Construction and Building Materials 68 (2014) 135–141

Contents lists available at ScienceDirect

Construction and Building Materials

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

Durability characteristics of straw bales in building envelopes

Andrew Thomson *, Pete Walker

BRE Centre for Innovative Construction Materials, Department of Architecture & Civil Engineering, University of Bath, Bath BA2 7AY, United Kingdom

HIGHLIGHTS

- Condition monitoring data from an exposure test facility is presented.
- Methods of data interpretation are presented and discussed.
- CO_2 evolution is used to assess durability of straw exposed to a range of hygrothermal conditions.
- Observed microbial growth behaviour provides new insight for straw integrity assessment.

ARTICLE INFO

Article history:
Received 17 April 2014
Received in revised form 23 June 2014
Accepted 25 June 2014

Keywords:
Straw bale
Building
Durability
Moisture

ABSTRACT

Cereal straw, including wheat, barley and rice, offers a renewable and sustainable resource stream for a variety of construction products, including compressed board panels, thatched roofing and bales. The successful use of straw bales as thermal insulation within the external envelope of buildings has been demonstrated by the increasing number of successful contemporary projects around the world. However, the warranty, insurance and financing of such projects is often still not as straightforward as competing solutions, which can be attributed to concerns relating to the long-term durability of the straw. This paper presents findings from an on-going experimental study into the condition monitoring of modern straw bale construction, and also reports on a study investigating the degradation behaviour of wheat straw cyclically exposed to elevated humidity levels. The findings of the study provide encouraging insight into the robustness of straw bale construction.

1. Introduction

In recent years the requirement for lower carbon buildings has acted as a catalyst for the use of, as well as research and development into, new types of wall construction. The use of cellulose based materials, such as timber, straw, bamboo and hemp, offers a simple means to reduce the total carbon impact of new buildings; photosynthesis captures atmospheric carbon dioxide, which remains locked into the plant material throughout the buildings life. Consequently there has been an increased use of novel cellulose based materials, such as straw bales, in contemporary architecture. Straw bale buildings can now be found in many locations around the world, including in particular the USA, Europe, Canada, Australasia, Japan and China [1,2]. Straw bales are used primarily to provide high levels of thermal insulation (*U* values for 450 mm thick walls 0.13–0.19 $W/m^2 K$); though they can also be used in load-bearing walls in lightly loaded low rise buildings. Increasingly straw bales are being used in prefabricated panelised construction, which combines the benefits of off-site manufacture [3,4] with the low carbon benefits of cellulose construction materials (Fig. 1). However, whilst there are significant advantages to using straw bales in buildings the mainstream adoption of this material remains restricted by concerns relating to long-term durability [5,6] and lack of certified supply chain for materials and products.

The aim of the study presented in this paper is to support the development of straw bale construction through a deeper understanding of the degradation characteristics of wheat straw bales. The paper presents results from the long-term condition monitoring of a straw bale exposure test facility combined with a novel laboratory study into wheat straw degradation. This study will hopefully enable building professionals to better understand and assess the risks associated with straw bale construction.

2. Background

Lawrence et al. [7] provide a concise literature review of the methods for measuring the moisture conditions and recommended moisture content limits for straw bale construction. Unobtrusive

* Corresponding author. Tel.: +44 01225 386621.
E-mail addresses: A.J.Thomson@bath.ac.uk (A. Thomson), P.Walker@bath.ac.uk (P. Walker).

http://dx.doi.org/10.1016/j.conbuildmat.2014.06.041
0950-0618/

Fig. 1. LILAC co-housing development in Leeds, UK (Courtesy of ModCell).

