## DETERMINATION OF THERMAL CONDUCTIVITY COEFFICIENT OF A BIOCOMPOSITE BASED ON WOOD SAWDUST


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*Climate changes are altering patterns of energy supply and demand, which directly impact the need for adequate building insulation. This presents an opportunity for the development of new biomass-based materials as a renewable source aimed at reducing energy consumption and protecting the environment. The goal of this research is the application of wood sawdust, a waste biomass, as an aggregate for producing a new thermal insulation material. This experimental investigation represents an opportunity for the development of new biomass-based materials with the aim of reducing energy consumption and improving environmental protection. The biocomposite was tested in terms of thermal conductivity, and the obtained results were compared with the characteristics of commercially available thermal insulation materials. The performed analysis suggested that sawdust can be transformed into a valuable biocomposite for insulation purposes as an alternative solution.*



Key words*: renewable resources, sawdust, biocomposite, thermal conductivity, thermal insulator*


### 1. BIOMASS ENERGY IN SERBIA

Biomass refers to waste materials, products, and residues of organic origin (animal and plant-based), which are biodegradable and represent by-products from wood processing, agricultural production, industrial waste, or even urban waste. Biomass, as a renewable energy source, represents the greatest potential for use in energy purposes. In the Republic of Serbia, biomass is commonly used as an energy resource for district heating systems and hot water production. In addition, biomass is used as fuel in cogeneration plants (CHP)- combined heat and electricity generation plants, as input material for the production of biofuels, in the industry for obtaining different types of chemicals and fibres, as well as aggregate in the production of new biomaterials in the construction industry. Therefore, the use of sawdust, the wooden biomass, for obtaining a new thermal insulation material in the construction industry represents the goal of this paper.

According to the National Plan for Renewable Energy Sources (RES) of the Republic of Serbia, biomass represents the most significant RES potential. The Fig. 1 shows the potential of various types of renewable resources in the Republic of Serbia.

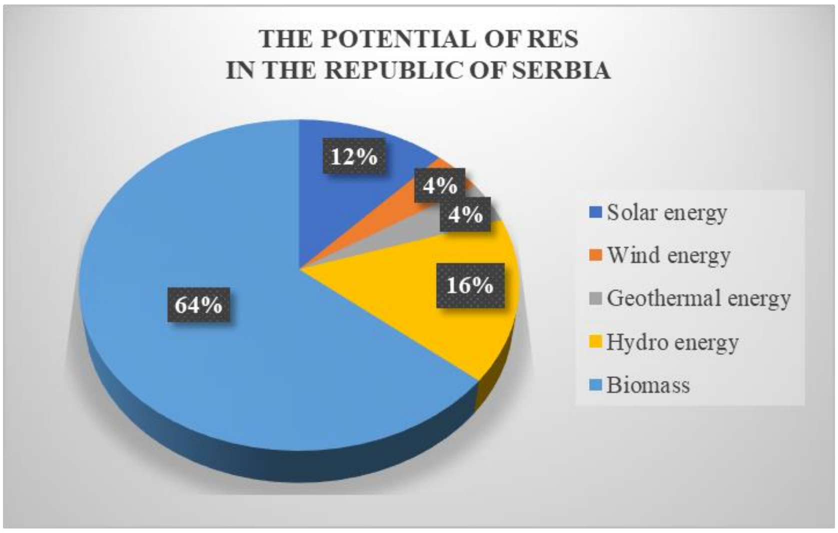


**Figure 1. The potential of renewable resources in the Republic of Serbia [1]**

## 2. MATERIAL ELEMENTS OF A NEW BIOCOMPOSITE

Composites made from natural fibers, based on local renewable resources and biomass, represent a significant step toward sustainable industrial production. Their use reduces the negative environmental impact, as they are based on renewable resources, which reduces dependence on non-renewable materials. Such biocomposites are used in various industries, such as construction, automotive, and aviation, to create environmentally friendly products offering similar or better performance than traditional materials.

