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Characteristics of Heat Absorbing Composite Layers of Galvalume Roof Reinforced with Seashell Waste on Temperature

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Abstract
This research focuses on the characteristics provided by the composite layer applied to galvalume roof as a coating with the addition of seashell waste when subjected to temperature. Galvalume roof has a significant drawback where heat penetrates the house, causing discomfort. The primary objective of this study is to determine the characteristics of the seashell waste addition on the composite layer when exposed to heat. This research is using a true experimental method with graphic analysis, including galvalume specimens, 100% resin, weight fraction between the seashell waste and the composite layers 20%:80%, 30%:70%, 40%:60%, and 50%:50%. The results obtained from the research show that seashell waste has a major content of $CaCO_3$ at 95,44%. Thermal conductivity testing reveals that the galvalume specimen has a thermal conductivity of 9,391 W/m°C, while 50%:50% has 0,24 W/m°C. In the temperature testing, it was found that the 50%:50% specimen has the ability to suppress the temperature by 5,49 °C compared to the galvalume specimen.

INTRODUCTION

The issue arising from the consumption of shell waste remains unresolved to date, particularly in Indonesia, where a significant portion of the waste is either dumped or only a small fraction is reused for other purposes such as fertilizer and handicrafts. The reuse of shell waste is limited, given that the majority of this waste is simply discarded. Accumulation of seashell waste on coastal areas becomes a breeding ground for bacteria, negatively impacting the surrounding communities. Illegal dumping of seashell waste into open waters and vacant coastal lands leads to foul odors due to the decomposition of remaining flesh in the shells and microbial degradation of salts into gases such as Hydrogen Sulfide (H_2S), Ammonia (NH_3), and Amines (Yoon et al., 2004).

With the development of this era, an increasing number of people are using galvalume roof as the top cover for houses, replacing asbestos roofs that have lower strength than galvalume. In addition, galvalume steel also has the advantage of higher strength and is lightweight and corrosion-resistant. However, behind these advantages, galvalum steel roofs have high thermal conductivity, causing the temperature beneath them to be high (Kurniawati, 1999). The heat generated by galvalume roofing significantly affects thermal comfort and human activities in a room, which essentially seeks a comfortable condition for activities. Generally, people spend the majority of their time engaging in activities indoors or within buildings (more than 90%) (Lee & Chang, 2000). For this reason, thermal comfort becomes a crucial aspect in the construction of a building to ensure the well-being and health of the building occupants. Indonesia, being one of the tropical countries with high air humidity reaching up to 80% and high air temperatures that can reach 35 °C (Talarosha, 2009), These climatic conditions lead to significant solar heat gain through the building envelope, especially through the roof, which is the most exposed surface to direct sunlight. Therefore, to achieve the desired thermal comfort, control or adaptive measures need to be taken by the occupants, one of which is addressing the parts of the building directly exposed to solar radiation to minimize high air temperatures (Santoso, 2012). One way is to modify the technology of the roof, as the roof is fundamentally the most exposed part of a building to sunlight, especially in residential buildings, thus influencing indoor comfort (Bauer et al., 2010).

The mechanism of heat transfer, particularly via conduction, plays a significant role in determining the thermal behavior of roofing materials. Galvalume, as a metallic material, possesses high thermal conductivity, which facilitates the rapid transmission of heat from solar radiation into the building interior. This process adheres to Fourier's Law of heat conduction, expressed as:

$$Q = \frac{kA\Delta T}{d}$$

where Q denotes the amount of heat transferred, k is the thermal conductivity of the material, A is the cross-sectional area through which heat is transferred, ΔT is the temperature difference across the material, and d is its thickness (Holman, 2010). A material with lower thermal conductivity (k) serves as a more effective insulator, thereby minimizing the heat flow into the indoor environment. Consequently, the application of low-conductivity coatings can substantially improve thermal comfort by reducing the heat absorbed through the roof.

