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Friction welding of wood – A fast, adhesive-free bonding technology for prefabricated elements in timber construction

Fig. 1: Zoom on friction welded layers of spruce boards including the distinctive black weld line.

INTRODUCTION

Up to now chemical adhesives based on polyurethane are used for the assembling of timber planks to large-scale structural elements, in particular cross-laminated timber panels (CLT). These panels opened new possibilities for architects and engineers in timber construction. However, the use of these adhesives still implicates, beside others, concerns about their impact on health and environment during application as well for later disposal. In order to overcome the geometrical limitations of timber by maintaining its physical and ecologic properties, adhesive-free friction welded bonds are a promising alternative to glued connections. The presented research focuses on the structural behaviour of the welded joint, its longevity and the numerical prediction of its load bearing capacity.

The friction welding technology is illustrated in Fig. 3 and 4. The welded bond is achieved by a fast heating of the interface due to a combination of a welding pressure *P* and a frictional movement with a frequency *f* and amplitude *a*. The movement can be distinguished between linear, orbital, circular and rotational vibration. The introduction of thermal energy leads to a thermal decomposition of the polymeric compounds in the wood cell material. The chemical products of this degradation process form a viscous layer of thermally softened material in the interface, which hardens when the friction movement is stopped and the interface is cooling down, while a certain cooling pressure is applied. In principle any type of wood can be welded. Nevertheless the research focuses on spruce and beech wood, two wood types that are commonly used for timber construction.

Fig. 2: Samples of glued CLT panels based on U-adhesives (a) and possible assembling of CLT panels to a folded structure (b).