Given the growing need for sustainable solutions, research in biocomposites continues to advance. Various natural materials, including wood, plant fibers, and other biomass, are being tested and combined with synthetic materials, such as styrofoam or plastic, to develop composite materials with improved properties. The combination of wood waste, such as sawdust, with polystyrene granules enables the creation of thermal insulation materials that help to reduce waste, creating a material that is both environmentally friendly and economically viable [2].

This type of biocomposite can contribute to improved energy efficiency, reduced carbon dioxide emissions, and decreased consumption of non-renewable resources. Therefore, biocomposites are considered a key element for future sustainable technologies and products, providing significant benefits for ecology, industry, and economy.

### 2.1. THE SAWDUST AS WOOD BIOMASS

Sawdust is the by-product or waste product in wood processing, which consists of small particles of different dimensions (Fig. 2). The important characteristic of wood as a construction material is its ecological acceptance. Sawdust is safe for the environment and human health, and it is used in various fields, such as the filling of children's toys. A huge amount of sawdust is dumped on the wild dumpsites. Improper disposal of wood waste can cause serious ecological problems, which can be significantly reduced by its use, e.g. for construction purposes. All of this represents one of the reasons for the possible reuse of this type of biomass for the production of new environmentally friendly insulation materials.

**Figure 2. Sawdust as a potential component in the biobased insulation material**

Despite the availability of various types of insulation materials, sawdust has been increasingly used for insulation purposes due to its low cost, accessibility and environmental benefits. The use of sawdust in the production of insulation material represents positive environmental benefits because less of it would be used as input fuel and burned. This leads to the reduction of $CO_2$ emissions and resolves the problem of wild dumpsites. However, sawdust also has certain disadvantages, such as its high flammability, ability to attract rodents, and tendency to stick together (coagulate) and absorb water. The previously mentioned facts should be taken into consideration when thinking about using sawdust as a potential component in the production of biobased insulation materials.

**Bamidele Charles Olaiya et al**. [3] examined the possible use of sawdust ash as a replacement in the production of sustainable construction materials. They use sawdust instead of one part of sand to make concrete blocks. The study concludes that sawdust composites are interesting due to their low thermal conductivity and sound absorption without compromising structural strength. **Ferriz-Papi** [4] conducted similar research, using sawdust and wood ashes as replacements for cement in mortars and concrete. **Abraham Mwango et al.** [5] examined the possibility of using untreated sawdust as a filler in polyvinyl chloride (PVC) – the effects of sawdust on structural and temperature changes, as well as mechanical properties. **Si Zou et al.** [6] produced a new composite material based on biomass, which can be used for insulation in the construction industry, using geopolymers as binders and sawdust waste as aggregates. Additionally, they investigated the impact of three main factors to determine the optimal material ratio by testing its thermal and mechanical properties, water resistance, and microstructure. Authors **Ikbal Cetiner and Andrew D. Shea** [7] experimentally examined the possibility of using different types of wood waste, including sawdust, as a thermal insulation material without adding binders, primarily as a filling material for prefabricated walls. **Chryster Tashana Danne M. Gamiao et al.** [8] explored the possibility of using sawdust as an alternative raw material for producing wooden panels as thermal insulation for ceilings. Additionally, the goals of their paper were to assess the efficiency of various treatments of sawdust as an alternative raw material for producing wooden panels for ceiling thermal insulation, focusing on its durability and thermal resistance. **Mateusz et al.** [9–12] examined the mechanical properties of sawdust. Research has proven that sawdust is an excellent natural absorbent with a wide range of applications. Consequently, scientific studies have primarily focused on identifying suitable materials and techniques for wastewater treatment, as well as the removal of paints and non-ferrous metals. **O. L. Rominiyi et al**. [13] examined the possible use of sawdust in three ways: Energy, Manufacturing, and Agricultural utilization. The sawdust is burned in an updraft gasifier with a limited supply of air to produce gas, which consists of carbon dioxide and hydrogen as its primary components. The sawdust and other biomass materials are mixed in certain proportions, bound together and palletized into small blocks called briquettes. The material was also considered to be composted by mixing it with animal digestion or wood ashes and calcium carbonate to form fertilizers.

