Thermal performance of building materials based on feather and polystyrene wastes

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Abstract. The development of composites using renewable resources has received attention of scientists over the last decade, with the aim of manufacturing environmentally friendly composites, reducing cost and the dependence on petroleum resources. This experimental study emphasizes the development of new cost-efficient composite based on feather/cotton nonwoven and polystyrene waste. Vacuum molding method was adopted for fabricating of the biocomposites with two contents of polystyrene matrix (30% and 50%). As a result, the morphological analysis revealed better compatibility and adhesion between the nonwoven and the polystyrene matrix. The manufactured composites showed an insulating character with thermal conductivity coefficient value of 35.95 and 33.85 mW / (m.K) respectively for the composite reinforced with 30 and 50% polystyrene. The origin of the variation of this property is due to densities and the percentage of the polystyrene matrix. The composites developed with polystyrene showed very high performance, combined with sufficient durability to be potential candidates for the development of new sustainable materials for the building sector.

Keywords: Polystyrene, thermal conductivity, vacuum molding, cost-efficient, waste management.

1. Introduction:

Currently, the atmospheric concentration of carbon dioxide increase which requires an urgent response through the manufacture and use of more environmentally friendly materials obtained from renewable energy sources that contribute to the reduction of CO2 emissions [1]. The development of green composites has attracted great interest, these new materials was more usable due to their interesting properties, durable, can be easily disposed without harming the environment, low construction cost and applicable in many consumer industries such as construction sector [2]. The global sector of natural fiber-reinforced polymer composites reached US$2.1 billion in 2010 [3]. This material was developed from different types of natural fibers, such as sisal [4], bamboo [5], feather [6] and wood [7]. The attractive characteristics of natural fibres were their reasonable cost, lightness, renewability, biodegradability and low energy consumption during manufacturing. Today, the solid waste generated by poultry sector also remains one of the most important renewable resources used in the formulation of composite materials [8]. Indeed, 2400,000 tons of feather waste was generated per year in Morocco.
[9]. The evaluation of this feather waste, which is fairly rich in 91% keratin in the form of nonwoven textiles, is extremely important to solve the incineration problem and to bring new materials to the economy. The feather fiber has remarkable reinforcing properties, they have been imported in all types of polymers: thermosetting (unsaturated polyesters, epoxy resins), or thermoplastics (PS, HDPE, PP and PLA). In all countries of the world, either was the level of their development, sale of the materials using the expansive polystyrene as packing generates important quantities of nonbiodegradable wastes. Management of these wastes is important. Polystyrene (PS) was one of the most versatile synthetic polymers due to its hardness, water resistance and low cost per unit weight. The properties of natural fibre reinforced polystyrene composite have made them the materials of choice for diverse applications. Eusèbe Agoua et al. [10] studied the thermal conductivity of composites manufactured with wood wastes and expanded polystyrene. The results revealed a good compatibility between the two components. The thermal conductivity achieved for different granulation and glue content have presented insulation character. The wood and polystyrene permits to produce economic and environment composites. Recycling of the feathers wastes and the expansive polystyrene packing to produce other building materials appears like an environmental and economic alternative.

In this context, the present work aims to finalize a composite composed of a mixture of feather/cotton nonwoven and glue obtained from polystyrene of recuperation dissolved in diethyl ether. The formulation will be made on a basis allowing to obtain products with various thermal and mechanical characteristics according to their uses.

2. Materials and methods

2.1. Preparation of reinforcement:

The nonwoven webs were prepared according to the needling technique. The feathers fiber was provided by a slaughterhouse in the province of Casablanca, Morocco and the cotton fibers were obtained from a Moroccan manufacture unity in form of staple fiber. The feathers fibers are less crimped; a percentage of cotton waste has been added to ensure the nonwoven formation. The treated fiber was cut into small portion of 10-30 mm of length and inserted with waste cotton (50% in weight) into the industrial manufacturing line (needling DILLO DI-LOOM OD-II 10069/2012 machine) which utilizes a mechanical consolidation method to entangle the fibers with each other without the addition of any binder. The carded webs are transferred directly to the bonding stage where they are repeatedly punctured by a battery of needles.

2.2. Preparation of matrix:

Polystyrene is obtained from the protective packaging waste of several companies; diethyl ether was purchased from Loba Chemie. The matrix is prepared by dissolution of PS waste in diethyl ether.

