more significantly affected by the increase in DE weight% proportion content, rather than by the incensement of SW weight% proportion. Because, the typical

chemical composition of diatomaceous earth is 80-90% silica, with 2-4% alumina, and 0.5-2% iron oxide, which exhibits can be withstand more loads (Zurayk et al., 2019). The statistical comparative study on compressive strength of these composite was examined using combined (D-optimal) method and the effects of the independent variables to the responses are discussed in the next section.

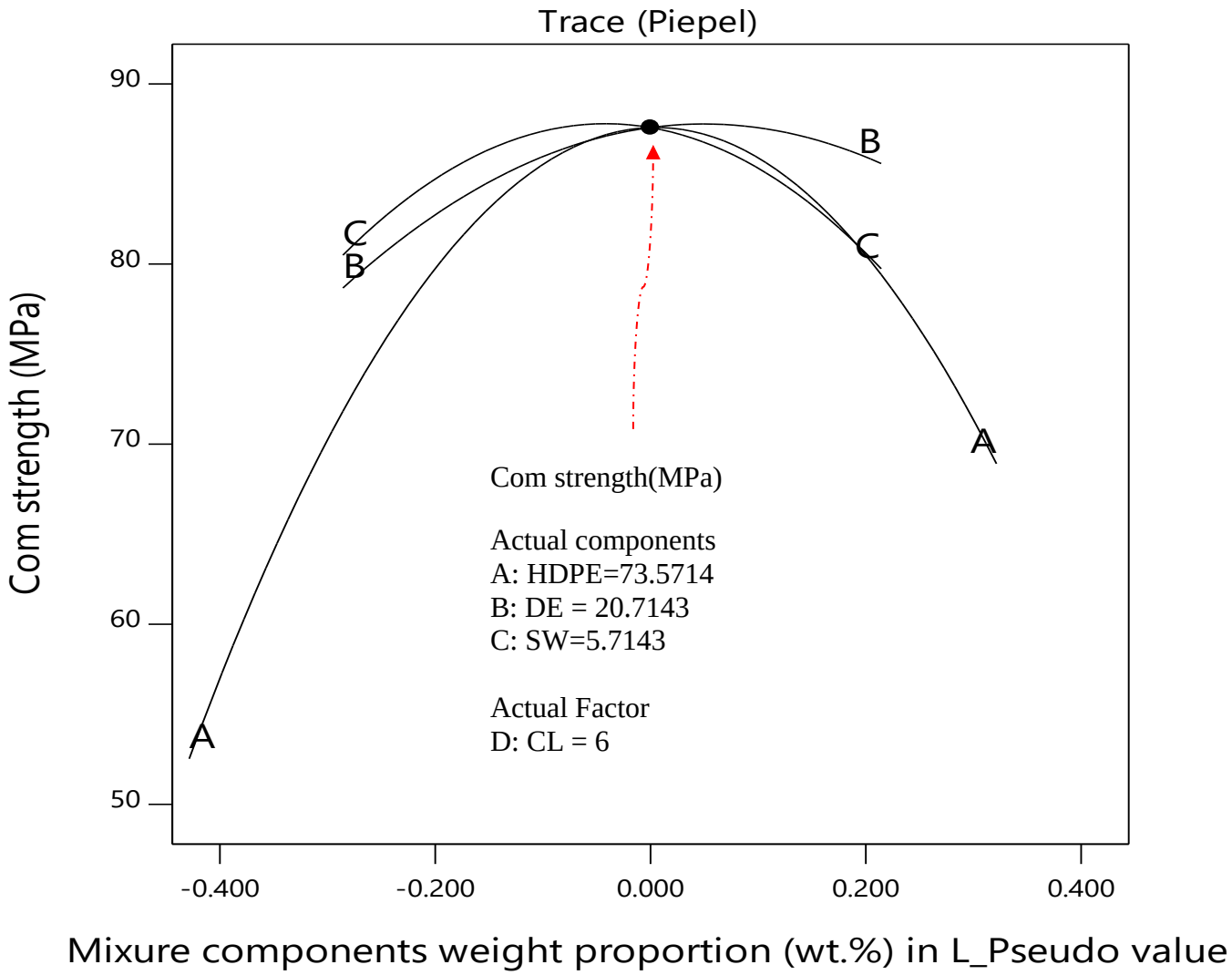


Figure 17. Piepel's response trace plot for compressive strength on changing HDPE, DE, and SW weight % proportion L-pseudo value over its range(low level to high level) at (6 MPa) CL keeping constant.

4.7 Thermal Conductivity

4.7.1 Effects of matrices and fillers weight proportion as a function of mold compression load on thermal conductivity**.**

Under the steady state regime, the measurement of thermal conductivity was conducted using the guarded hot plate method, as function of the temperature at temperature 23-60℃. After achieving the study state regime condition the measured thermal conductivity values of the TIDSPCs composite samples ranged from 0.0115 to 0.04 (W/m.k). The highest thermal conductivity value was 0.04 W/(m.k). Under the test conditions of HDPE:DE:SW (80:18.3333:1 .6667) (wt.%) weight proportion and 10 MPa mold compression; meanwhile the lowest thermal conductivity value was 0.0115W/(m.k), Under the test conditions of HDPE:DE:SW (65:25:10) (wt.%) weight proportion and 2 MPa mold compression. The variation in thermal conductivity of the composite materials highly depends on the weight% proportions of diatomite earth (DE) and sawdust (SW) in HDPE, and slightly depend on the different mold compression load. As observed from (Table 6), when the weight proportion of the diatomite earth (DE) increase from 18.3 to 25 wt.% and sawdust (SW) from 1.7 to 10 wt.% , but (HDPE) decrease from 80 to 65 wt.%, the thermal conductivity of the composites decrease from 0.04 to 0.0115 W/m.k. This reduction is might be principally due to the low thermal conductivity of the diatomite and sawdust that of certainly diminish that of the composite, combined with the creation of air-filled pores created inside the composite by DE and SW incorporation, which contribute to the decrease in thermal conductivity and bulk density (Figure 27). It can be seen that as the bulk density value increases it is accompanied by a decrease in the water absorption and an increase in the thermal conductivity value of the composites. The decrease in thermal conductivity value of the composite was slightly affected by the increase in SW weight % rather than the increase in DE weight% as shown by the gradient of the decrease (Figure 18). These results prove the efficiency of those materials application as interior and exterior wall coating and ceilings. Moreover, those composite construction materials shows a good adherent structure. The statistical comparative study on thermal conductivity of these composite was examined using combined (D-optimal) method and the effects of the independent variables to the responses are discussed in the next section.

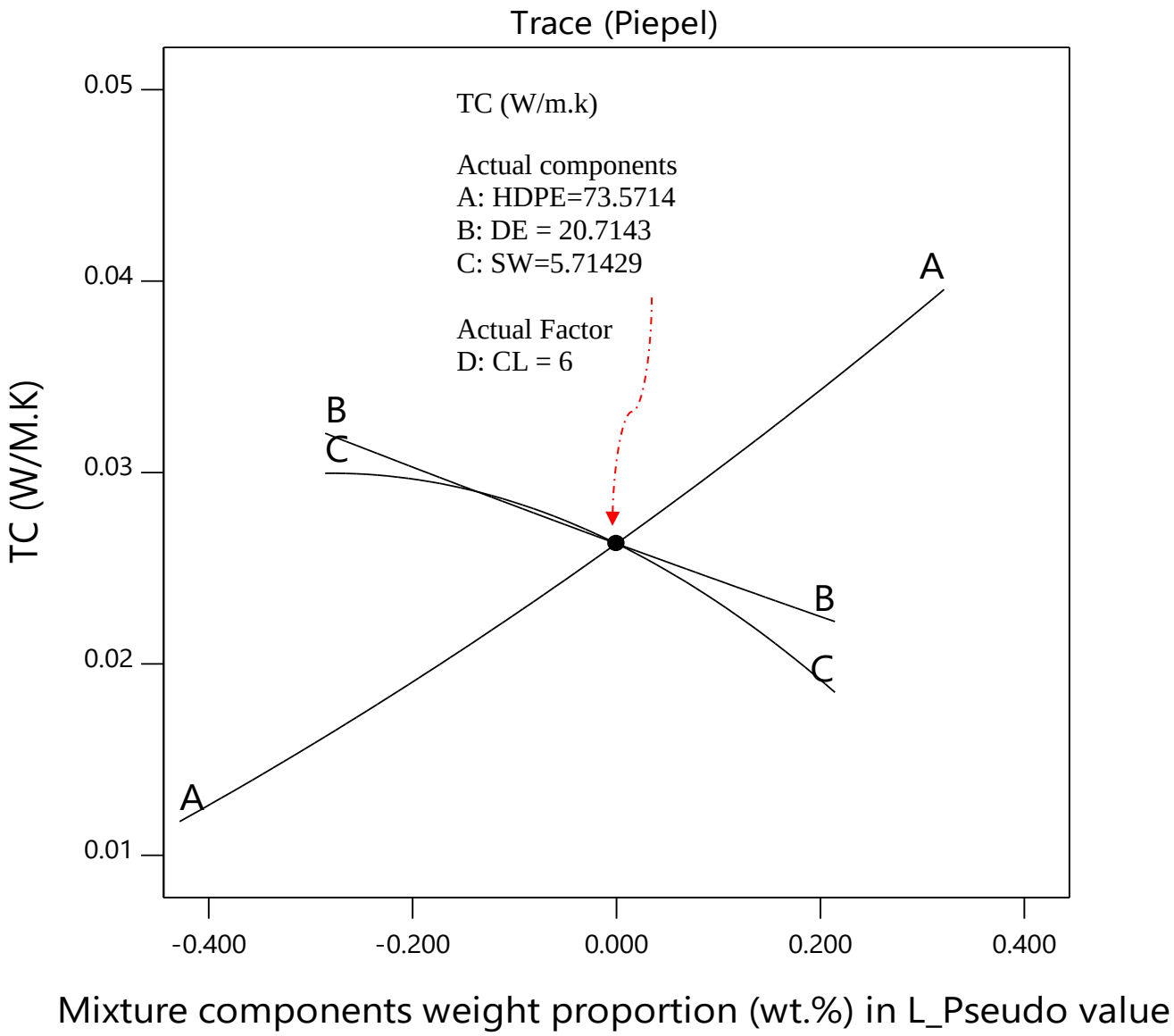


Figure 18. Piepel's response trace plot for thermal conductivity on changing HDPE, DE, and SW weight % proportion L-pseudo value over its range(low level to high level) at (6 MPa) CL keeping constant.

Table 7. The Combined Fitted Model Summary Table for water absorption test

Mixture Order	Process Order	Mixture p-value	Process p-value	Lack of Fit p-value	Adjusted R^2	Predicted R^2	
Q	**L**	**< 0.0001**	**< 0.0001**	**0.2514**	**0.9989**	**0.9952**	**Suggested**
Q	Q	< 0.0001*	0.1544*	0.5318	0.9998		Aliased
SC	L	0.8794	< 0.0001	0.1344	0.9997	0.9925	

Table 8. The Combined Fitted Model Summary table for compressive strength test

Mixture Order	Process Order	Mixture p-value	Process p-value	Lack of Fit p-value	Adjusted R^2	Predicted R^2	
Q	**L**	**< 0.0001**	**0.0029**	**0.3487**	**0.9975**	**0.9701**	**Suggested**
Q	Q	< 0.0001*	0.1988*	0.7793	0.9999		Aliased
SC	L	0.0823	0.0017	0.6903	0.9999	0.9989	

Table 9. The Combined Fitted Model Summary table for thermal conductivity test

Mixture Order	Process Order	Mixture p-value	Process p-value	Lack of Fit p-value	Adjusted R^2	Predicted R^2	
Q	**L**	**< 0.0001**	**< 0.0001**	**0.1098**	**0.9995**	**0.9973**	**Suggested**
Q	Q	< 0.0001*	0.0440*	0.8056	0.9998		Aliased
SC	L	0.5382	< 0.0001	0.0714	0.9994	0.9755	

Model summary statistics: Model summary statistics for water absorption, and compressive strength, and thermal conductivity, analysis.three main models were used to fit the experimental results obtained from batch experiments TIDSPCs preparation (Table 7, 8 and 9). As depicted in the Table, the quadric*linear model with a correlation coefficient (R^2) of 0.9989, 0.9975, and 0.9995 was selected and is suggested for fitting the analysis of the measuring water absorption, compressive strength and thermal conductivity respectively, of the prepared of specimens based on the corresponding independent variables.

4.8 Model selection and verification of water absorption, compressive strength, and thermal conductivity

The collected data was analyzed using software design expert 11. All the responses were analyzed using analysis of variance (ANOVA) and regression analysis for model fitting to evaluate the significance of the coefficient terms. The results are tabulated in Table 7 through 14. The analysis of variance(ANOVA) for quadratic * linear model of water absorption, compressive strength, and thermal conductivity present in tables 10, 11 and 12 respectively. The ANOVA demonstrated that the quadratic * linear regression model of water absorption, compressive strength, and thermal conductivity were highly significant as the *F*-test had very low probability values ($P<0.0001$). Those probability values mean that there were only 0.01% chance that the "model *F* values" of those magnitude could occurs due to noise (Wang et al., 2013). The lack of fit *F* value of 1.89 for water absorption, 1.44 for compressive strength, and 3.27 for thermal conductivity implied that the lack of fits was not significant relative to the pure error. There was a 25.14% for water absorption, a 34.87% for compressive strength, and a 10.98% for thermal conductivity probability that lack of fits *F*-values those magnitude could occurs due to some kind of noise. A non-significant lack of fit is good because a non-significant Lack of Fit shows the model is well fitted and is very nearer to the perfect fitness as it was obtained by the model. The goodness-of-fit of the models was further inspected using the R^2 value. The results showed that R^2 of the model for water absorption, compressive strength, and thermal conductivity were 0.9995, 0.9988, and 0.9998 respectively. In addition, the adequate precision values for the water absorption, compressive strength, and thermal conductivity were well above 4; therefore, all the D-optimal models had the satisfactory values. From the above analysis, it can be concluded that these models are suitable for predicting the water absorption, compressive strength, and thermal conductivity of (DE and SW)-reinforced HDPE composites within the limits of the experiment.

4.8.1 ANOVA for Quadratic x Linear model

Table 10. Analysis of variance for the quadratic *linear model of water absorption test**.**

Source	Sum of Squares	DF	Mean Square	F-value	p-value	
Model	3.05	11	0.2774	6729.16	< 0.0001	Significant
Residual	0.0004	10	0.0000			
Lack of Fit	0.0003	5	0.0001	1.89	0.2514	not significant
Pure Error	0.0001	5	0.0000			
Cor Total	3.05	21				

Table 11. Analysis of variance for the quadratic *linear model of compressive strength.

Source	Sum of Squares	DF	Mean Square	F-value	p-value	
Model	2156.11	11	196.01	9964.54	< 0.0001	significant
Residual	0.1967	10	0.0197			
Lack of Fit	0.1162	5	0.0232	1.44	0.3487	not significant
Pure Error	0.0805	5	0.0161			
Cor Total	2156.30	21				

Table 12. Analysis of variance for the quadratic *linear model of thermal conductivity

Source	Sum of Squares	DF	Mean Square	F-value	p-value	
Model	0.0012	11	0.0001	3690.98	< 0.0001	significant
Residual	3.037E-07	10	3.037E-08			
Lack of Fit	2.325E-07	5	4.651E-08	3.27	0.1098	not significant
Pure Error	7.113E-08	5	1.423E-08			
Cor Total	0.0012	21				

Table 13. ANOVA fit statistics for quadratic * linear model of water absorption, compressive strength and thermal conductivity

Fit Statistics	Std. Dev.	Mean	C.V. %	R^2	Adjusted R^2	Predicted R^2	Adeq Precision
Water absorption	0.0127	0.6373	1.99	0.9995	0.9989	0.9952	178.9957
Compressive strength	0.4708	78.81	0.5973	0.9988	0.9975	0.9701	101.6791
Thermal conductivity	0.0002	0.0254	0.6855	0.9998	0.9995	0.9973	226.8352

Table 14. Regression coefficients and probability values of approximate quadratic *linear model polynomials for response variables in experimental design.

Terms	Water absorption		Compressive strength		Thermal conductivity	
	Coefficient	Probability	coefficient	probability	coefficient	probability
X_1 -High density polyethylene(HDPE)	-0.1062	< 0.0001	27.757	< 0.0001	0.0513	< 0.0001
X_2 -diatomite earth(DE)	1.01	<0.0001	52.0	< 0.0001	0.0135	< 0.0001
X_3 -sawdust(SW)	1.44	< 0.0001	17.6	< 0.0001	-0.0163	< 0.0001
X_1X_2	0.0349	0.5676	179.33	< 0.0001	-0.0259	< 0.0001
X_1X_3	-1.01	< 0.0001	229.076	< 0.0001	0.0325	< 0.0001
X_2X_3	1.23	< 0.0001	70.92	< 0.0001	0.0527	< 0.0001
X_1Z_1	-0.3353	< 0.0001	0.557	0.0332	0.0028	< 0.0001
X_2Z_1	-1.12	< 0.0001	2.5651	0.0078	-0.0080	< 0.0001
X_3Z_1	-0.4396	< 0.0001	-2.891	0.0017	0.0087	< 0.0001
$X_1X_2Z_1$	2.76	< 0.0001	-5.50463	0.0040	0.0118	< 0.0001
$X_1X_3Z_1$	1.48	< 0.0001	4.123	0.0118	-0.0184	< 0.0001
$X_2X_3Z_1$	0.9068	< 0.0001	0.8764	0.5238	0.0004	0.8760

* Z_1 –mold compression load (CL)

The *P*-values for each response were summarized in Table 14. It was found that the terms in the model had a significant effect on the responses, for the water absorption of the composites, the weight % proportion HDPE and weight% proportion DE interaction (X_1X_2 **)** was not significant, while the other model terms were concluded to be significant. For compressive strength and thermal conductivity of the composites, the weight% proportion DE, weight% proportion SW, and mold compression load interaction ($X_2X_3Z_1$ **)** was not significant, while the model terms were all significant ($P < 0.05$). A higher value of regression coefficients can be directly translated to a greater effect of the independent variables on the responses (Chang et al., 2014). HDPE weight% proportion, DE weight% proportion, and mold compression load interaction showed the highest regression coefficient value for water absorption; therefore it can be said that weight% proportion HDPE, weight% proportion DE, and mold compression load interaction, compared to the other variables, had the greatest effect on water absorption. The weight% proportion HDPE and weight% proportion SW interaction showed the highest regression coefficient value for compressive strength; therefore, it can be said that weight% proportion HDPE and weight% proportion SW interaction, compared to the other variables, had the greatest effect on compressive strength. For the thermal conductivity; the weight% proportion DE and weight% proportion SW interaction showed the highest regression coefficient value; therefore, it can be said that weight% proportion DE and weight% proportion SW interaction, compared to the other variables, had the greatest effect on thermal conductivity. Moreover, the positive coefficients for the independent variables indicated a favorable effect on the water absorption, compressive strength, and thermal conductivity properties (Hadi et al., 2018). The negative coefficients among the four the independent variables indicated a partitioning favorable effect on the water absorption, compressive strength, and thermal conductivity properties. The results demonstrated that the composites were best fit by the quadratic* linear regression model for water absorption, compressive strength, and thermal conductivity. The estimated models built for the water absorption, compressive strength, and thermal conductivity methods are represented by the equation (9), (10), and (11) in terms of the coded values. It should be noted, however, that the following equations are only valid within the range of tested conductions: 65wt.% < HDPE weight proportion < 80 wt.%, 15wt.% < DE weight proportion < 25wt.%, 0wt.% < SW weight proportion < 10wt.%, and 2 (MPa) < mold compression load < 10 (MPa).

