Archives of Materials Science and Engineering

Volume 125
Issue 2
February 2024
Pages 49-57

International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

DOI: 10.5604/01.3001.0054.5855

The impact of additives on the insulation properties of the epoxy resin building substance

I.A. Mashkoor [a], M.A. Jabbar [b], M.Y. Yousif [c,*]
[a] Basrah Engineering Technical College, Southern Technical University, Basrah, Iraq
[b] Mechanical Engineering Department, Engineering College, University of Basrah, Basrah, Iraq
[c] Materials Engineering Department, Engineering College, University of Basrah, Basrah, Iraq
* Corresponding e-mail address: mohammed.yousif@uobasrah.edu.iq
ORCID identifier: https://orcid.org/0000-0001-6592-9222 (M.Y.Y.)

ABSTRACT

Purpose: Investigation of the possibility of converting a material from outside the scope of thermal insulation (building thermal insulator) to entire it.

Design/methodology/approach: Epoxy resin was used for this purpose, and this was done in two ways. First, the composite thermal insulators were prepared using the weight percent method, where the following additive materials were added to the epoxy (sunflower seed husks, used utensil waste, titanium dioxide powder). The other method, the above-manufactured materials, was used to prepare the composite thermal insulators using the volume ratio method, where the base layer was always epoxy, while the other two layers were among the other materials. The suitability and applicability of the insulator were assessed through the evaluation of its thermal conductivity, specific heat capacity, and hardness tests. All tests were performed under standardized conditions.

Findings: Significant findings were achieved in this study where the thermal conductivity of the epoxy (0.24 to 0.08 W/m.°C) after adding sunflower seed husks based on the weight percent method. Furthermore, when mixing epoxy with utensil waste materials, the specific heat capacity was lowered to 0.31 kJ/kg.K. It is important to note that all of these outcomes are within the methods' defined insulating range. Adding titanium dioxide, and TiO_2 powder was improved the surface hardness of epoxy, where the highest hardness value was obtained after adding this material compared to other additives.

Research limitations/implications: Sustainability and reducing energy consumption are among the most important aspects addressed in this research.

Originality/value: This research aims to study the impact of various additives, namely, Sunflower Seed husks, used utensil waste, and titanium dioxide powder for epoxy resin for obtaining a new material that serves as an efficient insulator inside buildings.

Keywords: Thermal insulator, Sunflower seed husks, Used utensil waste, Titanium dioxide powder

Reference to this paper should be given in the following way:

I.A. Mashkoor, M.A. Jabbar, M.Y. Yousif, The impact of additives on the insulation properties of the epoxy resin building substance, Tytuł, Archives of Materials Science and Engineering 125/2 (2024) 49-57. DOI: https://doi.org/10.5604/01.3001.0054.5855

PROPERTIES

1. Introduction

Global warming is a climatic phenomenon characterized by a rise in the average temperature of the Earth, primarily caused by the escalation of greenhouse gas emissions that intensify the greenhouse effect [1]. These circumstances necessitate the implementation of a resolution aimed at mitigating environmental pollutants to safeguard the lives of organisms and capitalize on this opportunity [2].

Considering increasing public consciousness regarding global environmental challenges, current approaches to waste management are focused on mitigating the volume of solid waste and maximizing the recovery and utilization of materials found in discarded waste as a valuable resource.

Due to the increase in population and the growing desire for enhanced indoor comfort and extended periods spent within buildings, the utilization of heating, ventilation, and air-conditioning (HVAC) systems has become responsible for approximately 50% of the energy consumption in buildings. Consequently, the adoption of high-performance superinsulation materials derived from waste materials, holds the potential to mitigate the accumulation of waste in landfills. Moreover, this approach can effectively diminish the pollution of air and water resulting from waste disposal while simultaneously facilitating energy and cost savings [3].

Energy conservation has become a matter of growing significance within the residential sector, which holds a significant portion of the overall global energy demand. Thermal insulation is considered a highly valuable tool in the pursuit of energy conservation in buildings [4]. The primary aim of installing insulation material within a building is to mitigate energy consumption associated with heating or cooling processes, achieved through enhancing the building envelope's thermal resistance. Thermal insulation plays a crucial role in reducing the overall energy demand; however, it is important to note that various types of insulation offer distinct advantages regarding wall protection and preventing mould formation [5]. Researchers have conducted several studies exploring various approaches to the production of thermal insulators. One such study, conducted by Elena Dieckmann et al. in 2019, focused on developing thermal insulation packaging materials using feathers [6]. Feathers obtained from the poultry industry were subjected to cleaning and disinfection procedures. Fibres were extracted from these feathers through commercially available pilot plant facilities. Non-woven mats feather fibre composites were produced after this process.