Based on these issues, there is a need for an environmentally friendly technology, namely in the form of cool roofing, which has been proven to effectively reduce the temperature of the space beneath it (Rahmani et al., 2021). From this technology, an innovation emerges, namely using a coating method with composite materials to reduce excessive heat absorption on galvalum roofing. One element that can be used as a filler in this composite is calcium carbonate ($CaCO_3$), which can enhance the thermal stability of the composite (Swain et al., 2014). The calcium carbonate element is one of the main components forming shells in seashells. Based on X-Ray Fluorescence testing, it was found that the composition of shells consists predominantly of CaO at 94% (Fombuena et al., 2014). The use of seashell waste is also supported by its abundant and easily accessible availability. Therefore, its utilization can be employed as a roof insulation material to reduce heat absorbed by galvalume roofing

With thermal conductivity ranging from 0.1 to 0.5 W/m°C (Zhao et al., 2022), Epoxy has the potential as a coating matrix on the roof that can reduce room temperature, supported by fillers that contribute to temperature reduction properties. Epoxy also possesses other advantages, such as chemical resistance and low shrinkage during the curing process, making it highly useful for coating applications. Additionally, it offers other benefits such as high tensile strength (Mousavi et al., 2022), making epoxy an excellent matrix for coating on the roof.

Therefore, this research aims to understand the characteristics of the heat-absorbing composite layer reinforced with seashell waste concerning temperature. It also aims to explore the transformative potential of the seashell-epoxy mixture as a coating and determine the appropriate weight fraction of seashell waste in the seashell waste and epoxy mixture.

RESEARCH METHODS

Composition Test and Conductivity Test Material

The obtained seashell waste is directly washed and soaked in a NaOH solution until residual elements, such as leftover flesh, are removed. It is then rinsed and dried in the sunlight until completely dry. Once dried, the seashell waste is crushed to achieve particle sizes corresponding to no. 100 on a sieve shaker, the result obtained will be refer to as Figure 1:

Figure 1. Powdered Seashell Waste

After obtaining the desired particle size, the shell waste powder can be directly subjected to X-Ray Fluorescence composition testing. The purpose of this testing is to determine the elemental content in the specimen to be used. A test sample of 15 grams of shell waste powder is prepared. Then, the specimen is tested in the FMIPA UM laboratory using the XRF machine with Minipa 14 Type

The Thermal Conductivity Specimen has a disk shape with a diameter of 4cm and a thickness of 4mm. The shell waste powder is then mixed with epoxy according to the weight fraction on a galvalume plate cut to the desired shape inside a mold, as shown in Figure 2. After the layer of shell waste powder and epoxy dries, the specimen is removed from the mold.

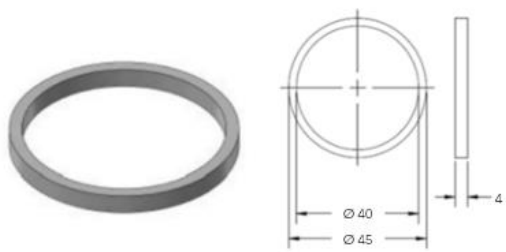

Figure 2. Mold for the Thermal Conductivity Test specimens

The specimens are tested in the Laboratory of Basic Phenomena in Mechanical Engineering at Brawijaya University.

Temperature Test

The Galvalume roof with a thickness of 0,3mm (?) was cut into dimensions of 50cm × 51,76cm(?). It undergoes a coating process using the Hand Lay-Up method with the application of seashell waste powder-filled epoxy at different weight fractions of 20%, 30%, 40%, and 50%

The Temperature Test Tool has a box-shaped design that functions as a room, with walls made of cube-shaped plywood with a thickness of 0,9cm. The top of the cube was lifted on one side by 13,397 cm, creating a 15° slope according to the Letterof the Minister of PUPR Number 1/SE/M/2022 regarding the Technical Guidelines for the Performance Assessment of Green Buildings. Three thermocouple sensors were installed to measure temperature, with sensor 1 placed on top of the galvalum roof, sensor 2 beneath the galvalume roof, and sensor 3 inside the room box. This setup is illustrated in Figure 3.

