Improvement of polyurethane thermal insulation materials by using corn stalk

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Abstract. The heat loss during the heating of buildings constitutes about 40% of the greenhouse gas emission that causes global warming. Thus, in order to decrease the energy for heating buildings, various kinds of insulation systems and materials have been used. In this study, by using corn stalks, a polyurethane insulation material was produced. The unit weight, ultrasonic pulse velocity and thermal conductivity coefficients of the produced material were determined. The thermal conductivity coefficient of this composite material was found to be 0.042. The insulation values obtained were in an acceptable range, i.e. they satisfy the Turkish Standard TS 805 EN 60155. Thus, with the zero-waste objective, this study presents an alternative construction material containing a certain type of waste material, also avoiding the environmental problems it causes.

1. Introduction

In recent years, concerns about the increase in energy consumption have arisen and researchers have been addressing this problem due to its environmental impact. It is well known that the construction industry uses one-third of the total energy consumption and produces a lot of CO₂ emissions [1, 2]. In Turkey, nearly 40% of total energy consumption takes place in buildings. It is also estimated that if the entire building stock in Turkey is insulated according to the current standards, the energy expense would decrease by about 15% [3]. As the thermal insulation in buildings has a significant contribution to energy saving, considerable attention must be paid during the selection of insulation materials.

In the conventional approach, petrochemical-based materials which have a negative environmental impact are used as insulation materials [4, 5]. Some natural resources are also used as an alternative. However, one of the major drawbacks to using natural resources is the high energy consumption in their processing. Thus, most studies tended to focus on sustainable thermal insulation materials [6]. To seek for an alternative environment-friendly insulation substance, reuse and recycling of agro-wastes in the production of thermal insulation materials has been investigated in the literature. Among these investigations, an experimental study drew attention to the microstructure and chemical composition similarities between the corn’s cob and the extruded polystyrene material [7]. The use of corn cobs due to the satisfactory results concerning their thermal properties was suggested. Using rice straws was another implementation to obtain sustainable composite materials having acceptable thermal properties [8]. In other studies, jute, flax and hemp were considered to be used to develop a new insulation material [9-11]. When the physico-mechanical properties of the proposed insulation material were analyzed, it was concluded that the results correlated fairly well with the properties of the conventional materials. The use of sugar cane bagasse fibres as reinforcement in cement composites was also studied and its effect on the thermal properties was discussed [12]. In the literature, there are many other examples of agro-waste use for developing an alternative insulation material [13-15]. In order to examine the thermal performance of sustainable materials, thermal conductivity was identified.
Since the alternative thermal insulation materials are generating considerable interest in terms of their positive contribution to energy saving and environment, this study aims to widen the knowledge of reusing waste materials in the production of thermal insulation materials. In this context, a new insulation material using corn stalks is investigated and the low thermal conductivity values obtained for this material have been very promising for further research.

2. Materials and Methods

2.1. Materials

**Corn stalk.** 600 thousand hectares of maize is grown in Turkey and according to 2018 statistics, 5.5 million tons of corn were produced per year. The Black Sea, Mediterranean, and Marmara regions, all together, have Turkey’s 90.4% corn acreage and 91.7% corn production.

**Polyurethane.** Polyurethane is a polymer that consists of organic chain units joined by carbonate linkages. They are used in flexible and rigid foams, durable elastomers and high-performance adhesives, fibres, gaskets, carpet underlays, and hard plastic constructions. Flexible polyurethane foams are also known to be indispensable as a material for the comfort of beds and furniture. Rigid foams are used more in heat and noise insulation. Being also known as ethyl carbonate, polyurethanes should not be confused with the specific substance urethane. In this study, Ceresit-1028043 CS 330 PU Foam is used as polyurethane and its properties are presented in Table 1.

| Table 1. Properties of the polyurethane foam. |
|----------------------------------------------|
| Properties                        | Values |
| Closed cell porosity               | 90%    |
| Water absorption                   | 2%     |
| Moist induced abrasion              | 5-10%  |
| Compressive strength of rigid       | 200 kPA|
| polyurethane                       |        |
| Density                           | 30 kg/m³|