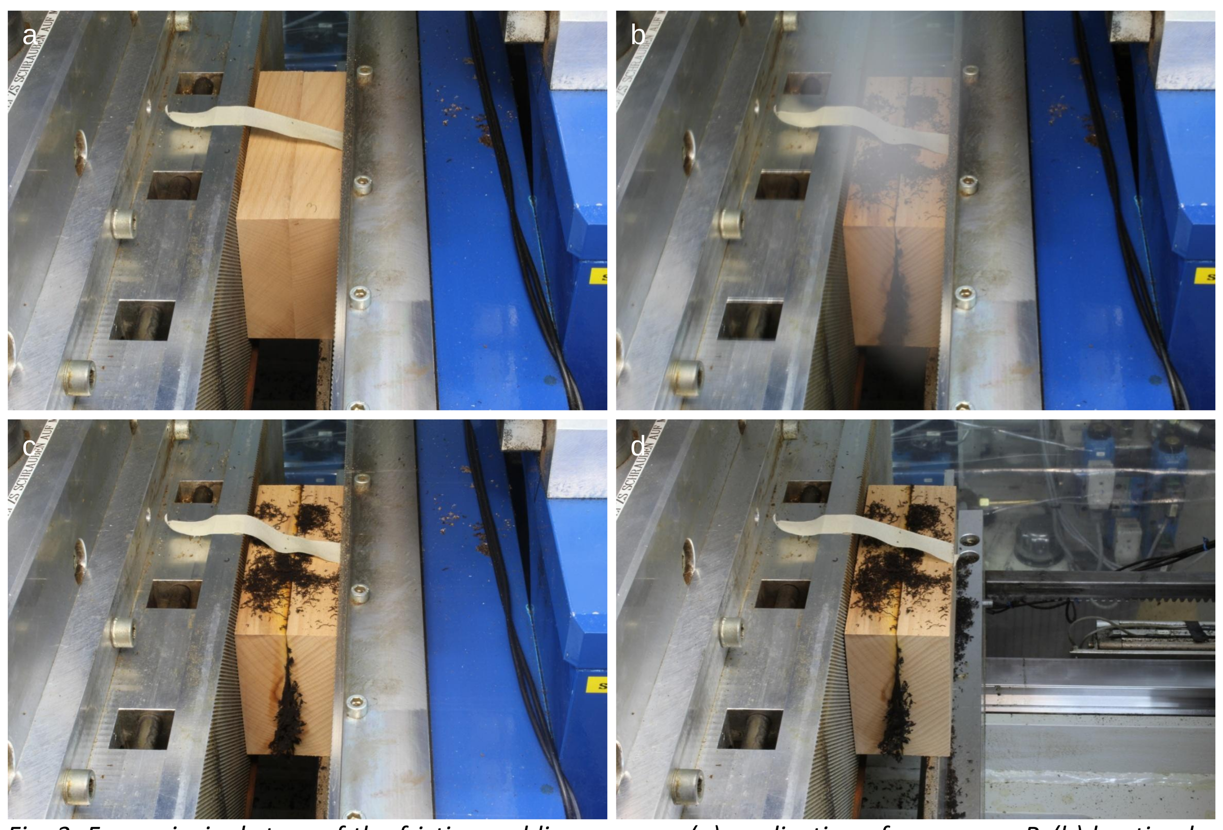

Fig. 3: Four principal steps of the friction welding process: (a) application of a pressure P, (b) heating by oscillating frictional movement , (c) hardening in combination with cooling pressure, (d) final bond.

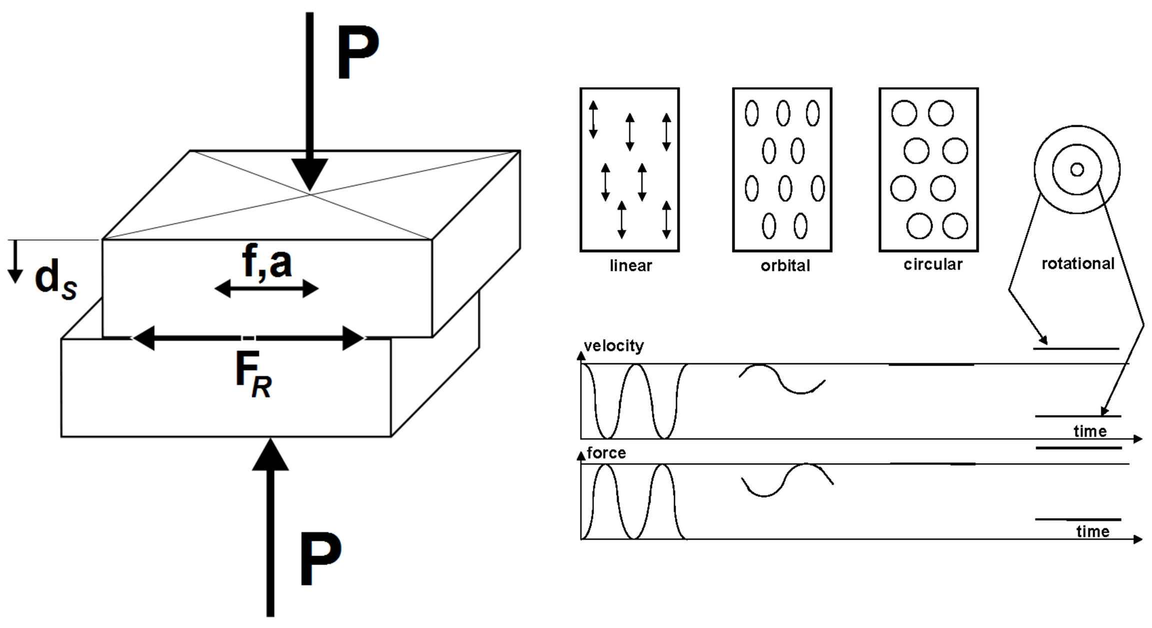

Fig. 4: Schematic representation of the friction welding technology and overview of possible types of the oscillating movements.

