Thermal Stability Analysis of Cyperus Rotundus L Reinforced HDPE Composite in Polymer Composite Roof Tiles

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(Received: 01 May 2024 / Revised: 16 May 2024 /Accepted: 26 May 2024)

Abstract*— One of the materials that may be utilized in polymer matrix composites is high-density polyethylene (HDPE) plastic. Large amounts of HDPE plastic waste can harm the environment. Therefore, a solution is needed to overcome this problem. One solution to reduce plastic waste is to utilise it into polymer composite roof tiles. Roof tile surfaces are subjected to the greatest amount of solar heat radiation. This study aims to analyze the effect of variations in the composition of HDPE and teki grass on the value of solar radiation heat transfer and the value of thermal stability in polymer composite roof tiles. This research uses an experimental method by composites HDPE and teki grass with variations in the weight of teki grass used by 0%, 10%, 15%, and 20%. The results show that 20% teki grass composition in the composite produces low radiant heat compared to 0% teki grass composition which tends to be higher. according to the findings of the thermal stability test., The maximum thermal stability was seen in the composite with 0% fiber composition. While the most unstable composite is at 20% fiber composition with a 5% weight loss at 164.47ºC and 10% at 278.27ºC.

Keywords— Plastic Waste, Compoiste, Teki Grass, Thermal Stability, TGA.

I. Introduction

Polymer matrix composites (PMC) are materials that use polymers as a matrix and fibres as reinforcement. The high specific strength and modulus of polymer matrix, in addition to its low material and production cost, has led to its widespread development [1]. The usage of thermoplastics, which are characterized by their hardness and lightweight features. Several different products rely on polymer composites, such as parts for cars, planes (both civilian and military), and athletic gear. [2]. High-density polyethylene (HDPE), which is a kind of thermoplastic polymer, is one of the polymeric materials that may be utilized in the production of composite compounds. Because it is readily available and not difficult to locate, HDPE matrix polymer is utilized. The prevalence of plastic in Indonesia leads to an accumulation of garbage, which in turn causes natural catastrophes and negative effects on the environment, such as floods and soil degradation. Plastic waste generation in Indonesia reached 3,599,530.19 tonnes/year in 2023 [3].

The water-resistant and non-degradable nature of plastic causes problems for the environment, one solution is to optimise its use by reusing it into more useful items. [4]. Polymer composite roof tiles are one of the products that have been developed from recycled plastic in an effort to maximise the use of plastic.

A composites is a material in which more than two different materials are mixed together to create a stronger, more durable material. [5]. Composites have favourable properties such as weight reduction, increased strength, and corrosion resistance. It is possible to tailor composites to specific chemical, mechanical, geometric, and structural needs [6].

The matrix is often ductile, soft, and binding, but the fibers are elastic and provide a large amount of tensile strength; nevertheless, they cannot be utilized at high temperatures during the manufacturing process [7]. The use of fibres in composites is classified into two types: natural and man-made fibres. [8]. Fibers made from water hyacinth, bamboo, and banana stems are examples of Natural Fiber Reinforced Polyether (NFRP) materials. Artificial fibers, on the other hand, can be made from Glass Fiber Reinforced Polyester (GFRP), Carbon Fiber Reinforced Polyester (CFRP), nylon, decron, and perlon [8], [9], [10]. The use of natural fiber reinforced polyether (NFRP) is an endeavor to manufacture materials that are kind to the environment and enhance the sustainability of fibers. When compared to the use of glass fiber, the use of natural fibers has a more positive influence on the environment . There has been a substantial increase in the utilisation of polymer matrix composites as a consequence of the multiple advantages that it provides in contrast to other materials. One of the advancements in its application for us in making polymer roof tiles. It is generally agreed that roof tiles are the most essential component for roofing in the building industry.