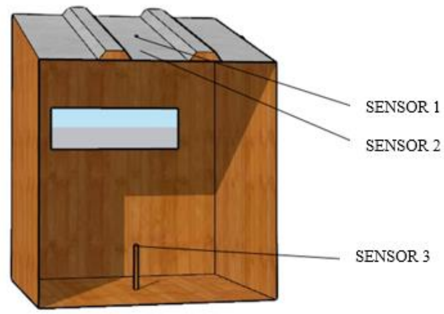

Figure 3. Temperature Test Tool

The temperature test was conducted by placing the testing tool in a prepared chamber conditioned at 35°C. Once this temperature is achieved, data recording is carried out for 10 minutes with a recording interval of every 30 seconds.

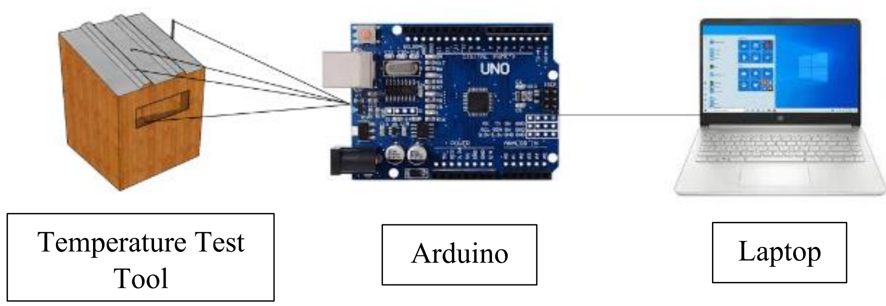

Figure 4. Data Recording Scheme

In Figure 4, the testing scheme is illustrated, where temperature data from the sensor points on the temperature testing tool was recorded and transmitted to Arduino. Subsequently, the obtained data is processed using a laptop.

The temperature data from the three thermocouple sensors connected to Arduino is automatically inputted into the laptop using Arduino version 1.8.19.

RESULTS AND DISCUSSION

Thermal Conductivity Test

From the Composition Test results, data for Shell Waste Powder was obtained as shown in Table 1."

Table 1. Composition Test

Compound	***Conc Unit (%)***
S	0,01%
Ca	95,44%
Ti	0,04%
Mn	0,062%
Fe	2,13%
Br	0,095%
Sr	1,20%
Mo	0,30%
Ba	0,20%
Yb	0,46%
Lu	0,10%

Source:Author's test results, Central Laboratorium Malang State University, Faculty of Mathematics and Science, 2023

Based on the XRF test, the research revealed that the main composition of Seashell Waste is the presence of Ca at 95,44%, followed by Fe at 213%, Sr at 1,20%, and Yb at 0,46%. From this result, it can be determined that the Ca is one of the main elements in the formation of calcium carbonate compounds. Ca is one of the elements involved in the formation of $CaCO_3$ reactions, and the reaction can be expressed as follows:

$$Ca_{(s)} + C_{(s)} + \tfrac{2}{3}O_{2(g)} \rightarrow CaCO_{3(s)}$$

The XRF test results for the seashell waste powder are considered consistent with several previous studies that examined the elements contained in seashell waste. The findings from those studies are as follows:

Table 2. Calcium Content (%) in Various Types of Seashell Waste

Seashell Type	Ca Percentage on the Seashells (%)	Source
Conch Shell	98,1	(Cao et al., 2023)
Oyster Shell	81,62	(Okoro & Oyebisi, 2023)
Oyster Shell	95,82	(Oyejobi et al., 2019)
Cockle Shell	99,0	(Othman et al., 2013)
Mussels Shell	87,21	(Felipe-Sesé et al., 2011)

The thermal conductivity unit used in this study is W/m°C, where W represents thermal energy flowing through a material, m is the length of the heat-conducting material, and C is the temperature difference or ΔT across the material. Therefore, thermal conductivity is the measure of energy through which heat penetrates a specific material.