For the water absorption, the model equation is as follows:

$$Y_1 = -0.1062X_1 + 1.01X_2 + 1.44X_3 - 1.01X_1X_3 + 1.23X_2X_3 - 0.3353X_1Z_1 - 1.12X_2Z_1 - 0.4396X_3Z_1 + 2.76X_1X_2Z_1 + 1.48X_1X_3Z_1 + 0.9068X_2X_3Z_1 \quad (10)$$

For compressive strength, the model equation is as follows:

$$Y_2 = 27.757X_1 + 52.0X_2 + 17.6X_3 + 179.33X_1X_2 + 229.076X_1X_3 + 70.92X_1X_2X_3 + 0.557X_1Z_1 + 2.565X_2Z_1 - 2.89X_3Z_1 - 5.50463X_1X_2Z_1 + 4.123X_1X_3Z_1 \quad (11)$$

For thermal conductivity, the model equation is as follows:

$$Y_3 = 0.0513X_1 + 0.0135X_2 - 0.0163X_3 - 0.0259X_1X_2 + 0.0325X_1X_3 + 0.0527X_2X_3 + 0.0028X_1Z_1 - 0.008X_2Z_1 + 0.0087X_3Z_1 + 0.0118X_1X_2Z_1 - 0.0184X_1X_3Z_1 \quad (12)$$

Where Y is the predicted response; X_1 is weight% proportion of HDPE; X_2 is weight% proportion of DE; X_3 is weight% proportion of SW; and Z_1 is mold compression load.

Figure 20 indicates the relationship between the experimental value and the predicted value of water absorption (a), compressive strength (b) and thermal conductivity (c). The variation is quite close between the experimental value and predicted value, which represents that model employed, is a perfect fit, and the development of correlation meets a substantial level. The R-squared indicates the percentage of fluctuation in the responses and it also finds out how well the model conforms to the experimental data (Shah et al., 2018). Furthermore, the variance in R-squared predicted (99.52%) and R-squared adjusted (99.89%) for water absorption, R-squared predicted (97.01) R-squared adjusted (99.75%) for compressive strength and R-squared predicted (99.73%) and R-squared adjusted (99.95%) for thermal conductivity is less than 20% (Table 13); hence, no changes are needed in the regression model. The R^2 value for water absorption, compressive strength, and thermal conductivity of 0.9995, 0.9988, and 0.9998 respectively. These R^2 values indicate that only 0.05% of the water absorption, 0.12% of the compressive strength, and 0.02% of the thermal conductivity variation were not explained by the models.

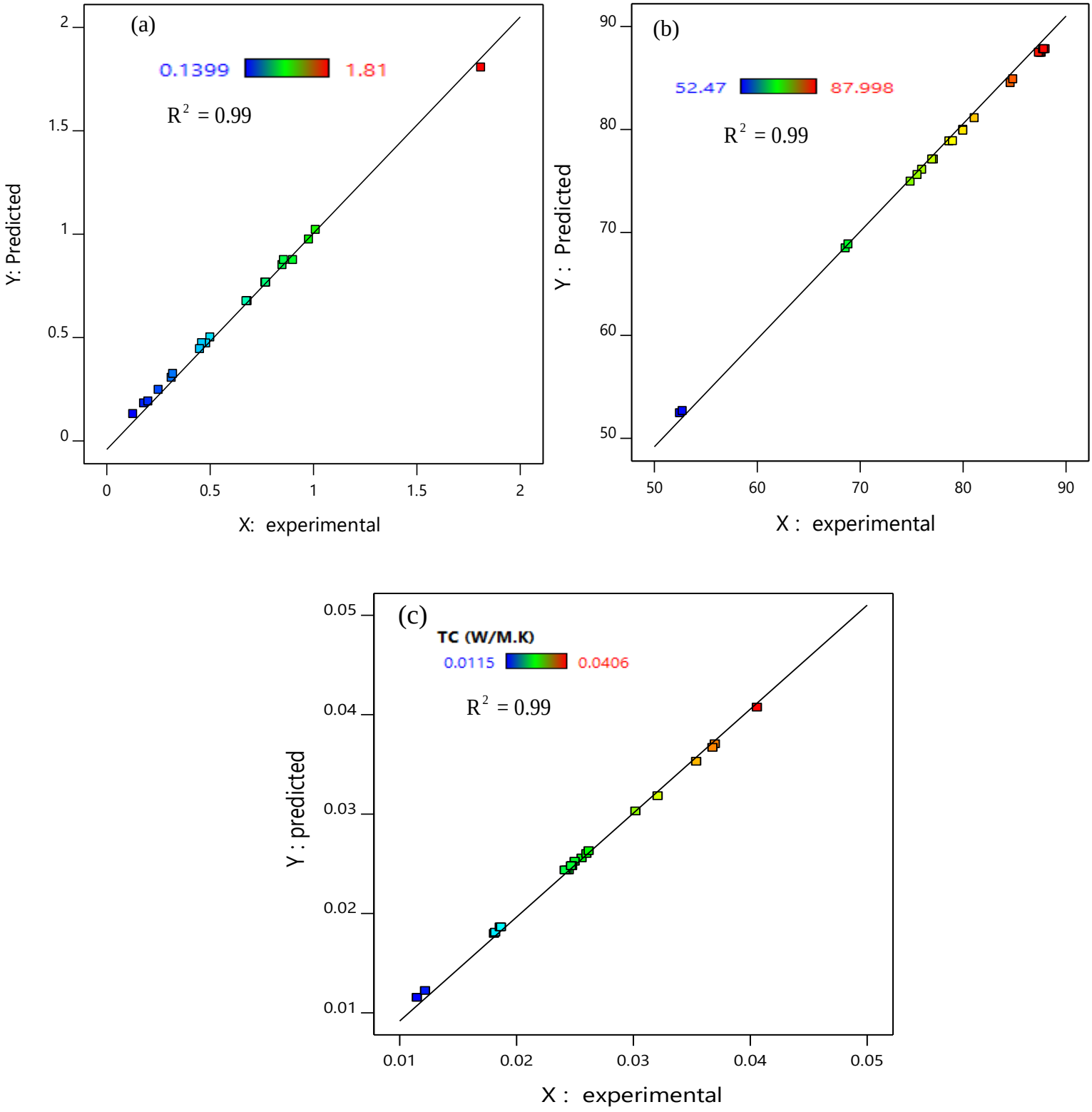


Figure 19. Correlation of predicted response versus experimental response: (a) water absorption, (b) compressive strength and (c) thermal conductivity

4.9 Effect of process parameters.

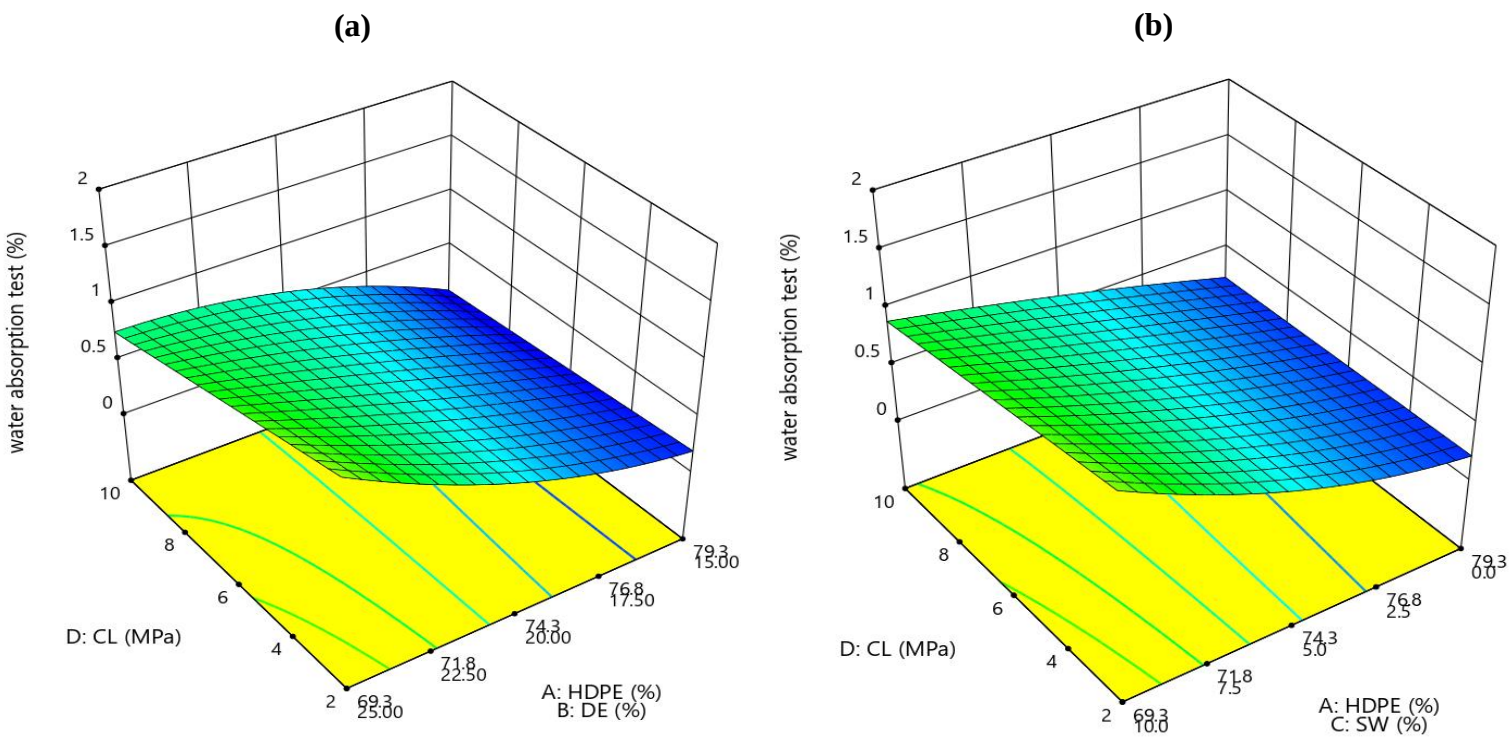
The 3D response surface plots of the interaction effects of the independent variables of weight % proportion HDPE, weight% proportion DE, weight % proportion SW, and mold compression load on water absorption, compressive strength, and thermal conductivity are shown in Figure 21, 22 and 24, according to equation (9), (10), and (11), respectively. In this study, 3D response surfaces were obtained by keeping one of the variables constant at a optimal level while varying the other three variables.

Both sawdust and diatomite earth structures possess rich hydrophilic groups, which will result increased water absorption as increase in mass percentage. The absorption mainly depends on the open porosity of the materials. These pores are produced in large numbers during the introduction of high weight% loads of diatomite earth (DE) and sawdust (SW) in HDPE (Figure 30B). The increase in water absorption was Slightly more affected by the increase in DE weight % rather than the increase in SW weight% as shown by the gradient of the increase (Figure 20 a and b). This is because, skeleton of the diatomite contains a multitude of pores causing it to have a sponge-like structure so that good-quality diatomaceous earth can absorb water (Abu et al., 2019). Another reason was may be due to the formation of less surface interaction between the matrix and fiber when mixed togher giving more water absorption (Dhakal et al., 2017). (DE and SW) have a robust polar characteristic because of various functionalities, resulting in increased water absorption at high loadings (Özdemir et al., 2019; Tabil et al., 2017). Polarity also creates voids because of the poor compatibility between hydrophilic fiber reinforcement and the polymer matrices (Özdemir et al., 2019; Tabil et al., 2017). Two or more Samples which are prepared with the same experimental conditions except mold compression load were present in Table 6. The sample which was prepared using the lowest compression load, had the highest water absorption values, resulting in the insulation composites having lighter structure and many separate voids. On the other hand, the lowest water absorption values was obtained for the samples which were prepared using higher mold compression load. Thus resulting in insulation composite having tighter structure and fewer voids. Another determining factor of the water absorption properties of the composites is the particle size as well as the particle size distribution, the larger the particle surface area, the more polymer resin required to fully coat it (Adewale et al., 2020). Also as regards of the size distribution, a higher percentage of small particles (particle

≤ 0.5mm ensures more effective coating from the polymer resin which will improve the water resistance(Adewale et al., 2020). This inference is implied in the study done by Chaudemanche et al. (2019) on wood based polyethylene. Because long immersion tests are necessary for evaluating the long therm performance of the thermal insulation materials. We performed immersion in distilled water for 72 hr at 25℃. The water absorption of TIDSPCs remined almost constant after 24hr immersion. Acording to ASTM AC62, the maximum water absorption value must be 17% for building thermal insulation composite materials when severe weathering considered (Munoz et al., 2020). Incase of negligible weathering water absorption is must be below 25% (Munoz et al., 2020). On the contrary, Eurocode 6 states a maximum water absorption ranges between 4.7% and 7% when insulation composite materials are used for facing walls (Schroeder et al., 2017). The water absorption of TIDSPCs samples considered in this study were lower than the above maximum standard water absorption requirement of the building thermal insulation materials. Lower than that reported for polymeric insulation materials, including polyester scrap tire(2.5-8.6%) (Abu et al., 2016), polyurethanes (1.8-5.6%) (Wan et al., 2017), and building blocks reinforced with mineral wool and sisal (3.6-8.7%) (Gutierrez et al., 2017), starch/PLA composite (1.5-4.5%) (Yang et al., 2013), modified mud bricks(10.8-25.6%) (Tiskatine et al., 2018), polyphenolic insulation board(1.9-3.8%) (Sun et al., 2020), poly(lactic acid)/date pit composites (1-8%) (Saeed et al., 2020) and (pine nut shell/corn straw)- Polypropylene (PP) insulation composite (1.4-4%) (Wang et al., 2021).

Table 15 Comparsion of thermal conductivity of bio-based reinforced composites(at 25 ℃)

Polymer	Bio-based fillers	Fillers amount (wt.%)	Time(days)	Water absorption(%)	Reference
Polyester	Emirati red shale	30	1	0.2	Abu et al., 2018
Polystrene	Isoberlinia doka wood	20	3	36.13	George et al., 2021
Polystrene	Banana fibres	27.1	1	29.90	Arun et al., 2016
Phenol formaldehyde	Date plam fibres	35	2	10.3	Mounika et al., 2017
Bisohenol	Date plam fibres	25	3	4.5	Sulaiman et al., 2019
Polyester	Waste wool	30	4	4	Patnaik et al., 2015
Waste HDPE	DE/SW	27.5	3	0.603	This study



I **(a)** the combined effect of DE and HDPE weight % proportion versus mold compression load (CL) on water absorption (%),at optimum SW weight % proportion.

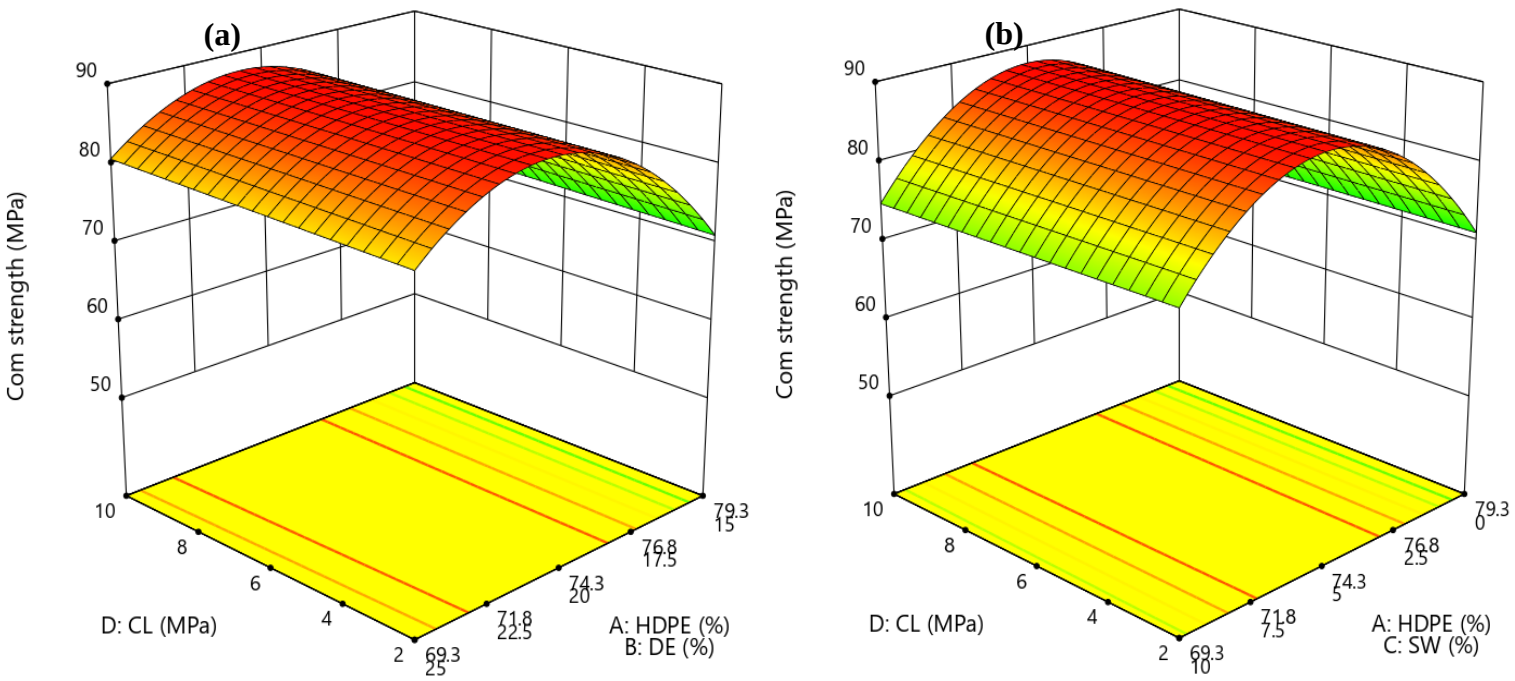
II **(b)** the combined effect of SW and HDPE weight % proportion versus mold compression load (CL) on water absorption (%), at optimum DE weight % proportion.

Figure 20. Response surface plot on water absorption.