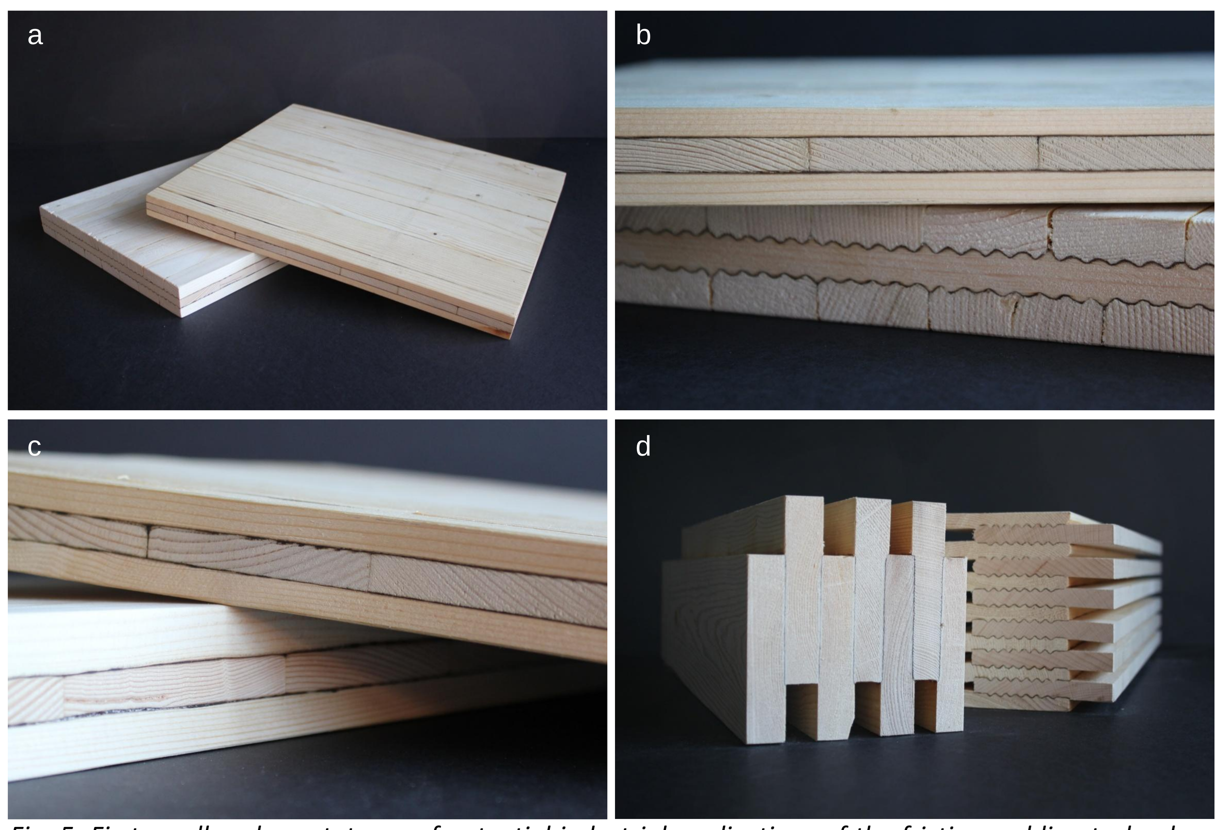

Fig. 5: First small scale prototypes of potential industrial applications of the friction welding technology in form of CLT panels and multi-layered beam and ceiling elements.

SCALE EFFECTS

Challenges and technical requirements for the enhancement of this technology from small specimens to samples of structural scale had to be addressed. With the construction of a new welding machine in 2006, that was specially conceived for wood, welding of bigger surfaces up to 750 cm² became possible. Visual evaluations have shown that the welding process, developed on small size specimens, cannot be applied in the same way to larger surfaces.

It turned out that the huge amount of smoke, generated during the welding process, strongly influences the bond quality. The vapour increases the internal gas pressure at the welding zone. Thus it highly influences the welding process and the quality of the joint. This pressure is suspected to reduce the friction between the contact surfaces and hence as well the generation of frictional heat, necessary to gain a weld. A test setup was developed in order to measure the internal gas pressure during welding. First, an important difference between the gas pressure in the centre and at the edge could be observed. Second, the internal gas pressure could be reduced significantly by introducing gas evacuation channels at the contact surface. The facilitated transport of the vapour from the interface to the outside also led to much more homogeneous distribution of the resulting shear strength resistance over the whole interface.