Table 3. Thermal Conductivity Data

Specimens	Thermal Conductivity (W/m°C)
Galvalume	9,391
Resin	1,598
20%:80%	0,267
30%:70%	0,265
40%:60%	0,26
50%:50%	0,24

Source: Author's test results, Metallurgical Testing Laboratory, Department of Mechanical Engineering, Brawijaya University, 2023

Based on the thermal conductivity test data, the thermal conductivity values obtained are as follows: for galvalum, it is 9,391 W/m°C, for the resin specimen, it is 1,598 W/m°C. In the specimen with a ratio of 20% seashell waste powder to 80% resin, the thermal conductivity is 0,267 W/m°C. For the specimen with a ratio of 30% seashell waste powder to 70% resin, the thermal conductivity is 0,265 W/m°C. In the specimen with a ratio of 40% seashell waste powder to 60% resin, the thermal conductivity is 0,26 W/m°C. Meanwhile, in the specimen with a ratio of 50% seashell waste powder to 50% resin, the thermal conductivity is 0,24 W/m°C. With an increase in weight fraction, the thermal conductivity values will be lower in layers with a higher content of $CaCO_3$. (Zhang et al., 2023).

It can be concluded that the larger the weight fraction of the filler used, the specimen will have a lower thermal conductivity value, making it a more effective insulator. On the other hand, the smaller the seashell addition of a specimen, the larger its thermal conductivity value will be. In this test, the seashell waste powder specimen with a weight fraction of 50%:50% proves to be the most effective insulator due to its lowest thermal conductivity value. Conversely, the specimen with a weight fraction of 20%:80% is the least effective insulator in heat resistance because it has the largest thermal conductivity value.

Temperature Increase Result for Each Recording Interval

After obtaining the temperature increase data table, the data is processed to generate a table of average increases for each sensor at each recording interval. The resulting table is as follows.

Table 4. Temperature Increase Data for Sensor 1 (Top of Galvalume Roof)

N-Increase-	Sensor 1 (°C)					
	Galvalume	Resin	20%:80%	30%:70%	40%:60%	50%:50%
20	1,32	1,28	1,22	1,21	1,18	1,17

According to Table 4, there is an indication that the seashells waste filler had an effect of reducing the spread of the heat on top of surfaces as the weight fraction of seashells raises up. The result from this data can be defined in figure 5.

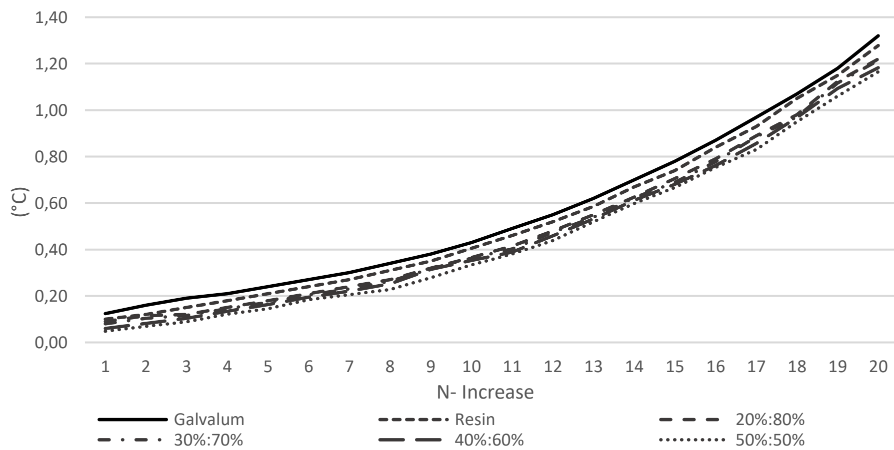

Figure 5. Graph of Temperature Increase for Each Interval (30s) on Sensor 1 (Top of Galvalume Roof)

The results from the Figure 5 shows the heat increase of each specimens with different weight fraction of seashells filler. Consequently, the higher the weight fraction of the seashells filler, the heat dispersion rate also decreases. This is attributed to the decreasing thermal conductivity values observed in each specimen, influenced by the increased $CaCO_3$ content (Zhang et al., 2023), along with the increase in the concentration of seashell waste in its composite layer, it is also evident that the $CaCO_3$ content in the seashell waste contributes to the improvement of thermal stability (Sahebian & Mosavian, 2019). Several factors that can influence these differences may also arise from the distribution of seashell waste used in the coating. The larger the weight fraction of the filler, the easier it is to achieve a more uniform distribution when using seashell waste particle as an addition to the composite layers on the galvalume roof.