## 2.2. COMPOSITION OF EXAMINED BIOCOMPOSITE

For making biocomposite samples and implementing experimental investigations, natural wood-based aggregate (sawdust) is combined with small particles of expanded polystyrene (EPS), where a mixture of alabaster gypsum and hydrated lime is used as a binder. The EPS is used for improving the thermal characteristics of the proposed biocomposite. Besides EPS, the necessary components for making samples of the proposed biocomposite are white-coloured alabaster gypsum, which consists of 95% of small particles, smaller than 0.2 mm (the maximal time of binding is 30 minutes), as well as hydrated lime $Ca(OH)_2$ obtained by slaking of a calcium carbonate $CaCO_3$.

The proposed biocomposite (in the following text biocomposite S) is composed of: 57 % sawdust, 10 % expanded polystyrene (EPS), and 33% paste made of hydrated lime and gypsum in ratio 4:1. Near 50% of sawdust particles in the composition of proposed biocomposite are in the range of 0.5-1mm in the diameter. EPS is one of the best thermal insulators with a coefficient of thermal conductivity in the range between 0.035-0.040 [$Wm^{-1}K^{-1}$]. The components of the new biocomposite S are shown in Fig. 3.

**Figure 3. Components of the examined biocomposite S**

## 3. PREPARATION OF SAMPLES AND EXPERIMENTAL TESTING

The previously defined volume quantities of components were mixed to obtain the tested biocomposite S samples. The samples were formed without pressure by using a circular cross-section mold with a diameter of 110 mm, shown in Fig. 4. The thickness of the samples was 50 mm, and the room temperature during preparation was in the range of 21±2°C. The total number of examined samples was 10.

The non-homogeneous structure of the samples was observed, reflected in the uneven distribution of material particles caused by manual mixing. Therefore, the final value of the thermal conductivity coefficient of the investigated biocomposite is taken as an average value of the individually measured sample coefficients. After 28 days of drying at a room temperature of 21±2°C, the samples were examined. The room temperature is measured using a TESTO 410-2 device with a measuring error of ± 0.5 °C.

**Figure 4. The mold for making the samples and the finished samples**

Tab. 1 shows the mass of the samples in wet conditions and the mass of each sample after 28 days of drying, referred to as dry conditions. It can be seen that the mass loss is significant, and it is in the range between 40.5-42.5%. The sample mass was measured using the measuring scale CONTROLS 11-D0629/A shown in Fig. 6.

**Table 1. The sample mass in wet and dry conditions**

| Sample | The sample mass -wet [g] | The sample mass - dry [g] | The loss of the sample mass [%] |
|---|---|---|---|
| **1** | 186.4 | 108.6 | 41.76 |
| **2** | 187.1 | 108.6 | 41.98 |
| **3** | 190.0 | 111.4 | 41.35 |
| **4** | 187.1 | 109.3 | 41.60 |
| **5** | 188.6 | 108.6 | 42.42 |
| **6** | 187.1 | 107.9 | 42.37 |
| **7** | 188.6 | 110.0 | 41.67 |
| **8** | 190.0 | 112.1 | 40.98 |
| **9** | 185.7 | 110.0 | 40.77 |
| **10** | 190.7 | 111.4 | 41.57 |

The stationary method with a fluxmeter was used for sample testing, characterized by its simplicity of the testing procedure, quick in obtaining results, and a wide range of applicability for different types of materials. The method is standardized with European standard EN 12667 [14] and two

American standards, ASTM C518 [15] and ASTM E 1530 [16]. The apparatus used in this method is similar to the apparatus used in the one-sided protected hot plate method. In both methods, the samples were placed between two plates that were at different temperatures, where one plate was heated and the other one was cooled down. The schematic representation of the method with a fluxmeter for sample testing is shown in Fig. 5.

