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Racking performance of timber studwork and hemp-lime walling

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HIGHLIGHTS

- Novel study of structural performance of low carbon construction system.
- Detailed experimental study, including five full-size panel tests, outlined.
- Design recommendations provided for racking resistance of hemp-lime insulated timber studwork panels.

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ABSTRACT

Hemp-lime is a natural, sustainable low carbon insulating material. It is formed from three main constituents: hemp shiv; lime based binder; and, water. Its use within the construction industry is a relatively recent development. In the UK hemp-lime is most widely used for solid wall insulation in conjunction with structural timber studwork, either cast in situ or more recently innovative prefabricated panels. Current design practice assumes that the hemp-lime does not contribute towards the structural capacity of the wall. Previous work by the authors has confirmed that hemp-lime significantly benefits vertical load bearing capacity of the timber studs. This paper presents research that has been undertaken to establish the enhancement hemp-lime provides to the in-plane racking strength of timber studwork framing. Laboratory testing was undertaken on a series of timber studwork frames both with and without hemp-lime. It was found that the hemp-lime significantly increases both the racking strength and stiffness.

1. Introduction

In 2008 the UK Government published a strategy for sustainable construction [9], with its key themes being to design buildings that are sustainable, resource efficient, fit for purpose and adaptive. Minimising the energy used in construction and running of buildings is key to meeting the UK targets of reducing greenhouse gas emissions to 80% of 1990 levels by 2050 [10]. These can be achieved through significant reductions in operational carbon emissions by reducing heating and cooling demands, with improved insulation levels, increased air tightness, better construction detailing, improved build quality and occupant behaviour amongst leading factors. It is increasingly recognised that low carbon buildings also require use of low carbon materials and components, as embodied carbon levels play an increasingly important role in the footprint of a building. The use of natural low carbon building materials is increasing within the UK in response to this need. Hemp-lime composites are one of the many natural, sustainable, low energy materials, that offer improved building performance for radically lower embodied carbon emissions compared to existing solutions.

Hemp-lime composites have been used in construction for around 20 years. The use of this lightweight composite, comprised of the woody core of the hemp plant (shiv) and lime binder with water to mix, originated in France [2]. Its use has become increasingly widespread across continental Europe and in recent years within the United Kingdom [20]. Hemp-lime was initially used in the restoration of historic timber buildings, as a replacement for wattle and daub that had deteriorated [2]. It was found that it provided a long lasting natural infill material that was stable, did not shrink and allowed the buildings to breathe, which is vital if their condition is to be maintained [2]. Hemp-lime is now used in new construction as a natural, sustainable and carbon neutral infill wall material around timber-framed construction [16]. It is typically used in domestic scale construction and a demonstration house, The Renewable House, constructed at the BRE Innovation Park in 2010 to showcase the material. Hemp-lime is currently used

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within the UK as a solid wall insulating material; current structural design generally does not assume any contribution to the structural performance of the walls from the hemp-lime. However, as hemp-lime encapsulates the structural studwork frame, there is the possibility that it could enhance the performance of the studwork frame despite its relatively low stiffness and strength. This has been shown to be the case when compressive loads are applied [15].

Due to its relative infancy there has been limited research on the structural performance of hemp-lime. Most studies have focused on the material properties, particularly the compressive strength of hemp-lime at different densities and with different mix proportions [13,12,8,17,18]. There have been limited studies on the composite behaviour of hemp-lime and structural studwork framing [6,7]. Several studies have been carried out on the compressive performance of composite walls at both the University of Bath [19,15] and Queens University in Kingston, Canada [11].

The in-plane racking performance of wall panels is important, as buildings gain their stability when subjected to lateral wind loading from the racking strength of the walls parallel to the direction of the load. To date there has been limited research published on the in-plane racking performance of hemp-lime walls or panels. One study by Munoz and Pipet (reported in Amziane and Arnaud [1]) has compared the in-plane racking performance of a timber stud frame with diagonal bracing and a timber stud frame with hemp-lime infill. In their study Munoz and Pipet spray applied hemp-lime with a design density of between 300 kg/m^2 and 350 kg/m^2, however the final cast density of the wall is not given in the report. The study found that the hemp-lime infill resulted in studwork frame having a higher racking stiffness and strength that the frame with diagonal bracing. Munoz and Pipet concluded that further repeat testing is required to confirm the results of this study. In recent years there has also been some similar research on ModCell prefabricated straw bale panels undertaken by the authors. These utilise similar materials to composite hemp-lime and studwork frame walls with a timber structural frame and a low stiffness insulating filling material. Several studies [21,14] have shown that through composite action between the timber framing, straw and lime render covering, the in-plane racking resistance of the prefabricated straw bale wall panels can be significantly increased. These studies have also shown the potential for this construction be used in load bearing applications.