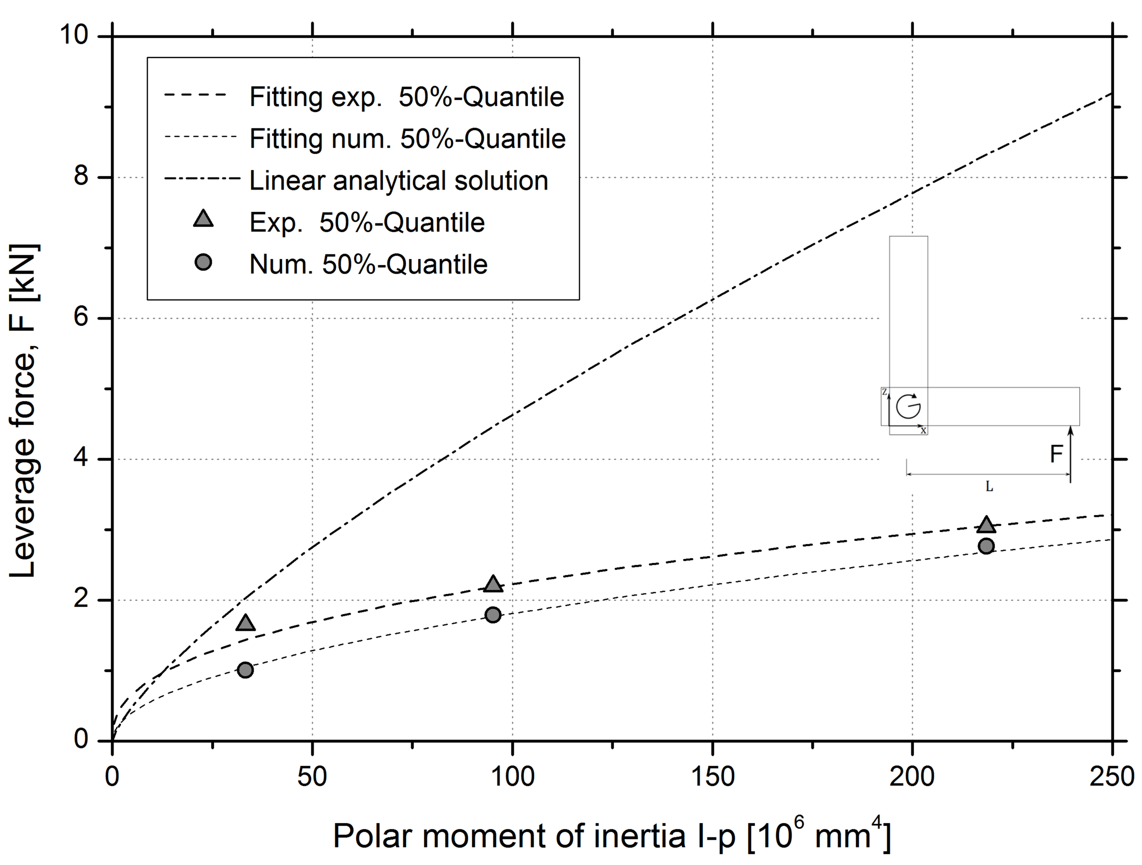

Fig. 6: Comparison between experimental, numerical and analytical average joint strength of moment resisting connections composed of spruce boards with regard to the polar moment of inertia of the interface