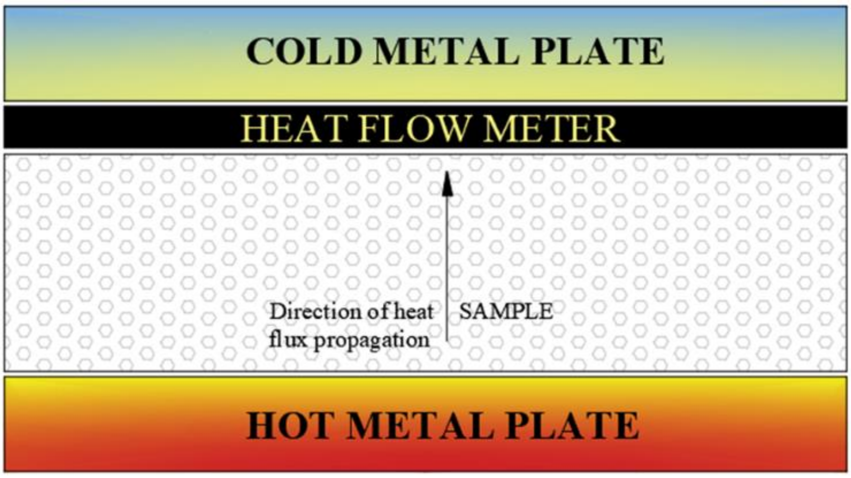


**Figure 5. Schematic representation of the method with a fluxmeter**

After applying the method with a fluxmeter, values for the thermal flux and temperature from both sides of the sample surfaces were measured, where the thickness of the sample was 50 mm. The heat flux was measured using a flux meter KYOTO HFM 201 TR2-B, and the temperature on the surface of the sample was measured using an infrared thermometer TESTO 830-T3, where the measuring error for TESTO 830-T3 is ± 1 °C. A polystyrene sample (expanded and extruded) was used to test the accuracy of KYOTO HFM 201 TR2-B, and the measurement results were within the adopted values of thermal conductivity [17]. The devices used for all measurements are shown in Fig. 6.

TESTO 830-T3 KYOTO HFM 201 TR2-B TESTO 410-2 CONTROLS 11-D0629/A

**Figure 6. The measuring devices**

Based on the previously measured values, the thermal conductivity of the samples was calculated using the equation for conduction in the case of a multi-layer flat wall (Fig. 7):

$$q = \frac{t_1 - t_{i+1}}{\sum_{i=1}^{n} \frac{\delta_i}{\lambda_i}} \quad (1)$$

where $t_1$ and $t_{n+1}$ are the temperatures of the hotter and colder surface of the sample, $\delta_i$ is the sample thickness, and $\lambda_i$ *is* the thermal conductivity of the i-th layer of the sample.

The thermal conductivity coefficient is calculated using equation (2), which was derived from equation (1), in the following form:

$$\lambda_1 = \frac{q \cdot \delta_1}{t_1 - t_2} \tag{2}$$

where, in this case, $\lambda_1$ represents the calculated coefficient of thermal conductivity for the tested biocomposite S, $\delta_1$ is the thickness of the biocomposite S, while $t_1$ and $t_2$ represent measured temperatures from the one and second sides of the examined sample.

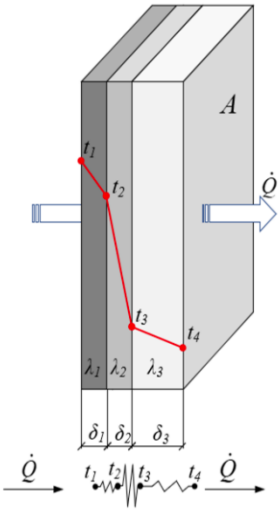


**Figure 7. Schematic illustration of a multi-layer flat wall**

## 4. RESULTS AND DISCUSSION

Based on measured heat flux values, the known temperature difference between the hotter and colder sample surfaces, and sample thicknesses of 50 mm, the thermal conductivity coefficient was calculated using equation (2) for each sample. The temperature differences between the hotter and colder surfaces of the samples were around 10 °C. The measured heat flux values are shown in Tab. 2 and Fig. 8, and the calculated values of thermal conductivity coefficients are shown in Tab. 2 and Fig. 9.