K. Manohar et al. (2016) studied the insulating properties of banana fibre. The aim was to compare these properties with those of conventional insulating materials to determine the potential suitability of banana fibre as an insulation material for building thermal. ASTM C-518-04 was determined to measure the thermal conductivity of 38 mm thick slab-like specimens made of banana fibre. Experiments were carried out within a density range of 20 kg/m^3 to 120 kg/m^3, with 10 kg/m^3 increments. Additionally, the mean test temperature varied between 20°C and 40°C, with increments of 5°C. The findings demonstrated that banana fibre displayed the typical behaviour observed in fibrous thermal insulation, wherein the thermal conductivity decreased as the density increased until reaching a minimum value. Subsequently, the thermal conductivity increased as the density continued to increase [7]. In the same context, vein, Panyakaew and Fotios (2008) used agricultural waste materials in Thailand to enhance thermal insulation properties in walls and ceilings. Following the addition of specific materials, a selection of optimal insulators was made based on the evaluation of thermal conductivity. The materials employed in the experiment comprised rice straw, coconut husks, sugar cane waste, palm oil leaves, corn stalks, and Durian husks. The initial three waste materials exhibited the most elevated levels of thermal insulation, as documented in reference [8].

This study examines the impact of various additives, namely Sunflower Seed husks, used utensil waste, and titanium dioxide powder, on the thermal conductivity, specific heat capacity, and hardness of an insulator composed of epoxy with the additives. A series of tests were conducted to assess the thermal properties, specifically thermal conductivity and specific heat capacity, as well as the mechanical properties of a material to determine its suitability as a thermal insulator.

2. Materials and method

2.1. Materials

Epoxy resin

Polymeric resins, also referred to as polyoxides, are a category of reactive prepolymers and polymers that incorporate epoxide functional groups. According to the source cited as [9], Epoxy resins are commonly synthesized through the chemical reaction between compounds that possess a minimum of two active hydrogen atoms, such as polyphenolic compounds, diamines, amino phenols, heterocyclic imides and amides, aliphatic diols, among others, and epichlorohydrin [10]. Sikadur-52 is a solvent-free injection liquid composed of high-strength epoxy resins. It is designed for use in both dry and damp conditions and is effective even at low temperatures. Sika Egypt manufactures this product for construction chemicals.

Titanium dioxide

Titanium dioxide, referred to as titanium (IV) oxide or titania, is classified as a transition metal oxide. It is the naturally occurring oxide of titanium, denoted by the chemical formula TiO_2. In its natural state, titanium dioxide exists in three distinct crystalline structures: anatase, rutile, and brookite [11].

Sunflower seed husks

A comprehensive analysis was conducted on the primary constituents of sunflower seed husks, namely lipids, proteins, and carbohydrates. Lipids constitute 5.17% of the overall hull weights, with 2.96% of this proportion being comprised of wax that consists primarily of long-chain fatty acids (C_{14}-C_{28}, predominantly C_{20}) and fatty alcohols (C_{12}-C_{30}, mainly C_{22}, C_{24}, C_{26}). The fractions of hydrocarbon, sterol, and triterpene alcohol were also subjected to analysis. The remaining portion of the lipid fraction exhibits an oil-like nature and possesses a composition that is comparably akin to that of the kernel oil. The protein fraction, which constitutes approximately 4% of the total weight of the hull, exhibits similarities to the protein fraction found in the oil cake, albeit with the presence of hydroxyproline. The carbohydrate component primarily consists of cellulose and reducing sugars (25.7%), predominantly pentoses [12]. Figure 1 shows sunflower seed husks.

Fig. 1. Image of sunflower seed husks

Polystyrene foam

Polystyrene foam, as shown in Figure 2, is a material which consists of talc ($Mg_3Si_4O_{10}(OH)_2$), Butane (C_4H_{10}), and polystyrene beads ($(C_8H_8)_n$). Polystyrene is a highly prevalent polymer material in contemporary society [13]. Polystyrene foam, commonly utilized in supermarkets and food stores for food preservation purposes, can be conveniently incorporated into construction applications, such as EPS insulation sheets and other EPS materials, by utilizing expanded polystyrene scrap, it has excellent thermal insulating power, so it is evident to use it in building insulation. The waste of used utensils waste is used in this study after grinding it into small pieces, as in the figure below [13].