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For instance, research on polymer composite roof tiles has looked at how modifying wood plastic composite with Polypropylene (PP) and Low-density polyethylene (LDPE) affects the physical and mechanical properties of eco-friendly roof tiles. In this investigation, wood powder, LDPE, and PP scraps were utilized as composite fillers. Composites manufactured with LDPE material had better physical properties and mechanical strength when compared to those constructed with PP plastic, according to the study [11]. Also, roof tiles made of polymer composite and reinforced with banana fiber have been the subject of investigation. The aims of this research is to enhance the material's mechanical strength by utilizing polypropylene polymer and reinforcing it with banana fiber. A polypropylene mixture was mixed using an extrusion machine with 10%, 20%, and 30% composition changes. testing was conducted with the use of a thermogravimetric analyzer (TGA). The study found that pure polypropylene lost half its strength and degraded between 240 and 400ºC [12]. Natural fiber composites reinforced with sustainable bamboo fibers have also been the subject of research. After combining bamboo fiber with a polymer matrix through an extraction process, new features are formed. The mechanical and thermal qualities are then determined through testing. Sustainable bamboo composites have several potential applications because to the excellent mechanical and thermal properties and little environmental impact they generate [13]. Additionally, research is being done on High Density Polyethylene (HDPE) composites that have been reinforced with water hyacinth fiber (Eichhornia crassipes) and have been subjected to alkali treatment at concentrations of 5%, 10%, 15%, and 20%. Additionally, there are several variations in composite composition that have been used, including 10%, 20%, 30%, and 40%. The objective of this research is to produce good thermal stability through testing that uses Thermogravimetric Analysis (TGA) and Differential Scanning Calorimetric (DSC). An increase in fiber was shown to be responsible for a decrease in thermal stability, as demonstrated by the results of the tests [14].

The use of polymers as a composite tile material has advantages such as resistance to tropical weather, no rust, strong, lightweight, and also eco-friendly. However, there has been no research on thermal testing with direct solar radiation exposure and thermal stability testing of polymer composite roof tiles using a base material in the form of High density polyethylene (HDPE) plastic waste reinforced with natural fibre in the form of teki grass (Cyperus rotundus L). An attempt to make eco-friendly roof tiles while simultaneously reducing plastic waste has led to the usage of HDPE plastic waste. The roof surface exhibits the greatest temperature, mostly from radiation, which accouonts for about 50% to 70% of the total heat influx into the room [15]. HDPE is highly durable and resistant to extreme weather including sunlight, heat, and cold. The tensile test results of HDPE plastic are classified as hard, lightweight, has a low water absorption rate and has good stretchability [16]. while teki grass is used as a reinforcement due to its abundance and is often found in the tropics as a weed in agricultural land [17].

The study aims to analyzed the value of solar radiation heat transfer and the value of thermal stability to variations in the composition of High density polyetylene (HDPE) and teki grass (Cyperus rotundus L) on polymer composite roof tiles. Tests were conducted through direct exposure to solar radiation and through Thermogravimetric Analysis (TGA) testing.

II. METHOD

A. Research Object and Variations

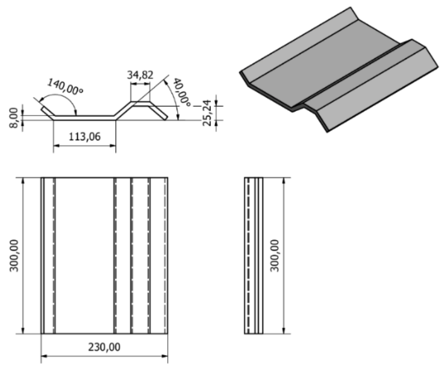


Figure 1. Dimension of Composites Roof Tile

TABLE 1.
VARIATION OF COMPOSITE COMPOSITION

Variation	HDPE (%)	Teki Grass (%)
I	100	0
II	90	10
III	85	15
IV	80	20

Teki grass reinforced polymer composite roof tile is used as the object of this research. Test specimens measuring (300 x 230 x 8) mm were used in this research and there are 4 specimens tested as presented in Figure 1.

The composites used are HDPE waste and teki grass. The teki grass used has undergone 5% alkali treatment for 4 hours. Alkali treatment aims to remove lignin so as to improve fibre bonding and can improve mechanical characteristics and thermal stability [18]. The variation used in this study is the volume fraction ratio of HDPE composite and teki grass 0%. 10%, 15%, and 20% contained in Table 1 are written as variations I, II, and III.

B. Data Collection

Thermomechanical testing is used to evaluate polymer composite tiles made of high-density polyethylene (HDPE) with tiki grass added. Thermogravimetric analysis (TGA) and direct solar radiation testing are two methods for determining the thermal stability and heat generation of polymer composite roof tiles in comparison to environmental heat radiation. The Engineering Faculty Building of the Universitas Pembangunan Nasional Veteran Jakarta in Depok City, West Java was used for testing the endurance of HDPE polymer composite tiles with teki grass. The tiles were angled at 30º and exposed directly to sun radiation. Every hour from 10:00 am to 4:00 pm for one month straight, data was collected.

