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Wood waste as an alternative thermal insulation for buildings

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ABSTRACT

Current insulation materials in the construction market, which are predominantly inorganic materials, have a high performance in relation to heat transfer, i.e. high R-values, but the environmental impacts in their production processes are significant. The use of bio-based natural fibre materials such as cork, cotton, wood fibre, hemp, etc. with their lower embodied energy, moisture buffering capacity and, consequently, improved Indoor Environmental Quality have received increasing focus in both research and application, particularly amongst environmentally-conscious clients and designers.

In this study a natural fibre material in the form of wood waste is examined experimentally to assess its suitability for use as a thermal insulation material, without the addition of any binder, within a timber frame wall construction. The wood waste is from primary production sources using untreated material. According to our experimental results, the thermal conductivity values of wood waste with different densities, ranged from 0.048 to 0.055 W/mK. These values are slightly higher than commonly used inorganic based insulation materials, although comparable to other natural insulation materials in the market, but have the economic advantage of being a low-cost by-product. The values relating to the material hygric performance including the water vapour diffusion resistance factor, water vapour permeability, and water absorption coefficient were also determined and presented, which will help facilitate future hygrothermal modelling.

1. Introduction

Buildings and the construction industry are major contributors to global CO_2 emissions through embodied and operational energy use. The industry is a major consumer of natural resources and many products contain materials that are detrimental to the indoor environment and human health [30]. One of the most effective measures to reduce operational energy use is to insulate the building envelope, which confers benefits in both heating and cooling energy use. Current thermal insulation materials in the construction market are generally inorganic materials e.g. extruded polystyrene (XPS), expanded polystyrene (EPS), polyisocyanurate and polyurethane foam. These materials have a high performance in resisting heat transfer but the environmental impact of their production processes is high. Accordingly, the use of natural materials, which undergo minimal production processing, for application as building insulation is an important aspect in the creation of a healthy and sustainable environment.

Recently, many studies have been conducted into the use of bio-based/natural fibre insulation materials as a replacement for inorganic materials. Bio-based, i.e. plant- or animal-based, insulation materials are a novel class of insulation materials which include products such as cork, cotton, wood fibre, flax, hemp, coconut, cellulose, rice, sheep's wool and others. The plant-based materials sequester atmospheric carbon dioxide through photosynthesis and consequently their use in construction can reduce the net embodied carbon dioxide of a building [26]. When used appropriately, these materials can deliver thermal and acoustic insulation performance comparable to other insulation materials, but with a lower, or potentially negative, carbon footprint and fewer health issues during installation [40]. Moreover, they have hygroscopic properties, which have positive effects on building energy consumption [29], HVAC system energy consumption in dwellings [39,45] and indoor air quality in buildings [37]. Hygroscopic materials exposed to room air equilibrate indoor humidity through their ability to absorb, store, and release water vapour from the air [23,35,38]. This property favourably influences the indoor air humidity, primarily in winter when prolonged periods of low indoor air humidity may be experienced [24], and reduces the potential for mould growth [18].

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In the following studies, the use of natural fibre insulation materials without the addition of any binder is discussed and their mechanical, thermal or hygrothermal characteristics are presented. Zhou et al. [43] developed a binderless cotton stalk fibreboard (BCSF) from cotton stalk fibres without resins and other chemical additives by hot-pressing. The boards were produced at densities of 150–450 kg/m^3 and achieved thermal conductivity values ranging from 0.0585 to 0.0815 W/mK, which are close to those of expanded perlite and vermiculite within the same density range. Korjenic et al. [24] investigated the use of jute, flax, and hemp for use in the development of novel insulating materials made from renewable resources and reported comparable thermal and mechanical properties to those of established conventional insulation materials such as mineral wool, polystyrene and polyurethane. Panyakaew and Fotios [32] developed two low density thermal insulation boards, one made from coconut husk and another from bagasse, both formed without the use of chemical binding additives. The results of their experimental study indicated that both insulation boards had thermal conductivity values ranging from 0.046 to 0.068 W/Mk which, at the lower end, were close to those of conventional insulation materials such as mineral wool. Zach et al. [42] conducted a series of measurements to evaluate the thermal performance and application of sheep's wool insulation. Results indicated that the sheep's wool had comparable thermal performance to mineral/rock wool. Furthermore, the ability of sheep's wool to absorb moisture helped to prevent condensation, regulate humidity, and created a pleasant indoor atmosphere. Briga-Sá et al. [3] experimentally studied the potential applicability of woven fabric waste (WFW) and a waste of this residue, named woven fabric sub-waste (WFS), as thermal insulation for use in construction. The results showed that the WFW had better insulation characteristics than the WFS, and the thermal conductivity value of WFW was similar to the conventional thermal insulation materials, such as expanded polystyrene, extruded polystyrene and mineral wool. Charca et al. [11] studied the thermal properties of Ichu, which is an Andean feather grass, as a local and cheap natural insulation material for rural dwellings. The results revealed that the thermal conductivity varied from 0.047 to 0.113 W/mK for mats with unidirectional oriented fibres. Wei et al. [41] investigated the effect of high frequency heating, board density, particle size and ambient temperature on the properties of a new thermal insulation material made from rice straw. The results indicated that the optimum physical and mechanical properties of the boards were obtained with a moisture content of 14% and board density of 250 kg/m^3. Additionally, the thermal insulation boards had good thermal performance, recording a thermal conductivity in the range of 0.051 to 0.053 W/mK.