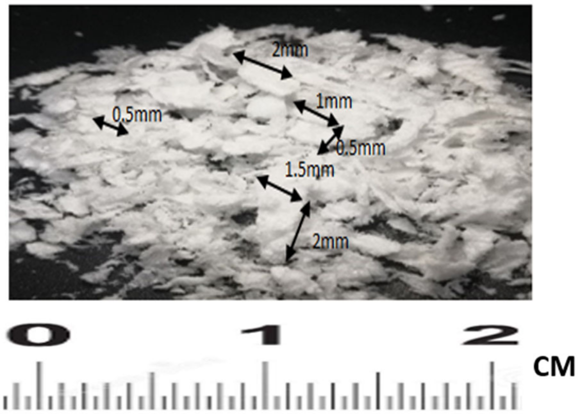

Fig. 2. Image of used utensil waste

2.2. Preparation of test specimens

The models were developed under standard atmospheric conditions of pressure and temperature. The samples that have been prepared consist of two distinct pathways:

1. Preparation of materials composites as mass ratio:
   Four basic samples were made. The first is epoxy only, and then materials were added to epoxy, which are:
   i) Epoxy only,
   ii) (Epoxy - used utensil waste),
   iii) (Epoxy - sunflower seed husks),
   iv) (Epoxy - titanium dioxide);
2. Preparation of materials composites as volume ratio:
   Prepare three composite samples in the form of three layers from the five basic samples by volume friction, where the layer of epoxy was basically for each of these six samples, which are as follows:
   i) Epoxy (epoxy - used utensils waste), (epoxy - sunflower seed husks), which represent comp1,
   ii) Epoxy, (epoxy - titanium dioxide), (epoxy - used utensils waste), which represent comp2,
   iii) Epoxy, (epoxy - titanium dioxide), (epoxy - sunflower seed husks), which represent comp3.

2.3. Analysis

The prepared samples as a mass ratio (epoxy-used utensil waste, epoxy-sunflower seed husks, epoxy-titanium dioxide) were analysed using the XRD technique. The scanning electron microscope (SEM) was utilized to observe the structure and morphology of material wastes. The (SEM) employs a concentrated beam of high-energy electrons to produce a range of signals on the surface of solid specimens. The signals resulting from interactions between electrons and the sample provide valuable insights into various aspects of the sample, such as its external morphology (texture), chemical composition, and crystalline structure and orientation. X-ray diffraction (XRD) refers to a phenomenon where electromagnetic waves, characterized by their wavelength falling within the interatomic distance range of 0.1-10 Å, are utilized. The compatibility of these length scales renders them appropriate for investigating crystalline materials, as they enable the measurement of crystal size, strain, and preferred orientation in polycrystalline materials. The technique of X-ray reflection is utilized to ascertain the thickness of a film accurately.

2.4. Thermal conductivity measurement

The property of thermal conductivity is an inherent characteristic of a substance that signifies its capacity to facilitate the transfer of thermal energy. Lee's disc method employs the thermal equilibrium principle to quantify the heat transfer rate across a material with poor conductivity. As shown in Figure 3, Lee's disc apparatus comprises a steam chamber in the form of a hollow cylinder, which is supported by a thin metallic disc of the same diameter. The steam chamber is equipped with both inlet and outlet tubes for the passage of steam, as well as slots located on its sides that allow for the insertion of a spencer. A state of equilibrium is achieved when steam is introduced into the cylindrical vessel. In the state of thermal equilibrium, the amount of heat conducted through the poor conductor is equivalent to the amount of heat radiated from the lower disc. The rate of heat transfer across two faces with temperatures T_1 and T_2 can be expressed as a function of the coefficient of thermal conductivity (k), the thickness of the material (d), and the radius (r) [14].

$$\frac{dQ}{dt} = k\frac{\pi r^2\,(T_1 - T_2)}{d} \tag{1}$$

where M represents the mass of the disc and c denotes the specific heat of the disc, the expression for the rate of cooling at temperature T_2 can be derived.

$$\frac{dQ}{dt}dt \;=\; Mc\,\frac{dT}{dt} \tag{2}$$

According to the equilibrium concept, the heat transfer rate must be equivalent to the cooling rate. Consequently,

$$K \;=\; \frac{Mcd}{\pi r^2\,(T1 - T2)}\;\frac{dT}{dt} \tag{3}$$

The test is done for basic samples, and the following composites equation is applied as volume ratio [15].

$$\frac{V1}{K1} + \frac{V2}{K2} + \frac{V3}{K3} = \frac{1}{Kc} \tag{4}$$

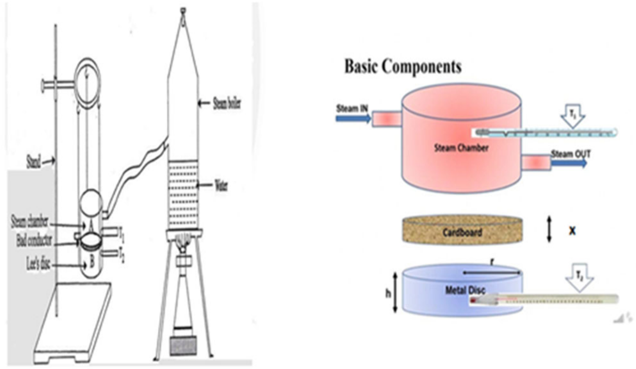

Fig. 3. Lee's disc apparatus for measure thermal conductivity

2.5. Specific heat capacity (CP)

The thermal insulator possesses a significant characteristic wherein it exhibits a delayed heat absorption process prior to reaching a state of thermal equilibrium and subsequently transferring the absorbed heat. The term "specific heat capacity" refers to the quantity of heat energy absorbed or released when a material sample with a unit mass undergoes a unit temperature change during the cooling or heating processes. The measurement of specific heat capacity was conducted using a Heat Exchange method in this study. The approach is characterized by its simplicity, ease of implementation, and suitability for samples with a weight exceeding 5 mg [16].