Figure 2. Schematic of Solar Radiation Testing on Composite Roof Tile

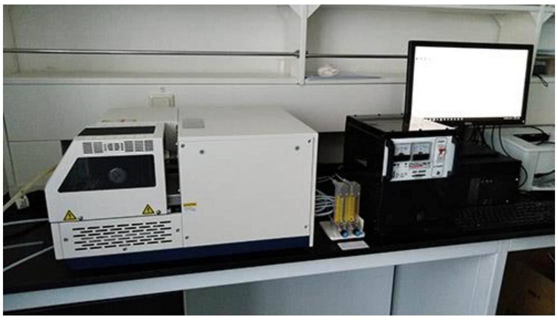


Figure 3. TGA Analysis Hitachi STA7300

Included in the data set is information on the temperatures of the polymer composite tiles themselves, as measured by a DS18B20 thermometer placed on both the top surface and bottom surface of the roof tiles and exported to Excel. Figure 2 shows the plan for the solar radiation testing of composite roof tiles.

When solar radiation is tested for seven hours, there will be a difference in temperature between surfaces on the roof tiles between their both upper and lower, so the radiation heat transfer value can be calculated using the radiation heat rate equation in steady state conditions as follows:

$$p = \varepsilon \cdot \sigma \cdot A \cdot \Delta T^4 \quad (1)$$

With p is the rate of radiant heat (J/s), ε is the emissivity of the object, σ is the Stefan-Boltzman constant $(5{,}67 \times 10^{-8}\, W/m^2k^4)$, A is the object's surface area (m2), ΔT is the change of temperature (K).

Thermal stability testing was carried out using Thermogravimetric analysis (TGA) testing carried out at the ITB Nanoscience and Nanotechnology Research Centre (PPNN) using the Hitachi STA7300 TGA machine found in Figure 3. The composite's thermal stability value was determined by TGA testing. The beginning temperature was set at 30°C and the end temperature at 600°C, with a heating rate of 10°C per minute. Microsoft Excel was used for data processing. Data processing will provide graphical representations of the findings, which will shed light on the interplay of the variables under investigation. The graphs will be used to derive the findings and conclusions of the study.

III. Results and Discussion

A. Solar Radiation Data Analysis

The study approach used involved direct experiments to measure exposure to solar radiation. As a consequence, graphs and data showing average temperatures per hour were generated. The data was comprised of the temperatures of the roof tiles' top surface and bottom surfaces. (T.I, T.II, T.III, and T.IV) were the labels given to the samples, with variants already planned. Table 2 contains the relevant data for every sample.

Table 2 presents the test findings for the average temperature of the top and bottom surfaces in four samples, each sample consists of a mixture of HDPE and

TABLE 2.
AVERAGE ROOF TILE SURFACE TEMPERATURE (C)

TIME	AVERAGE TOP TEMPERATURE (C)			
	T. I	T. II	T. III	T. IV
10:00	45,5	45,1	45,1	44,9
11:00	47,4	47,1	46,9	46,6
12:00	46,7	46,4	45,8	45,5
13:00	43,0	43,0	42,8	42,3
14:00	37,1	36,9	36,8	36,4
15:00	33,6	33,2	32,3	32,0
16:00	30,8	30,5	29,6	29,5
AVERAGE BOTTOM TEMPERATURE (C)				
10:00	41,4	41,0	40,8	40,3
11:00	42,8	42,3	42,0	41,6
12:00	42,8	42,3	41,6	41,1
13:00	39,3	39,3	39,0	38,4
14:00	35,4	35,1	35,1	34,3
15:00	32,7	31,9	31,5	31,0
16:00	30,3	29,5	28,8	28,8

teki grass, with compositions of 0%, 10%, 15%, and 20% accordingly. The temperature measurement time starts from 10:00 AM to 4:00 PM which is done every 1 hour.

From the table, a graph is obtained for the difference in temperature distribution upper and lower on the surface, recorded with T. TOP and T. BOTTOM of each sample.

