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Mechanical, thermal and acoustical characterizations of an insulation composite made of bio-based materials

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ABSTRACT

Heating costs in winter and cooling costs in summer, nowadays, are very high and these costs a can be reduced by the insulation of buildings. This study is related to the development of bio-based composites and the determination of their thermal, mechanical and acoustical insulation properties. The composites were prepared using corn stalk particles as the reinforcement components. An experimental design was established to study the effect of the stalk particle size and the epoxy/corn stalk particle ratio on the thermal and mechanical properties of the composites prepared. Their mechanical properties and thermal performance characteristics are compared with the commercially available bio-based insulation materials.

This study shows that waste corn-on-the-cob can be used for the reinforcement of epoxy resin to prepare insulation materials that can be used commercially. Natural products of high insulating value can be obtained that can provide alternative insulation materials and reduce the import of insulation materials and satisfy the criteria of the Turkish Standard TS 805 EN 601. The results of this study can solve two industrial problems. One of them is providing a new useful construction material and the other is utilizing agricultural wastes to reduce their harm to the environment.

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1. Introduction

Insulation materials in buildings have been widely used since the beginning of the 20th century. The new building and construction materials and systems provide many benefits and some drawbacks in terms of the comfort conditions of buildings. The exterior walls must be thin to prevent unnecessary loading on the structure (Binici, Gemci, & Kucukonder, 2012; de Wilde & Voorden, 2004; Thorsnes & Bishop, 2013). In recent years, energy resources in Turkey have rapidly decreased and approximately 40% of the energy is spent on buildings. Although the total energy consumption per capita in the last 25 years has increased by 5%, this ratio has increased by over 100% in Turkey (Aksoy, 2008; Mengeloglu & Alma, 2002) due to the energy consumption for heating uninsulated houses with an average of 200 kW h/m^2 per year. Today, the cost of the energy required for the heating of houses is estimated to be more than US$ 4 billion.

The current stock of buildings do not have adequate insulation and if insulation is added, it will reduce the necessary heating energy. If the insulation of the entire building is complete, an energy saving of over US$ 2 billion per year can be made (Binici, Eken, Dolaz, Aksogan, & Kara, 2014). Therefore, the use of insulation materials has become a necessity and the production of appropriate materials for insulation is of great importance. Although most insulation materials are produced from inorganic materials, recently, some of these materials have been prohibited due to their suspected health risks (Mati-Baouche et al., 2014; Monika, Ramaniah, Ratna Prasad, Mohana Rao, & Hema Chandra Reddy, 2012). Thus, it is important to investigate organic-based insulation materials. Research related to the use of agro-industrial residues in the development of composite materials for the construction industry is now of growing interest (Briga-Sa, Paiva, Boaventura-Cunha, & Lanzinha, 2012; Cristel et al., 2010; Frydrych, Dziworsko, & Bilska, 2002; Sathre & González-García, 2014; Zhou, Zheng, Li, & Lu, 2010). One of the major challenges of this industry for the next decade is to improve the energy performance of existing buildings taking into account the increasing social emphasis on issues concerning the environment, waste disposal, and the depletion of non-renewable resources. The motivating factors include cost, mechanical, thermal and acoustic performance enhancements, weight reduction,

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and the environment friendliness (Bolat, 2005). In this context, bio-based insulating materials made from by-products of agriculture waste constitute an interesting alternative to those obtained from fossil carbon. Thermal insulation is known to play a critical role in saving energy by reducing the rate of heat transfer (Keynakli, 2012). Through the use of useful composite materials in building structures, many issues related to heat and sound insulation and moisture management have been resolved and this has resulted in the reduction of the cost of structure maintenance, repair and operation (Saarinen, 2002).

There have been previous attempts to develop similar bio-based materials. In Turkey simple construction techniques have been used in ancient times using bio-based materials as wall materials (Binici et al., 2014). The reason for this preference is that bio-based material is easily manufactured and obtained (Pinto et al., 2011). Similar aplications have been used in different countries. For instance, Tabique construction is one of the main Portuguese traditional building techniques that uses earth based building materials. The research conducted by Pinto et al. (2011) showed that corn cob, an agricultural waste, has the potential to be used as a sustainable building material for thermal insulation. An experimental work concluded that there are significant similarities between the corn cob and the extruded polystyrene material in terms of microstructure and chemical composition. Furthermore, the results obtained from experimental thermal procedure indicate that the corn cob may have adequate thermal properties for building purpose (Pinto et al., 2011).

Fibres from agricultural raw materials constitute an important class of sustainable materials with applications in construction. Many wood product standards make mention of alternative sources of ligno-cellulosic fibres. They are the primary sources of useful lingo-cellulosic fibres in biomass. Agricultural material fibres and particles are in many ways similar to wood fibres and particles. Specific characteristics depend on species and degree of processing. The agricultural fibre-based construction materials industry in the US has been in a nascent stage for many years, with few companies enjoying long term success. Agricultural fibres in construction compete primarily with wood, but also with fossil fuel, and mineral products. Agricultural fibres can also be mixed with wood fibres to improve properties (ASTM WK30419, 2011; Korjenic, Petránek, Zach, & Hroudová, 2011; Kymalainen & Sjoberg, 2008).