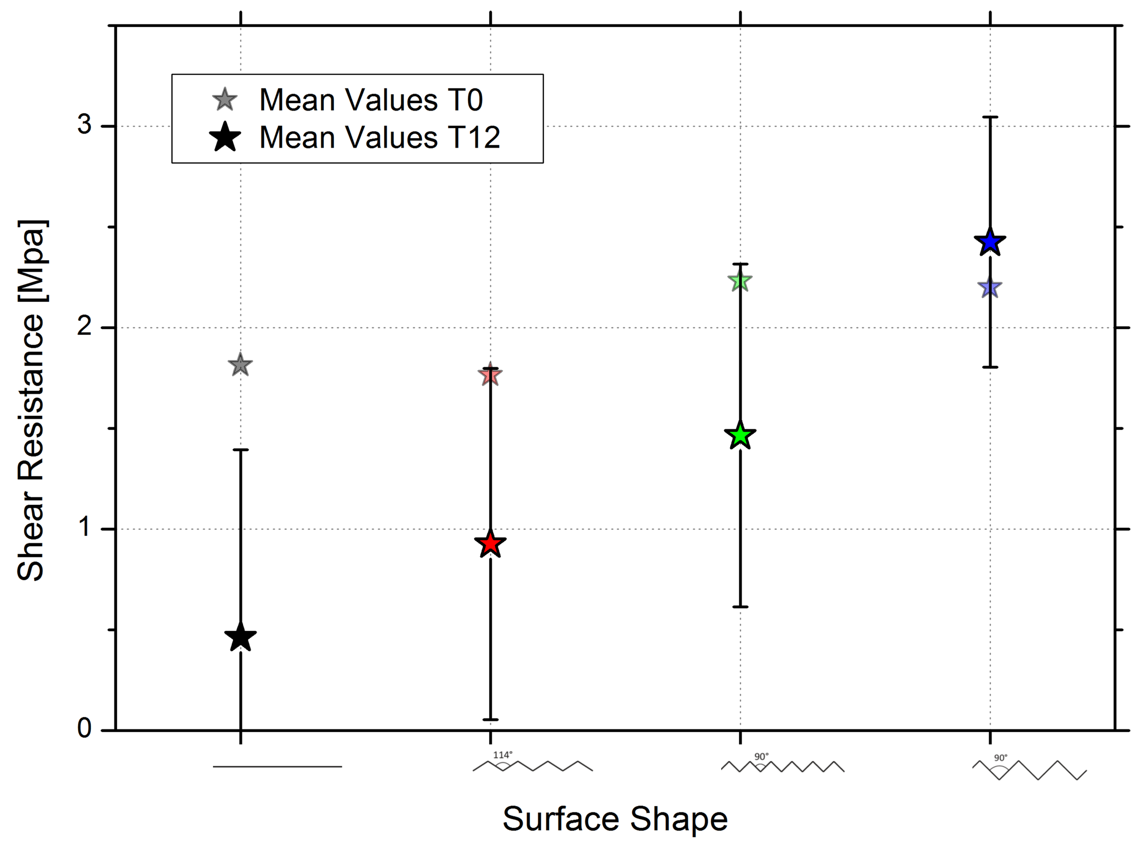

Fig. 7: Pull-out resistance of friction welded double lap joints directly after welding (T0) and after 12 climatic cycles (T12) using different surface shapes

STRENGTH PREDICTION

Experimental investigations were carried out on perpendicular welded moment resisting specimens, representing one single load bearing element in a horizontally loaded bracing CLT walls. Load transfer occurs by transmission of shear stresses induced by a torsional moment. For the dimensioning of structures with brittle failure mechanism, like it has been observed for welded timber joints, probabilistic strength prediction has proved advantages against deterministic methods. The probabilistic approach is based on the weakest link theory, i.e. the failure of a single finite element of the contact surface leads to a failure of the entire connection. With increasing surface size the probability, that such a weakest link element is present, increases as well, and the nominal strength over the surface decreases.

By means of small representative specimens off-axis tests were carried out for the purpose of a characterisation of the welded interface. The resulting failure criterion was implemented in the probabilistic strength prediction algorithm, allowing for estimation of the prediction mean values as well as the 5%- and 95%-quantiles of the statistical distribution of the experimental results. The results, illustrated in Fig. 6, show that a good agreement between experimental and predicted results compared to classical analytical methods was obtained. Further research will extend the investigations on more complex systems composed of more than one intersection point, like panel elements from Fig. 8, in order to simulate more realistic scenarios closer to full scale elements.