As seen in the Table 6, the highest compressive strength value was found for sample PS17 made of 72.5:22.5:5 (wt.%) (HDPE:DE:SW) and 10 MPa mold compression load. As reported by Islam, this may be due to the effect of satisfactory mechanical interlocking or entanglement of the polymer chain matrix with the Sawdust (SW) and Diatomite earth (DE), which results in effective stress transfer from the matrix to the reinforcement (Islam et al., 2015). The forgoing result show that as the amount of mold compression load increase in the composite the compressive strength slightly increased (Figure 21). Thus resulting in insulation composite having tighter structure and fewer voids and also may be improve the composites interlocking or entanglement of the polymer chain matrix with the Sawdust (SW) and Diatomite earth (DE). In other word the effects of DE and SW weight % contents on the compressive strength of the insulation HDPE:DE:SW composite materials are shown in (Figure 21 a) and (Figure 21 b) repactively. The result in Figure 21 show that the compressive strength of the produced composites increases with the increase in the SW and DE Contents together up to 27.5 wt.%. This is due to the reinforcement imparted by the SW and DE which allows stress transfer from the matrix to the SW and DE, higher DE/SW filler –HDPE matrix compatibility, insulation composites being more compact or dense, and good interfacial bonding between the reinforcements and matrix (Ferede, 2020). Be said of this, as seen from the Figure 21 that the compressive strength of the produced insulation composites increases with the increase in the HDPE contents up to 72.5 wt.%. This increment in compressive strength, as a result of increment of HDPE weight proportion (wt.%) content, can be attributed to the intrinsic adhesion enables good stress transfer from the polymer matrix to DE and SW particles during stressing, causing an increase in compressive strength up to the optimum levels (Agnantopoulou et al., 2012). However, as it is clearly seen in Figure 21, the increment of the percentage of HDPE content beyond 72.5 wt.%, results in decline of the compressive strength of the produced composites. This decrease is attributed to the inability of the reinforcement to support stresses transferred from the polymer matrix, and poor interfacial bonding generates partially spaces between reinforcement and matrix, materials which generate weak structure (Agnantopoulou et al., 2012). This was similar to the finding in previous studies (Jdayicl et al., 2016, Gordobil et al., 2015).

The produced samples in this study showed a compressive strength between 52.47 MPa and 87.998 MPa. In particular, Compressive strength and water absorption indexes are limited by the moste standards stablish depending on the weathering and or the type of masonary walls end-use.

In particular ASTM AC62 states most restrictive values. Thus, 20.7 MPa is the minimum compressive strength and 17% the maximum water absorption for building thermal insulation composite materials when severe weathering is considered (Munoz et al., 2020). In case of negligible weathering compressive strength must be above 10.3 MPa (Munoz et al., 2020). On the contrary, Eurocode(EN) 6 states a minimum compressive strength of 5 MPa and maximum water absorption ranges between 4.7% and 7% when insulation composite materials are used for facing walls (Schroeder et al., 2017). However, according to ANSI (American National Standard Institute) the minimum compressive and flexural strength standard value is 16 MPa for building thermal insulation materials which can be used for load-bearing structures (Chen et al., 2018). The compressive strength of TIDSPCs samples considered in this study were exceeded the above minimum standard compressive strength requirement of the building thermal insulation material s. Greater than those of the traditionally used insulation materials (between 2 and 10 MPa) (Khedan et al., 2011), comparable to the strength of the building materials, such as cement with natural pozzolan (60.8MPa), poly(lactic acid)/date pit composites (64.4 to 84.3 MPa)(Saeed et al., 2020), poly(lactic acid)/date palm wood (~65MPa) (Abu et al., 2021) and better than that of concrete (40MPa) (engineeringtoolbox.com/concrete properties, 2020; Yetgin et al., 2016, Lakraff et al., 2012). In addition, the compressive strength is very high compared with those of other thermal insulation materials such as polyester and its composites; their compressive strength was 10.3 to 19 MPa (Abu et al., 2016), the strength was higher than those associated with some of the building insulation materials (between 2.4 and 3.3 MPa) (Khedari et al., 2010) and soil cement blocks reinforced with mineral wool and sisal fibers (the compressive strength was 3 to 4.5 MPa) (Gutierrez et al., 2017). The compressive strength may be further improved by adding chemical modifiers of spent brewery diatomite earth and adding compatibilizers to improve the filler-polymer interface (Gordobil et al., 2015).



X1=A: HDPE
X2 = B: DE
X3 = D: CL
Actual component
C: SW =5.7

Design-Expert® software
Factor coding: actual

52.47 87.998

Maximum compressive strength (MPa) value

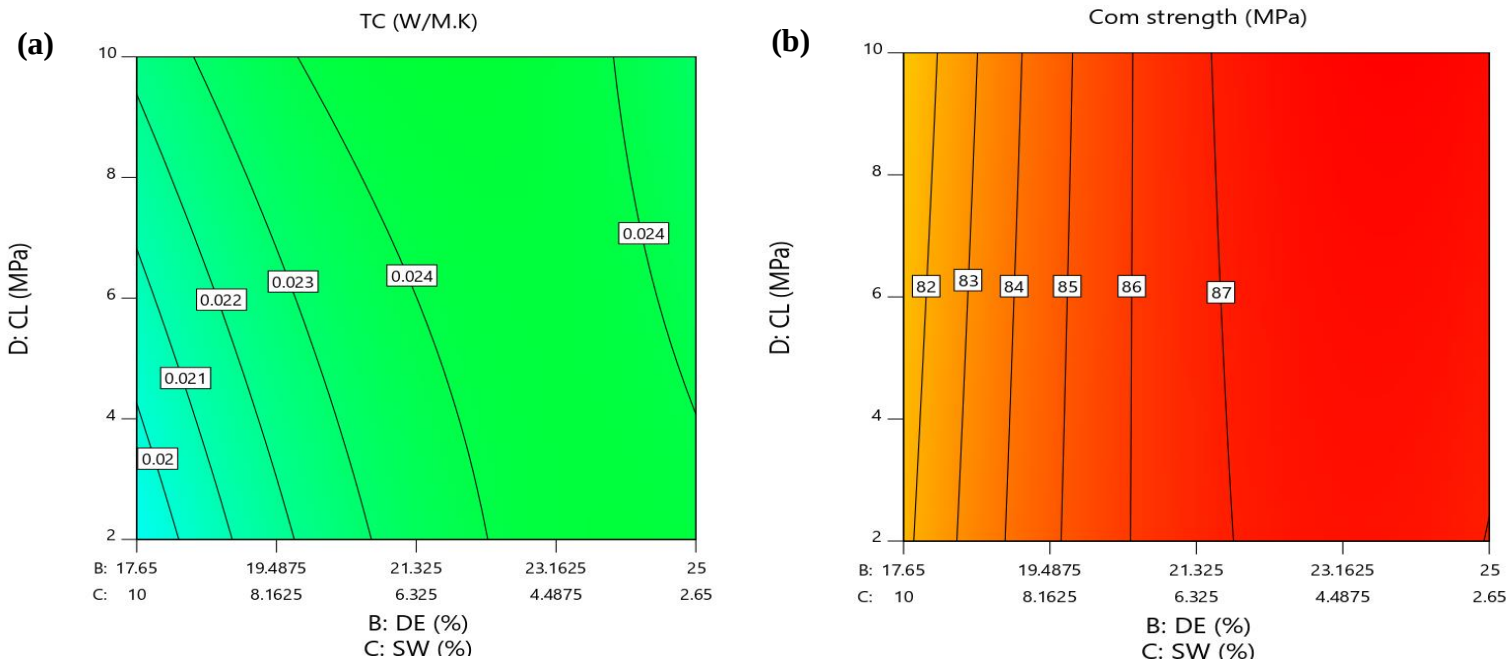
Minimum compressive strength (MPa) value

X1=A: HDPE
X2 = C: SW
X3 = D: CL
Actual component
D: DE =20.7

I **(a)** the combined effect of DE and HDPE weight % proportions versus mold compression load(CL) on compressive strength (MPa), at optimum SW weight % proportion.

II **(b)** the combined effect of SW and HDPE weight% proportions versus mold compression load (CL) on compressive strength (MPa), at optimum DE weight % proportion.

Figure 21. Response surface plot on mechanical strength.



X1=B: DE
X2 = C: SW
X3 = D: CL

Actual component
A: HDPE loading = 72.35

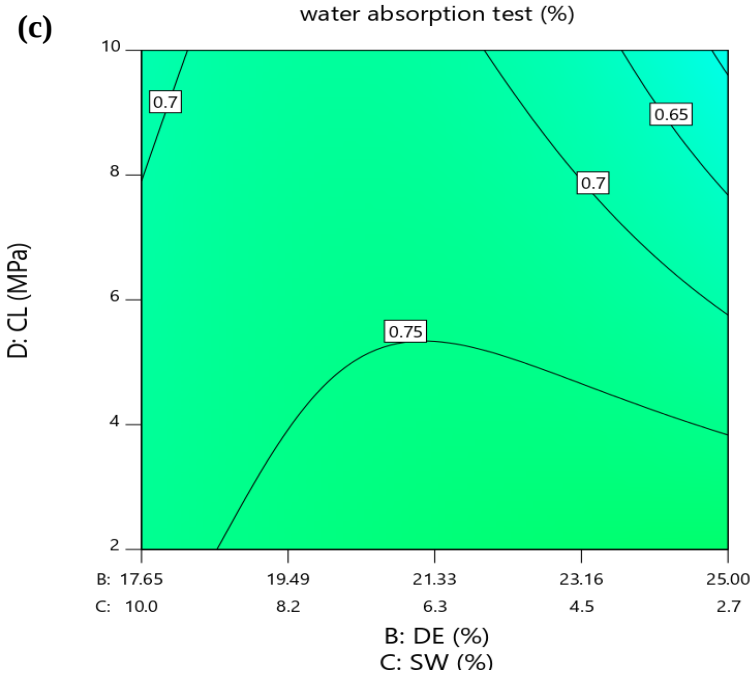
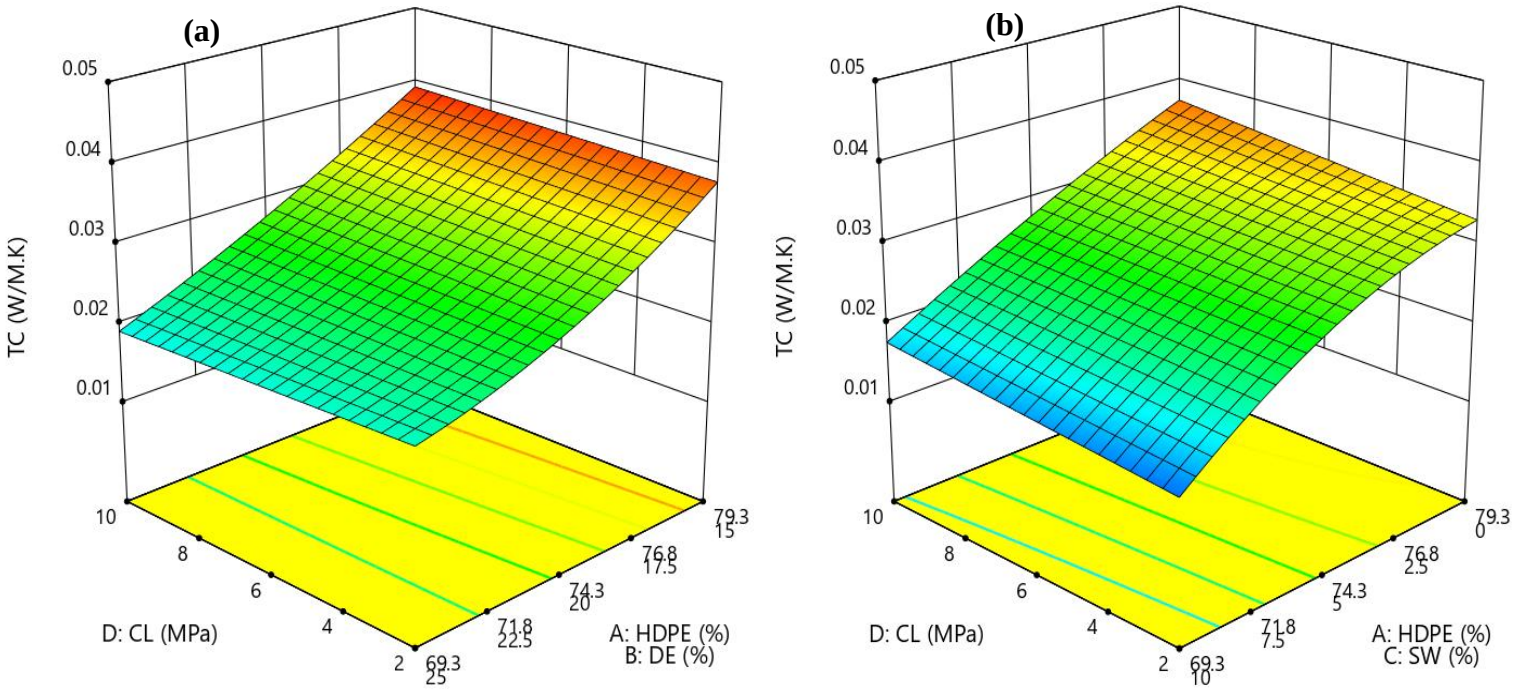


Figure 22. At optimum HDPE weight % proportion, the combined effect of DE and SW weight % proportion versus mold compression load (CL) **(a)** on thermal conductivity(w/(m.k)), **(b)** compressive strength (MPa), and **(c)** water absorption (%).

The thermal insulation performance of materials is determined by the magnitude of thermal conductivity coefficient (λ). The smaller the thermal conductivity of the material, the better the thermal insulation performance of the materials. Thermal conductivity of concreate is approximately 1.74 W/(m.k). Thermal conductivity of ordinary cement mortar is 0.93 W/(m.k). Thermal conductivity of air is 0.0112 W/(m.k) (Jiang et al., 2015). Which is a much smaller than that of the solid thermal insulation composite and cement based materials. Therefore, when the material contains a closed and uniform pores, the resistance of heat transfer speed is greatly reduced. It why porous organic or inorganic insulation material filler -polymer based composites have the functions of heat preservation and heat thermal insulation (Rashidi et al., 2018; Zhang et al., 2015). As tried to discussed in the above and seen in the (table 6), the highest value of the thermal conductivity was obtained for sample PS6 made of HDPE:DE:SW (80:18.3333:1.6667 (wt.%)) and 10 MPa mold compression load composite, this appears to be related, to the high HDPE (wt.%) Content present in the insulation composite. As observed in the (Table 6) samples which was prepared using the highest HDPE (wt.%) contents, had the highest thermal conductivity values. When the weight% proportion of HDPE increased from 65% to 80%, the thermal conductivity of the composite increased by 71.7 %. This may be due to thermal conductivitive proporties of the pure HDPE is higher than the thermal conductivitive proporties of the DE and SW (Figure 18). And also the samples which were prepared using higher mold compression load have higher thermal conductivity cofficent (λ). Thus may be in insulation composite having tighter structure and fewer voids, which can be directly affects the thermal insulation capacity of the composites. As the mold compression load increased from 4 to 10 MPa the thermal conductivity of the sample was increased by 5.7% when compared with the samples (PS12 vs PS19), which were prepared using the same experimental conditions (Table 6) except mold compression load. As observed from (Table 6) the samples which was prepared using lower mold compression loads, had the lowest thermal conductivity values resulting in the insulation composite having lighter structure and many separate voids. Generally the forgoing result show that as the amount of HDPE weight % proportion contents and mold compression load increase, the thermal conductivity cofficent (λ) values of the samples increased (Figure 23).



X1=A: HDPE
X2 = B: DE
X3 = D: CL
Actual component
C: SW =5.7

Design-Expert® software
Factor coding: actual

TC (W/M.K)
0.0115 0.0406

X1=A: HDPE
X2 = C: SW
X3 = D: CL
Actual component
D: DE =20.7

- Maximum thermal conductivity(W/m.k) value
- Minimum thermal conductivity (W/m.k) value

I **(a)** the combined effect of DE and HDPE weight% proportion versus mold compression load (CL) on thermal conductivity(W/m.k),at optimum SW weight % proportion.

II **(b)** the combined effect of SW and HDPE weight % proportion versus mold compression load (CL) on thermal conductivity (W/m.k), at optimum DE weight % proportion.

Figure 23. Response surface plot on thermal conductivity

although increasing the perecentage of HDPE increase the thermal conductivity of the composite, it was still lower than that of some other developed polymer-natural fiber filler composites (Gulitah et al., 2019). The low value of the thermal conductivity of the composite can be explained by the porous nature of the fillers (Spent brewery diatomite earth and Sawdust) fibers. The results show that, in general, thermal conductivity coefficients of the insulation TIDSPCs materials were lower than 0.1 W/(m.k), below which a materials is classified as an insulation materials according to TS805 EN601 (Binici et al., 2018). As well as very promissing when it is compared with those of other materilas used for similar applications, such as composite containg date plam fibers (0.075-0.6 W/(m.k)) (Ameh et al., 2015). Hem fibers (0.115 W/(m.k)) (Basim et al., 2019), and banana fibers (0.117W/(m.k)) (Azeez et al., 2017). On the other hand, thermal conductivity of composites reported here is much lower is much less than the thermal conductivity of hem, jute, and glass fiber – reinforced polyester compiste studied by (Raju et al.(2019), as the thermal conductivity of their composites varied between 0.207 and 0.190 W/(m.k)) at 30℃. Morever, another some comaration of the present study with ecological and conventional thermal insulation materials are shown in Table16.

Table 16. Comparison of thermal conductivity vs density of the present study with conventional and ecological thermal insulation materials

thermal insulation Composite material	Thermal conductivity(W/(m.k)) at room temperature(25℃)	Density(Kg/m^3)	Reference
plaster/ pea pod fibers	0.4 -0.5	1000-1100	Azzouzi et al., 2020
plaster/olive fibers	0.4-0.5	1400-1450	Liuzzi et al., 2018
gypsum plaster/chicken feathers waste	0.3-0.4	1000-1100	Ouakarrouch et al., 2020
polystyrene	0.2-0.3	50-100	Vilasmil et al., 2019
Plaster/ spent coffee grounds	0.3-0.4	1200-1300	Lachiheb et al., 2019
Glass wool	0.1-0.2	100-1000	Vilasmil et al., 2019

Plaster/ hemp	0.1-0.2	1200-1300	Mazhoud et al., 2016
polyurethane	0.03-0.1	1100-1200	Vilasmil et al., 2019
date pit/polystyrene	0.0515-0.0562	457-650	Abu et al., 2019
banana/sisal-polyester	0.181-0.213	1000-1200	Abu et al., 2016
diatomite/sawdust-high density polyethylene	0.0115-0.0406	441.86-667.5	present work

4.10 Optimization of the expriments.

Optimial (combined) design (D-optimality) methodology was used to optimize the conditions for the preparation of composites. The design of expriment was carried out using Design Expriment 11. In the optimizations selection, there were four factors for a goal to construct desirability indices: HDPE weight % proportion, DE weight % proportion, SW weight % proportion, and mold compression load. After optimization, there were some solutions for the thermal conductivity, water absorption, and compressive strength proporties as shown in Table 14. The goal for both thermal conductivity and water absorption of the composites was to minize the conduction and water uptake proporties of the composites; therefore, the target value of the responses was the lowest values from the exprimental results obtained, and for the compressive strength, the goal of the composites was to maximize the strength; therefore, the target value of the responses was the highest values from the exprimental results obtained. The optimization of the responses of thermal conductivity, water absortpion, and compressive strength is displayed in Figure 24. In this study, thermal conductivity, water absorption, and compressive strength properties of the thermal insulation biocomposites compromised with 72.13 wt.%, 25 wt.%, 2.8688 wt.%, and 10 MPa mold compression load (CL) had 75.6% desirability. These levels the independent variables yeild the highest response of mechanical (Compressive strength) : 87.579 MPa, and the lowest responses of thermal conductivity and water absortpion: 0.023 (w/(m.k)) and 0.603 % , respactively. This study found that the addition of DE and SW contents increased in HDPE matrix, could decreased the thermal conductivity of the composite, but increased the water absorption capacity of the composites. In addition, as the DE/SW weight proportions increased up to 27.5 wt.% in HDPE polymer matrix, the compressive strength of the composite

increased. However, the addition of DE/SW weight proportions above 27.5% wt.% caused a decreasing compressive strength of the composites due to the inability of the reinforcement to support stress transfer from the polymer matrix (Ferede, 2020).