The experimental protocol Figure 4 involves the application of heat to water until it reaches a specific temperature, followed by the placement of the sample within the calliper. Finally, the temperature differential needed was recorded. The specified heat capacity can be calculated using the equation below [16].

$$Q = m\;Cp\;\Delta T \tag{5}$$

Q is the amount of heat, m is the mass of the substance, and ΔT is the temperature difference. By the law of conservation of energy in the following equation

$$mh\;Cph\;\Delta Th = mc\;Cpc\;\Delta Tc \tag{6}$$

The left side represents parameters for the hot body, while the right side contains parameters for the cold body. The loos energy can be neglected. The specific heat capacity of the composite material can be determined by dividing the total heat absorbed per unit temperature increase by the total mass of the material.

Hence,

$$Cpc = \frac{Cp1f1M + Cp2f2M}{M} = Cp1f1 + Cp2f2 \quad (7)$$

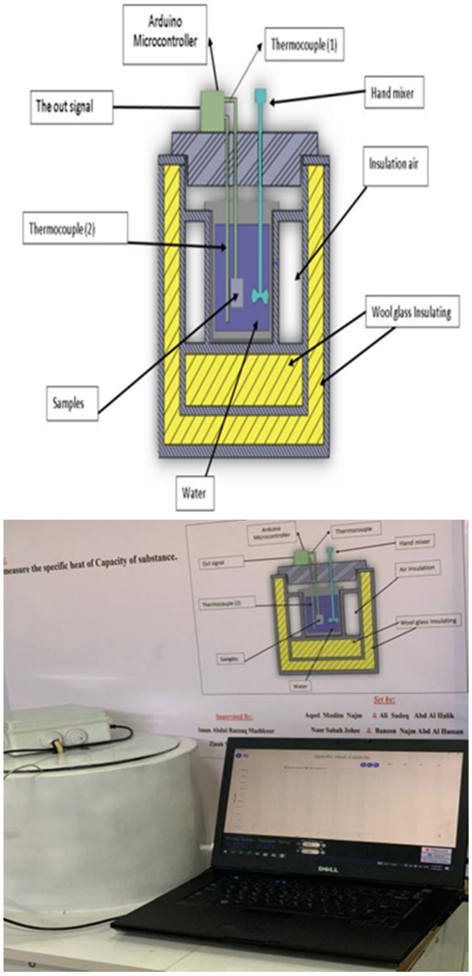

Fig. 4. Schematic presentation of method for measure specific heat capacity

2.6. Hardness

Hardness tests are used to measure a material's resistance to local surface plastic deformation. Vickers hardness-testing techniques are applied for this purpose as per ASTM E384 [15]. A specimen's surface is subjected to the application of force by a minute diamond indenter with a pyramidal geometry. The magnitudes of applied loads are significantly reduced to (0.025 kg). The hardness test is done also returned three times for each sample and then takes average value of it.

3. Results and discussions

3.1. Microstructural analysis

The SEM image in Figure 5(a) shows the structure of (epoxy-used utensil waste). The particles of used utensil waste have different sizes, lengths, and air pockets. Image (b) demonstrates for crystal structure (epoxy-titanium dioxide) that micro-size crystal aggregates in spherical shape have formed with small air pockets among them. Also, the distribution of particles and air pockets is very ordinary. For the two above basic composites structure, the small size of particles helps to improve mechanical properties while forming air pockets enhances thermal insulation by deflecting a heat conduction path. Images (c and d) show the structure of (epoxy-sunflower seed husks), the fibres of sunflower seed husks have different lengths and pores in their structure, which led to slow up the transfer of heat from one point to another.