**Table 2. Measured and calculated values for heat flux and coefficient of thermal conductivity**

| Sample | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Heat flux q [W/m$^2$]** | 28.8 | 28.6 | 27.6 | 27.8 | 28.2 | 28 | 28.6 | 29.4 | 29.8 | 29.6 |
| **Thermal conductivity coefficient λ [W/mK]** | 0.144 | 0.143 | 0.138 | 0.139 | 0.141 | 0.14 | 0.143 | 0.147 | 0.149 | 0.148 |

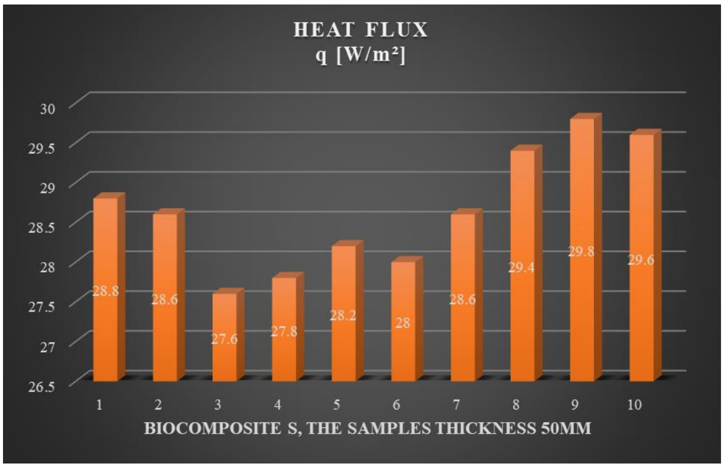


**Figure 8. The measured heat flux values**

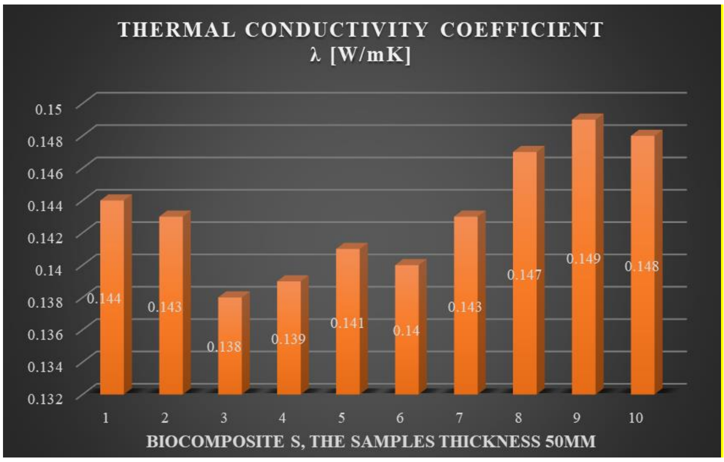


**Figure 9. Calculated values of the thermal conductivity coefficient**

To compare the coefficients of thermal conductivity for biocomposite S and commercially available insulating materials, like expanded polystyrene (EPS) and rock wool, which are widely used in civil engineering, the mean value of the thermal conductivity coefficient for biocomposite S is adopted. The thermal conductivity coefficients for all previously mentioned materials, including biocomposite S, are presented in Tab. 3.

**Table 3. The coefficient of thermal conductivity for insulation materials and biocomposite S [17]**

| Insulation material | Biocomposite S | Expanded polystyrene | Rock wool |
|---|---|---|---|
| The thermal conductivity coefficient [W/mK] | 0.143 | 0.041 | 0.033-0.039 |

Based on values shown in Tab. 3, it can be concluded that the thermal conductivity for biocomposite S is 3.5 times higher in comparison with expanded polystyrene, and 3.5 to 4 times higher than rock wool. This means that if the tested biocomposite S is used as a thermal insulation material, the heat losses through the external shell of the building would be greater in comparison with rock wool and expanded polystyrene. In terms of heat demands, more heat would be required for a same-size building.

### 4.1. STANDARD DEVIATION

Generally, the standard deviation measures the variation or dispersion of a set of values. In this case, the difference between measured values for heat flux and calculated values for the coefficient of thermal conductivity is the consequence of the non-homogeneous structure of the samples, which represented the most influential factor. Furthermore, the different porosity of aggregates and errors that occur during measurement are influential factors in the previously mentioned differences. All of the above fall under the standard deviation (SD) values. Based on calculated standard deviation values, the difference between measured values for heat flux and the calculated thermal conductivity coefficients of tested biocomposite S is insignificant, which can be seen from Fig. 10 and Tab. 4.