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\frac{m_{\text{Diethyl Ether}}}{m_{\text{Polystyrene}}} = 8 \quad \text{eq.1}
\]

Where, \(m_{\text{Diethyl Ether}}\) is the mass of diethyl ether and \(m_{\text{Polystyrene}}\) is the mass of the polystyrene PS.

2.3. Composite manufacturing process:

Vacuum molding method was adopted for fabricating the feather/cotton nonwoven reinforced polystyrene composites. Composites with dimension of 200 mm x 200 mm were manufactured with two content of polystyrene matrix (30% and 50%). The relaxing agent was applied firstly, then the matrix was poured into the mat of feather/cotton until it is completely soaked. The mould was closed and the lamination is evacuated under vacuum of 500 bar using the vacuum pump at temperature 40°C for 4 hours. The samples were left to harden for 24 hours and then removed from the mold. The figure 1 shows a schematic of composite manufacturing process.
2.4. Characterization:

The morphology and adhesion between components of composite materials was studied by HIROX SH-4000 M scanning electron microscopy at acceleration voltages between 10 and 20 kV. The thermal conductivity of the manufactured materials was determined using a thermal conductivity analyzer (λ-meter EP500e) in accordance with EN 12667 with a sample size of 200 mm×200 mm at three temperatures 10, 25 and 40 °C[11].

3. Results and discussion

3.1. Morphological analysis

The morphological analysis of composites shows a good compatibility of fiber with polystyrene matrix, the fibres are completely covered with the matrix; forming a homogeneous material with no defects and a good fiber-matrix interface (figure 2). The fibers are well dispersed in polystyrene matrix and do no revealed agglomerates and microvids on the surface of the composite due to the reinforcement structure (nonwoven) and composite processing technique (vacuum molding). The feathers fibers permit an even arrangement due to nonwoven structure and adherence to polystyrene owing to their hydrophobic nature. The adhesion of the nonwoven-matrix is improved with the increase in the PS matrix rate in the composites.

3.2. Thermal conductivity:

The thermal conductivity coefficients identify the insulating nature of the sample; it depends on several parameters such as the morphology of fiber, the density, surface, the void content, matrix and homogeneity of sample. The thermal conductivity values of the various samples are shown in the figure 3. The measurements of the thermal conductivity of the samples are respectively obtained in the margins of 40.25 to 33.85 mW/m.K at 10°C. The best value 33.85mW/m.K is attributed for
feather/cotton nonwoven reinforced 50% polystyrene composite. The origin of the variation of this property is due to insulating character of polystyrene leads to a decrease the thermal conductivity. The thermal conductivity of all the samples increases with the increase of temperature; this is explained by the increase of heat conduction through the samples. According to the results composites samples had thermal conductivity $\lambda < 60$ (mW)/ (K.m) up to 40°C temperature, it can be concluded that these samples are suitable for all applications that require a resistivity against the heat flow.

Figure 3. Thermal conductivity at 10, 25 and 40°C

The thermal conductivity results are very satisfactory compared to fiber–reinforced polystyrene composites, the thermal conductivity of polystyrene composites reinforced with natural fiber typically exceed 100 (m.W) / (m.K) [10, 12]. The composites prepared present many advantages such as: Economical by introducing low cost materials and ecological advantage with the use of renewable waste, less energy in the construction, recovery of polystyrene.

4. Conclusion:

In order to promote the use of waste fibers in the thermal insulation of civil and mechanical constructions, a new composite material based on feather/cotton waste and polystyrene is developed. In this study, the feather / cotton nonwoven is used as reinforcement and the polystyrene waste, dissolved in diethyl ether, is used as a matrix. In this study, morphological and thermal measurements were performed to characterize the feather/cotton nonwoven reinforced polystyrene composite. From the above results, the following conclusions have been given:

- Needled nonwoven fabrics have many advantages for use as reinforcement in polymer composites, such as good z-directional strength which greatly reduces delamination problems.
- The results of the thermal conductivity obtained for different samples showed that such materials can be developed to be used for example as insulating material that depend on a resistivity against the heat flow.
- The lowest value of thermal conductivity was observed for feather/cotton nonwoven reinforced with 50% of polystyrene 33.85 at 10°C.

These eco-friendly materials can found applications in various fields such as construction sector due to interesting properties and their good cost-performance ratio.
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