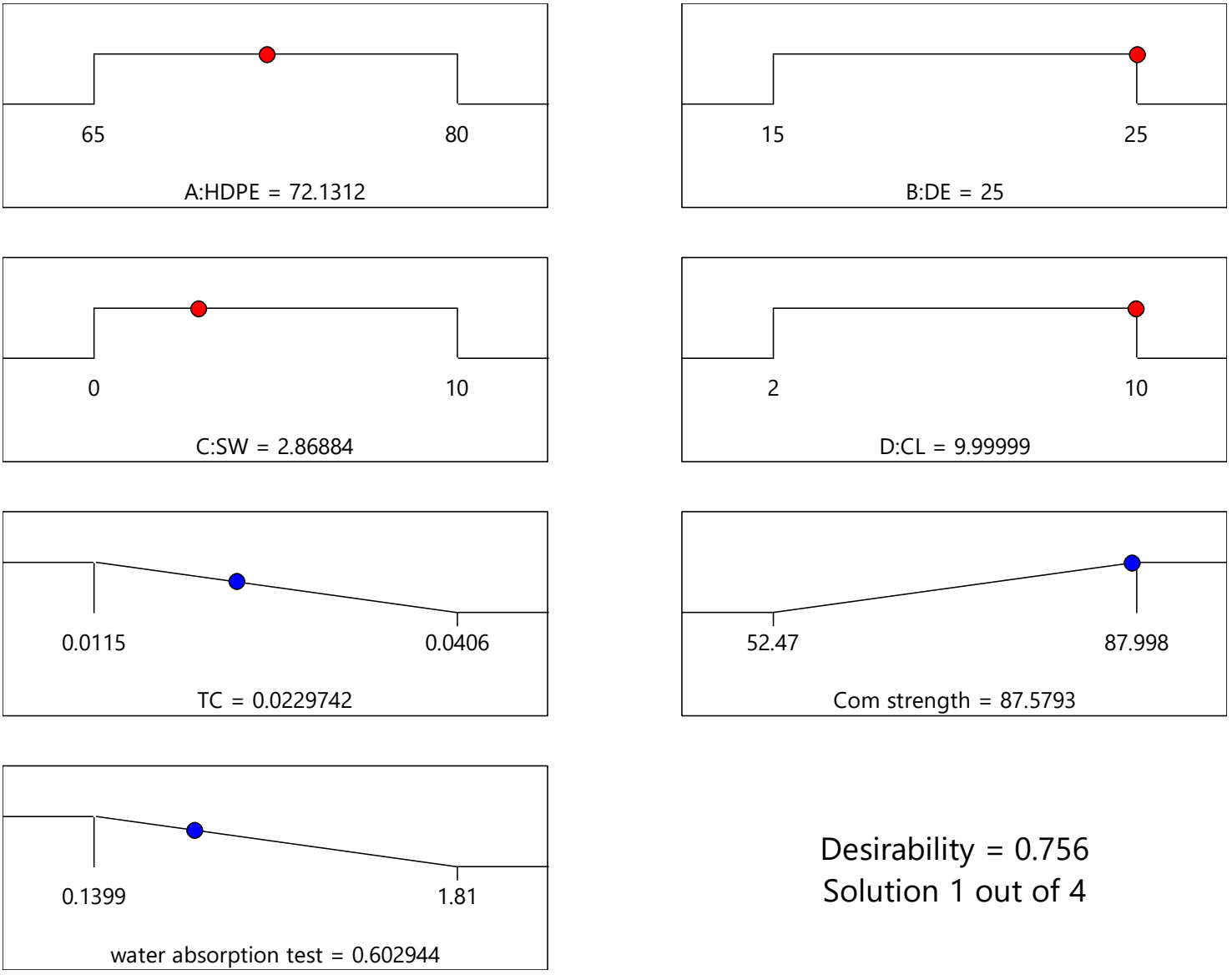


Figure 24. Optimum condition of the independent variables and the responses of the TIDSPCs

4.11 Model validation

To confirm the developed model, triplicate experiments were conducted using the predicted optimum process parameters that were obtained by a design expert software and the average value was reported in Table17. These optimum points were HDPE weight proportion 72.13 wt%, DE weight proportion 25 wt%, SW weight proportion 2.8688 wt% and mold compression load 10 MPa. For checking validation, the experimental value, predicted value, and the percentage of error are required and listed in (Table 17). As observed from the confirmation result in (Table 17), the percentage accuracy was 99.7 %, 99.6 %, and 99.96% for water absorption, compressive strength, and thermal conductivity respectively. It was found that the predicted and experimental values were close to each other. There were only small percentage differences (< 5%) between the predicted and experimental values. Thus, the validity of the model was confirmed (Raju et al., 2019).

Table 17 Model validation for optimization of response variables

	HDPE wt%	DE wt%	SW wt%	CL (MPa)	Predicted value	Exprimental value	% Error	% Accuracy
	72.13	25	2.8688	10				
Water absorption (%)					0.603	0.600	0.3	99.7
Compressive strength(MPa)					87.579	87.575	0.4	99.6
Thermal conductivity(W/(m.k))					0.023	0.022602	0.04	99.96

4.12 Characterization of another important properties of the developed TIDSPCs materials

The features of the composites' flexural strength, thermal diffusivity, specific heat capacity, bulk density, thermal stability and morphological properties that were not studied by the design of the

experiment software are also investigated based on the varying independent parameter levels, as shown in Table 6.

4.13 Flexural strength

4.13.1 Effects of Matrices and Fillers Weight Proportion as a Function of Mold Compression Load on Flexural Strength. The properties of flexural strength TIDSPCs at different HDPE, DE and SW weight proportion and mold compression load content are shown in (Figure 26). The measured flexural strength values of the TIDSPCs ranged from 50.8125 to 94.2 Mpa. The highest flexural strength value was 94.2 Mpa (PS17), under the test condition of HDPE:DE:SW (72.5:22.5:5) (wt. %) weight proportion and 10 MPa mold compression load. Meanwhile, lowest flexural strength value was 50.8125 Mpa (PS12), under the test condition of HDPE:DE:SW (65:25:10) (wt.%) weight proportion and 2 MPa mold compression load. Generally the result showed that the flexural strength increase with the increase in HDPE proportion from 65 to 72.5 wt% , DE from 15 to 22.5 wt %, and SW from 0 to 5 wt % and mold compression load from 2 to 10 MPa. This is due to strong interfacial bonding between the (DE/SW) and HDPE matrix, and probably more stress transfer from the matrix HDPE to the (DE/SW). The increment in flexural strength, as a result of diatomite earth (DE) and sawdust (SW) incorporation at optimum weight proportion of HDPE, can be attributed to the intrinsic adhesion of the (DE/SW) – matrix HDPE interface, this adhesion enables good stress transfer from the polymer matrix to inorganic additive and wood particles during stressing, causing an increase in the flexural strength up to the optimum levels (Agnantopoulous et al., 2012). The increase in flexural strength with an increase in the DE and SW weight fraction at optimum weight proportion of HDPE (72.5wt.%), reveals that the incorporation of the wood sawdust and spent brewery diatomite earth in to the matrix provides effective reinforcement (Ferede, 2020). But, as compare to DE with SW, an increase in the weight% proportion amount of DE leads to more increase the flexural strength of the composites, this may be that the chemical structur proportie of DE, which contain 90% silica ($SiO_2.nH_2O$) is can withstand more loads than wood particle fibrous materials. The flexural strength of the composite slightly increase when the mold compression load increase frome 2 to 10 MPa under the same experimental condition, this is due to that as mold compression load increases resulting in insulation composite having tighter structure and fewer voids which directly relating the mechanical properties of the composites, and this may be help in composites

more stress transfer from the matrix HDPE to the reinforcement of (DE/SW). These are clearly representing in samples (PS2 and PS18), (PS4 and PS17), and (PS12 and PS19) (Figure 25) which were prepared under the same experimental conditions except mold compression load (Table 6). From this result, it can be observed that the optimum flexural strength was achieved at 22.5 wt. % DE, 5 wt. % SW, 72.5 wt. % HDPE and 10 MPa mold compression load. However, the flexural strength of the produced composites starts decreasing with further addition of DE and SW weight proportion above 22.5 wt.% and 5 wt.% respectively, as well as HDPE weight proportion decreasing below 72.5 wt.% (Figure25 i.e.PS12 and PS19). This decrement might be due to the poor interfacial interaction between the DE/SW and HDPE. This could happened due to the availability of more DE/SW particles per unit cross-section area of the composite, HDPE polymer resins not enough to fill it and hence the fracture stress concetration (breaking strength) increases. The reduction in flexural strength as the DE/SW content increased, can also be, attributed to the weak interfacial bonding between fillers (hydrophilic) and the matrix polymer (hydrophobic), which decreased the flexural strength of the composite because of the inability of the reinforcement to support the stress transferred from the polymer matrix. In general this weak interfacial adhesion allowed the formation of micro crack and particle agglomerates due to preferential particle – particle interaction as well as no uniform stress transfer from the DE/SW particle to the matrix (Gulitah et al., 2019; Islam et al., 2015). The decrement in flexural strength with an increase in the DE/SW weight % proportions is probably due to either the aggregation of DE/SW or insufficient bonding between the HDPE matrix and the DE/SW. Usually, the orientation of the DE/SW in the composites influence the flexural strength of the particles or fibers- reinforced composite (Ferede, 2020). This happens because as the DE/SW weight % proportion increases, weak interfacial area between the DE/SW and the matrix (HDPE), due to the hydroxyl group in the DE and SW increases. On other hand, the increase of filler content also produced more filler end, this means that there are consider able stress concentration points, and the poor interfacial bonding cases partially separated micro space between DE/SW and polymer matrix HDPE (Raman et al., 2010). However, the flexural strength values of the TIDSPCs considered in this study were greater than those of the traditionally used insulation materials (between 2 and 8.9MPa) (Khedan et al., 2011), comparabl e to the strength of the building materials, such as cement with natural pozzolan (56.8MPa), and better than that of concrete (45MPa) (engineeringtoolbox.com/concrete properties, 2020; Yetgin

et al., 2016, Lakraff et al., 2012), exceeded the ANSI (American National Standard Institute) minimum specification thermal insulation materials flexural strength standard value 16 MPa (Chen et al., 2018). In addition, the flexural strength is very high compared with those of other thermal insulation materials such as polyester and its composites; their flexural strength was 7.5 to 20 MPa (Abu et al., 2016), the strength was higher than those associated with some of the building insulation materials (between 2.5 and 4.3 MPa) (Khedari et al., 2010) and soil cement blocks reinforced with with mineral wool and sisal (the flexural strength was 2.7 to 4.5 MPa) (Gutierrez et al., 2017). The flexural strength may be further improved by adding chemical modifiers of diatomite earth and compatibilizers to improve the filler-polymer interface (Gordobil et al., 2015).

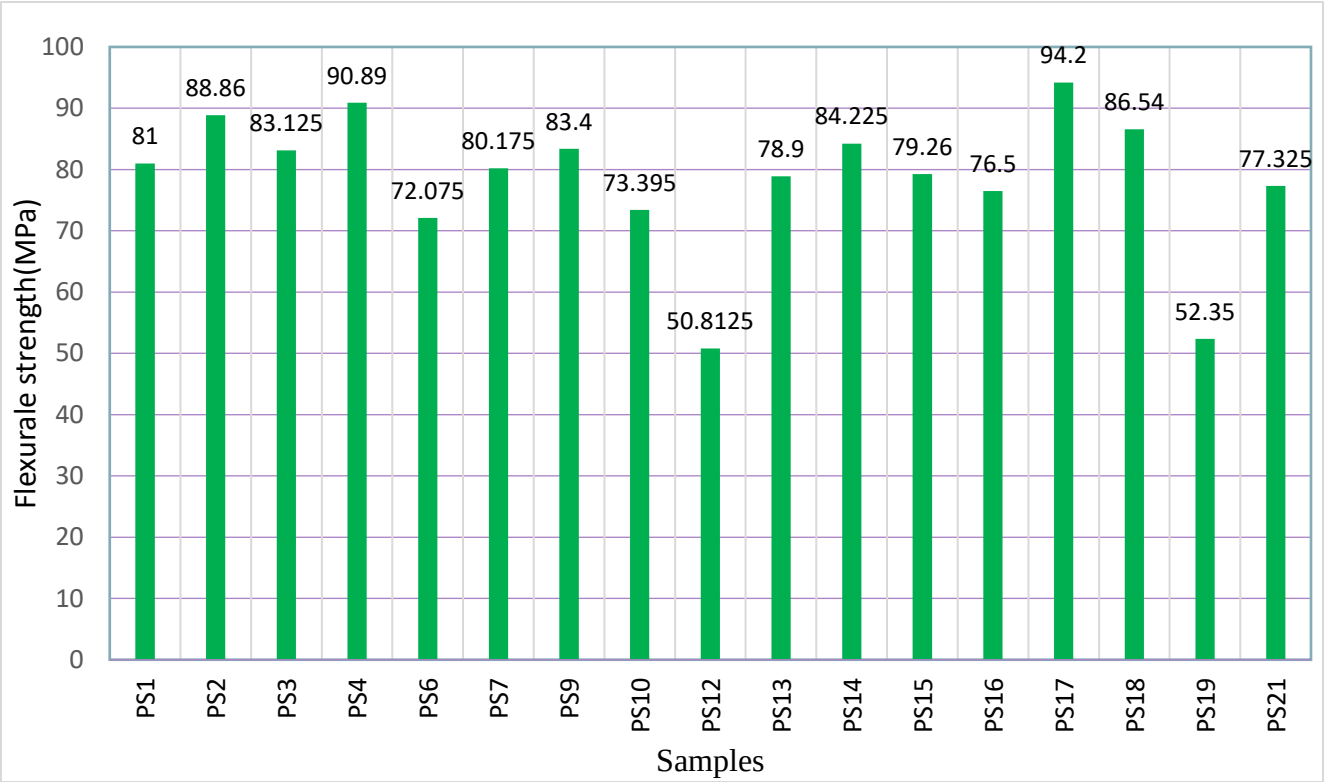


Figure 25. The flexural strength value of TIDSPC materials

4.14 Bulk density

4.14.1 Effects of Matrices and Fillers Weight Proportion as a Function of Mold Compression Load on Bulk Density. The density refers to the mass per unit volume of a materials and is measured in kg/m^3. A high-density material maximizes the overall weight and is a feature of high thermal mass materials. The exprimental density was calculated as the ratio of the weight to the measeurd vlume of the prepared samples. The bulk density density of pure HDPE, DE and SW were 970 kg/m^3, 220 kg/m^3, 124 kg/m^3 respactively (Table4). The density of the composites decreased with the increased DE and SW content (Figure 26). The considerable decreased the composite density with the increasing of DE and SW weight% proportion contents, was may be atributed to the extremely low density of DE and SW and addition of more reinforcement of (DE/SW) made more voids in composites due to agglomerates. Under the same exprimental condition, as mold compression load of the composite increased the density value of the composites increased, due to the volume of the samples were decreased (Figure 26 PS6 and PS10). Moreover, the density of TIDSPCs was lower compared to that of the polyester –filled tire and poly(lactic acid)/date pit thermal insulation composites, which were reported to be 700kg/m^3 -1200 kg/m^3 and 800-1200kg/m^3 respactively (Saeed et al., 2020). And other natural fiber based composites like banana(1350 kg/m^3) and sisal (1450kg/m^3) (Abu et al., 2019). The difference in densiy was more prominent compared to the thermal insulation materials listed in previous study (Tiskatine et al., 2018).

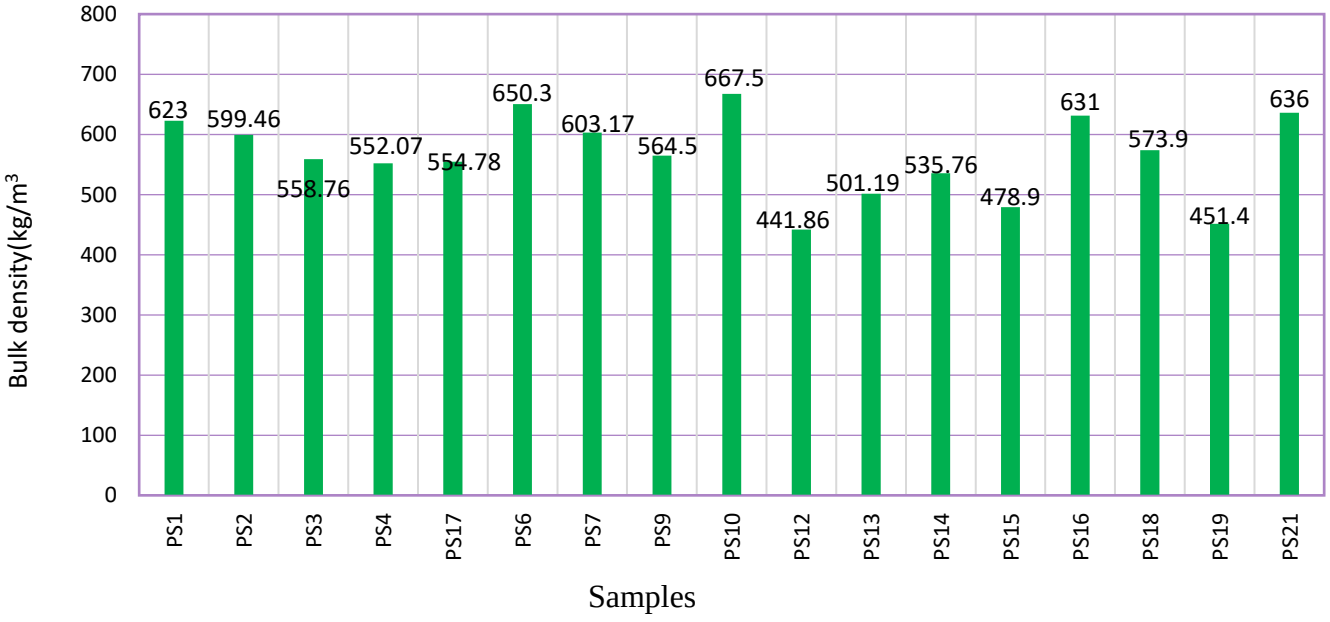


Figure 26. The apparent density value of TIDSPC materials.