**Pumice.** During the formation of pumice, the structure suddenly loses the gases in it and cools, thus, numerous pores from the macro scale to the micro scale form in the remaining material [16]. Since these pores are generally free of interconnections, pumice is lightweight, can swim for a long time in water and has low permeability and a highly insulating property. Its chemical content involves up to 75% silica and its SiO₂ content gives it an abrasive characteristic. Al₂O₃ in it gives it a high resistance to fire and heat. The pumice used in this study was obtained from Osmaniye-Tüysüz region and the physical properties are given in Table 2. Sand size pumice was used to provide fire resistance.

| Table 2. Physical properties of the pumice. |
|--------------------------------------------|
| Properties                        | Values |
| Density                            | 2.87 g/cm³|
| Water absorption                   | 88%    |
| Maximum size                       | 5 mm   |
| Abrasion                           | 7.2 %  |

2.2. Method

Corn stalks were used as the ingredient and polyurethane foam was the matrix of the composite. Corn stalks with different lengths and 10 mm diameter have been used in different sample groups.
Throughout this paper, the samples reinforced with different lengths of corn stalks are named as N1, N2, N3, N4, and N5 whereas the control samples with no corn stalks are named as C. Henceforth, the name N1 will be used for the sample with the longest corn stalks whereas the name N5 will be used for the one with the shortest corn stalks. The lengths of corn stalks used in the samples are given in Table 3. Polyurethane foam was sprayed into the moulds of 10x10x5 cm dimensions and immediately after that, previously prepared corn stalks were placed on the foam. Then polyurethane foam was sprayed till the mould got full. Sand size pumice was used to provide fire resistance. The pumice was sifted through a 5mm sieve and coated on the prismatic polyurethane matrix on all six sides with an approximate thickness of 2-3mm before hardening. Thus, laminated composite samples were manufactured.

| Samples | Corn stalk (cm) |
|---------|----------------|
| C       | -              |
| N1      | 8              |
| N2      | 7.5            |
| N3      | 7              |
| N4      | 6.5            |
| N5      | 6              |

### 3. Experimental Studies

#### 3.1. Bulk density
After the composite samples were dried, their final unit weights were determined by using the changes in the dimensions.

#### 3.2. Ultrasonic pulse velocity
There is a certain relationship between the ultrasonic pulse velocity and the density of the materials. As the amount of voids in the material increases, the ultrasonic pulse velocity becomes less. After measuring the time duration for the ultrasonic pulses to travel from one face of the material block to the other, the velocity of ultrasonic pulses was calculated as follows

\[ V = \left( \frac{S}{t} \right) \times 10^6 \]  \hspace{1cm} (1)

Here; \( V \) (m/sec) is pulse velocity, \( S \) (m) is the distance between the two faces of the material block and \( t \) (microseconds) is the measured time of travel. Ultrasonic pulse velocity experiment was conducted in accordance with ASTM C597-09 [17] on all samples and their ultrasonic pulse velocities were found.

#### 3.3. Thermal conductivity coefficient
The thermal conductivity coefficient of the composite insulation material was measured by the KEM/QTM-500 model thermal conductivity meter. The thermal conductivity test was performed in accordance with ASTM C1113-90 Hot Wire Method [18].

#### 3.4. Fire resistance
In order to determine the fire resistance of the samples, they were prepared for cautery in the muffle furnace test in accordance with ASTM E119-07 [19]. Six of the dried samples, each representing a different group, were selected and their weight changes were determined after exposing them to 100 °C and 125 °C temperature for 10 min with respect to ASTM E119-07, each at a time.
4. Results and Discussions

The unit weights, ultrasonic pulse velocities, and thermal conductivity coefficients of all samples are obtained and presented in Table 4. As expected, when the unit weight of the control sample is compared with the unit weights of the samples with corn stalks, it is seen that the unit weights of the samples with or without pumice coating, increase as the length of the corn stalks increase. Since corn stalks in bulk are heavier than polyurethane, this result is expected.

If the ultrasonic pulse velocity values in Table 4 are discussed, it is seen that the lowest ultrasonic pulse velocity was obtained for the control sample. Among the composite samples, the lowest ultrasonic pulse velocity was obtained for sample N5 whereas the highest for sample N1. As a result of the sound insulation test, ultrasonic pulse velocity value of N1 sample, having the longest corn stalks, has been found 68% higher than the control sample, C. As is well known, with a decrease in the unit weight of a material, its ultrasonic pulse velocity also decreases. The results in Table 4 confirm this general tendency. The results found for the composite samples in this work can be explained by the void in corn stalks being a single very large one but polyurethane having very many voids with no interconnections. Thus, the sound is better absorbed by the tiny unconnected countless voids in polyurethane than in the corn stalks with the single isolated large void.