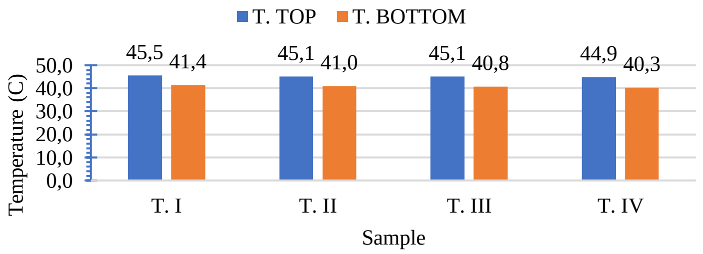


Figure 4. Distribution of Mean Top Surface and Bottom Surface Temperatures at 10:00 AM

In Figure 4 the observation results at 10:00 AM show that the temperatures of the top surface and bottom surfaces in each sample for the highest value are in sample 1 with a top surface temperature value of 45.5°C and a bottom surface temperature of 41.4°C. As for the lowest value obtained in sample IV with a top surface temperature value of 44.9°C and a bottom surface of 40.3°C.

At 11:00 AM, the observations indicated that the temperature on the top surface and bottom surfaces of each test sample shown in Figure 5 started to rise. The highest temperature increase on the top surface and bottom surface occurred in sample I of 47.4°C, 42.8°C. And the lowest temperature increase is found in sample IV with an increase in the temperature of the top and bottom surfaces of 46.6°C, 41.6°C.

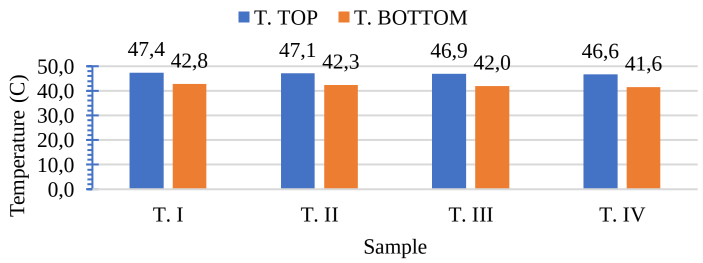


Figure 5. Distribution of Mean Top Surface and Bottom Surface Temperatures at 11:00 AM

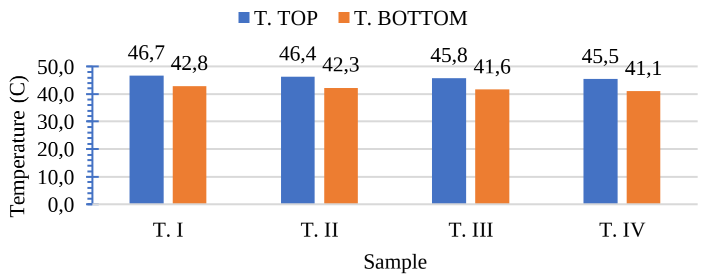


Figure 6. Distribution of Mean Top Surface and Bottom Surface Temperatures at 12:00 PM

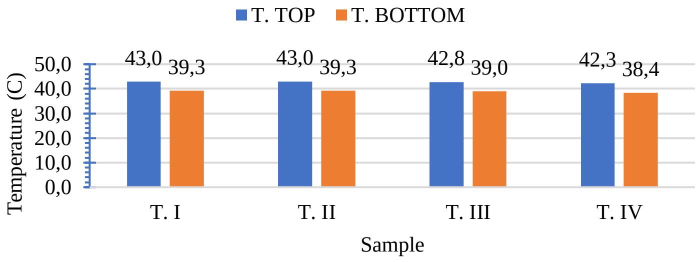


Figure 7. Distribution of Mean Top Surface and Bottom Surface Temperatures at 1:00 PM

Figure 6 displayed observations at 12:00 PM indicating a decline in the average temperature on the top as well as the bottom of each test sample. In sample I, the temperatures of the top surface and bottom surfaces decreased to 46.7°C and 42.8°C respectively. For sample II, the temperatures of both the top surface and bottom surfaces decreased to 46.4°C and 42.3°C, respectively. for sample III the top surface and bottom surface temperatures became 45.8°C, and 41.6°C. Surface temperatures decreased to 45.5°C and 41.1°C, respectively, in sample IV.

Results from observations of each sample's top and bottom surfaces at 1:00 PM can be seen in Figure 7. The highest top and bottom surface temperatures are found in sample I with values of 43.0°C and 39.3°C. As for the value, the lowest top and bottom surface temperatures are found in sample IV with top and bottom surface temperatures showing 42.3°C and 38.4°C.