4.15 Specific heat capacity

4.15.1 Effects of Matrices and Fillers Weight Proportion as a Function of Mold Compression Load on Specific heat Capacity. The specific heat capacity of the HDPE:DE:SW composites was measured via DSC by considering a temperature of 25 ℃. The specific heat capacity varied from 1688.57 to 1915.93 J/(kg.k). The maximume specific heat capacity value was 1915.93 J/ (kg.k) (PS12), which obtained under the test condition of HDPE:DE:SW (65:25:10) (wt.%) weight proportion. Meanwhile, the minimum specific heat capacity value was 1688.57 J/(kg.k) (PS16), under the test condition of HDPE:DE:SW (78.3333:15:6.6667) (wt.%) weight proportion. The variation of mold compression load on specific heat capacity value of the composite was insignificant, the specific heat capacity values of the composite was strongly depand on the weight % proportion contents of the samples. Generally, when the DE and SW contents ranged from 15-25 wt % and 0-10 wt % increase respectively had increased the specific heat capacity (C_P) value of the TIDSPCs. The lowest specific heat capacity value was obtaned 1688.57 J/(kg.k) under the test conditions of HDPE:DE:SW (78.3333:15:6.6667) (wt%) i.e. PS16 composite, followed by the HDPE:DE:SW (80:18.3333:1.6667) (wt %) i.e.PS6 composite with a specific heat capacity of 1700.04 J/(kg.k). The increase in the specific heat capacity value was significantly affected by the increase DE weight% content rather than the SW weight% content, as shown by the gradient of the increase (Figure 27. PS9 and PS18). The specific heat capacity of a materials is the amount of heat needed to raise the temperature of 1Kg of the materials by 1K(or by ℃). A good insulator has a higher specific heat capacity, meaning it takes time to absorb more heat before actual heating up (showing a temperature raise) and transfering the heat it absorped. High specific heat capacity is a feature of materials providing thermal mass or thermal buffering. The specific heat capacity values of the developed TIDSPCs were higher than those of another composite made of fishtail plam polyester, which had 900 J/(kg.k) at 30 ℃ (Ramanaiah et al., 2013), poly (latic acid)-date pit (1208.4 to 1652.3 J/(kg.k) at 25℃ (Saeed et al., 2020), to that of traditional insulators such as expaneded polystrene(1200-1400 J/(kg.k), polyurethan(1300-1450 J/(kg.k), rock wool(1000 J/(kg.k) and fiberglass(830 J/(kg.k) (Tiskatine et al., 2018). Moreover, the composites out perform many other building materials, including

concrete (1000J/(kg.k)), brick (800 J/(kg.k)), and gypsum plaster (1000 J/(kg.k)) (Greenspece, Accessed 5 April 2020).

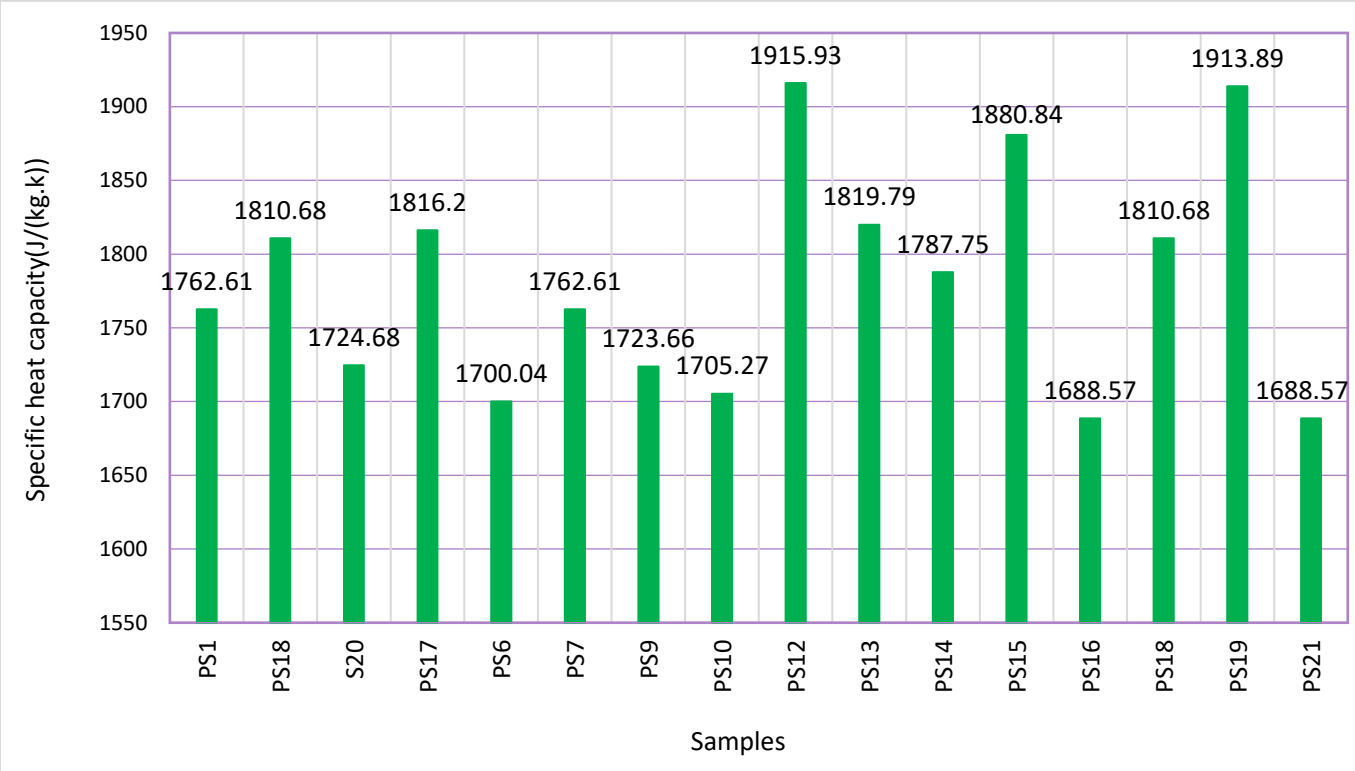


Figure 27. The specific heat value of TIDSPC materials

4.16 Thermal diffusivity (α)

4.16.1 Effects of Matrices and Fillers Weight Proportion as a Function of Mold Compression Load on Thermal Diffusivity. Thermal diffusivity indicates the rate of heat transfer in a material from the hotter extremity to the cooler end. The thermal diffusivity is obtained, as described in EQ.(13) (Saeed et al., 2020), by dividing the thermal conductivity (λ) with density (ρ) and specific heat capacity (C_P).

$$\text{Thermal diffusivity } (\alpha) \ \frac{\lambda}{\rho * C_p} \qquad (13)$$

Thermal diffusivity is considered as an essential parameter for heat conduction analysis because it measures the ability of a materials to conduct thermal energy relative to its ability to store it. Figure 28 present the thermal diffusivity of the TIDSPCs samples. When the DE/SW weight proportion contents increase, the thermal diffusivity (α) value of the sample was decreased. The highest thermal diffusivity value was 0.035778 mm^2/sec, under the test condition of

HDPE:DE:SW (80:18.3333:1.6667) (wt.%) weight proportion and 10 MPa mold compression load. Meanwhile, the lowest thermal diffusivity (α) value was 0.01358 mm^2/sec, under the test condition of HDPE:DE:SW(65:25:10) (wt.%) weight proportion and 2 MPa mold copression load. This indicating a reduction of ~62.0% compared with that of the HDPE:DE:SW (80:18.3333:1.6667) (wt.%) composite. Generally as the weight % proportion of the DE and SW increased, the thermal duffusivity of the composite decreased. Because, the specific heat capacity (C_P) increased and thermal conductivity decreased, as increased the DE/SW weight % proportion contents in the composite. Which, exhibited an increment of by ~11.3% for specific heat capacity as well as reduced by 71.7% for thermal conductivity in the composite (65:25:10) (wt.%) (i.e. PS12) compared with that of the composite (80:18.3333:1.6667) (wt.%) (i.e. PS10) . The thermal diffusivity of the composite was highly depand on the weight % proportion content of the mixure components, rather than the mold compression load of the composite. The thermal diffusivity (α) observed in this study was lower than those observed in the case of fiber-concrete composites (α = 0.37 - 0.31 mm^2/sec) (Miao et al., 2013*)*, construction rocks such as granite (α = 0.8 – 0.103 mm^2/sec) (Othuman et al., 2014) and thermal insulation poly (lactic acid) date pit composite (α = 0.0549 - 0.0342 mm^2/sec) (Saeed et al., 2020). Thus, the addition DE/SW in HDPE matrices enhanced the thermal insulation characteristics of the composites because the thermal diffusivity (α) and thermal conductivity(λ) value of the TIDSPCs samples very low.

Table 18.Thermal properties of TIDSPCs with different weight % proportion of DE, SW and HDPE, as well as mold compression load.

trials	Thermal conductivity(W/(m.k)	Apparent Density(kg/m^3)	Specific heat capacity(J/(kg.k)	Thermal diffusivity(mm^2/s)
PS1	0.0321	623.0	1762.61	0.02923215
PS18	0.0262	599.46	1810.68	0.02413789
PS20	0.025	558.76	1723.66	0.02595751
PS4	0.0245	552.07	1815.23	0.02444783
PS17	0.02476	554.78	1815.23	0.02458658
PS6	0.037	650.3	1700.04	0.03346793

PS7	0.0302	603.17	1762.61	0.02840606
PS9	0.026	564.5	1723.66	0.02672131
PS10	0.0406	667.5	1700.04	0.03577796
PS12	0.0115	441.86	1915.93	0.01358418
PS13	0.0187	501.19	1819.79	0.02050302
PS14	0.0181	535.76	1787.75	0.01889738
PS15	0.0182	478.9	1880.84	0.02020574
PS16	0.0182	631.0	1688.57	0.01708138
PS18	0.0256	573.9	1810.68	0.02463554
PS19	0.0122	451.4	1915.23	0.01411164
PS21	0.0368	636.0	1688.57	0.03426665

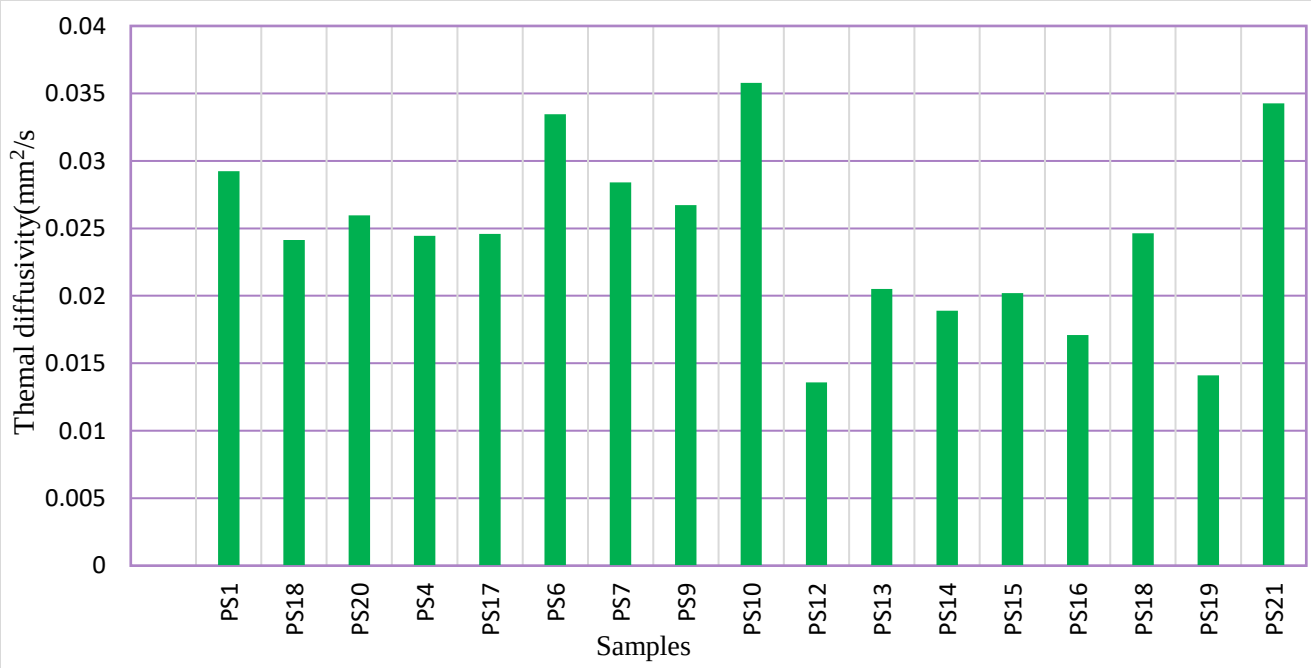


Figure 28. The thermal diffusivity value of TIDSPC materials

4.17 Thermal stability

4.17.1 Effects of Matrices (HDPE) and Fillers (DE and SW) Weight Proportion as a Function of Mold Compression Load on Thermal Stability. Weight change with temperature in PS10, PS22,PS17 and PS18 Composites is shown in Figure 29. Referring to the TG profile, TIDSPCs mainly demonstrate over three regions of weight loss. The weight of PS10, PS22 and PS17 were almost constant until it reached a temperature of 150℃, but the weight of PS18 which was prepared using HDPE:DE (75:25) (wt.%) was almost constant until it reached a temperature of 250℃. After that, the weight of the composites reduced moderately in the temperature range of 150-350℃ and 250-350℃ for the samples of (PS10, PS22, PS17) and PS18 respactively, before dropping sharply between 350-500℃. In the next stage, the weight reduced steadily until 650℃. The frist stage of weight loss may be due to the volatilization of absorbed water, mold polished oil and other oganic highly volatile non polymeric additives (Scuracchio et al., 2017). The second degradation stage may be due to the decomposition of lignocellulose, hemicellulose and cellulose parts of sawdust (SW) and some volatile parts of organic compound additives like starch in spent brewery diatomite earth, while the degradation of HDPE may explain the third degradation stage (Belhassen et al., 2019). The remaining constant weight loss occurring above 650℃ may explain the silica part of diatomite earth, which can resist up to 1100℃(Shah et al., 2014). Moreover, the temperature at which the composite loses 5% (T5*) and 50% (T50*) of its initial weight and the temperature for the maximum rate of material decomposition(T_{max}) are given in Table 19.

The addition of DE in the HDPE:SW composites had two effects: increase in intial degradation temperature and reduction in weight loss of the composites. The temperature at which the composites suffered a weight loss of 5% from its initial weight increase from 230℃ for PS10 (HDPE:DE:SW) (80:18.333:1.667) (wt.%) to 277, 299 and 318 for PS22, P17 and PS18 respactively. And a weight loss of 50% from its initial weight increase from 452℃ for PS10 to 456℃, 460℃ and 475℃ for PS22, PS17 and PS18 respactively. The maximum weight loss was about 94.25% for sample PS10, attributed to the thermal stability of SW and HDPE as well as their phase compatibility with DE. This is because the high weight content of HDPE in the composite(PS10) which is allowing easily heat follow to the composites and rise the degradation process. The maximum decomposition peak in the TG profile which accounts major weight loss, the shifted of the degradation temperature took place from 622 to approximately 667℃ for

HDPE:DE:SW (80:18.3333:1.6667) (wt.%) and HDPE/DE (75/25) (wt.%) composites respe ctively. The maximum weight loss also seems to reduced from 94.25% for PS10 to 86.5% for the composite which was prepared using higher weight proportion content of DE (PS18). As shown in the Figure 29 and Table 19, except for sample PS10 which contained 80 wt.% HDPE, thermal degradation was decreased up on addition of high weight % proportion content of DE ,showed best enhancement of thermal behavior (lowest thermal degradation, highest T_{max}(℃)). This can attributed to the fact that the presence of Diatomite earth (DE) hindered diffusion of volatile decomposition products caused by the dispersed DE particles. This effect is larger for composite, with an increased the weight proportion content of SW in the composites (PS17 and PS22). Theoretically, the reduction in weight loss indicates enhancement in thermal stability (Wang et al., 2015). It is noted that, DE has not weight loss at low temperature and this justifies the improved thermal stability. In fact the presence of metal oxides in DE such as silica, aluminum, iron, and magnesium are responsible for this improvement (Othman et al., 2016). The remarkable reduction in weight loss of this composite (PS18. Table 19) results from the fact that, during the composition, the silicate layers with high aspect ratios are able to migrate towards the surface, followed by a char barrier layer formation which could be sustain high temperatures and hinder heat and mass transfer effectively (Hemati and Garmabi, 2010). Furthermore, the initial weight lose and the residual weight of the PS17 sample increased by approximately 7.35% and 2.8% respectively, compared with that of PS22 sample which were prepared using the same experimental conditions except mold compression load (PS17 higher and PS22 lower) mold compression load. Thus resulting in the insulation composite having tighter structure, the fillers consistently dispersed and fewer voids, leads to enhancing the weight loss. In the case of polymer composites, dispersion of filler in polymer matrix play in a significate role in changing thermal behavior (Jose et al., 2012). Generally increasing the filler content significantly reduced the weight loss, particularly for higher-filler-content of DE composites and at temperature of less than 650℃.

