Brettstapel panels: in-plane strength and stiffness

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Abstract

Brettstapel panels are an increasingly popular form of mass timber panel that has been pioneered by European countries particularly Germany, Austria and Switzerland. The panels are completely free of adhesives and metallic fasteners which boosts recyclability over alternatives such as cross-laminated timber. This has made them popular in the design of sustainable and environmentally-friendly construction projects. A general lack of knowledge in the UK of the behaviour of these panels, in particular how they resist in-plane forces, has led to conservative and potentially over-precautious design detailing to reinforce the panel.

The aim of this study was to gauge whether the addition of this reinforcement, often in the form of sheet timber such as orientated strand board fixed to the external face, is necessary and assess potential methods for improving the in-plane capacity of a panel.

The behaviour of the dowels in a Brettstapel panel is assumed to be integral to its performance. It was found that the behaviour of a dowel between two lamellae and acting in shear could be modelled as a double shear specimen. The literature reviewed in this study demonstrated that the European Yield Model is not valid for the prediction of timber dowels in shear connections. Alternative methods of prediction, based on force and energy equilibrium, have been shown to be more accurate.

Two novel binder-less dowel modification techniques were identified and have been investigated: (i) thermo-mechanically compressed timber and (ii) high-speed rotation welded fasteners. A series of preliminary tests were devised to ascertain the feasibility and applicability of these binder-less dowelling methods. Following this initial investigation, an experimental testing programme was completed to investigate the performance of hot-pressed western red cedar dowels. The results of the experimental work provide a comparison of the hot-pressed dowels to the dried beech dowels currently used in the manufacture of Brettstapel panels. Based on the experimental findings it is recommended that hot-pressed western red cedar dowels are not used as shear fasteners in Brettstapel panels because of the relatively poor initial elastic stiffness and brittle failure mode they exhibit in a connection.

Based on the failure modes observed in the testing, a model for the prediction of ultimate strength of a Brettstapel panel has been proposed. The model uses an energy equilibrium technique and assumes plastic hinge formation of the dowel. A model for the initial elastic stiffness of a Brettstapel panel, based on assumptions from the tests and elastic beam bending equations, has also been developed.

6 Conclusions and future work

6.1 Introduction

This study has focused on characterising the strength and stiffness of a Brettstapel panel. This has been approached by analysing the behaviour of timber dowelled double shear specimens and has used models presented in the literature to develop a model for the prediction of strength and stiffness of a Brettstapel panel.

The literature review highlighted a current lack of information regarding the in-plane behaviour of Brettstapel panels. This had led to the potential over specification of materials that negate some of the benefits of the Brettstapel panel system. The information in the literature review presented several novel methods of dowel bonding that had the potential to improve the capacity of the dowel-lamella joint in the Brettstapel panel: (i) hot-compressed western red cedar and (ii) high speed rotation welded fasteners. These novel methods were investigated through experimental tests and analysed for their applicability as fasteners within a Brettstapel panel.

6.2 Conclusions

6.2.1 Preliminary testing

Hot-pressed western red cedar dowels and high speed rotation welded beech dowels were investigated experimentally to assess their suitability for application as an all-timber fastener in a Brettstapel panel.

High speed rotation welded beech dowels are not recommended for use as a shear fastener in timber. This is due to the technical difficulties associated with achieving a successful bond over insertion depths of greater than approximately 60mm. Rotation welded dowels would be difficult to implement and are unlikely to achieve consistent results in a manufacturing environment.

Hot-pressed western red cedar dowels that are inserted into a connection and rehydrated can produce a relatively tighter fitting connection over hammered in dowels. The hot-press parameters may need to be adjusted on a sample by sample basis depending on the composition of timber but high levels of compression set recovery are achievable.

6.2.2 Double shear testing

Glued dowels result in the highest elastic stiffness in initial loading and the highest peak failure load. Failure is ductile with relative slow loss of residual post-yield strength. Glued dowels used in the study are purely for comparison purposes as the Brettstapel system is 100% adhesive free.