Table 5. Temperature Increase Data for Sensor 2 (Underneath Galvalume Roof)

N- Increase	Sensor 2 (°C)					
	Galvalume	Resin	20%:80%	30%:70%	40%:60%	50%:50%
20	1,30	1,19	1,12	1,09	0,83	0,60

According to the Table 5, there is an indication on the final recording of the specimen which shows that the temperature increase differs from the top surface of the galvalume roof to the bottom surface as the weight fraction of the fillers increase, with the highest difference of 0,70°C between the Galvalume specimen and the 50%:50% specimens. The result from this data can be defined in figure 6.

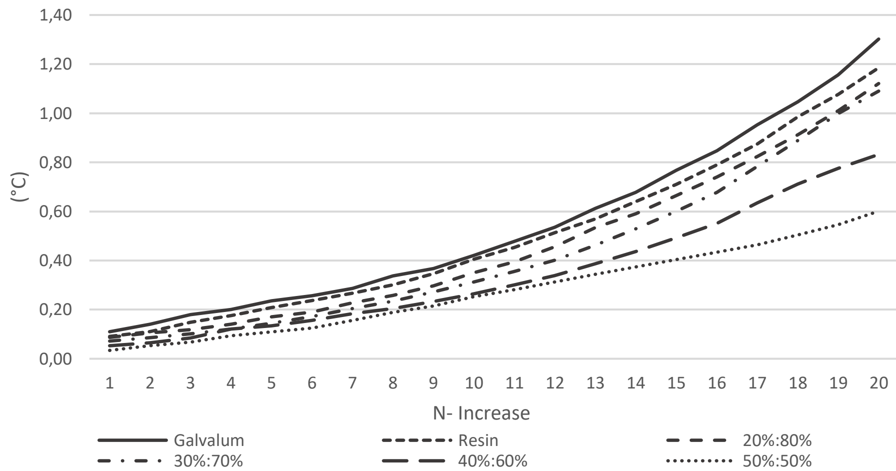

Figure 6. Graph of Temperature Increase for Each Interval (30s) on Sensor 2 (Bottom of Galvalume Roof)

In Figure 6, the graph shows the data on temperature increase at each data recording interval, which is at a 30-second interval on Sensor 2, specifically at the bottom of the galvalume roof. From the graph, it can be observed that there is an increase in temperature at each recording interval for every weight fraction and the case without coating. The data indicates that the weight fraction of 50%:50% exhibits characteristics of a lower temperature increase. For instance, at the 20th increase, there is a temperature rise of 0,60°C, compared to the galvalume specimen, which records a temperature increase of 1,30°C at the 20th interval.

The characteristics of the temperature increase are attributed to the low thermal conductivity possessed by the specimen with a coating ratio of clamshell waste at a weight fraction of 50%:50%. This is caused by the high content of $CaCO_3$, leading to a drastic decrease in the heat conduction rate through the conduction process from the top to the bottom of the Galvalum, resulting in excellent thermal stability. (Sahebian & Mosavian, 2019).

Table 6. Temperature Increase Data for Sensor 3 (Indoor)

N- Increase	Sensor 3 (°C)					
	Galvalume	**Resin**	**20%:80%**	**30%:70%**	**40%:60%**	**50%:50%**
20	1,28	1,18	1,10	1,08	0,82	0,59

According to the Table 5, indicated that after the heat travels through the galvalume and the composite layers, the temperature of the sensor received a various temperature decrease as its travels through air. The result from this data can be defined in figure 7.