The use of natural fibres in insulation is closely linked to the ecological building sector (Murphy, Behring, & Wieland, 1997), where selection of materials is based on factors including recyclable, renewable raw materials and low resource production techniques. Furthermore, cellulosic insulations have a higher moisture regain than inorganic materials, and therefore only cellulosic materials are recommended for old timbered houses (Heier & Heintges, 1999; Nova-Institut, 2003). One reason for the relatively low utilization is the approximately two-fold higher price of fibre insulations compared to mineral wool (Nova-Institut, 2003).

The thermal performance of bio-based fibres has been investigated and compared to conventional insulations in some studies (Murphy et al., 1997; Ringleb & Schulz, 1996). Considerable data is available concerning the technical properties of conventional insulations, whereas, data for cellulosic insulations has typically been given only for cellulose as a generic material (Strother & Turner, 1990; Turner & Malloy, 1981).

The implementation of agro-industrial residues in the development of composite materials for building trades is now a research of growing interest (Cole, 1999; Gustavsson & Sathre, 2006; Morel, Mesbah, Oggero, & Walker, 2001; Wei et al., 2015). One of the major importance of this industry for the next decade is to improve the energy performance of existing buildings taking into account the increasing social emphasis on issues of the environment, waste disposal, and the depletion of non-renewable resources. The motivation includes cost, mechanical, thermal and acoustical performance enhancements, weight reduction, and environment concerns (Glé, Gourdon, & Arnaud, 2012). Thermal insulation is known to play a vital role in saving energy by reducing the rate of heat transfer (Binici & Aksogan, 2015). Among them, those obtained from agricultural by-products have numerous advantages as they are eco-friendly and renewable. Moreover the high fibre content of some of them authorizes the reinforcement of composites (Liu, Erham, Akin, & Barton, 2006). The bio-sourced material obtained had higher thermal conductivity and mechanical strength compared to cement alone (Korjenic, Petranek, Jiri, & Jitka, 2011).

Besides building concept, solar house (S-house) builders are concerned with the components and materials being used satisfying the present needs of the users without causing extra burden on the offsprings with waste disposal problems or forcing them to use an out-dated building for decades (Robbins & Morrell, 2001; Wimmer, Hohensınner, & Drcak, 2002). Hence, sustainable architecture is the result of a careful consideration of functions, materials and their life-cycle performance, present and future human needs and social aspects. A passive S-house made of renewable resources is the basic principle under which the S-house is constructed.

Regarding the supply of bio-based resources, the possibility of providing domestic agriculture with a new source of income could turn out to be an important driver for the production and use of bio-based materials. Additional impetus could come from the New Member States and Associated States of the European Union owing to their enormous agricultural and silvicultural areas and large potential for improvement in agricultural practice (Patel, in press). Common choices of thermal insulation are fibreglass, rock wool and mineral wool. These materials may be the cause of environmental hazards. The small particles from fibreglass and glass wool insulation can end up with health hazard and respiratory or skin irritant (Occupational Safety & Health Administration, 2003). Breathing fibres may cause coughing and throat irritation. Glass fibres of respirable size was listed by The Seventh Annual Report on Carcinogens as a substance which is a candidate to cause cancer in humans (Infante, Schuman, & Dement, 1994). Most thermal insulation batts include formaldehyde resin which may affect sensitive people and cause asthma (U.S. Environmental Protection Agency, 2000). Cellulose insulation with toxic, fire-retarding chemicals like boric acid, were mentioned to harm human health (The U.S. Occupational Safety and Health Administration (OSHA), 1999). Thermal insulation materials have low thermal conductivity, moisture protection, and mould and fire resistance. Mostly used kinds of insulating materials are inorganic fibrous and organic foamy materials – expanded and extruded polystyrene and polyurethane (Papadopoulos & Giama, 2006). It is warned that environmental and health impacts must also be considered besides other points. Since the current popular insulation materials have harmful side effects (Papadopoulos, 2005), alternative insulation materials satisfying the new standards must be searched.

United States, China, Brazil, Mexico, Indonesia and India being the main producers of corn in the world, total production was above 600 million tonnes in 2003. Turkey produced around 9 million tonnes of corn in 2008 (Yolcu & Tan, 2008). Corn stalks and cobs can be made into particleboards and fibre boards (Panyakaew & Fotios, 2008). Low density boards made with the hot press method using corn stalks and cob with urea formaldehyde resin ended up with a high mechanical strength and a thermal conductivity of 0.096 W/mK (Sampathrajan, Vijayaraghavan, & Swaminathan, 1992).

Little is known about the different building-physics-related properties of such insulation materials. The present contribution, therefore, illustrates recent efforts of determining these important attributes. As shown in previous studies, waste is of great importance in our world. It has been shown that the use of waste in