Table 19. Decomposition temperature of the composites

Sample	T5*(℃)	T50**(℃)	T_{max} (℃)	Overall mass change (%)
PS18	318	475	667	86.5
PS17	299	460	646	90.04
PS22	277	456	640	92.0
PS10	230	452	622	94.25

*Temperature at which 5% weight loss occurs, **Temprature at which 50 % weight loss occurs

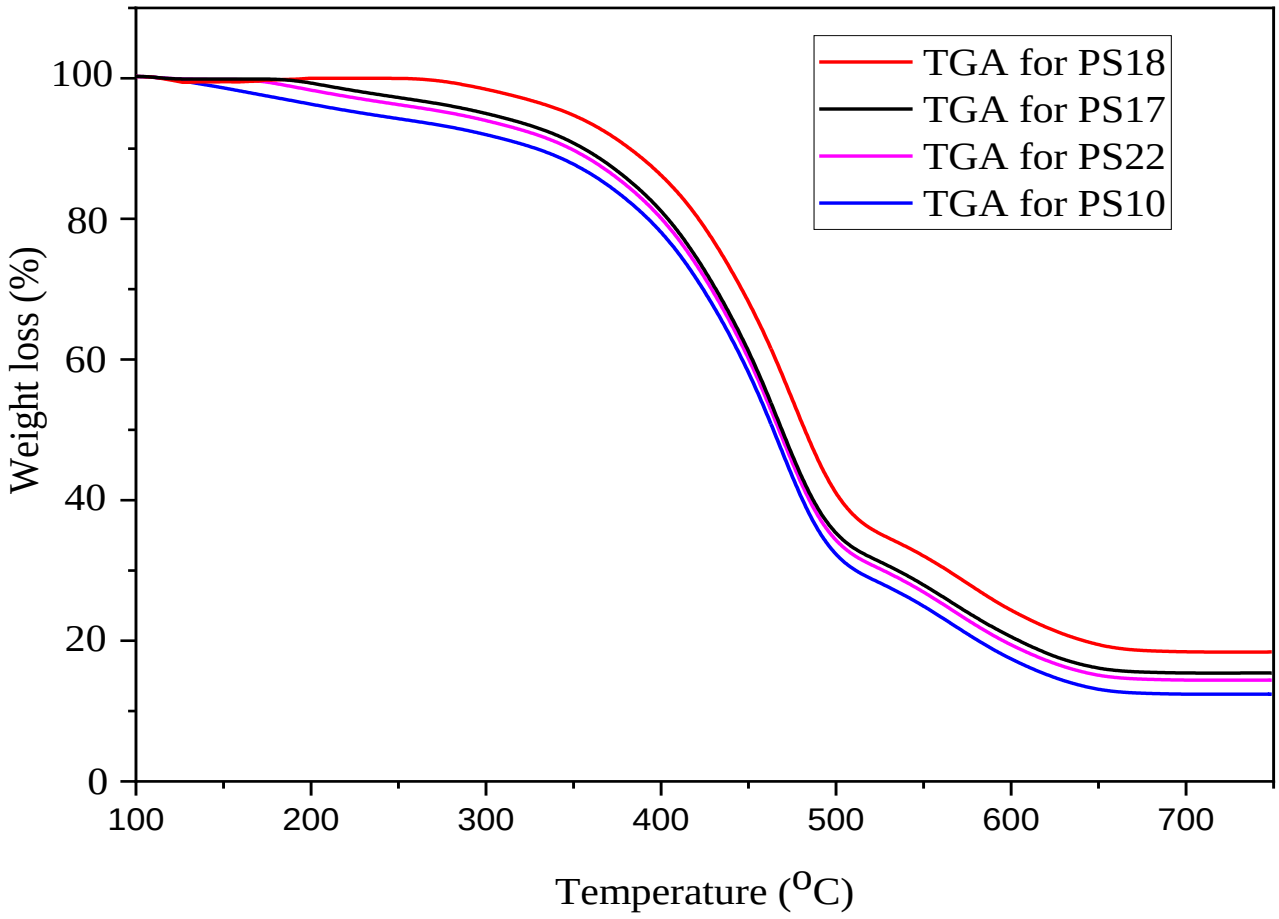


Figure 29. TGA thermogram for composite PS18, PS17, PS22, and PS10

4.18 Morphological properties

4.18.1 Effects of Matrices (HDPE) and Fillers (DE and SW) Weight Proportion as a Function of Mold Compression Load on Morphological properties. The TIDSPCs materials which had specially, the best and worst mechanical (compressive and flexural strength) and water absorption properties performance was used for SEM analysis. The composite HDPE:DE:SW (72.5:22.5:5) (wt.%) (PS17) shows the best performance with compressive strength, flexural strength and water absorption 87.998 MPa, 94.2 MPa, and 0.679 % respectively, while the composite of HDPE:DE:SW (65:25:10) (wt.%) (PS12) shows the worst performance with composite strength, flexural strength and water absorption 52.47 MPa, 50.81 and 1.81 % respectively.

From the Figure 30, it can be seen that small amount of fiber fractures is observed in PS17 sample than PS12 sample. The mechanical properties of the composites strongly depend on the filler morphology and their distribution within fibers and matrices. Referring to Figure 30 A, the fracture surface of HDPE:DE:SW composite spotted irregular shapes with rough surface of DE/SW particles, were filling in micro voids or vacant spots in between the fibers and matrices (Ismail and Mathialagan, 2012). There was an inhomogeneous dispersion of DE/SW fillers that can be perfectly distinguished as indicated the scattering occasional micro-size aggregate. This strongly indicate that mixing of fillers and matrices preparation process of the developed composites had not sufficient. Even though, there were some voids that still can be observed, the rough surface area were associated to adequate compressive and flexural properties (Ismail and Mathialagan, 2012; Gwon et al., 2011). The irregular shape of diatomite earth and rough surface of sawdust provides sufficient surface area that allows these fillers to disperse well, fix in the polymer chain, and link the fillers and matric, establishing a good interfacial interaction (Suhaida et al., 2013). It has been mentioned that the improvement in mechanical properties of composites can be influenced by the dispersion of fillers. Ideally, it is difficult to achieve a good dispersion of powder size fillers in a thermoplastic due to the tendency of the fillers agglomerate (Ning et al., 2017). However, the appropriate weight proportion content of fillers (DE/SW) being wrapped in the matric and no deboned tubes cavities can be seen (Figure 30A).

Also, the composite sample of PS12 consists of considerable amount of pores. The porous structures lead to the poor mechanical (compressive and flexural strength) and water absorption

properties of the composites. By investigating the SEM images, it is rational to suggest that PS12 composite specimen were subjected to poor homogeneous mixing as fibers fractures are evident. This phenomenon leads to a decrease in stress transfer capability of the matrix to the reinforcement. As a result, a decrease in compressive and flexural strength and increase water absorption is observed. The morphology of (PS12) composite in Figure 30B whereas, shows DE/SW particles were embedded between the matrices. However, the high weight proportion contents of DE/SW filler particles revealed their poor dispersion in the matrix, as agglomeration can clearly be spotted (Suhaida et al., 2013). The formation of these gaps between the filler and the polymer matrix can be attributed to two factors, namely, the poor compatibility between the natural fillers and the matrices and the agglomeration of the fillers (Figure 30B). Specifically, the hydroxyl groups (-OH) that are present in natural fillers that make them hydrophilic, whereas the polymers are hydrophobic, resulting in poor compatibility (Tabil et al., 2017). It also can elucidate that, the nonreinforcing behavior of DE/SW due to their high weight proportion content. Mohammed et al (2017) reported in their review that because of pendant hydroxyl and polar groups in natural fiber, this leads to extremely high moisture absorption of fiber, resulting in weak interfacial bonding between the fiber and the hydrophobic matrix polymers. In addition, the presence of hydrogen bonds between the particles of natural fillers leads to particle agglomeration (Abu et al., 2019).

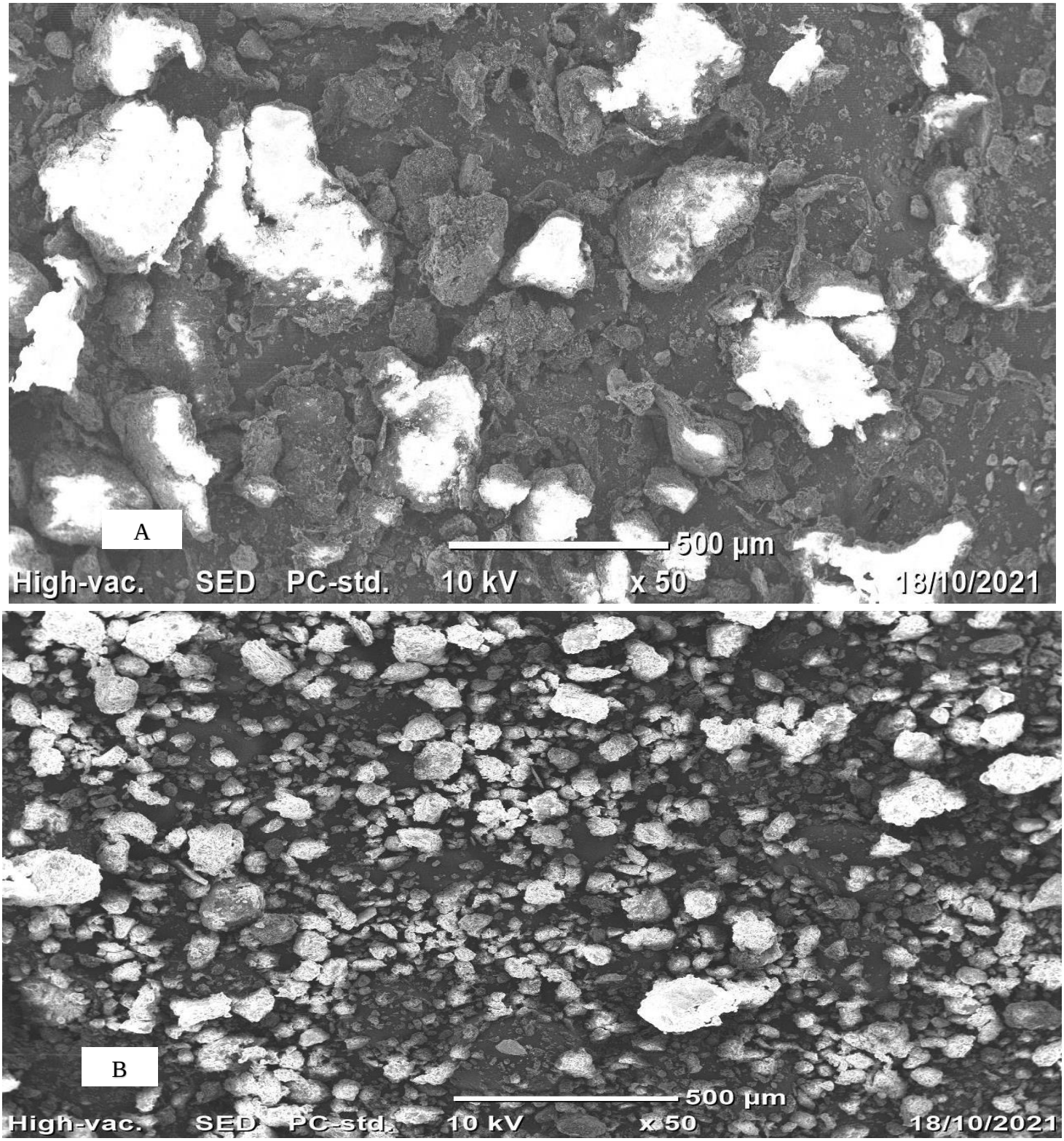


Figure 30. Morphological properties of the (A) PS17 and (B) PS12 composites at x50 magnification

5 Conclusion and Recommendation

5.1 Conclusion

The study intended to find a renewable bio-based thermal insulation material comparable to traditional insulation materials and some common construction materials. The TIDSPCs developed using different HDPE, DE, and SW weight % proportion and mold compression load (CL), achieving high-level waste resource re-utilization. The obtained results indicate that the TIDSPC materials could serve as promising bio thermal insulation materials because of their low thermal conductivity, thermal diffusivity and water absorption ability and high compressive and flexural strength. the amount of water absorption by the composites increase mainly with increases in the (DE/SW) weight proportions due to the formation of interaction between OH groups in (DE/SW) and water. The optimal conditions considering the water absorption, thermal conductivity and compressive strength properties found to be at 72.13 wt. % HDPE, 25wt. % DE, 2.87 wt. % SW, and 10 MPa mold compression load (CL), leading to a desirability of 75.6 %. Under the optimum condition, the thermal conductivity, water absorption, and compressive strength of the bio-composites were 0.023 W/(m.k), 0.603 %, and 87.579 MPa, respectively. Percent deviations between actual and predicted responses for the selected optimized formulation were very small with a maximum of 0.4%. The thermal insulation coefficient, thermal diffusivity and density results indicate that as the (DE/SW) weight % proportion content increases and mold compression load (CL) decreases, the thermal insulation coefficient, thermal diffusivity and density properties of the samples decrease; this is due to the present of voids in the composite samples that can trap air within the structure. It is observed that DE enhanced the thermal stability of the composites which was related the fact that DE contain 90% amorphous silica, hindered the diffusion of volatile decomposition products. Following the above results, it is concluded that when the percentage of HDPE wastes is 72.5 wt. %, DE 22.5 wt.%, SW 5 wt.% with 10 MPa the overall properties of the TIDSPC materials have high quality, comparable and better the commercial and ecological developed thermal insulation materials. The result of this work revealed that TIDSPCs have high potential as promising bio-based thermal insulation materials owing to their low thermal conductivity, thermal diffusivity, and water absorption while maintaining high mechanical strength.

This research offers a promising and practical solution for the recycling utilization of various

spent brewery diatomite earth and sawdust wastes, and the reduced environmental impacts initiated by waste plastics, contributing to enormous economic benefits and can be utilized the preparation of commercially feasible satisfactory insulation materials which is of organic origin. The present new insulation materials is a candidate to be commercialized in the future.

5.2 Recommendation

In this study on Preparation, thermos-physical and mechanical performance investigation of Spent Brewery Diatomite earth, Sawdust and HDPE waste plastic-based composite material for thermal insulation in buildings is developed successfully. The result from the experimental study showed that useful thermal insulation composite with good properties can be successfully manufacture by reinforcing waste HDPE with DE and SW. However, the mixing temperature, mixing time, useful lifetime and flammability properties of the composites needs further investigations. In addition, for further improve the mechanical and thermal properties of the sample, surface modification of the raw material DE or adding compatipilizers are needed.

References

Zealand, A. insulation subsidy programme in N., found reduced hospitalization costs due to fewer re-admissions, F., & transfers and shorter stays in hospital. (2018). *Who housing and health guidelines.*

Palmer, A. L., Sese, A., & Montano, J. J. (2005). T*ourism and statistics: Bibliometric study 1998–2002*. Annals of Tourism Research, 32(1), 167-178.

Lai, Y. L., & Palmer, S. (2018). *Understanding evidence-based coaching through the analysis of coaching psychology research methodology*. In Handbook of Coaching Psychology (pp. 80-90). Routledge.

Rüttinger, L., & Feil, M. (2010). Sustainable prevention of resource conflicts: New risks from raw materials for the future? Case study and scenarios for China and rare Earths. Adelphi.<http://www.adelphi.de/files/de/news/application/pdf/rohkon_report_3. 4_china.pdf>[URL accessed September 27, 2011].

Bergstrom, J. C., & Randall, A. (2016). Resource economics: an economic approach to natural resource and environmental policy. Edward Elgar Publishing.

Gigli, N. (2018). Nonsmooth differential geometry–an approach tailored for spaces with Ricci curvature bounded from below (Vol. 251, No. 1196). American Mathematical Society.

Jelle, B. P. (2011). Traditional, state-of-the-art and future thermal building insulation materials and solutions–Properties, requirements and possibilities. Energy and buildings, 43(10), 2549-2563.

Iwaro, J., & Mwasha, A. (2010). A review of building energy regulation and policy for energy conservation in developing countries. Energy Policy, 38(12), 7744-7755.

Al-Homoud, M. S. (2005). Performance characteristics and practical applications of common building thermal insulation materials. Building and environment, 40(3), 353-366

Pavel, C. C., & Blagoeva, D. T. (2018). Competitive landscape of the EU's insulation materials industry for energy-efficient buildings. *Publications Office of the European Union: Luxembourg*.

Asdrubali, F., D'Alessandro, F., & Schiavoni, S. (2015). A review of unconventional sustainable

building insulation materials. *Sustainable Materials and Technologies*, *4*, 1-17.

Harrison, P., Holmes, P., Bevan, R., Kamps, K., Levy, L., & Greim, H. (2015). Regulatory risk assessment approaches for synthetic mineral fibres. *Regulatory Toxicology and Pharmacology*, *73*(1), 425-441.

Caniato, M., Sbaizero, O., Schmid, C., & Bettarello, F. (2015). Recycled materials for noise reduction in floating floor. In *22nd International Congress on Sound and Vibration, ICSV 2015* (No. 159 (R) T09. SS05). International Institute of Acoustics and Vibrations.

Shahnawaz, M., Sangale, M. K., & Ade, A. B. (2019). Bioremediation Technology for Plastic Waste.

Muthuraj, R., Lacoste, C., Lacroix, P., & Bergeret, A. (2019). Sustainable thermal insulation biocomposites from rice husk, wheat husk, wood fibers and textile waste fibers: Elaboration and performances evaluation. *Industrial Crops and Products*, *135*, 238-245.

Erkmen, J., Yavuz, H. I., Kavci, E., & Sari, M. (2020). A new environmentally friendly insulating material designed from natural materials. *Construction and Building Materials*, *255*, 119357.

Zach, J., Korjenic, A., Petránek, V., Hroudová, J., & Bednar, T. (2012). Performance evaluation and research of alternative thermal insulations based on sheep wool. *Energy and Buildings*, *49*, 246-253.

Aladejana, J. T., Wu, Z., Fan, M., & Xie, Y. (2020). Key advances in development of straw fibre bio-composite boards: An overview. *Materials Research Express*, *7*(1), 012005.

Cibinel, M., Pugliese, G., Porrelli, D., Marsich, L., & Lughi, V. (2021). Recycling alginate composites for thermal insulation. *Carbohydrate Polymers*, *251*, 116995.

Ariga, K., Ji, Q., Mori, T., Naito, M., Yamauchi, Y., Abe, H., & Hill, J. P. (2013). Enzyme nanoarchitectonics: organization and device application. *Chemical Society Reviews*, *42*(15), 6322-6345.

Bhardwaj, A., Jones, S. Z., Kalantar, N., Pei, Z., Vickers, J., Wangler, T., ... & Zou, N. (2019). Additive manufacturing processes for infrastructure construction: a review. *Journal of Manufacturing Science and Engineering*, *141*(9), 091010.

Cotes-Palomino, M. T., Martínez-García, C., Eliche-Quesada, D., & Pérez-Villarejo, L. (2016). Production of ceramic material using wastes from brewing industry. In *Key Engineering Materials* (Vol. 663, pp. 94-104). Trans Tech Publications Ltd.

Shah, M. A., & Khan, A. A. (2014). Use of diatomaceous earth for the management of stored-product pests. *International journal of pest management*, *60*(2), 100-113.

Worku, S. G., Xu, C., Zhao, J., & He, X. (2014). Secure and efficient privacy-preserving public auditing scheme for cloud storage. *Computers & Electrical Engineering*, *40*(5), 1703-1713.

Duraković, B. (2020). *PCM-Based Building Envelope Systems: Innovative Energy Solutions for Passive Design*. Springer Nature.

Muthuraj, R., Lacoste, C., Lacroix, P., & Bergeret, A. (2019). Sustainable thermal insulation biocomposites from rice husk, wheat husk, wood fibers and textile waste fibers: Elaboration and performances evaluation. *Industrial Crops and Products*, *135*, 238-245.

Erkmen, J., Yavuz, H. I., Kavci, E., & Sari, M. (2020). A new environmentally friendly insulating material designed from natural materials. *Construction and Building Materials*, *255*, 119357.

Limam, A., Zerizer, A., Quenard, D., Sallee, H., & Chenak, A. (2016). Experimental thermal characterization of bio-based materials (Aleppo Pine wood, cork and their composites) for building insulation. *Energy and Buildings*, *116*, 89-95.