Hammered in dried dowels display good initial elastic stiffness and peak load values that are closely aligned to the model presented in the literature. Failure mode is typically ductile, but staggered brittle failures can occur as a result of pull out failure of the dowel. Due to the characteristics of the failure mode, the dried and hammered in dowels provide the most suitable option of the dowel methods assessed in this study for use as shear fasteners in Brettstapel panels.

Hot-pressed dowelled specimens exhibited a greatly reduced stiffness: 20% of the stiffness of hammered dowels and 12% of the glued specimens. The peak load at failure was less than the glued dowels but comparable to hammered dowels. This has led to the conclusion that bending strength (σb) of the confined hot-pressed timber dowels was similar to the bending strength of the beech dowels. Dissection of samples loaded up to peak failure and to destruction allowed the failure mechanism of glued-in, hammered in and hot-pressed dowels to be closely inspected. The glued and hammered-in dowels showed that a four hinge dowel failure is common for the typical joint geometry tested. The joint geometry used in sample testing is representative of the lamellae geometry in a panel, therefore it can be assumed that dowels in a Brettstapel panel will fail with two hinges per slip plane.

Hot-pressed western red cedar dowels showed a failure mechanism that displayed excessive crushing deformation perpendicular to the grain up to peak failure load. This can be attributed to the poorer compressive strength of the hot-pressed samples when compared to beech. The compression of the dowel is responsible for the significantly reduced elastic stiffness of the connection.

6.2.3 Strength and stiffness modelling

The yield strength of a timber dowelled double shear connection can be accurately predicted using the energy equilibrium method detailed in the literature (Shanks 2005). The method has been adapted to predict the yield strength of a single dowel segment in one slip plane of a Brettstapel panel and factored to facilitate the prediction of an entire panel.

The force equilibrium model for the prediction of initial elastic stiffness of a double shear connection presented in the literature has been shown to accurately predict the stiffness at low loads. A similar force equilibrium method has been used to model the displacements of a single dowel segment in one slip plane of a Brettstapel panel and adapted to allow for the prediction of the stiffness of an entire Brettstapel panel.

6.2.4 Overall conclusions

The behaviour of current lamella-lamella fastening methods and novel proposed fastening methods have been explored in the context of application to a Brettstapel panel. It is concluded that the current method of inserting a beech (or similar hardwood) dowel dried to 6-8% MC into higher MC content lamellae provides the best option of the technologies investigated in this report.

It is likely that the addition of a timber board product fixed to the outer face of a Brettstapel to enhance the in-plane racking strength and stiffness is an advisable design detail. The stiffness and strength of such a panel is such that careful specification of racking reinforcement to particular walls in a building is likely to provide enough stiffness to allow other non-critical panel sections to be designed without reinforcement.

6.3 Continuation of research

Testing of full scale panels is required to validate the proposed models for the strength and stiffness behaviour of a Brettstapel panel subjected to in-plane stresses. These tests should include racking tests on both simply supported panels and panels incorporating top and base plates with typical fastening methods. This will allow design guidance to be further developed.

A Brettstapel panel subjected to differential settlement at the supports will experience long term creep of the fasteners. The characteristic behaviour of the panel in this situation and the effect that it may have on instantaneous stiffness and strength should be explored through further studies.

There may be scope to combine the hot-pressing technique with hardwood dowels such as beech or oak. Tests involving compression and swelling cycles under different parameters should be conducted to determine the viability of this combination. If compression set recovery can be achieved in a beech or oak dowel then the resulting swelling pressure in application is likely to improve the mechanical behaviour of the dowel and therefore the panel as a whole. In addition, if radial swelling can be consistently achieved then a comparable fit of the connection could be obtained with a slightly larger clearance hole.

This may ease manufacturing limitations of getting long lengths of dowels through smaller clearance holes.