International Biodeterioration & Biodegradation 116 (2017) 124–132

Contents lists available at ScienceDirect

International Biodeterioration & Biodegradation

journal homepage: www.elsevier.com/locate/ibiod

A rapid screening method to determine the susceptibility of bio-based construction and insulation products to mould growth

B.K. Stefanowski [a, *], S.F. Curling [a], G.A. Ormondroyd [a, b]

[a] BioComposites Centre, Bangor University, Bangor, Gwynedd, LL57 2UW, United Kingdom
[b] Department of Architecture and Civil Engineering, University of Bath, Bath, United Kingdom

ARTICLE INFO

Article history:
Received 29 February 2016
Received in revised form
21 September 2016
Accepted 14 October 2016

Keywords:
Mold
Construction materials
Insulation
Susceptibility
Moisture

ABSTRACT

Mathematical models have been developed to evaluate materials' durability and susceptibility to biodeterioration by moulds, however models are material and mould species specific. Ultimately the best way to determine a materials' susceptibility is to expose the material to microorganisms. This study attempted to develop a quick, reliable screening method to evaluate a number of different materials for their susceptibility to moulds at optimal and limiting conditions. This test method was based on modified versions of ASTM 4445-91 and BSEN 846. The water absorption coefficient and Dynamic Vapour Sorption tests were also conducted to determine any correlation between the materials hygric properties and mould growth. The materials used to validate the novel screening method were: MDF, laminated MDF, Chipboard, Laminated chipboard, Wool, Hemp, Wood fibre insulation and pine. It was found chipboard was the most susceptible to mould growth and wool the least when in direct and indirect contact with agar. Primary colonisers (*A. niger*) easily colonised the materials, regardless of the environmental conditions, whereas secondary (*A. alternate*) and tertiary (*T, virens*) colonisers were absent on materials under limiting conditions.

1. Introduction

During the service life of buildings, bio based construction materials could be at risk of biodeterioration such as that caused as a result of the biotic processes of microorganisms. In the environment saprophytic organisms such as mould and decay fungi are the main agents responsible for the decomposition and recycling of organic matter. However, in the built environment they are associated with physical and aesthetic damage and human health problems such as allergic and toxic reactions (Airaksinen et al., 2004; Cooley et al., 1998; Jarvis and Miller, 2004; Mensah-Attipoe et al., 2015; Nielsen and Fog, 2003). Modern building practices have, in some cases, exaggerated this problem with increased insulation hindering ventilation, resulting in increased areas of condensation and subsequent mould growth (Schmidt, 2006). Moulds will readily colonise lignocellulosic materials but can also attack synthetic floor coverings, airplane fuels, oils, glues, paints and textiles (Pasanen et al., 1992; Schmidt, 2006). This ability to attack a wide variety of materials is enabled by the variety of physiological responses demonstrated by mould fungi in regards to temperature, water activity, relative humidity and pH (Schmidt, 2006).

Hygroscopic (water sorption) properties are an inherent characteristic of materials that influence both the application and microbiological resistance (Airaksinen et al., 2004; Xie et al., 2010). Natural fibres are hygroscopic because their cell walls contain high amounts of water sorption sites (hydroxyl groups) and can expand to accommodate the water (Xie et al., 2010). Moulds have been shown to appear in succession on a material as the moisture content of the material fluctuates, according to their minimum moisture demands of the mould, (Pasanen et al., 1992).

Therefore, although the need for determining a materials' vulnerability to mould growth is obvious, it is clear that not all materials have equal susceptibility (Johansson et al., 2012; Mensah-Attipoe et al., 2015), which adds complexity when considering composite materials. Isopleths have been used to describe relationships between temperature, moisture and fungal growth on nutrient media and although isopleths can be very useful, they are, however, only suitable for predicting growth of known fungi on one material at a time and are time intensive (Johansson et al., 2013b).

* Corresponding author.
E-mail addresses: b.stefanowski@bangor.ac.uk (B.K. Stefanowski), s.curling@bangor.ac.uk (S.F. Curling), g.ormondroyd@bangor.ac.uk (G.A. Ormondroyd).

http://dx.doi.org/10.1016/j.ibiod.2016.10.025
0964-8305/

There have been a number of mathematical models developed and reported in recent years that can be used to evaluate durability and susceptibility of wood and wood-based materials to biological deterioration (Ojanen et al., 2007; Viitanen et al., 2010). Basic models are used to indicate mould germination conditions, such as the isopleth technique, but these do not account for fluctuations in environmental conditions. More advance models such as the VTT model and the bio-hygrothermal model (Sadovský et al., 2013) can be used but these have also shown significant variations in results due to simplifications and assumptions (Sadovský et al., 2013). There are, however, further disadvantages to using some models to predict microbiological growth, in that most are based on laboratory data, where optimum conditions are used, and are therefore often not comparable to construction materials, which are comprised of less nutrient rich materials (Clarke et al., 1999). Very rarely do they take into account species dominance (Gu and Gu, 2005). One key characteristic in predicting the susceptibility of materials requires a knowledge of the organisms' minimum water requirements, that are specific to the individual mould species (Nielsen et al., 2004). Models also do not consider the materials ability to absorb moisture, in contact or as vapour. It is possible that errors occur, due to a delay in a change in the surface conditions at different relative humidities, when compared to adjacent conditions.