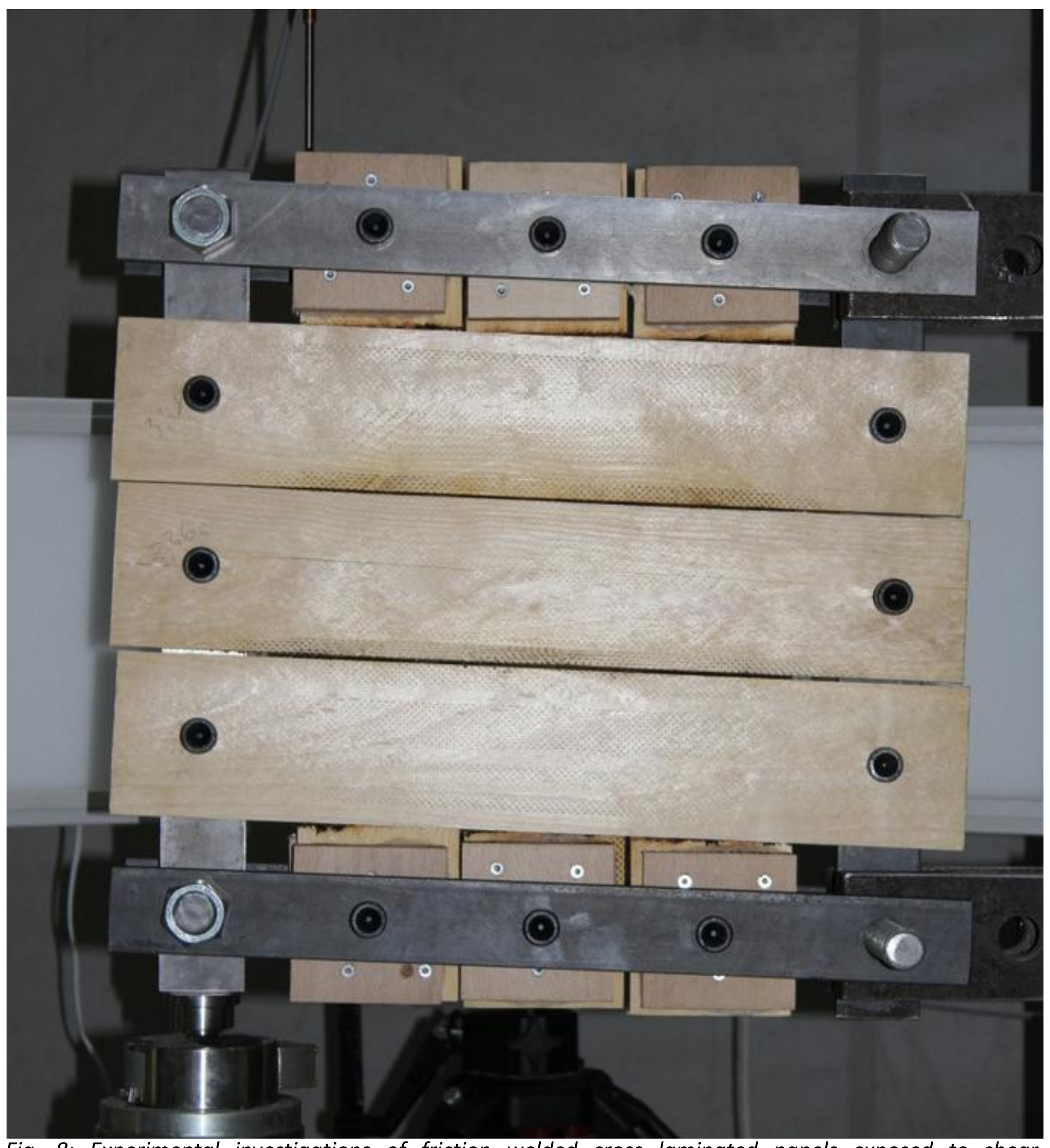

Fig. 8: Experimental investigations of friction welded cross laminated panels exposed to shear deformations

LONG-TERM RESISTANCE OF THE CONNECTION

For industrial application of the technology the long-term resistance of the joint has to be ensured. In fact, the biggest challenge towards industrial application is the susceptibility of the weld with regard to varying moisture contents. The relatively brittle bond is highly sensitive to swelling and shrinking deformations of the wood under changing climatic conditions. These deformations can lead to cracks within the interface. Welded samples of a larger scale are much more sensitive than smaller samples used so far, since the deformations are much higher. This problem becomes important especially when the boards are welded perpendicular to their grain direction like in Fig. 9, as it is the case for CLT panels. The swelling and shrinking coefficients differ strongly between each layer, which results in high important internal stresses. The use of jagged surface shapes could improve the behaviour of parallel welded joints (Fig. 7). This approach will further be applied on cross-wise welded samples (see Fig. 9)