The figure 8 shows the test results at 2:00 PM top and bottom surfaces temperatures for each sample. Highest temperature is found in sample I with top and bottom surface showing 37.1°C and 45.4°C. As for sample II, the top surface and bottom surface temperature have values of 36.9°C, 35.1°C. for sample III, the top and bottom surfaces temperatures are 36.8°C, 35.1°C, and the lowest surface temperature is found in sample IV with the top and bottom surface temperatures showing 36.4°C and 34.3°C.

At 3:00 PM, the highest top and bottom surfaces temperatures were found in sample I at 33.6°C and 32.7°C. While the lowest temperature is found in sample IV with the top and bottom surface temperature values showing 32°C and 31°C which can be seen in Figure 9.

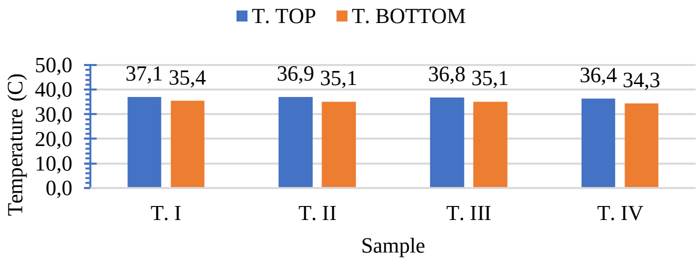


Figure 8. Distribution of Mean Top Surface and Bottom Surface Temperatures at 2:00 PM

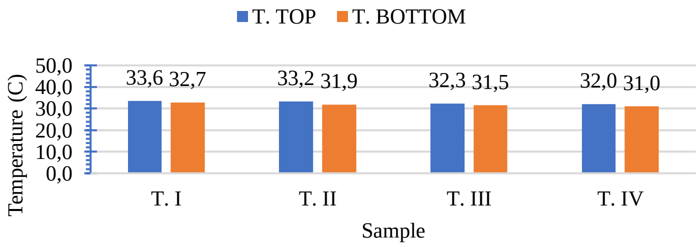


Figure 9. Distribution of Mean Top Surface and Bottom Surface Temperatures at 3:00 PM

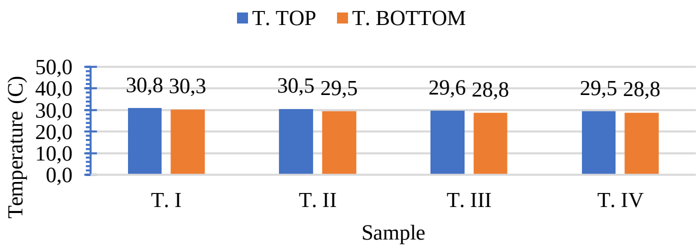


Figure 10. Distribution of Mean Top Surface and Bottom Surface Temperatures at 4:00 PM

At 4:00 PM, the top and bottom surface temperatures in each sample show the highest temperature in sample I with values of 30.8ºC and 30.3ºC. Meanwhile, the lowest top and bottom surface temperatures are found in sample IV with top and bottom surface temperatures showing 29.5ºC and 28.8ºC found in Figure 10.

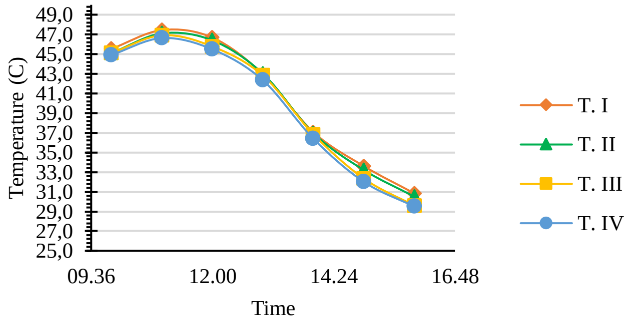


Figure 11. Temperature Distribution of Top Surface (C)

From the results of observations that have been made from 10:00 AM to 4:00 PM, the average temperature distribution on the top surface of the overall sample is shown in Figure 11. Based on Figure 11 for the average distribution value of the highest top surface temperature occurs at 11:00 AM at that hour for the top surface temperature value of each sample the highest is found in sample I with a value of 47.4ºC. And the lowest temperature increase is found in sample IV with an increase in the temperature of the top surfaces of 46.6ºC.

The results of the observations that have been made for the average temperature distribution on the bottom surface of the whole sample can be seen in Figure 12.