These models may therefore not be the most applicable way of determining a materials' susceptibility to mould growth. As stated above, these models are often developed using the moulds optimal growing conditions and therefore, if materials are destined for use outside of these environmental ranges, such as furniture in a bathroom or kitchen, the level of biological attack may be based on false assumptions. Moulds can still colonise materials and grow in sub optimal conditions and it has been shown that even at low humidities, where substantive growth may be retarded or prevented, spores and mycotoxins can still be released (Abbott, 2002; Nielsen et al., 2004). This can be detrimental to both the material, as it may enable degradation by other fungal species and in the case of mycotoxins, to human health.

It is highly important to understand how a mould responds to a different substrates and materials susceptibility to microbial attack. Any misunderstanding or poorly informed decisions can have damaging consequences to product industry, economy and human health (Gu, 2016; Gu and Gu, 2005; Mensah-Attipoe et al., 2015). Ultimately the best way to determine a materials' susceptibility to moulds is to physically test the subject material. The aim of this study was the development of a rapid screening method for evaluating the susceptibility of different materials to mould growth under varying conditions and methods of inoculation. The hygric properties of the materials tested were also determined in order to evaluate correlations between mould growth and the materials' hygric properties.

2. Materials and methods

The method described below, is a further development of the study conducted by Stefanowski et al. (2015) which was derived from BS EN ISO 846: 1997 Plastics – Evaluation of the action of microorganisms and ASTM D 4445-91, 1991 Standard Method for Testing Fungicides for Controlling Sapstain and Mould on Unseasoned Lumber (Laboratory Method).

2.1. Materials

The materials tested include three commercial grade construction medium density fibre board (MDF), laminated MDF, chipboard and laminated chipboard and three commercial insulation materials sheep's wool, hemp and wood fibre insulation with solid pine wood (*Pinus sylvestris*) used as a control. The construction panel specimens were prepared to give an upper surface area of 30 mm^2 with the thickness being that of the test material. As the insulation materials were 50–60 mm thick, a subsample of 5 mm thickness was removed from the top surface of the material for use as the test specimen.

2.2. Preconditioning

All specimens were conditioned in conditions of 23 ± 1 °C and 60 ± 3% RH and once constant mass was reached the specimens were weighed. The specimens to be inoculated with moulds were sterilised with ethanol and water 70:30 (BSI, 1997).

2.3. Hygric

The sorption dynamics of natural fibres are complex partly due to fibre internal structure and partly due to continuous nano-structural changes, associated with dynamic behaviour of cell walls (Xie et al., 2010). Two methods were used to determine the material's sorption properties; Dynamic Vapour Sorption (DVS) and water absorption coefficient (BSI, 2002). Pine (*Pinus sylvestris*) was excluded from the hygric tests.

2.3.1. Water absorption coefficient

This was conducted following the standard BS EN ISO 15148: 2002, Hygro-thermal Performance of Building Materials and Products – Determination of water absorption coefficient by partial immersion.

2.3.2. Dynamic vapour sorption (DVS)

DVS is designed to accurately measure weight changes of a sample (less than 10 mg), as it absorbs and desorbs moisture at differing relative humidities and temperatures. The sample was suspended in a microbalance within a sealed thermostatically controlled chamber, where a constant flow of dry nitrogen gas was passed over the sample at a flow rate of 200 cm^3s^{-1} and a temperature of 21 ± 0.2 °C (Popescu et al., 2013). The inert gas carried a controlled quantity of water, maintaining a set RH. The schedule for the DVS was set to start at 0% RH and then increase in 5% steps up to 95% for the adsorption phase and the reverse for the desorption phase (Popescu et al., 2013). The DVS maintained a given RH until the weight change of the sample was less than 0.002% min^{-1}. Mass change data were acquired every 20 s. Sorption and desorption isotherms were produced for each material by plotting mass change against relative humidity (RH).

2.4. Mould tests

2.4.1. Moulds

The mould species chosen for this experiment are based on standards used, however they are also consistently found in indoor environments (Cooley et al., 1998). The mould species were acquired from Fungal Biodiversity Centre, Institute of the Royal Netherlands Academy of Arts and Science (KNAW). The species selected were: *Aspergillus versicolor* (Vuill) CBS 117286, *Cladosporium sphaerospermum* (Penz) CBS 122.63, *Chaetomium globosum* (Kunze ex Fr.) CBS 107.14, *Penicillium rubens* (Biourge) CBS 401.92, *Alternaria alternata* ((Fr.) Keissl) CBS 120829, *Paecilomyces variotti* (Bainier) CBS 108945, *Trichoderma virens* (J.H. Mill, Giddens & A.A. Foster) CBS 100946 and *Aureobasidium pullulans* (var.pullulans) CBS 101160.

On the basis of the minimal requirement of available water for fungal growth on material surfaces, indoor fungi and moulds can be