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The effect of natural and extreme weathering on the mechanical properties of structural timber mortise and tenon joints

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Abstract

When used in the appropriate context, timber structures might have lower embodied carbon than their concrete and steel counterparts, making timber a popular material for sustainable construction practices. To continue constructing with timber we require more in-depth exploration into timber joinery which dictates the structural stability and performance of timber framed construction. In this study, the influence of cyclic humidity fluctuations and wetting and drying is tested on mortise and tenon joinery with different detailing (no additional fastening, with glue and with a dowel) for a comparative appraisal of their impact on the joint rotational stiffness. The outcomes show that exposed samples go through a reduction in rotational stiffness independently of the detailing.
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Keywords: Timber; moisture; wetting and drying; humidity; rotational stiffness; traditional joinery construction

1. Introduction/Background

Timber as a regenerative material with lower-than-most embodied carbon is a popular choice for sustainable construction practices. However, the mechanical properties of timber are more susceptible to degradation than most other building materials when it is exposed to elements [1]. Fluctuations in humidity under normal service conditions, as well as extreme weather events due to rapidly changing climatic conditions across the globe, such as flooding and wind-driven rain, can cause wood cracking and decay [2] impacting connections which dictate structural performance [e.g. 3,4]. The aim of this study is to analyse the effect ageing on the rotational stiffness of simple, glued and doweled mortise and tenon joints to deduce the expected long-term behaviour of timber-frame joints based on these experimental research measurements.

2. Methodology

For the rotational stiffness testing, a Zwigg/Roell machine was used at a test speed of 20mm/min to allow the joint to be incrementally loaded and failure modes to fully develop (as opposed to immediate failure). Failure was determined (and the loading stopped) when a displacement of 54.0 mm was reached as this was the point at which the deformed beam contacted the machine. A metal apparatus was designed and manufactured to hold the specimens in place during testing (Figure 1a). A total of 45 specimens were produced using European Redwood, traditional, with glue and dowel reinforcement in equal numbers (Figure 1b) to be used for testing under normal service conditions (humidity fluctuations) and under extreme conditions (cyclic wetting and drying). 3 joints of each variant were tested to identify a baseline for the rotational stiffness of these joints before weathering. Then the remaining specimens were exposed to ageing protocols, which are: (i) **Cyclic Humidity Variations**: The specimens were exposed to RH changes between 40% and 90% in 50 min, keeping the same relative humidity value for 10 min at each end. Each cycle therefore lasts two hours under the constant temperature of 20°C throughout the experiment. Specimens were tested in two instalments every 120 cycles (10 days) (Figure 2(a)). (ii) **Cyclic Wetting and Drying**: Specimens were submerged for 2 days (wetting) and dried under lab conditions for 3 days (drying). Nine of the specimens were tested after 4 cycles (20 days), and another nine after 7 cycles (35 days) (Figure 2(b)).

3. Results and Discussions

The results show that both protocols caused a decline in the rotational stiffness of the joints at varying degrees depending on the typology. Under **cyclic humidity variations** the conventional joint and the joint with dowel showed a similar trend, with rotational stiffness values decreasing by 12.43% and 10.26% respectively in the first cycling period. In the second cycle period, the conventional joint showed only a 2.23% decrease in rotational stiffness, while the joint with dowels showed a slight increase of 0.8%. This indicates that the decay in the rotational stiffness of these two joints is not linear and is a very slow process. On the other hand, the glued joints show a clear and steady decay in rotational stiffness over the different cycling

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periods, with a 27.94% decay in the first stage and a 40.21% decay in the second stage. The glued mortise and tenon construction have a very strong initial rotational stiffness, 13.4 times that of the conventional joint, compared to the conventional mortise and tenon construction (control group). However, it is highly influenced by changes in air humidity and its stability is poor, making it unsuitable for long-term stable rotational stiffness applications in timber frame construction.

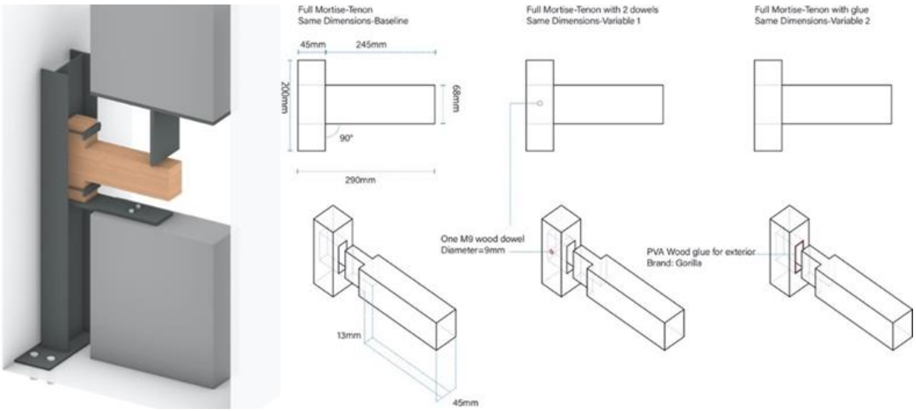

Figure 1(a). The metal clamp used to support specimens; (b). Dimensional drawings of the three variables

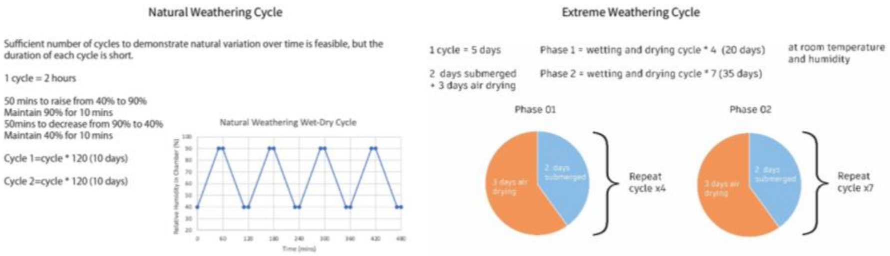

Figure 2. (a)Natural Weathering Test Design; (b)Extreme Weathering Test Design

Under **cyclic wetting and drying**, the joint that saw the most significant decrease in rotational stiffness was the dowel joint with a 33.3% decrease between baseline and first testing, compared to only a 29.0% decrease for the glued joint. It was likely that the cycles have a larger effect on the dowel samples due to there being more gaps in this joint compared to the others (due to the hole the dowel sits in) for water to enter the connection and weaken the joint. The dowel joint had a marginally lower stiffness reduction than the glued joint even though the glued joint had a higher overall stiffness.

4. Conclusions

The impact of environmental factors on the mechanical characteristics and performance of structural timber joinery has been systematically overlooked. The mechanical properties of timber are more susceptible to degradation than other building materials when exposed to moisture: natural humidity fluctuations or extreme weathering such as flooding and wind-driven rain, which can cause wood cracking and decay. Comprehensive assessment of timber's potential for use is not rigorously documented, which makes further investigation into the effects of natural and extreme weathering vital for the standardised and efficient use of timber in timber-frame construction today. Durability is a critical concept to ensure longest possible service life and hence a holistic outlook when we assess mechanical performance is a must.

This study in natural weathering conditions demonstrates that traditional tenon and mortise joints with wooden dowels, although having relatively lower rotational stiffness, perform better in terms of stability, and are suitable for use in wooden buildings that require long-term stability. On the other hand, the adhesive-reinforced tenon and mortise joints have very high initial rotational stiffness but very poor stability and may only be suitable for temporary buildings or short-term use.

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