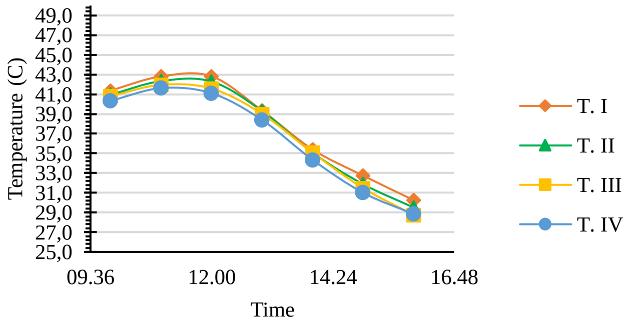


Figure 12. Temperature Distribution of Bottom Surface (C)

TABLE 3.
AVERAGE ROOF TILE RADIATION RATE (J/S)

SAMPLE	TIME	T. TOP (C)	T. BOTTOM (C)	RADIATION RATE (J/S)
T. I	10:00	45,5	41,4	3,8
	11:00	47,4	42,8	4,4
	12:00	46,7	42,8	3,6
	13:00	43,0	39,3	3,4
	14:00	37,1	35,4	1,3
	15:00	33,6	32,7	0,5
	16:00	30,8	30,3	0,3
T. II	10:00	45,1	41,0	3,9
	11:00	47,1	42,3	4,6
	12:00	46,4	42,3	3,9
	13:00	43,0	39,3	3,5
	14:00	36,9	35,1	1,5
	15:00	33,2	31,9	0,8
	16:00	30,5	29,5	0,5
T. III	10:00	45,1	40,8	4,0
	11:00	46,9	42,0	4,7
	12:00	45,8	41,6	3,9
	13:00	42,8	39,0	3,6
	14:00	36,8	35,1	1,4
	15:00	32,3	31,5	0,5
	16:00	29,6	28,8	0,4
T. IV	10:00	44,9	40,3	4,2
	11:00	46,6	41,6	4,7
	12:00	45,5	41,1	4,1
	13:00	42,3	38,4	3,7
	14:00	36,4	34,3	1,6
	15:00	32,0	31,0	0,6
	16:00	29,5	28,8	0,3

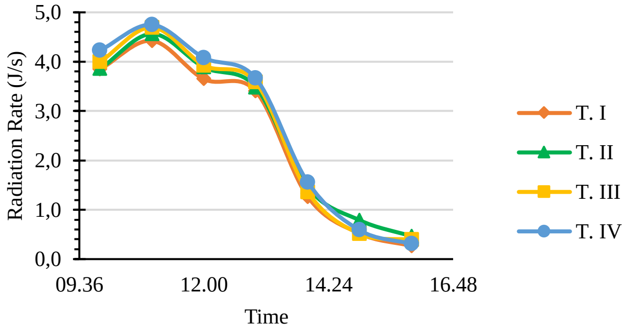


Figure 13. Average Radiation Rate (J/s)

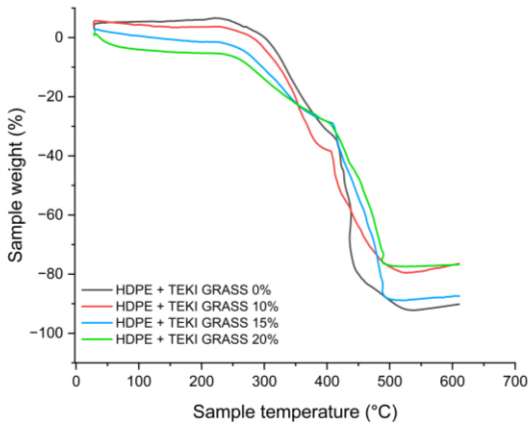


Figure 14. TGA Curve Mass Loss With Respect to Temperature

Based on Figure 12 for the average distribution value of the highest bottom surface temperature occurs at 11:00 AM at that hour for the bottom surface temperature value of each sample the highest is found in sample I with a value of 42.8ºC. And the lowest temperature increase is found in sample IV with an increase in the temperature of the bottom surfaces of 41.6ºC.

The results of the research data show that the highest top and bottom temperatures are found in sample I with a composition of 0% teki grass. While the lowest temperature is found in sample IV with a composition of 20% teki grass. For the radiation rate in each sample can be calculated using equation (1) so that the results in Table 3 are obtained.

Table 3 shows that the results of the radiation rate calculation are obtained using the radiation rate equation and based on the average difference in top and bottom surface temperatures in each sample. From the table, a graph is obtained for the difference in radiation rate of each sample in Figure 13.