Amara, I., Mazioud, A., Boulaoued, I., & Mhimid, A. (2017). Experimental study on thermal properties of bio-composite (gypsum plaster reinforced with palm tree fibers) for building insulation. *International journal of heat and technology*, *35*(1), 576-584.

Binici, H., Aksogan, O., & Demirhan, C. (2016). Mechanical, thermal and acoustical characterizations of an insulation composite made of bio-based materials. *Sustainable Cities and Society*, *20*, 17-26.

Shao, H., Zhang, Q., Liu, H., Guo, W., Jiang, Y., Chen, L., ... & Shupe, T. F. (2020). Renewable natural resources reinforced polyurethane foam for use of lightweight thermal insulation. *Materials Research Express*, *7*(5), 055302.

Park, J. Y., Yoon, D. S., Li, S., Park, J., Bang, J. I., Sung, M., & Jeong, J. W. (2017). Empirical

analysis of indoor air quality enhancement potential in a liquid-desiccant assisted air conditioning system. Building and Environment, 121, 11-25.

Ouakarrouch, M., El Azhary, K., Laaroussi, N., Garoum, M., & Kifani-Sahban, F. (2020). Thermal performances and environmental analysis of a new composite building material based on gypsum plaster and chicken feathers waste. Thermal Science and Engineering Progress, 19, 100642.

Zhao, P., Lu, Z., Fang, J., Paramati, S. R., & Jiang, K. (2020). Determinants of renewable and non-renewable energy demand in China. Structural Change and Economic Dynamics, 54, 202-209.

Kaynakli, O. (2012). A review of the economical and optimum thermal insulation thickness for building applications. Renewable and Sustainable Energy Reviews, 16(1), 415-425.

Gupta, P., Verma, C., & Maji, P. K. (2019). Flame retardant and thermally insulating clay based aerogel facilitated by cellulose nanofibers. The Journal of Supercritical Fluids, 152, 104537.

Schiavoni, S., Bianchi, F., & Asdrubali, F. (2016). Insulation materials for the building sector: A review and comparative analysis. Renewable and Sustainable Energy Reviews, 62, 988-1011.

Orlik-Kożdoń, B. (2021). Polystyrene Waste in Panels for Thermal Retrofitting of Historical Buildings: Experimental Study. Energies, 14(7), 1844.

Gong, J., Duan, Z., Sun, K., & Xiao, M. (2016). Waterproof properties of thermal insulation mortar containing vitrified microsphere. Construction and Building Materials, 123, 274-280.

Dong, X., Wang, S., Gong, C., & Lu, L. (2014). Effects of aggregate gradation and polymer modifiers on properties of cement-EPS/vitrified microsphere mortar. Construction and Building Materials, 73, 255-260.

Pásztory, Z., Horváth, T., Glass, S. V., & Zelinka, S. (2018). Experimental investigation of the influence of temperature on thermal conductivity of multilayer reflective thermal insulation. Energy and Buildings, 174, 26-30.

Zhou, T., Wang, X., Liu, X., & Xiong, D. (2010). Improved thermal conductivity of epoxy

composites using a hybrid multi-walled carbon nanotube/micro-SiC filler. Carbon, 48(4), 1171-1176.

Xu, C., Li, S., & Zhang, X. (2020). Energy flexibility for heating and cooling in traditional Chinese dwellings based on adaptive thermal comfort: A case study in Nanjing. Building and Environment, 179, 106952.

Lin, Y., Li, X., & Huang, Q. (2021). Preparation and characterization of expanded perlite/wood-magnesium composites as building insulation materials. Energy and Buildings, 231, 110637.

Kour, R., Patel, N., & Krishna, A. P. (2016). Climate and hydrological models to assess the impact of climate change on hydrological regime: a review. Arabian Journal of Geosciences, 9(9), 1-31.

Al-Fakih, A., Mohammed, B. S., Liew, M. S., & Nikbakht, E. (2019). Incorporation of waste materials in the manufacture of masonry bricks: An update review. Journal of Building Engineering, 21, 37-54.

Sghiouri, H., Charai, M., Mezrhab, A., & Karkri, M. (2020, February). Comparison of passive cooling techniques in reducing overheating of clay-straw building in semi-arid climate. In Building Simulation (Vol. 13, No. 1, pp. 65-88). Tsinghua University Press.

Yan, M., Jiao, W., Ding, G., Chu, Z., Huang, Y., & Wang, R. (2019). High strength and toughness epoxy nanocomposites reinforced with graphene oxide-nanocellulose micro/nanoscale structures. Applied Surface Science, 497, 143802.

Dalhat, M. A., & Wahhab, H. A. A. (2016). Cement-less and asphalt-less concrete bounded by recycled plastic. Construction and Building Materials, 119, 206-214.

Asdrubali, F., D'Alessandro, F., & Schiavoni, S. (2015). A review of unconventional sustainable building insulation materials. Sustainable Materials and Technologies, 4, 1-17.

Mehrali, M., Latibari, S. T., Mehrali, M., Metselaar, H. S. C., & Silakhori, M. (2013). Shape-stabilized phase change materials with high thermal conductivity based on paraffin/graphene oxide composite. Energy conversion and management, 67, 275-282.

Mofijur, M., Mahlia, T. M. I., Silitonga, A. S., Ong, H. C., Silakhori, M., Hasan, M. H., ... &

Rahman, S. M. (2019). Phase change materials (PCM) for solar energy usages and storage: an overview. Energies, 12(16), 3167.

Zhu, J., Zhao, F., Xiong, R., Peng, T., Ma, Y., Hu, J., ... & Jiang, C. (2020). Thermal insulation and flame retardancy of attapulgite reinforced gelatin-based composite aerogel with enhanced strength properties. Composites Part A: Applied Science and Manufacturing, 138, 106040.

Samson, G., Phelipot-Mardelé, A., & Lanos, C. (2017). A review of thermomechanical properties of lightweight concrete. Magazine of Concrete Research, 69(4), 201-216.

Jianming, Y., Luming, W., & Jie, Z. (2019). Experimental study on the deformation characteristics of magnesium potassium phosphate cement paste at early hydration ages. Cement and Concrete Composites, 103, 175-182.

Huang, H., Zhou, Y., Huang, R., Wu, H., Sun, Y., Huang, G., & Xu, T. (2020). Optimum insulation thicknesses and energy conservation of building thermal insulation materials in Chinese zone of humid subtropical climate. Sustainable Cities and Society, 52, 101840.

Krishna, S. A., Shridhar, T. N., & Krishnamurthy, L. (2016). Microstructural characterization and investigation of thermal conductivity behaviour of Al 6061-SiC-Gr hybrid metal matrix composites.

Aditya, L., Mahlia, T. M. I., Rismanchi, B., Ng, H. M., Hasan, M. H., Metselaar, H. S. C., ... & Aditiya, H. B. (2017). A review on insulation materials for energy conservation in buildings. Renewable and sustainable energy reviews, 73, 1352-1365.

Yang, H., Jiang, Y., Liu, H., Xie, D., Wan, C., Pan, H., & Jiang, S. (2018). Mechanical, thermal and fire performance of an inorganic-organic insulation material composed of hollow glass microspheres and phenolic resin. Journal of colloid and interface science, 530, 163-170.

Pinterić, M. (2017). Building Physics: from physical principles to international standards. Springer.

Qin, M., Belarbi, R., Aït-Mokhtar, A., & Seigneurin, A. (2006). An analytical method to calculate the coupled heat and moisture transfer in building materials. International Communications in Heat and Mass Transfer, 33(1), 39-48.

Lakatos, Á. (2016). Moisture induced changes in the building physics parameters of insulation materials. Science and Technology for the Built Environment, 22(3), 252-260.

Schritt, H., Vidi, S., & Pleissner, D. (2021). Spent mushroom substrate and sawdust to produce mycelium-based thermal insulation composites. Journal of Cleaner Production, 127910.

Jerman, M., & Černý, R. (2012). Effect of moisture content on heat and moisture transport and storage properties of thermal insulation materials. Energy and Buildings, 53, 39-46.

Khoukhi, M. (2018). The combined effect of heat and moisture transfer dependent thermal conductivity of polystyrene insulation material: Impact on building energy performance. Energy and buildings, 169, 228-235.

Abdou, A., & Budaiwi, I. (2013). The variation of thermal conductivity of fibrous insulation materials under different levels of moisture content. Construction and Building materials, 43, 533-544.

Gusyachkin, A. M., Sabitov, L. S., Khakimova, A. M., & Hayrullin, A. R. (2019, July). Effects of moisture content on thermal conductivity of thermal insulation materials. In IOP Conference Series: Materials Science and Engineering (Vol. 570, No. 1, p. 012029). IOP Publishing.

Wang, J. S., Demartino, C., Xiao, Y., & Li, Y. Y. (2018). Thermal insulation performance of bamboo-and wood-based shear walls in light-frame buildings. Energy and Buildings, 168, 167-179.

Ochs, F., Heidemann, W., & Müller-Steinhagen, H. (2009). Performance of large-scale seasonal thermal energy stores. Journal of solar energy engineering, 131(4).

D'Alessandro, F., Baldinelli, G., Bianchi, F., Sambuco, S., & Rufini, A. (2018). Experimental assessment of the water content influence on thermo-acoustic performance of building insulation materials. Construction and Building Materials, 158, 264-274.

Liu, Z. H., Ding, Y. D., Wang, F., & Deng, Z. P. (2016). Thermal insulation material based on SiO2 aerogel. Construction and Building Materials, 122, 548-555.

Liu, W., Yang, D., Shen, X., & Yang, P. (2018). Indoor clothing insulation and thermal history: A clothing model based on logistic function and running mean outdoor temperature.

Building and Environment, 135, 142-152.

Gawin, D. J., Koniorczyk, M., Wieckowska, A., & Kossecka, E. (2004). Effect of Moisture on Hygrothermal and Energy Performance of a Building with Cellular Concrete Walls in Climatic Conditions of Poland. ASHRAE Transactions, 110(2).

Taoukil, D., Sick, F., Mimet, A., Ezbakhe, H., & Ajzoul, T. (2013). Moisture content influence on the thermal conductivity and diffusivity of wood–concrete composite. Construction and Building Materials, 48, 104-115.

Barkhad, M. S., Abu-Jdayil, B., Iqbal, M. Z., & Mourad, A. H. I. (2020). Thermal insulation using biodegradable poly (lactic acid)/date pit composites. Construction and Building Materials, 261, 120533.

Korjenic, A., Petránek, V., Zach, J., & Hroudová, J. (2011). Development and performance evaluation of natural thermal-insulation materials composed of renewable resources. Energy and Buildings, 43(9), 2518-2523.

Rahim, M., Douzane, O., Le, A. T., & Langlet, T. (2016). Effect of moisture and temperature on thermal properties of three bio-based materials. Construction and Building Materials, 111, 119-127.

Boukhattem, L., Boumhaout, M., Hamdi, H., Benhamou, B., & Nouh, F. A. (2017). Moisture content influence on the thermal conductivity of insulating building materials made from date palm fibers mesh. Construction and Building Materials, 148, 811-823.

Sonderegger, W., & Niemz, P. (2012). Thermal and moisture flux in soft fibreboards. European Journal of Wood and Wood Products, 70(1), 25-35.

Abdou, A., & Budaiwi, I. (2013). The variation of thermal conductivity of fibrous insulation materials under different levels of moisture content. Construction and Building materials, 43, 533-544.

Erkmen, J., Yavuz, H. I., Kavci, E., & Sari, M. (2020). A new environmentally friendly insulating material designed from natural materials. Construction and Building Materials, 255, 119357.

Zach, J., Hroudová, J., Brožovský, J., Krejza, Z., & Gailius, A. (2013). Development of thermal

insulating materials on natural base for thermal insulation systems. Procedia Engineering, 57, 1288-1294.

Laaroussi, N., Lauriat, G., Raefat, S., Garoum, M., & Ahachad, M. (2017). An example of comparison between ISO Norm calculations and full CFD simulations of thermal performances of hollow bricks. Journal of Building Engineering, 11, 69-81.

Charai, M., Sghiouri, H., Mezrhab, A., Karkri, M., Elhammouti, K., & Nasri, H. (2020). Thermal performance and characterization of a sawdust-clay composite material. Procedia Manufacturing, 46, 690-697.

Munir, M. J., Kazmi, S. M. S., Wu, Y. F., Hanif, A., & Khan, M. U. A. (2018). Thermally efficient fired clay bricks incorporating waste marble sludge: An industrial-scale study. Journal of cleaner production, 174, 1122-1135.

Jiang, D., An, P., Cui, S., Sun, S., Zhang, J., & Tuo, T. (2020). Effect of modification methods of wheat straw fibers on water absorbency and mechanical properties of wheat straw fiber cement-based composites. Advances in Materials Science and Engineering, 2020.

Wang, C., Mei, J., & Zhang, L. (2021). High-added-value biomass-derived composites by chemically coupling post-consumer plastics with agricultural and forestry wastes. Journal of Cleaner Production, 284, 124768.

Hittini, W., Mourad, A. H. I., & Abu-Jdayil, B. (2021). Utilization of devulcanized waste rubber tire in development of heat insulation composite. Journal of Cleaner Production, 280, 124492.

Murillo-Amador, B., Morales-Prado, L. E., Troyo-Diéguez, E., Córdoba-Matson, M. V., Hernández-Montiel, L. G., Rueda-Puente, E. O., & Nieto-Garibay, A. (2015). Changing environmental conditions and applying organic fertilizers in Origanum vulgare L. Frontiers in plant science, 6, 549.

Binici, H., Aksogan, O., & Demirhan, C. (2016). Mechanical, thermal and acoustical characterizations of an insulation composite made of bio-based materials. Sustainable Cities and Society, 20, 17-26.

Habib, B. A., & AbouGhaly, M. H. (2016). Combined mixture-process variable approach: a

suitable statistical tool for nanovesicular systems optimization. Expert opinion on drug delivery, 13(6), 777-788.

Gozálvez Zafrilla, J. M., Santafé Moros, M. A., Catalán Martínez, D., Toldra Reig, F., & Martí Calatayud, M. C. (2019, September). Desarrollo y aplicación del software DISEVAP_edu como apoyo al aprendizaje del diseño y análisis de procesos de evaporación de múltiples efectos. In IN-RED 2019. V Congreso de Innovación Educativa y Docencia en Red (pp. 1165-1177). Editorial Universitat Politècnica de València.

Koleske, J. V. (2012). Radiation curing of coatings (No. 45). West Conshohocken, PA: ASTM international.

Theng, B. K. G. (2012). Formation and properties of clay-polymer complexes. Elsevier.

Cui, T., Li, Q., Xuan, Y., & Zhang, P. (2015). Preparation and thermal properties of the graphene–polyolefin adhesive composites: Application in thermal interface materials. Microelectronics Reliability, 55(12), 2569-2574.

Idrus, M. M. A., Saat, A. M., Bazin, M. M., & Zoolfakar, R. (2020). Fire Retardant and Physical Properties of Kapok-Chopped Strand Mats Fiberglass Composites for Marine Application. In Advancement in Emerging Technologies and Engineering Applications (pp. 231-238). Springer, Singapore.

Abu-Zurayk, R., Hamadneh, I., & Al-Dujaili, A. H. (2020). Preparation and characterization of polyethylene/cellulose composite with diatomite and bentonite as fillers. Polymer-Plastics Technology and Materials, 59(5), 546-554.

Yetgin, S. H., Unal, H., & Mimaroglu, A. (2016). Usability of injection moulded polypropylene and TALC-EPDM filled PP composite foam materials in automotive industry. International Journal of Vehicle Design, 71(1-4), 364-376.

Gordobil, O., Delucis, R., Egüés, I., & Labidi, J. (2015). Kraft lignin as filler in PLA to improve ductility and thermal properties. Industrial Crops and Products, 72, 46-53.

Hadi, B. K., & Rofa, B. K. (2018, April). Experimental tensile strength analysis of woven-glass/epoxy composite plates with central circular hole. In Journal of Physics: Conference Series (Vol. 1005, No. 1, p. 012001). IOP Publishing.

Özdemir, F., Ayrilmis, N., & Yurttaş, E. (2021). Mechanical and thermal properties of biocomposite films produced from hazelnut husk and polylactic acid. Wood Material Science & Engineering, 1-7.

Abu-Jdayil, B., Mourad, A. H., & Hussain, A. (2016). Thermal and physical characteristics of polyester–scrap tire composites. Construction and Building Materials, 105, 472-479.

Ferede, E. (2020). Evaluation of Mechanical and Water Absorption Properties of Alkaline-Treated Sawdust-Reinforced Polypropylene Composite. Journal of Engineering, 2020.

Rashidi, S., Esfahani, J. A., & Karimi, N. (2018). Porous materials in building energy technologies—A review of the applications, modelling and experiments. Renewable and Sustainable Energy Reviews, 91, 229-247.

Cibinel, M., Pugliese, G., Porrelli, D., Marsich, L., & Lughi, V. (2021). Recycling alginate composites for thermal insulation. *Carbohydrate Polymers*, *251*, 116995.

Barkhad, M. S., Abu-Jdayil, B., Iqbal, M. Z., & Mourad, A. H. I. (2020). Thermal insulation using biodegradable poly (lactic acid)/date pit composites. *Construction and Building Materials*, *261*, 120533.

Korjenic, A., Petránek, V., Zach, J., & Hroudová, J. (2011). Development and performance evaluation of natural thermal-insulation materials composed of renewable resources. *Energy and Buildings*, *43*(9), 2518-2523.

Khalid, F. S., Azmi, N. B., Mazenan, P. N., Shahidan, S., Othman, N. H., & Guntor, N. A. A. (2018, February). Self-consolidating concretes containing waste PET bottles as sand replacement. In *AIP Conference Proceedings* (Vol. 1930, No. 1, p. 020034). AIP Publishing LLC.

Fomin, I., Kokarev, K., Ananyev, B., Neklyudov, N., Bondik, A., Glushkov, P., ... & Wohlforth, W. (2021). International studies in an unpredictable world: still avoiding the difficult problems?. *European Journal of International Relations*, *27*(1), 3-28.

Pritchard, C. C., Mateo, J., Walsh, M. F., De Sarkar, N., Abida, W., Beltran, H., ... & Nelson, P. S. (2016). Inherited DNA-repair gene mutations in men with metastatic prostate cancer. *N Engl J Med*, *375*, 443-453.

Ilieș, A., Wendt, J. A., Ilieș, D. C., Herman, G. V., Ilieș, M., & Deac, A. L. (2016). The patrimony of wooden churches, built between 1531 and 2015, in the Land of Maramureș, Romania. *Journal of Maps*, *12*(sup1), 597-602.

Chandni, T. J., & Anand, K. B. (2018). Utilization of recycled waste as filler in foam concrete. *Journal of Building Engineering*, *19*, 154-160.

Chang, Y. K., Chi, L., Etnier, J. L., Wang, C. C., Chu, C. H., & Zhou, C. (2014). Effect of acute aerobic exercise on cognitive performance: Role of cardiovascular fitness. *Psychology of Sport and Exercise*, *15*(5), 464-470.