There is a need for further research in this area into the performance of composite hemp-lime and studwork frame walls, particularly when in-plane racking loads are applied. This is the focus of the research that is the subject of this paper. The aims of the work presented here are to establish the in-plane racking performance of timber studwork frames with low density hemp-lime (275 kg/m^3) and the contribution of the hemp-lime. To meet these aims the following objectives were developed for this work: undertake laboratory testing of studwork frame wall panels both with and without hemp-lime; analyse the results, develop and implement improvements.

2. Experimental programme

During this study timber studwork frames with and without hemp-lime were constructed and tested under in-plane racking loads. Frames without hemp-lime were tested to provide a comparison of performance. When using composite hemp-lime and timber framed construction the studs are generally positioned in either the centre of the wall or on the inside edge of the wall. Both of these techniques are currently used in the construction of composite hemp-lime and studwork framing. When the studwork frame is in the centre of the hemp-lime it is fully encapsulated. Additionally full encapsulation may be structurally beneficial as the hemp-lime may restrain the stud against movement about both its major and minor axis. When the studwork frame is on the edge of the hemp-lime permanent shuttering can be used against one face of the wall. This allows for faster construction and easier finishing of the walls internally as the permanent shuttering can simply be skim plastered. However, as the studwork frame could separate from the hemp-lime, additional horizontal rails have to be fixed to the studs to prevent this detachment. In total five full-size wall panels were tested, four with hemp-lime and one with timber studwork frame only. The details of the wall panels are shown in Table 1. Wall panels R1, R2 and R3 were constructed and tested initially. The results of the testing on these wall panels informed the design of wall panels R4 and R5. In addition to studwork framing and hemp-lime Wall R5 included a magnesium silicate sheathing board fixed to the studs to act as permanent shuttering.

The wall panel tests are supported by material tests on the timber and hemp-lime materials. The materials used throughout the experimental programme were maintained from one supplier, with only the positioning of the studwork frames and the connectors used in the leading stud connections varied. The timber studs used were 38 mm by 89 mm C16 softwood. Due to the limited number of specimens the studs were carefully selected to ensure they were free from major defects, such as knots and shakes, that could disproportionately influence the results. All of the frames were constructed to the same dimensions to suit the test standard methodology for timber stud walling set out in BS EN 594 [4]. The frames were 2.4 m high by 2.4 m long. The studs were at 600 mm centres. Walls R2, R4 and R5 also have 19 mm by 38 mm softwood timber battens at 600 mm vertical centres fixed to the studs, as the frames were positioned on the edge of the hemp-lime. The studs were fixed to the header and footer rails in wall panels R1, R2 and R3 with two 3 mm diameter by 75 mm long nails in each connection. All of the joints in wall panels R4 and R5 were also connected in the same way, apart from the leading stud connections, which used two 6.5 mm dia. × 150 mm long double thread screws in each end. Fig. 1 shows the stud and batten layout for the test panels.

The hemp-lime mix used for this study was kept constant throughout, as was the target dry density. The hemp shiv used was Tradical® HF and the binder was Tradical® HB, both sourced from Lime Technology Ltd. The mix proportions used are as follows: 19.5% hemp shiv, 32% binder and 48.5% water by weight. This is equivalent to using one bale of Tradical HF hemp shiv with 1.5 bags of Tradical HB binder and 50 l of water. The hemp-lime was cast to achieve a target dry density of 275 kg/m^3. The shuttering was removed 24 h after the hemp-lime casting had been completed. Following this the panels were left to dry and cure for between 4 and 5 months prior to testing. During this time (April to October) the panels were stored inside an open sided unheated barn to protect them from rainfall.

3. Test set up

The racking test set up was the same for all of the wall panels. The test set up is shown in Figs. 2 and 3. Frame R3 was tested lying flat on the laboratory floor, for reasons of stability during the test; the setup is shown in Fig. 4. All of the racking tests followed the set up outlined in BS EN 594 [4]. A horizontal racking load was applied to the header plate via a hydraulic jack. Vertical point loads were applied to the top of each stud through the header plate. All of the loads were measured using load cells. In-plane deflections around the perimeter of the panels were recorded using LVDTs measuring both the movement of the hemp-lime and the timber studwork frame. Both the loads and displacements were recorded using a System 6000 data acquisition module.

All of the test panels were securely fixed to the laboratory floor to prevent sliding and uplift of their bases as set out in BS EN 594 [4]. The loading regime for all of the in-plane racking tests was based on the process set out in BS EN 594 [4] and was as follows:

Stabilising cycle:

- Apply 5 kN vertical loads to studs (F_v – constant vertical load applied to top of studs).
- Apply horizontal load of 0.1$F_{max,\ est}$ (estimated racking failure load) and hold for 2 min.
- Unload horizontal load and hold for 5 min.

Table 1
Wall panel details.

Wall no.	Frame position	Hemp-lime	Sheathing
R1	Centre	300 mm thick	None
R2	Edge	300 mm thick	None
R3	NA	Frame only	None
R4	Edge	300 mm thick	None
R5	Edge	300 mm thick	Multi-pro XS sheathing