Based on Figure 13 for the average radiation rate in each sample the highest occurred at 11:00 AM, This aligns with the solar output curve, which indicates that the peak occurs around midday, namely at 11:00 AM [19]. The highest average radiation rate value is found in sample IV with a composition of 20% teki grass fiber 4.7J/s, while the lowest average radiation rate value of 4.4J/s is found in sample I with a composition of 0% teki grass fiber.

B. Thermogravimetric Analysis (TGA)

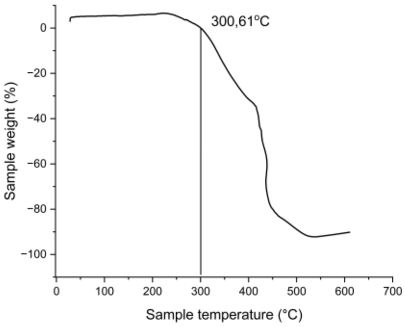
By using a research method in the form of Thermogravimetric analysis (TGA) using a Hitachi STA7300 TGA machine that aims to determine the thermal properties of a composite. The thermal properties discussed are about the thermal stabilization of the composite. Thermal stability refers to a material's capacity to endure high temperatures without undergoing any changes in its mass or structure, the thermal stability of composites depends on the matrix components and constituent fibers used [20]. So that the value of thermal stability can be seen from the graph that shows the decrease in material mass change at a certain temperature found in Figure 14.

Figure 14 is a curve of TGA test results showing the thermal stability of each sample given a heating temperature from 28ºC to 600ºC with an increase in tempetur by 10oC/minute. The testing process was carried out for 120 minutes under inert conditions with oxygen flowing at 20 ml/minute. From the TGA test results, it is divided into 3 temparture zones, the first (T <= 250)ºC, the second (250 <T <= 525)ºC, and the third (T >= 525)ºC. The first temperature zone demonstrates that the mass loss is still relatively stable. However, in the zone in each sample, different mass changes are observed. For example, in the temperature zone of 525ºC, HDPE and teki grass composites experienced a mass decrease of 92.23%. In the same temperature zone, HDPE composites and 10% teki grass experienced a mass decrease of 79.58%. Furthermore, in the case of HDPE composites and 15% teki grass, the mass decrease occurred as much as 88.88%. Finally, for HDPE composites and 20% teki grass, the mass decrease occurred by 77.4%. As the temperature of the material increases, the mass of the polymer decreases because the polymer hydrocarbon bonds release hydrogen atoms, causing the mass to decrease.where as the temperature increases the mass will decrease [21].

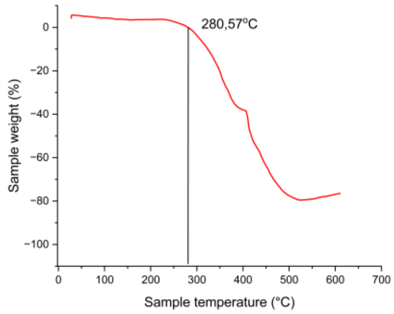
The amount of thermal stability value in each sample can be determined by looking at the mass reduction against temperature, the difference in fiber composition used gives the composite different thermal resistance properties. In HDPE composites and 0% teki grass, the mass decrease occurs continuously starting at a temperature of 300.61°C at that temperature is the initial temperature of decomposition in the composite. As for the HDPE composite and 10% teki grass, the initial temperature of decomposition is at 280.57°C, Figure 15, sections (a) and (b) show the temperature of decrease in mass for these samples. The first temperature of material degradation occurs at temperatures of 260.04 degrees Celsius and 253.89 degrees Celsius, respectively, in the HDPE composite composition and 15% teki grass and HDPE composite and 20% teki grass, as shown in Figure 15 sections (c) and (d), respectively.

The temperature at which a certain percentage of the composite material's weight is lost is one way to measure the thermal stability of a material. If the weight loss occurs at a high temperature then the thermal stability of the material is considered high. An initial weight reduction of 5% or 10% of the polymer can affect the thermal stability. Increases in the temperature needed to accomplish a 5% or 10% weight reduction are indicative of more stable polymer types [22]. From the TGA test that has been carried out, the temperature required from each sample to produce a weight loss of 5% and 10% is found in Table 4.