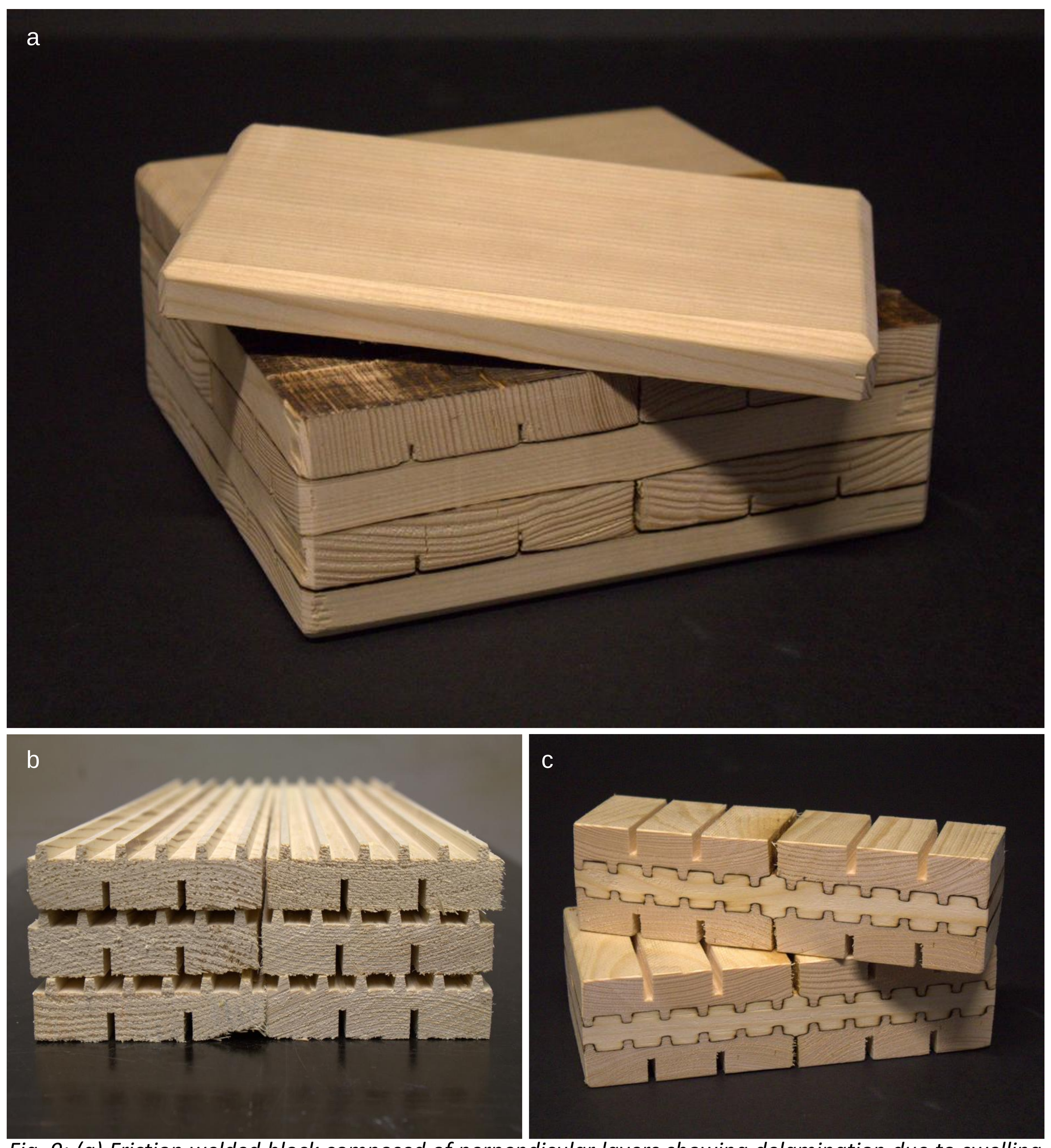

Fig. 9: (a) Friction welded block composed of perpendicular layers showing delamination due to swelling and shrinking deformations of the wood (b) Profiled spruce boards before welding (c) Welded samples using specific surface shapes and stress cuts for improved long-term resistance

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