Table 4. Test results.

| Samples | Unit weight (kg/m$^3$) | Ultrasonic pulse velocity (km/s) | Thermal conductivity coefficient (W/mK) |
|---------|-------------------------|---------------------------------|---------------------------------------|
|         | Before pumice coating   | After pumice coating            |                                      |
| C       | 22.5                    | 22.5                            | 0.56                                  | 0.054                                 |
| N1      | 36.3                    | 43.4                            | 0.94                                  | 0.042                                 |
| N2      | 35.1                    | 41.4                            | 0.90                                  | 0.043                                 |
| N3      | 33.8                    | 40.1                            | 0.88                                  | 0.044                                 |
| N4      | 32.7                    | 39.2                            | 0.83                                  | 0.044                                 |
| N5      | 31.5                    | 38.3                            | 0.78                                  | 0.045                                 |

The thermal conductivity coefficient values obtained are also given in Table 4. The lowest thermal conductivity coefficient value was seen in sample N1. This can be explained by the high value of the hollow of the corn stalks. The highest thermal conductivity coefficient value has been observed in the control sample. In the case of laminated composites produced, the thermal conductivity coefficients were found very close to each other.

Taking into consideration Table 4, corn stalks added samples, namely N1, N2, N3, N4, and N5 can be admitted as insulation materials. This can be explained by the structure of these samples containing inner parts.

The fire resistance values of all the samples were determined by checking their mass loss percentages at elevated temperatures. The fire test results are given in Table 5. According to the mass losses with the fire effect on the composites, as the temperature increased, the mass loss increased, too. At 125 °C, control sample, C, lost its integrity completely and melted. The mass losses of pumice added samples obtained at both 100°C and 125°C were much lower than the control sample, C. The lowest mass loss ratio was obtained for N1 sample. The high mass loss at elevated temperatures raises ambiguities about the durability and integrity of the material during fires. The test results show that the mass loss percentages of pumice coated samples N1, N2, N3, N4 and N5 were lower than sample C.
Therefore, seeing that the mass loss percentages are so close to each other in the pumice coated composites, it can be said that the amount of corn stalks in the sample does not make an appreciable difference in the mass loss. In any case, it is seen that pumice coating renders appreciable improvements compared to the uncoated case.

Table 5. Fire resistance test results.

| Samples | The mass loss at 100°C (%) | The mass loss at 125°C (%) |
|---------|----------------------------|---------------------------|
| C       | 78.5                       | Sample lost integrity and melted |
| N1      | 16                         | 19.3                      |
| N2      | 17.2                       | 19.6                      |
| N3      | 17.5                       | 20.5                      |
| N4      | 18.4                       | 21.2                      |
| N5      | 18.7                       | 22.3                      |

5. Conclusion

The test results revealed the conclusions given below.

- The highest ultrasonic pulse velocity was found for the sample having the longest corn stalks N1 which has the highest unit weight whereas the lowest ultrasonic pulse velocity was found for the control sample, C having the lowest unit weight.
- The lowest thermal conductivity coefficient was obtained for sample N1. It is observed that all the laminated composites produced with corn stalks have lower thermal conductivity coefficients than the control sample, C.
- Checking the mass loss in all samples, it is seen that the ones coated with pumice had higher fire resistance than the control sample, C.

Consequently, according to this investigation, the findings validate the usefulness of corn stalks for producing insulation materials. All the composite materials produced by using polyurethane with corn stalks have satisfactory thermal conductivity values according to TS 805 EN 60155 which requires values lower than 0.1. When the thermal properties of the composite samples are compared with the control sample, the composite samples show a remarkable improvement with a decrease of 22% in the thermal conductivity coefficient values. This result offers a potential application for lightweight composite insulation material.

An additional important implication is the use of corn stalks as agro-wastes in this type of composite material production. This study demonstrated that a new insulation material with a low thermal conductivity coefficient can be produced using corn stalks. With the zero-waste objective, by reusing corn stalk wastes, a potential environment-friendly insulation material which contributes to decrease the CO₂ emission is obtained. Also, the volume contribution of corn stalks in the composites is 10% on average which leads to a decrement in the polystyrene usage. Hence, besides the environmental point of view, also from the economic point of view, there is a benefit of reusing corn stalk wastes in the production of this alternative composite insulation material.
6. References

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