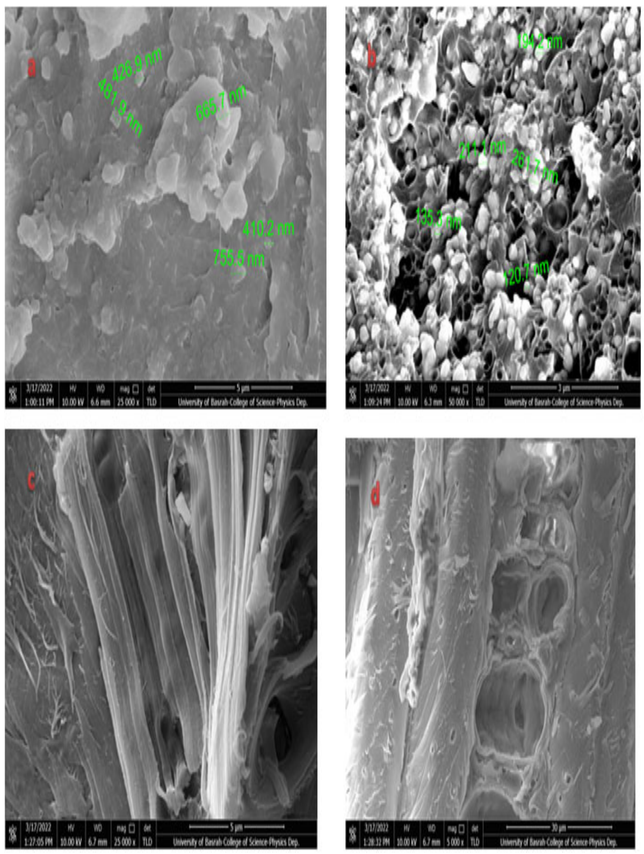

Fig. 5. SEM images of the three basic composites are as follows: (a) epoxy - used utensil waste and (b) epoxy - titanium dioxide. (c, d) epoxy - sunflower seed husks

3.2. XRD results

X-ray diffraction is an analytical technique primarily used for phase identification of a crystalline material. The aim of conducting XRD tests is to estimate the effect of preparing processes of the samples on the microstructure of different additives. Figure (6) exhibits the XRD behaviour of the prepared samples with different additives. From the evaluation of X-ray spectra, the basic band (S3) that represents epoxy resin has a specific peak at (2θ =20) and observes no change in peak compared with composite (epoxy-used utensil waste (S4); that is, mean an indication of the distribution of the additive (filling) inside the epoxy crystal with a higher interstitial. Sample (S2) illustrates the XRD spectra of (epoxy - sunflower seed husks) composite with a slight change in the appearance of two peaks at (2θ = 33.46), which indicates an increase in the orientation of the crystal structure of the material. This can be explained by the fact that some size fibres of the additive (sunflower seed husks) are more significant than the atoms of the base material (image of SEM Fig5 c, d illustrate that), which led to distribution in a way more than one orientation of the material to appear in the form of polycrystalline. The last sample (S1) is titanium dioxide, observing new peaks disappearing from the original peak in the base material. These peaks were new and had multiple orientations completely different from the original peaks of the matrix material, which indicates a redistribution of the material in the shape of amorphous orientation [17].

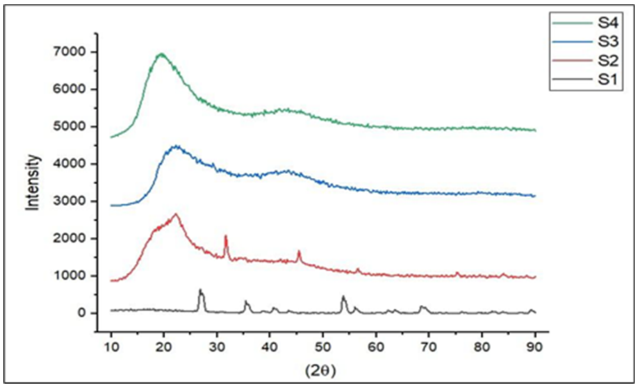

Fig. 6. XRD patterns of composites

3.3. Thermal conductivity results

One of the most important properties of thermal insulation is thermal conductivity. It is important to evaluate the performance of the insulation and the possibility of using it as thermal insulation. The utilization of thermally insulated materials, specifically in wall construction, has emerged as a prominent concern within the contemporary construction industry with the objective of energy conservation. The outcome results of thermal conductivity are illustrated in Figures 7, 8 and 9, respectively. Figure 7 shows the thermal conductivity of basic layers. In contrast, Figure 8 shows the behaviour of path thermal conductivity after prepared as volume ratio where COMP1 (epoxy, epoxy - used utensils waste, epoxy - sunflower seed husks), COMP2 (epoxy, epoxy - titanium dioxide, epoxy - used utensils waste) and COMP3 (epoxy, epoxy - titanium dioxide, epoxy - sunflower seed husks). Figure 9 illustrates a comparison between COMP1, COMP2 and COMP3.