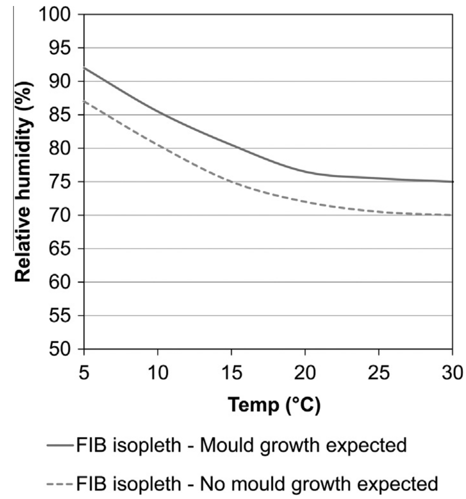

Fig. 2. Isopleth 'traffic-light' for wheat straw [10].

methods for moisture monitoring include electrical resistivity measurements of either, indirectly, embedded wood blocks or directly of the straw. The relationship between moisture content of embedded wood blocks and the surrounding straw is not well developed. Alternatively, moisture contents have been derived indirectly using relative humidity measurements, but again the reliability of this approach to derive straw moisture levels is unproven.

Recommendations suggest that the initial moisture of straw bales at construction should not exceed 14–15% (by dry mass of straw), though in-service acceptable moisture content limits rise to around 25% before there are concerns for the degradation of the straw. These guidelines provide a clear limit for best construction practise, but the consequences for duration of exposure and subsequent severity of degradation are not yet sufficiently understood.

Experimental testing by the Fraunhofer Institute of Building Physics has been undertaken to characterise the mould resistance of building materials [8–10]. As part of this study wheat straw specimens were subjected to a range of climatic conditions through varying temperature and relative air humidity levels. Each specimen was exposed for a period of 100 days and mould growth was visually monitored during this time. Within the 100 day period mould growth was not observed below 80% RH at 10 °C and at 70% RH at 25 °C. As relative humidity is increased mould growth is initiated and becomes progressively more severe. These findings were presented using a graphical isopleth system. The isopleth provides a simple 'traffic-light' guide to climatic conditions that can support mould growth on wheat straw and is shown below in Fig. 2. The Fraunhofer tests were initially undertaken to investigate risk of surface mould development on different building substrates, but has been developed further to assess the degradation risk of straw bale insulation.

Existing approaches provide two distinct methods for degradation risk assessment of wheat straw insulation:

- Assessment of straw moisture content against an upper limit of 25% dry basis.
- Use of an isopleth to assess hygrothermal (temperature and relative humidity) data.

The moisture content limit of 25% provides a safe threshold for ensuring wheat straw will not degrade but there are difficulties associated with its use. Firstly, how to assess the risk if the limit is exceeded; literature does not provide sufficient evidence for a reliable technical assessment to be made above 25% moisture content. The second difficulty is associated with how to monitor straw moisture content inside straw bale walls. Direct measurement is invasive and time consuming whilst wood block monitoring requires species specific calibration with the straw [11,12]. In addition, interpretation of straw moisture content with an isotherm relationship has been found to be highly sensitive to variations in RH > 90%.

The use of an isopleth system could, however, help to address some of the limitations associated with using a moisture content approach for assessment. The isopleth offers the following potential advantages:

- Compatibility with moisture transfer modelling such as WUFI simulations.
- Temperature and relative humidity sensors can be remotely and wirelessly logged.
- The influence of temperature is incorporated into the isopleth.

Nonetheless, determining limits for assessing degradation risk of straw bales with elevated moisture contents is not straightforward. Straw degradation is influenced by many environmental factors, perhaps most importantly the exposure duration.

In this paper two broad cases to consider when assessing the durability of straw bales in construction are proposed. Firstly, it is necessary to understand the risk associated with the germination and growth of mould arising from elevated relative humidity levels. Secondly, the risk of serious decay resulting from the ingress of water or sustained levels of high humidity associated with the use of the building or the climate that it is built in has to be evaluated. Decay would be recognised as causing detrimental damage to the building structure through significant breakdown of the straw. A comparable example of this approach is to be found in the field of timber construction. Blue stain fungi, or surface mould, can grow causing staining and discoloration of the timber when high relative humidity or moisture content allows. However, whilst the discoloration caused by the blue stain fungi affects the value of the timber it does not cause loss of mechanical strength [13,14]. In comparison the presence of wet or dry rot is of greater concern in timber. These fungi occur when timber is maintained at moisture contents above 20% for a sustained period. They cause decay of the cellulose and lignin that forms the structure of the timber and are thus detrimental to its integrity.

3. Condition monitoring

Monitoring the hygrothermal conditions within straw bale walls is important as it provides benchmark data for the assessment of