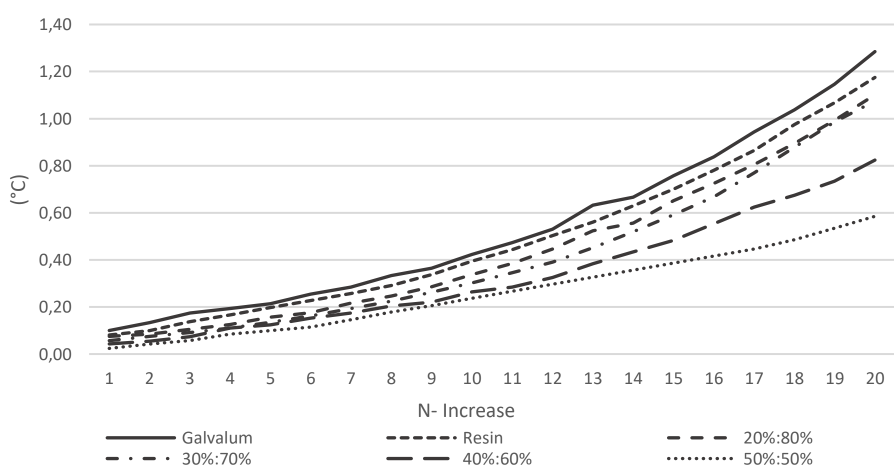

Figure 7. Graph of Temperature Increase for Each Interval (30s) on Sensor 3 (Indoor)

In Figure 7, the graph shows the data on temperature increase at each data recording interval, which is at a 30-second interval on Sensor 3, specifically within the room. From the graph, it can be observed that there is an increase in temperature at each recording interval for every weight fraction and the case without coating. The data indicates that the weight fraction of 50%:50% exhibits characteristics of a lower temperature increase. For instance, at the 20th increase, there is a temperature rise of 0,59°C, compared to the galvalume specimen, which records a temperature increase of 1,28°C at the 20th interval.

This is caused by the influence of the composite layer applied to the specimen with a 50%:50% weight fraction, affecting the temperature at the bottom of the galvalume roof. As a result, the heat conduction between the bottom of the galvalume roof and the point of Sensor 3 decreases. The heat conduction in this area is influenced by the heat treatment through convection, where the rapid propagation affects the temperature recorded on Sensor 3. Thus, it is evident that the temperature on the roof can affect the temperature inside the room. (Fatimah et al., 2019).

Temperature Data on Galvalume Coating Specimens

The data collection was carried out after conditioning the test chamber at a temperature of 35°C on sensor 1. Next was the recording of data for each specimen in the temperature test with a data collection duration of 10 minutes and a data recording interval of every 30 seconds. After obtaining the data, further processing was conducted using Microsoft Excel. The data for the temperature increase for each specimen is presented in table 7.

Table 7. Data Temperature on Sensor 1 (Above Galvalum Roof)

Time (s)	**Sensor 1 (°C)**					
	Galvalume	**Resin**	**20%:80%**	**30%:70%**	**40%:60%**	**50%:50%**
Difference (600s – 0s)	11,19	10,56	9,84	9,70	9,412	9,06

Based on Table 7, containing temperature test data on sensor 1, which recorded the temperature data at the top of the galvalume specimen, the specimens showed a temperature increase from the beginning of the recording to the end.

This discrepancy can be attributed to the efficient flow of heat received by the galvalume roof, facilitated by its high thermal conductivity. As a result, the heat accumulation on the top of the roof is faster and more uniform. Conversely, the specimen with a coating ratio of 50%:50% shows the least effective heat flow among the specimens after heat treatment. This graph indicates that the thermal conductivity properties derived from $CaCO_3$ in the seashell waste significantly impact heat flow performance, even on the top surface of the roof, resulting in relatively good thermal stability (Sahebian & Mosavian, 2019).

Table 8. Data Temperature Sensor 2 (Under Galvalume Roof)

Time (s)	**Sensor 2 (°C)**					
	Galvalume	**Resin**	**20%:80%**	**30%:70%**	**40%:60%**	**50%:50%**
Difference (600s -0s)	10,91	10,09	9,19	8,51	6,96	5,56

Based on Table 8, which contains temperature test data for sensor 2 recording temperature data on the lower part of the galvalume specimen, results showed a various temperature increase as the weight fraction of the filler increases. The significant temperature increase is attributed to the presence of $CaCO_3$ in the seashell waste powder, where $CaCO_3$ exhibits excellent thermal stability. (Vasanthkumar et al., 2022), additionally, with the increase in $CaCO_3$ content, the thermal conductivity becomes lower. (Zhang et al., 2023), thus enhancing its ability to withstand the received heat increase.