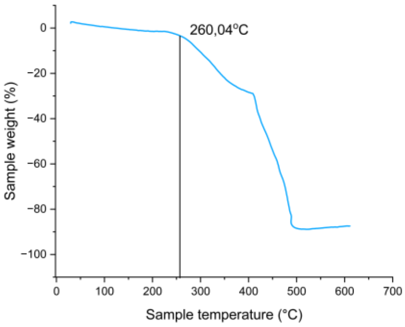
The thermal stability of high- density polyethylene and teki grass composites with 5% and 10% weight loss varies between samples, as shown in Table 4. In the composition of HDPE composite and teki grass fiber 0%, A decrease in weight of 5% was seen at temperatures of 319.82°C, while a 10% decrease in weight observed at a heat of 333.49 °C. While in the composition of HDPE composites and 10% teki grass, there is a decrease in the value of stability at a weight reduction of 5% and 10% respectively, namely 305.07°C and 323.55°C. A decrease in thermal stability also occurs in the composition of HDPE and 15% teki grass where at the time of 5% weight reduction the temperature in the sample is 271.03°C while for a 10% weight loss occurs at a temperature of 297.04°C. In HDPE composite specimens and 20% teki grass, A decrease in weight of 5% was seen at temperatures of



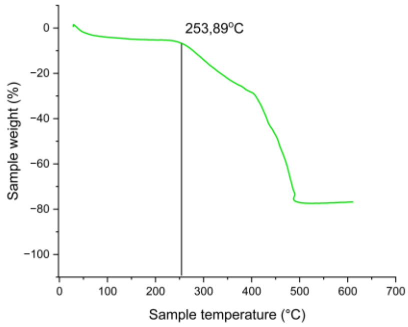
(a) TGA Graph of HDPE and Teki Grass 0%



(b) TGA Graph of HDPE and Teki Grass 10%



(c) TGA Graph of HDPE and Teki Grass 15%



(d) TGA Graph of HDPE and Teki Grass 20%

Figure 15. Temperture of Mass Loss in The Sample

TABLE 4.
THERMAL STABILITY

SAMPLE	THERMAL STABILITY	
	WEIGHT LOSS TEMPERATURE 5% (°C)	WEIGHT LOSS TEMPERATURE 10% (°C)
HDPE+ Teki Grass 0%	319,82	333,49
HDPE+ Teki Grass 10%	305,07	323,55
HDPE+ Teki Grass 15%	271,03	297,04
HDPE+ Teki Grass 20%	164,47	278,27

164.47°C, while a 10% decrease in weight observed at a heat of 278.27°C. From the results of the research that has been done, it can be seen for the highest 5% and 10% weight reduction temperatures based on the composition of the constituent fibers occur in the composition of HDPE composites and 0% teki grass. While the lowest weight reduction temperature is found in the composition of HDPE composite and 20% teki grass.

IV. Conclusion

The objective of this research was to examine the impact of different combinations of HDPE and teki grass on the solar radiation heat transfer and thermal stability of polymer composite roof tiles. This research data was obtained through experimental methods on HDPE composites and teki grass with variations in the weight of teki grass used of 0%, 10%, 15%, and 20%. According to what was found in the research, it shows that there is an effect on the variation of HDPE composition and teki grass on the value of solar radiation heat transfer and the value of thermal stability on polymer composite roof tiles. The results show that the 20% teki grass composition in the composite produces low radiant heat compared to the 0% teki grass composition which tends to be higher. So that the greater the composition of teki grass, the lower the radiant heat generated, while if the composition of teki grass is small, the high radiant heat is generated.

Thermal stability testing using Thermogravimetric analysis (TGA) shows that the composition of HDPE and teki grass significantly affects the thermal stability of the composite. With a smaller teki grass composition, it has a high thermal stability, while with a greater teki grass composition, the lower the thermal stability value. The composite of HDPE and teki grass 0% shows the maximum thermal stability, with a 5% weight loss at 319.82°C, and a 10% weight loss at 333.49°C. In contrast, the HDPE and teki grass 20% composite composition has the lowest stability value with a weight loss of 5% at 164.47°C and 10% at 278.27°C.

Acknowledgements

Gratitude is extended to the Manufacturing and Materials Laboratory of UPN Veteran Jakarta for granting permission to create polymer composite tile samples, and to the ITB Nanoscience and Nanotechnology Research Centre (PPNN) for providing the necessary facilities to conduct thermal stability tests on the materials, as well as all those who have supported this research.

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