Abstract

The present work deals with the large-scale application of the friction welding bonding technology on timber. The investigations that are described in the following were carried out on a prototype of a welding machine that was previously developed for the purpose of this research. By means of this machine timber elements can be welded in a scale that is comparable to structural applications.

Detailed experimental experience with the welding of large-sized specimens was not available at the beginning of this work. Preliminary results of initial tests on welded spruce boards indicate a correlation between the size of the sample and the occurrence of larger areas within the interface where no or only an incomplete welding result is attained. Therefore, these scaling effects were investigated in more detail in a first step. The results show that this phenomenon is associated with an internal gas pressure, which is generated at the interface during the evaporation of moisture content and other gaseous by-products. The latter result from the thermal decomposition of wooden cell wall molecules during the friction phase. It can be shown that the scaling effects can be restricted through a reduction of the moisture content or by the arrangement of gas evacuation channels at the interface, which leads to a decrease of the internal gas pressure.

Subsequently the potential of the technology with regard to structural applications was estimated and evaluated by means of mechanical studies. First, investigations on the load bearing behaviour of parallel welded connections in form of double lap joints, and in particular the influence of the overlap length on the load capacity, are described. The results show that due to the extremely rigid behaviour of the bond so-called size effects occur, a phenomenon that describes a decrease in nominal strength with increasing size of a load-bearing structure. In addition to the load tests, a numerical strength prediction method is presented, which is based on a probabilistic approach and which allows for a precise prediction of the experimental results and the size effects.

Furthermore, it is shown that timber boards with perpendicular fibre orientation can be welded in order to form stiff and resistant connections. Therefore, specimens of different sizes were prepared and tested for their moment transmitting capacity. In this context, a new method for the determination of a failure criterion of cross-welded joints is presented. Probabilistically determined strength values, which are based on this criterion, show good agreement with the experimental results. The non-linear relationship between the size of the specimens and the nominal strength is confirmed by the results of the numerical calculation.

The results from the experiments on cross-wise welded bonds show that the strength of those connections is suitable for an application in timber construction. For this reason small scale prototypes of cross-laminated timber panels were fabricated and examined for their load bearing capacity. For this purpose the most critical load case of in-plane shear is regarded mainly since the load is transmitted only by the moment resisting behaviour of the welded bond. Based on the previously developed probabilistic strength prediction method, the load bearing capacity of the panels can be calculated numerically. A theoretical application of the proposed design method on a case study of a multi-storey timber building demonstrates that current wind loads acting on such buildings could be braced by means of friction-welded wood panels.

In addition to the mechanical investigation simultaneous research on the moisture stability of the joint was carried out. Until now, welding and shrinkage deformations resulting from variations in the moisture content frequently lead to cracks within the joint. Based on the results obtained from long-term investigations on parallel welded joints it is shown that this behaviour can be improved by an application of jagged surface shapes on the interface. As a result, the sensibility to moisture variations is reduced and the load capacity can be maintained even after several cyclic variations between dry and humid climate conditions.

The final investigations of this work describe an application of this principle on cross-laminated timber bonds. Therefore load tests as well as long-term studies under changing climate conditions were carried out on shaped interfaces within cross-laminated timber panels. The results show that the initial load bearing capacity of the panels can be increased through the profiling. At the same time, the cracking is significantly reduced by this modification of the joint. In addition, the extremely brittle failure mechanism changes from a very brittle and fragile to a quasi-brittle behaviour, which is characterised by a decelerated decrease of the load capacity after reaching the maximum load capacity.

In a concluding evaluation of the results future possible applications of the technology are assessed in terms of its structural suitability, efficiency and sustainability. Due to the very short welding time that is needed and the improved moisture stability of the bond, the technology yields interesting qualities that can be advantageous for an application in the production of glued-laminated beams and laminated stacked timber panels. A final outlook gives different approaches for further research which is necessary for the future developing process. Furthermore the final chapter contains some suggestions for the conception of new welding machines that are required in order to enlarge the friction welding technology towards industrial application.

Keywords: Friction Welding of Wood, Wood Bonding, Scale Effects, Probabilistic Strength Prediction, Brittle Failure, Statistical Size Effects, Moisture Stability, Cross-laminated Timber Panels, Surface Shapes, Crack Propagation