These studies highlight that natural building materials are increasingly being investigated as viable thermal insulation materials for the external envelope of new and existing buildings. The highlighted studies focused primarily on thermal and mechanical properties of these materials; few of them considered their hygric behaviour.

In this paper, the use of Wood waste (WW) as an insulation material for building envelopes is investigated and characterisation of its thermal and hygric performance is reported. WW is a common by-product of construction and demolition, packaging, municipal activities, joinery and furniture manufacture [12]. The use of this material within timber frame wall construction, without the addition of binder, facilitates improved management of wood waste, ease of recycling, and potentially healthier indoor environments. At the present time, wood fibres are used in the production of wood fibre insulation boards by adding low quantities of PUR resin in a dry process. In this case, the thermal conductivity values of the boards range between 0.037–0.05 W/mK [17]; however, this production process also requires a large amount of energy [20]. The use of wood waste received from local sawmills without treating will reduce energy use and relatedly carbon dioxide release.

Wood waste can be defined as a material that has been used for some time and then disposed by the users as well as the residues from primary wood processing such as sawdust [1]. In this study, the properties of the wood waste from primary production sources using untreated material are examined. These residues are industrial wastes generated by either sawmills and other millwork companies, which are primary wood product manufacturers, or companies that use products from wood materials milled by primary wood, which are secondary wood product manufacturers. The primary wood manufacturers produce a variety of WW including bark, chips, edgings, sawdust, and slabs. These residues typically have a moisture content of 40–50%. The secondary wood product industries produce a variety of WW including chips, ends, and sawdust. The moisture content of these wastes varies considerably because both green, harvested wood and kiln-dried wood are used in secondary manufacturing. An average moisture content of 45% is commonly used in the wood energy industry [15].

Our paper reports the characterisation of the aforementioned WW from experimental testing of samples under a range of environmental conditions as this is necessary to assess the performance of a thermal insulation material used in the building envelope.

2. Hygrothermal behaviour

The assessment of building envelopes subject to temperature and moisture gradients is a prerequisite in the investigation of building energy efficiency and the evaluation and creation of a comfortable indoor environment [28]. If such environmental conditions are not assessed with a holistic approach and appropriate solutions integrated into the building design, the resulting building may suffer from excess energy use through increased heat transmission coefficients of the building envelope elements. The building may also experience structural damage from interstitial condensation and elevated moisture content, e.g. leading to timber decay, or surface condensation damage in the form of mould which will lead to poor indoor air quality and an unhealthy environment. The building element or zone response to temperature and moisture gradients is generally referred to as 'Hygrothermal behaviour'. This behaviour considers the simultaneous and interdependent occurrence of heat absorption, storage, and release, and moisture (liquid/vapour) absorption, storage and release [18]. In air with a given relative humidity and temperature, a porous building material, after some period of time exposed to such an environment, will reach a state of equilibrium with this environment, exchanging the water in its pores with the ambient air. This relationship between the water content and relative humidity is described by the sorption isotherm [19]. If the equilibrium is achieved during drying, desorption isotherm is produced, and if achieved during wetting, the sorption isotherm is realised [9].

3. Material

The WW material used in the experiments was taken from a Welsh saw mill, and was the by-product of furniture and joinery manufacturing. The material was used as received without addition of binders. The material particle size was variable but within the range of approximately 1–4 mm and in a shape of long and thin curl (Fig. 1).

WW can be applied to timber frame wall construction in the same way as the current application of cellulose fibres (CF). CF can either be installed by 'loose fill' or 'wet spray method'. In the loose fill application, CF are first separated by pneumatic equipment, and then are delivered by air pressure into wall cavities through a hose.