Table 9. Temperature Data from Sensor 3 (Indoor)

Time (s)	Sensor 3 (°C)					
	Galvalume	Resin	20%:80%	30%:70%	40%:60%	50%:50%
Difference (600s-0s)	10,78	9,89	8,89	8,29	6,74	5,29

Based on Table 9 containing temperature test data on sensor 3 recording room temperature. The specimen with a 50%:50% weight fraction of the filler proves to have excellent thermal stability (Vasanthkumar et al., 2022), thus it can reduce the temperature inside the room, in contrast to the galvalume specimen which shows the highest temperature due to its less favorable thermal characteristics.

CONCLUSION

Based on the analysis and discussion in the Results and Discussion section, the following conclusions can be drawn: (1) Based on the thermal conductivity test regarding the addition of filler in the form of sea shell waste powder to epoxy coating applied to the Galvalum roof, it is observed that there is a characteristic decrease in thermal conductivity for each weight fraction ratio of clamshell waste. (2) Based on the temperature increase test data, it is evident that specimens with seashell waste filler in the coating exhibit characteristics of heat resistance against temperature rise in the room. The final temperature increase values for each sample starting from resin specimen and 20%:80% through to the 50%:50% specimen show a temperature difference of 0,1°C; 0,18°C; 0,2°C; 0,46°C; 0,69°C, respectively at the end of the recording. (3) Seashell waste powder as an addition to the composite layers has proven to have the potential to be transformed into a coating material that serves as an effective way to mitigate the increase in room temperature by reducing the temperature rise from the galvalume roof to the interior. The weight fraction of 50%:50% as a coating specimen demonstrates the best results in the thermal conductivity test with a value of 0,24 W/m°C. This characteristic enables the coated galvalume roof to suppress the temperature increase by 5,49°C compared to the uncoated galvalume at the end of the temperature test, specifically at the 10th minute of recording.

REFERENCES

Bauer, M., Mösle, P., & Schwarz, M. (2010). Green building: Guidebook for sustainable architecture. In *Green Building: Guidebook for Sustainable Architecture*. https://doi.org/10.1007/978-3-642-00635-7

Cao, X., Zhang, R., Zhang, N., Chen, L., Chen, D., & Li, X. (2023). Performance improvement of lauric acid-1-hexadecanol eutectic phase change material with bio-sourced seashell powder addition for thermal energy storage in buildings. *Construction and Building Materials*, *366*, 130223. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2022.130223

Fatimah, F., Juanda, J., & Santoso, I. (2019). Types of Roofs, Indoor Temperature and Humidity. JOURNAL OF ENVIRONMENTAL HEALTH: Journal and Application of Environmental Health Engineering, *16*(1), 727–732. https://doi.org/10.31964/jkl.v16i1.108

Felipe-Sesé, M., Eliche-Quesada, D., & Corpas-Iglesias, F. A. (2011). The use of solid residues derived from different industrial activities to obtain calcium silicates for use as insulating construction materials. *Ceramics International*, *37*(8), 3019–3028. https://doi.org/10.1016/j.ceramint.2011.05.003

Fombuena, V., Bernardi, L., Fenollar, O., Boronat, T., & Balart, R. (2014). Characterization of green composites from biobased epoxy matrices and bio-fillers derived from seashell wastes. *Materials and Design*, *57*, 168–174. https://doi.org/10.1016/j.matdes.2013.12.032

Holman, V. (2010). Heat Transfer (10th Ed.). In *Visual Resources* (10th editi, Vol. 15, Nomor 3). McGraw-

Hill, a business unit of the McGraw-Hill Companies, Inc. https://doi.org/10.1080/01973762.1999.9658510

Kurniawati, N. (1999). Determination of thermal conductivity (K) of several types of metals: Pure aluminum, stainless steel (18% Cr, 6% Ni), and carbon steel (0.5% C). *Journal of Scientific Research*, *5*. https://doi.org/10.36706/jps.v0i5.370