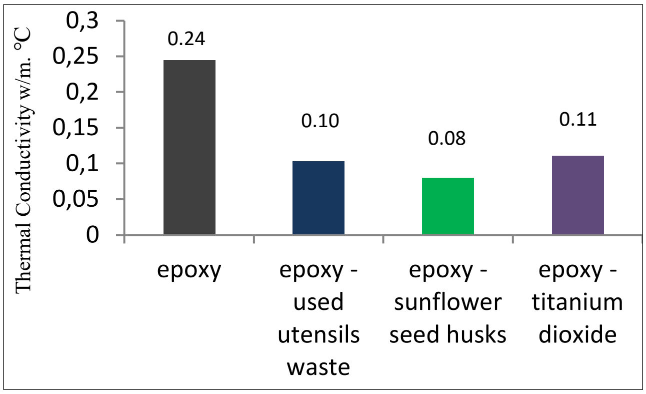

Fig. 7. Thermal conductivity of basic samples

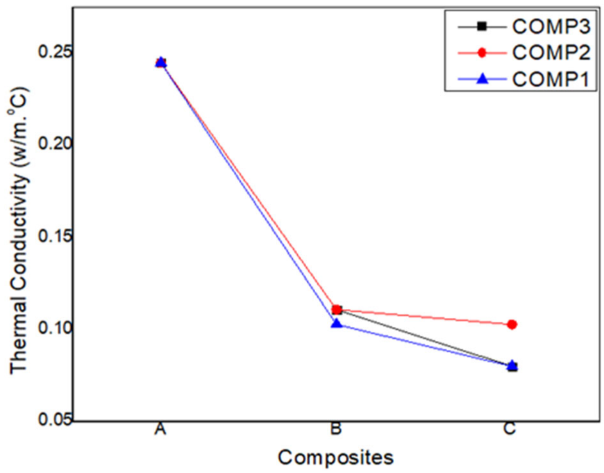

Fig. 8. Path of thermal conductivity in layers

The addition of materials such as (sunflower husks, used utensil waste and titanium dioxide), which were prepared in a (mass ratio), decreased the thermal conductivity of the epoxy (0.2448 w/m.°C), which is outside the scope of insulation, and the thermal insulation range of buildings ranges between (0.034-0.173 w/m.°C) and this is illustrated in Figure 8 [18].

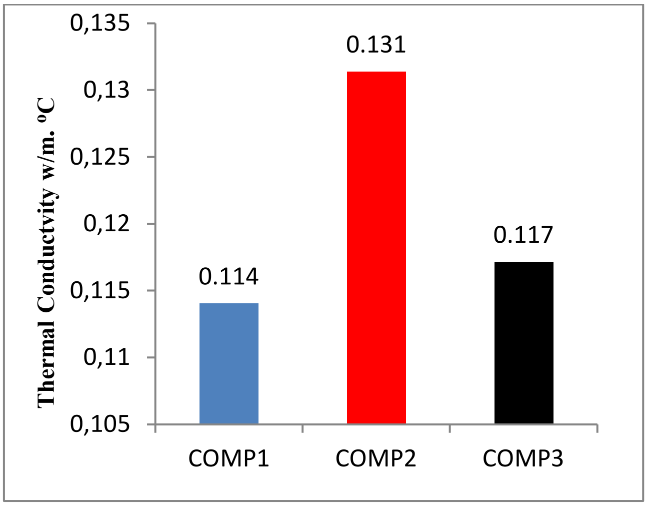

Fig. 9. Thermal conductivity variation

The preparation of the insulating material by (volume ratio) to reduce the thermal conductivity of epoxy reason, led to a significant reduction, as illustrated in Figures 7 and 8. Figure 9 shows a comparison between the composites that were prepared as the lowest is composite (COMP1) and the value is (0.114 W/m.°C). The heating property of the composite is reduced due to the incorporation of additives, which function as small air pockets, thereby enhancing the thermal insulation properties of the composite. The introduction of additional material resulted in the scattering of particles within the air pockets and the epoxy resin matrix. This scattering effect led to an increased dispersion of electrons and a reduction in vibrational energy, consequently lowering the thermal conductivity of the composites [19].

3.4. Specific heat capacity results

A substance possessing a high specific heat capacity has the potential to be employed to store thermal energy. An elevation in temperature results in energy accumulation, whereas a reduction in temperature leads to the liberation of the stored energy. It is imperative to ensure that the design of a building incorporates a substantial heat capacity, thereby minimizing the rate at which the internal temperature fluctuates in response to external temperature variations.

Figures 10 and 11 show the specific heat capacity values of composites. Figure 10 depicts the relationship between the heat capacity of composites and their mass ratio. The data presented in the figure demonstrates that the incorporation of additional materials in composites results in a decrease in their specific heat capacity. This phenomenon can be attributed to the reduced degrees of freedom for vibrations and rotations within the solid phase, characterized by a more organized structure [19].