**Table 4. The standard deviation value for heat flux and thermal conductivity coefficient**

| | Mean value | Standard deviation (SD) |
|---|---|---|
| **Thermal conductivity coefficient λ [W/mK]** | 0.143 | 0.004 |
| **Heat flux $q$ [W/m$^2$]** | 28.64 | 0.765 |

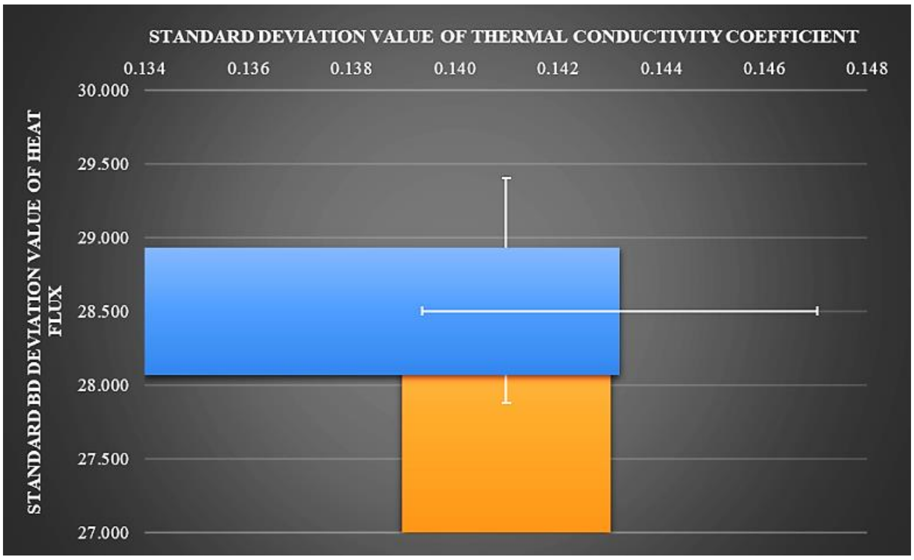


**Figure 10. The standard deviation for heat flux and thermal conductivity coefficient**

### 5. CONCLUSION

Bio-based composites are advancing rapidly, offering significant potential for the biomaterials industry to shift toward more sustainable practices and reduce environmental impact. One promising strategy is incorporating waste materials and by-products from other industries as raw materials for new, eco-friendly products. Reusing sawdust as wood waste for construction purposes presents a solution not only from the perspective of pollution control but also in terms of decreasing waste disposal, the cost of construction materials, and the preservation of natural resources for future generations.

The scientific contribution of this study is the development of a new biocomposite featuring a specifically compounded mixture and a simple panel fabrication process, which would contribute to a decrease in production costs. Experimental results provide new benchmarks and insights that can guide future research and practical applications in sustainable insulation materials. The performed analysis and obtained results suggested that sawdust, which represents a wood waste, can be transformed into a valuable biocomposite for insulation purposes. The obtained result may not be the best in comparison with rock wool and polystyrene but it shows that sawdust can be used as a component of a biobased insulating material. This not only enhances the value of waste products but also contributes to sustainable development in this sector of the economy. From the aspect of environmental protection, using sawdust or some other waste material will contribute to decreasing of wild dumpsites and to the reduction of carbon dioxide because, in the Republic of Serbia, this kind of waste is mainly thrown away or burned in boilers and other industrial kilns. Further exploration and different material combinations with the aim of improving the thermal characteristics of biocomposites, presents an additional research opportunity.

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**Nomenclature**

$\dot{q}$ - heat flux, [W]
$t_1$ – the temperature of the hotter surface of a sample, [°C]
$t_2$ – the temperature of the colder surface of a sample, [°C]
***Greek letters***
$\delta$ - thickness of the samples, [cm]
$\lambda$ - thermal conductivity, [$Wm^{-1}K^{-1}$],
***Subscripts***
$i$ - i-th layer of the sample

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