Lee, S. ., & Chang, M. (2000). Indoor and outdoor air quality investigation at schools in Hong Kong. *Chemosphere*, *41*(1–2), 109–113. https://doi.org/10.1016/S0045-6535(99)00396-3

Mousavi, S. R., Estaji, S., Kiaei, H., Mansourian-Tabaei, M., Nouranian, S., Jafari, S. H., Ruckdäschel, H., Arjmand, M., & Khonakdar, H. A. (2022). A review of electrical and thermal conductivities of epoxy resin systems reinforced with carbon nanotubes and graphene-based nanoparticles. *Polymer Testing*, *112*, 107645. https://doi.org/https://doi.org/10.1016/j.polymertesting.2022.107645

Okoro, W., & Oyebisi, S. (2023). Mechanical and durability assessments of steel slag-seashell powder-based geopolymer concrete. *Heliyon*, *9*(2), e13188. https://doi.org/https://doi.org/10.1016/j.heliyon.2023.e13188

Othman, H., Hisham, B., Bakar, A., Don, M. M., Azmi, M., & Johari, M. (2013). Cockle shell ash replacement for cement and filler in concrete. *Malaysian Journal of Civil Engineering*, *25*(2), 201–211.

Oyejobi, D. O., Raji, S. A., Aina, S. T., & Siva, A. (2019). Physio-chemical and microstructural characteristics of selected pozzolanic materials for cement and concrete production. *Nigerian Journal of Technological Development*, *16*(3), 111. https://doi.org/10.4314/njtd.v16i3.4

Rahmani, F., Robinson, M. A., & Barzegaran, M. R. (2021). Cool roof coating impact on roof-mounted photovoltaic solar modules at texas green power microgrid. *International Journal of Electrical Power and Energy Systems*, *130*(November 2020), 106932. https://doi.org/10.1016/j.ijepes.2021.106932

Sahebian, S., & Mosavian, M. H. (2019). Thermal stability of CaCO3/polyethylene (PE) nanocomposites. *Polymers and Polymer Composites*, *27*(7), 371–382. https://doi.org/10.1177/0967391119845994

Santoso, E. I. (2012). Kenyamanan termal indoor pada bangunan di daerah beriklim tropis lembab. *Indonesian Green Technology Journal*, *1*(1), 13–19.

Swain, S. K., Dash, S., Kisku, S. K., & Singh, R. K. (2014). Thermal and Oxygen Barrier Properties of Chitosan Bionanocomposites by Reinforcement of Calcium Carbonate Nanopowder. *Journal of Materials Science & Technology*, *30*(8), 791–795. https://doi.org/10.1016/j.jmst.2013.12.017

Talarosha, B. (2009). *Menciptakan Kenyamanan Thermal Dalam Bangunan*.

Vasanthkumar, P., Balasundaram, R., Senthilkumar, N., Palanikumar, K., Lenin, K., & Deepanraj, B. (2022). Thermal and thermo-mechanical studies on seashell incorporated Nylon-6 polymer composites. *Journal of Materials Research and Technology*, *21*, 3154–3168. https://doi.org/10.1016/j.jmrt.2022.10.117

Yoon, H., Park, S., Lee, K. S., & Park, J. (2004). Oyster shell as substitute for aggregate in mortar. *Waste Management \& Research*, *22*, 158–170. https://doi.org/10.1177/0734242X04042456

Zhang, L., Deng, K. k., Nie, K. b., Wang, C. j., Xu, C., Shi, Q. x., Liu, Y., & Wang, J. (2023). Thermal conductivity and mechanical properties of graphite/Mg composite with a super-nano CaCO3 interfacial layer. *iScience*, *26*(4), 106505. https://doi.org/10.1016/j.isci.2023.106505

Zhao, Y., Kikugawa, G., Kawagoe, Y., Shirasu, K., & Okabe, T. (2022). Molecular-scale investigation on relationship between thermal conductivity and the structure of crosslinked epoxy resin. *International Journal of Heat and Mass Transfer*, *198*, 123429. https://doi.org/https://doi.org/10.1016/j.ijheatmasstransfer.2022.123429