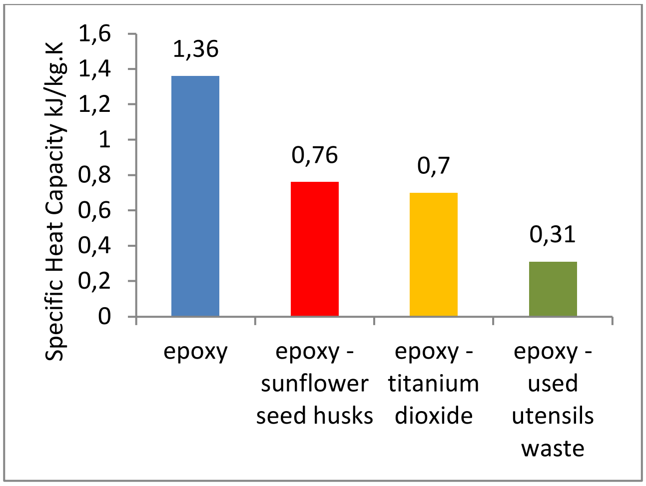

Fig. 10. Specific heat capacity of samples based on mass ratios

Figure 11 illustrates the specific heat of composites as a function of volume ratio. It is observed that the specific heat capacity of composites exhibits an improved range when compared to that of basic composites. The observed phenomenon can be attributed to the alteration in the crystal lattice between adjacent layers, resulting in an augmented level of disorder within the material. Consequently, this disorder enhances the mobility of the constituent molecules [19].

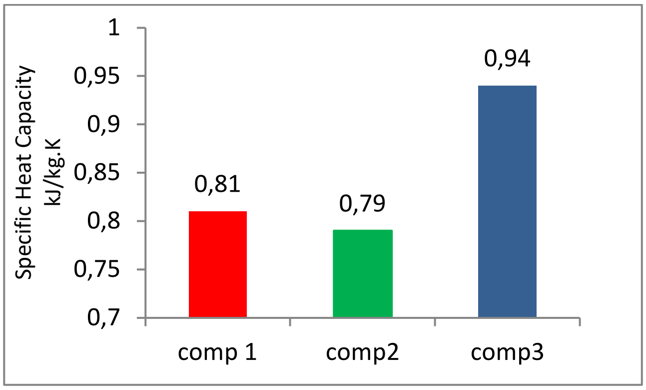

Fig. 11. Specific heat capacity of samples based on volume ratios

3.5. Hardness results

The hardness values will be changed for all composite layers, as shown in Figure 12; this can be attributed to the good distribution of the additives and the presence of additives as a result of the low of mixture. TiO_2 particles are a ceramic and are therefore used as a reinforcement. The hardness of utensils waste and sunflower seed husks as a grinding power will be less than that of epoxy, leading to decreasing the hardness values for composites condition utensils waste and sunflower seed husks [16].

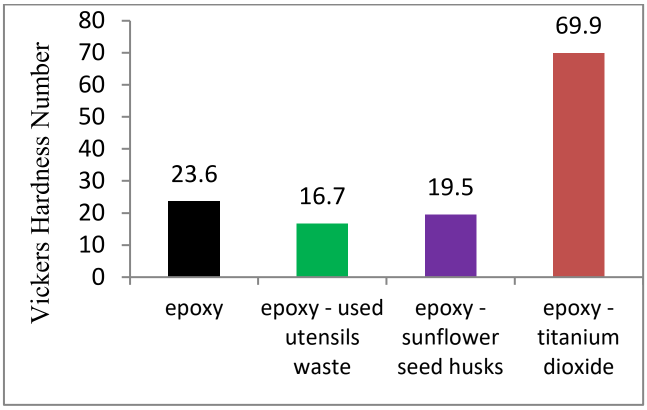

Fig. 12. Hardness of composites

4. Conclusions

Loading filler in the epoxy resin converts it from outside the scope of thermal insulation of buildings to the entire building.

1. The two methods used in the present work were successful in achieving the research objectives. Filler materials are used from waste materials, which highlights the possibility of these materials being a new source of energy, and this means the possibility of using waste materials as an alternative source to produce materials.
2. The use of waste materials contributes to the proper disposal of solid environmental waste.
3. Composites thermal conductivity falls within the range of thermal conductivity exhibited by thermal insulators commonly used in building construction. A minimum thermal conductivity of 0.08 W/m.°C were obtained where epoxy was incorporated with sunflower seed husks.
4. Thermal properties of composites are in direct competition with those of conventional building materials, as they possess unique specific heat capacities. The specific heat capacity property showed a clear variation after additions. The best results were achieved after mixing the base material (i.e. epoxy) with utensil waste.
5. Values of hardness property showed very distinct variations of composite, which reflects the quality of the sample surface. The sample of epoxy-TiO_2 showed the maximum value.