Özdemir, Ş. K., Rotter, S., Nori, F., & Yang, L. (2019). Parity–time symmetry and exceptional points in photonics. *Nature materials*, *18*(8), 783-798.

Gao, W., Tabil, L. G., Dumonceaux, T., Ríos, S. E., & Zhao, R. (2017). Optimization of biological pretreatment to enhance the quality of wheat straw pellets. *Biomass and Bioenergy*, *97*, 77-89.

Gordobil, O., Delucis, R., Egüés, I., & Labidi, J. (2015). Kraft lignin as filler in PLA to improve ductility and thermal properties. *Industrial Crops and Products*, *72*, 46-53.

Rashidi, S., Esfahani, J. A., & Karimi, N. (2018). Porous materials in building energy technologies—A review of the applications, modelling and experiments. *Renewable and Sustainable Energy Reviews*, *91*, 229-247.

Azeez, M. A., Lateef, A., Asafa, T. B., Yekeen, T. A., Akinboro, A., Oladipo, I. C.& Beukes, L. S. (2017). Biomedical applications of cocoa bean extract-mediated silver nanoparticles as antimicrobial, larvicidal and anticoagulant agents. *Journal of Cluster Science*, *28*(1), 149-164.

Agnantopoulos, A.,& Lambiri, D. (2015). Variegated capitalism, the Greek crisis and SYRIZA's counter-neoliberalisation challenge. *Geoforum*, *63*, 5-8.

Gulitah, V.,& Liew, K. C. (2019). Three different recycle codes of plastic/acacia fibre composites: Physical and morphological properties. *International Journal of Biobased Plastics*, *1*(1), 1-7.

Parthasarathy, J., Starly, B., Raman, S., & Christensen, A. (2010). Mechanical evaluation of

porous titanium (Ti6Al4V) structures with electron beam melting (EBM). *Journal of the mechanical behavior of biomedical materials*, *3*(3), 249-259.

Floros, M., Hojabri, L., Abraham, E., Jose, J., Thomas, S., Pothan, L. & Narine, S. (2012). Enhancement of thermal stability, strength and extensibility of lipid-based polyurethanes with cellulose-based nanofibers. *Polymer degradation and stability*, *97*(10), 1970-1978.

Belhassen, R., Boufi, S., Vilaseca, F., Lopez, J. P., Méndez, J. A., Franco, E.,& Mutje, P. (2009). Biocomposites based on Alfa fibers and starch-based biopolymer. *Polymers for Advanced Technologies*, *20*(12), 1068-1075.

Othman, A. M.,González-Domínguez, E., Sanromán, Á.,Correa-Duarte, M.,& Moldes, D. (2016). Immobilization of laccase on functionalized multiwalled carbon nanotube membranes and application for dye decolorization. *RSC advances*, *6*(115), 114690-114697.

Hemmati, F., Garmabi, H., & Modarress, H. (2014). Compatibilization mechanisms of nanoclays with different surface modifiers in UCST blends: opposing effects on phase miscibility. *Polymer*, *55*(25), 6623-6633.

Mathialagan, M. (2012). Tensile, swelling and morphological properties of bentonite filled ethylene-propylene-diene monomer (epdm) composites. *Malaysian Journal of Microscopy*, *8*(1).

Suhaida, S., & NurAinIzzati, M. Z. (2013). The efficacy of Trichoderma harzianum T73s as a biocontrol agent of fusarium ear rot disease of maize. *International Journal of Agriculture and Biology*, *15*(6).

Ahmad, S. I., Mohammed, T., Bahafi, A., & Suresh, M. B. (2017). Effect of Mg doping and sintering temperature on structural and morphological properties of samarium-doped ceria for IT-SOFC electrolyte. *Applied Nanoscience*, *7*(5), 243-252.

TS 805 EN 601, Turkish Standard.(2018). Thermal insulation requirements for buildings.

APPENDIX

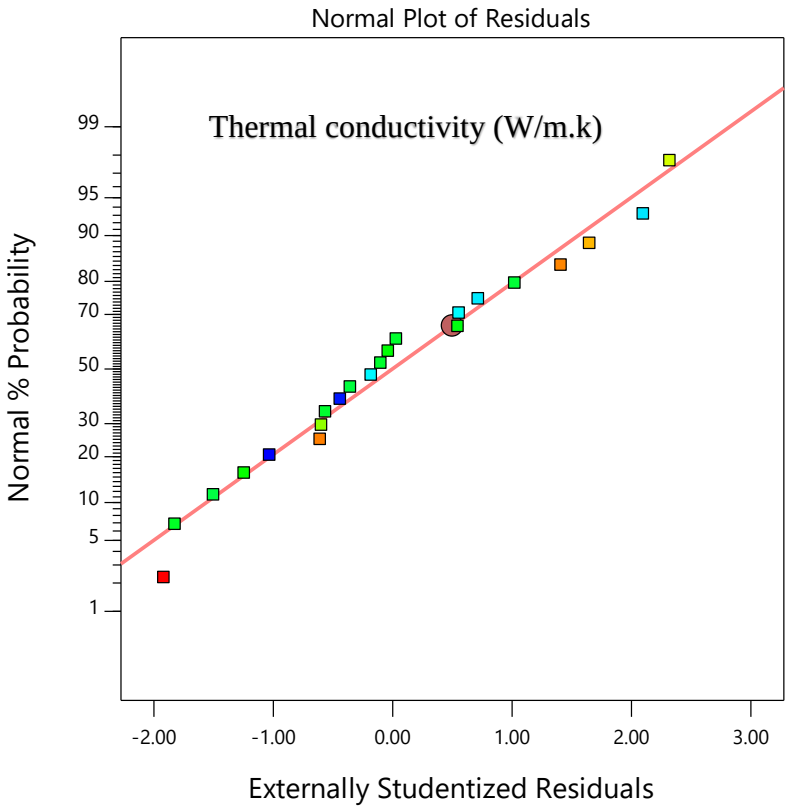
Appendix A: Some Properties of the manufactured TIDSPCs design expert software results

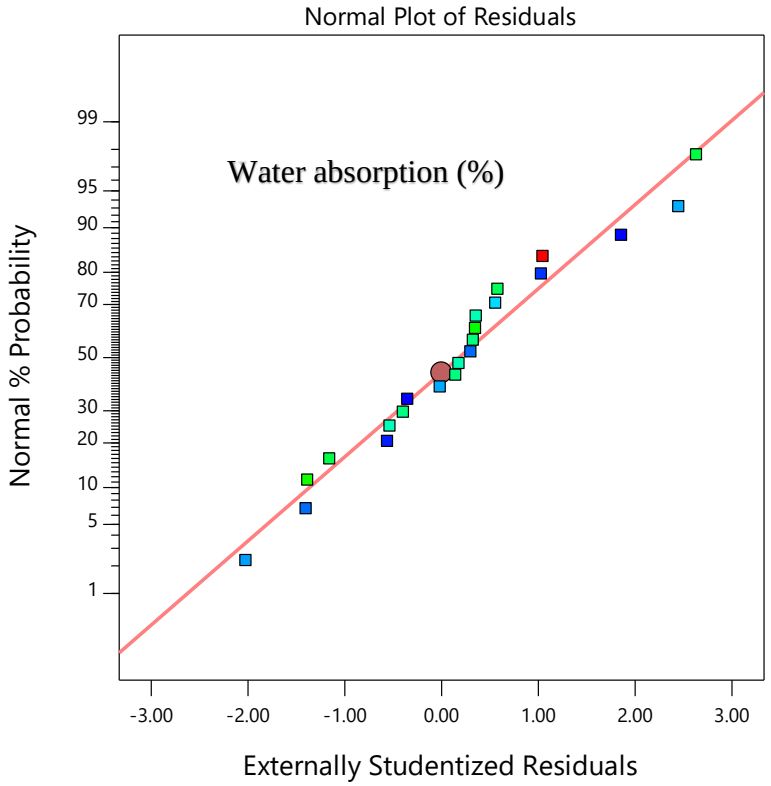
Table A 1: Process parameters and goals for optimization

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A:HDPE	is in range	65	80	1	1	3
B:DE	is in range	15	25	1	1	3
C:SW	is in range	0	10	1	1	3
D:CL	is in range	2	10	1	1	3
TC	minimize	0.0115	0.0406	1	1	3
Com strength	maximize	52.47	87.998	1	1	3
water absorption test	minimize	0.1399	1.81	1	1	3

Table A 2: Optimum possible conditions for preparation of TIDSPCs

Number	HDPE	DE	SW	CL	TC	Com strength	water absorption test	Desirability	
1	**72.131**	**25.000**	**2.869**	**10.000**	**0.023**	**87.579**	**0.603**	**0.756**	**Selected**
2	73.207	16.793	10.000	2.000	0.021	81.918	0.628	0.738	
3	72.573	19.045	8.382	2.000	0.022	84.646	0.729	0.723	
4	71.000	19.000	10.000	2.003	0.017	80.095	0.930	0.693	





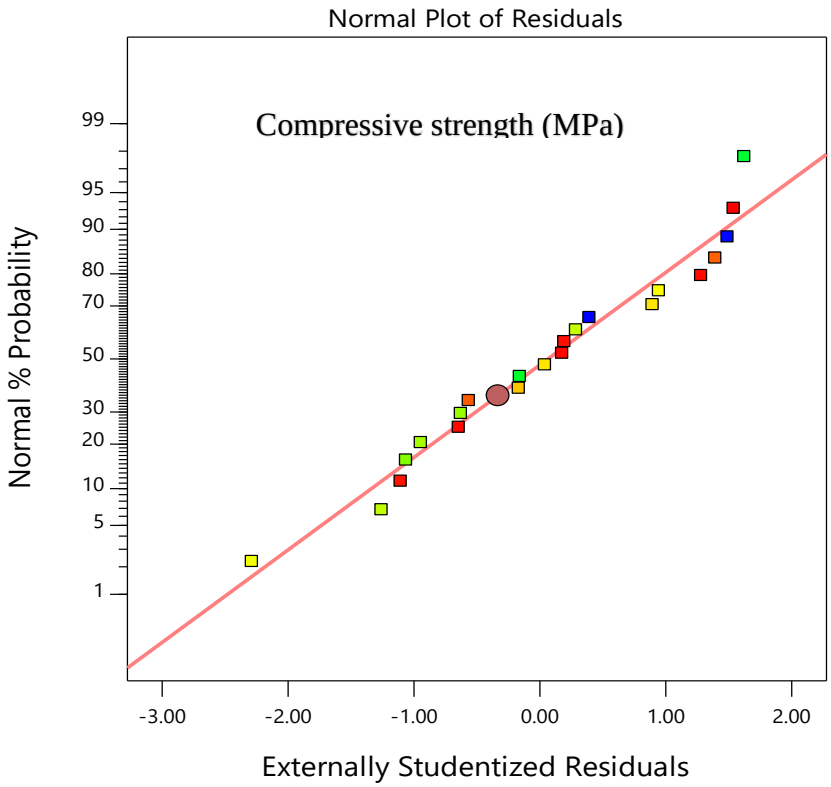


Figure A 1: Normal % probability versus residuals for preparation of TIDSPCs

Appendix B: Some selected picture of laboratoy work

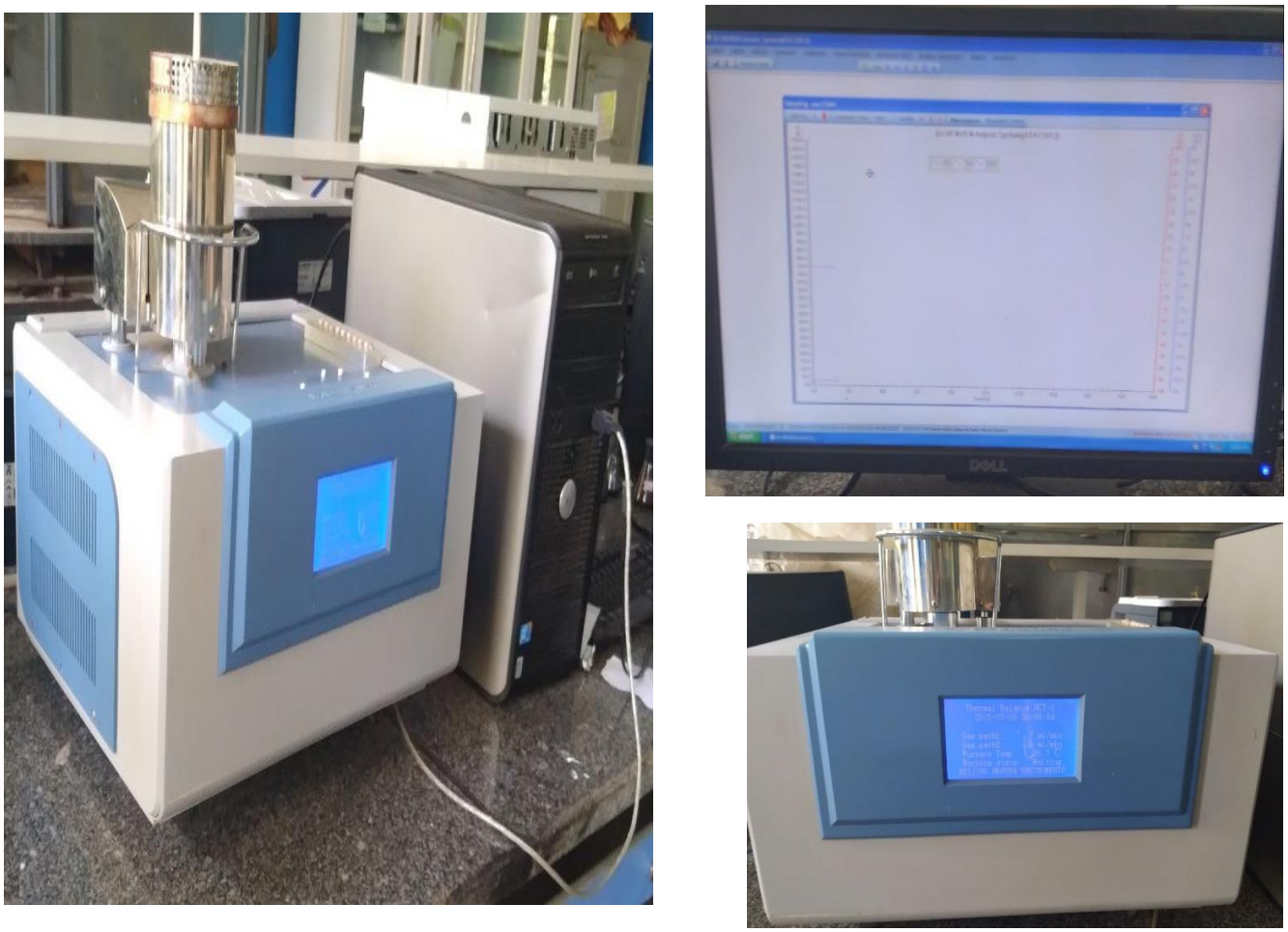


Figure B 1: Thermogravimetric (TGA) instruments used for thermal stability analaysis in this study.

Figure B 2: Sawdust Preparation

Figure B 3: Sawdust Preparation

Figure B 4: Diatomite earth Preparation

Figure B 5: Highdensity polyetylene

Figure B 6: Preparation of TIDSPCs thermal insulation composite materials

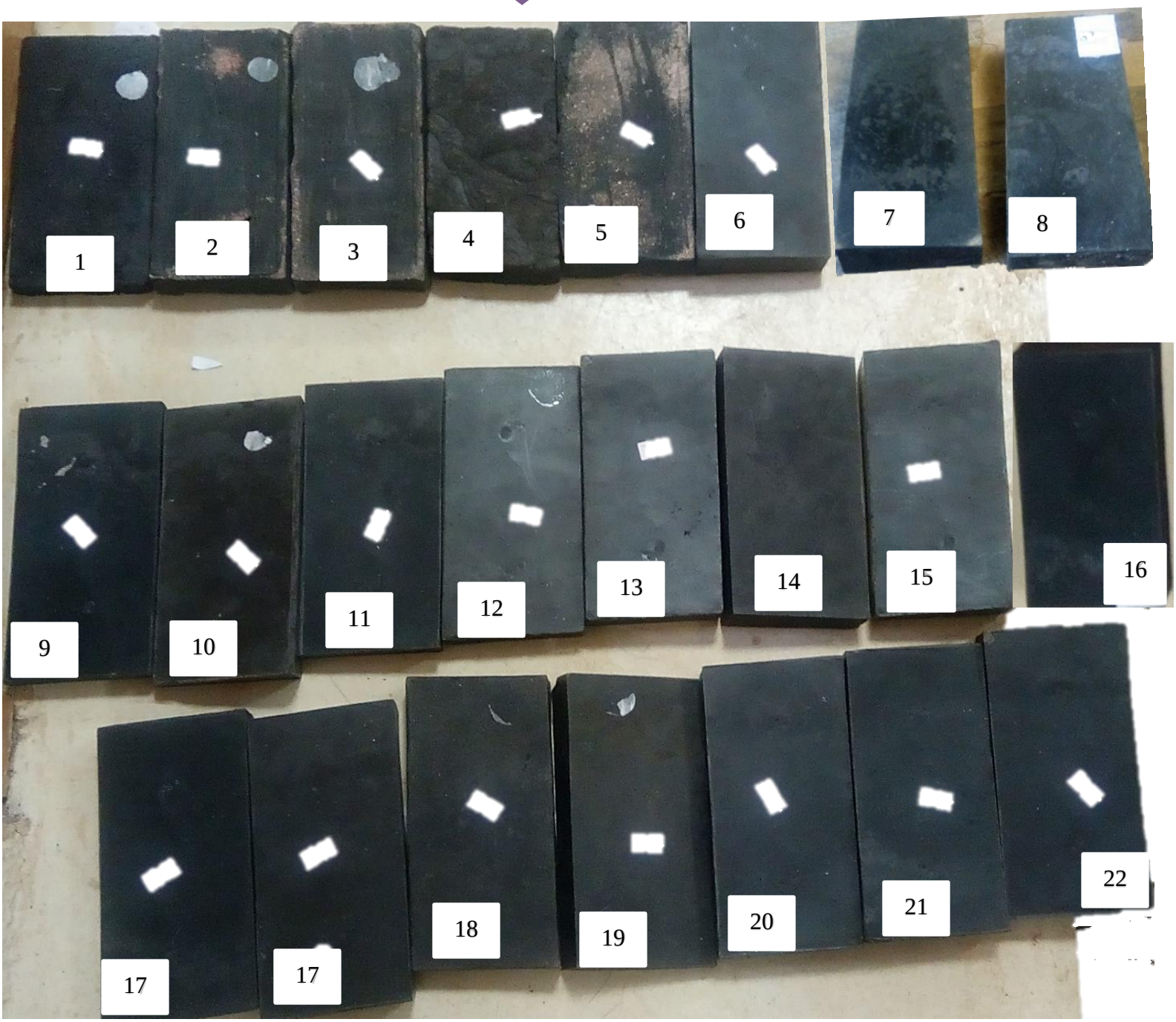


Figure B 7: The prepared TIDSPC samples