References

[1] P. Nema, S. Nema, P. Roy, An overview of global climate changing in current scenario and mitigation action, Renewable and Sustainable Energy Reviews 16/4 (2012) 2329-2336.
DOI: https://doi.org/10.1016/j.rser.2012.01.044

[2] L. Parker, We Depend on Plastic. Now We're Drowning in It, 2018. Available from: https://www.nationalgeographic.com/magazine/article/plastic-planet-waste-pollution-trash-crisis

[3] H.W. Koh, D.K. Le, G.N. Ng, X. Zhang, N. Phan-Thien, U. Kureemun, H.M. Duong, Advanced Recycled Polyethylene Terephthalate Aerogels from Plastic Waste for Acoustic and Thermal Insulation Applications, Gels 4/2 (2018) 43.
DOI: https://doi.org/10.3390/gels4020043

[4] O. Kaynakli, Parametric Investigation of Optimum Thermal Insulation Thickness for External Walls, Energies 4/6 (2011) 913-927.
DOI: https://doi.org/10.3390/en4060913

[5] L.S. Paraschiv, S. Paraschiv, I.V. Ion, Increasing the energy efficiency of buildings by thermal insulation, Energy Procedia 128 (2017) 393-399.
DOI: https://doi.org/10.1016/j.egypro.2017.09.044

[6] E. Dieckmann, B. Nagy, K. Yiakoumetti, L. Sheldrick, C. Cheeseman, Thermal insulation packaging for cold-chain deliveries made from feathers, Food Packaging and Shelf Life 21 (2019) 100360.
DOI: https://doi.org/10.1016/j.fpsl.2019.100360

[7] K. Manohar, A.A. Adeyanju, A Comparison of Banana Fiber Thermal Insulation with Conventional Building Thermal Insulation, Current Journal of Applied Science and Technology 17/3 (2016) 1-9.
DOI: https://doi.org/10.9734/BJAST/2016/29070

[8] S. Panyakaew, S. Fotios, 321: Agricultural Waste Materials as Thermal Insulation for Dwellings in Thailand: Preliminary Results, Proceedings of the 25th Conference on Passive and Low Energy Architecture "PLEA 2008", Dublin, 2008.

[9] C. May, Epoxy Resins: Chemistry and Technology, 2nd Edition, Routledge, New York, 1988. DOI: https://doi.org/10.1201/9780203756713

[10] H. Sukanto, W.W. Raharjo, D. Ariawan, J. Triyono, M. Kaavesina, Epoxy resins thermosetting for mechanical, Open Engineering 11 (2021) 797-814. DOI: https://doi.org/10.1515/eng-2021-0078

[11] A.J. Haider, Z.N. Jameel, I.H.M. Al-Hussaini, Review on: Titanium Dioxide Applications, Energy Procedia 157 (2019) 17-29. DOI: https://doi.org/10.1016/j.egypro.2018.11.159

[12] P. Cancalon, Chemical composition of sunflower seed hulls, Journal of the American Oil Chemists' Society 48/10 (1971) 629-632. DOI: https://doi.org/10.1007/BF02544577

[13] J. Maul, B.G. Frushour, J.R. Kontoff, H. Eichenauer, K.-H. Ott, C. Schade, Polystyrene and Styrene Copolymers, in: Ullmann's Encyclopedia of Industrial Chemistry, Wiley, Hoboken, New Jersey, 2007. DOI: https://doi.org/10.1002/14356007.a21_615

[14] M. Alam, S. Rahman, P.K. Halder, A. Raquib, M. Hasan, Lee's and Charlton's method for investigation of thermal conductivity of insulating materials, IOSR Journal of Mechanical and Civil Engineering 3/1 (2012) 53-60. DOI: https://doi.org/10.9790/1684-0315360

[15] ASTM E384-17, Standard Test Method for Microindentation Hardness of Materials, ASTM International, West Conshohocken, PA, 2017. DOI: https://doi.org/10.1520/E0384-17

[16] I.A. Mashkoor, H.M. Mohammad, S.F. Dakhil, Preparation of sustainable thermal insulators from waste materials, IOP Conference Series: Materials Science and Engineering 987/1 (2020) 012008. DOI: https://doi.org/10.1088/1757-899X/987/1/012008

[17] F. Ali, N. Ali, M. Altaf, A. Said, S.S. Shah, M. Bilal, Epoxy Polyamide Composites Reinforced with Silica Nanorods: Fabrication, Thermal and Morphological Investigations, Journal of Inorganic and Organometallic Polymers and Materials 30 (2020) 3869-3877. DOI: https://doi.org/10.1007/s10904-020-01518-5

[18] D.D.L. Chung, Composite Materials Science and Applications, 2nd Edition, Springer, London, 2010. DOI: https://doi.org/10.1007/978-1-84882-831-5

[19] H. Lakrafli, S. Tahiri, A. Albizane, M. Bouhria, M.E. El Otmani, Experimental study of thermal conductivity of leather and carpentry wastes, Construction and Building Materials 48 (2013) 566-574. DOI: https://doi.org/10.1016/j.conbuildmat.2013.07.048