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Experimental investigations of timber–glass composite wall panels

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HIGHLIGHTS

- We present experimental research of adhesive bonded timber–glass composite shear walls.
- Research results are compared to previous research on timber-frame walls sheathed with glass as well as OSB and FPB boards.
- Stiffness of timber–glass walls is lower comparing to timber-frame walls with OSB and FPB boards.
- Walls show higher stiffness with epoxy adhesive, while silicone and PU adhesive make the wall element more ductile.
- Innovative load-bearing wall element can contribute to the energy efficiency with solar gains.

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ABSTRACT

The importance of building large-size glazing into timber structures has significantly grown over the last decade due to the enhanced physical characteristics of glass panels and owing to the fact that proper integration of both materials, timber and glass, has a positive impact on the energy efficiency of buildings, which was one of the major reasons for carrying out our investigation. This paper presents the results of the experimental research on timber–glass wall elements where glass panes are directly bonded to the timber frame, leading to a load-bearing and visually interesting wall element which is suitable for lightweight timber structures.

1. Introduction

The design of modern houses is orientated towards occupants' comfort and low energy consumption. In their decisions relevant to the orientation of a building and its transparent areas, investors and architects aim at maximising the use of natural solar radiation gains. With suitable technological development and appropriate use, timber and glass are nowadays becoming essential construction materials as far as the energy efficiency is concerned. Integration of large and properly oriented glazed areas into timber structures represents a great potential for the construction of environment-friendly and energy-efficient buildings, Fig. 1. The appropriate positioning of large glass areas enables better energy performance of a building, where the solar gains obtained through the glazing can be evidently higher than the transmission losses through the same glazing areas. A comparison of transmission losses through the building envelope and possible solar gains through the glazing is of great importance in defining the optimal size of the glazing areas and performing a suitable selection of the glazing type [1].

However, the use of both materials in a composite way can be rather complicated, from both the constructional point of view as well as from the aspect of energy efficiency. The main concerns are long term behaviour and deformations of the structural element. A good knowledge of advantages and drawbacks of timber–glass structures is thus vitally important. When designing with glass it is necessary to focus on the connection between the glass element and the substructure to avoid stress concentration.

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Fig. 1. Timber–glass residential building with a large south-oriented glazing area (photo archive of the company Kager).

In contrast to more ductile materials like steel or timber, monolithic glass is a brittle material with no post-fracture capacity. Although brittle, modern glass proves to be a material with higher compressive strength than steel and essentially higher tensile strength than softwood, as seen in Table 1 [2]. For these reasons, it is sensible to use benefits of glass by ensuring appropriate boundary conditions.

1.1. Timber-frame wall elements

Selecting an appropriate construction system of a timber structure depends primarily on architectural demands with the orientation, location and the purpose of a building being of no lesser importance. Prefabricated timber construction systems differ from each other in the appearance of the structure and in the approach to planning and designing a particular system [3]. Residential timber buildings can be classified into six main structural systems: timber-frame construction, balloon and platform-frame construction, panel construction, frame construction, log construction and solid timber construction.

The focus will be dedicated to the panel construction system where timber-frame wall elements are the main vertical and horizontal load resisting elements, composed of a timber frame and sheathing boards. The timber frame consists of vertical studs and horizontal girders of square cross-sections and ensures vertical transmission of the static load. The sheathing boards are stapled to the timber frame assuring in-plane stability of the wall panel, Fig. 2. Timber studs are positioned lengthwise within a certain span which depends on the sheathing board dimension. Most frequently used sheathing materials are fibre-plaster boards (FBP) along with wood-based boards (e.g. plywood, oriented strand board – OSB, laminated strand board, particleboard, etc.). The main advantage of the prefabricated timber-frame panel construction system is factory prefabrication, assuring ideal weather conditions in addition to constant supervision over construction works and the materials installed. Another asset is the subsequently faster assembly process as the ready-made elements are crane-lifted onto the foundation platform, adjusted and screw-fastened. Furthermore, the transition from the single-panel construction system, Fig. 2 (right) to the macro-panel construction system, Fig. 2 (left) means an even higher assembly time reduction and higher stiffness of the entire structure due to a lesser number of joints.

1.2. Timber–glass composite wall elements, adhesives and adhesive joints

The past twenty years have witnessed a number of research projects in the area of structural glass applications. Linear glass structures as beams, fins and pillars [4,5], as well as glass plates with the in-plane and out-of-plane load-bearing capacity have been investigated [6–9].

The research is further focused on two-dimensional timber–glass structures only, i.e. timber–glass walls with the in-plane load. The main idea of using fixed glazing areas in prefabricated timber-frame panel wall elements is in adopting the load-bearing functions from the wall panels with the classical sheathing boards (FPB, OSB) described above. Such combining of timber and glass in order to get an appropriate load-bearing composite element is a challenging task since the combination involves two materials with rather different physical characteristics. As seen in a wide range of the already performed experimental researches [4–9], the most important parameter to influence the load-bearing capacity and stiffness of timber–glass composite elements seems to be the type of connection between the timber frame and the glass pane. The use of adhesives thus opens new possibilities, such as the ability to connect materials with different mechanical properties. For example, when connecting two materials having different coefficients of thermal expansion (α_T) a flexible adhesive layer can accommodate thermal strains. With using adhesive joints a higher bonding strength can be achieved at a lower cost in comparison to alternative methods, e.g. joints with mechanical connectors. One of the major advantages of adhesive joints is that of the bonded materials not being weakened by holes and the loads being transferred homogeneously over the entire surface rather than a point [10].

Therefore, in the case of the timber–glass composite wall elements the following parameters have the most significant influence on the response under static as well as dynamic loads:

- Type of the adhesive.
- Durability of the adhesive.
- Joint type.
- Thickness and width of the glue line.
- Glass type.
- Thickness of the glass pane.
- Position of the glass pane.

Several authors studied these parameters and the possibility of using in-plane loaded glass panels as reinforcing elements in combination with lightweight timber structures. Geometry of the bonding line and the type of adhesive have a great impact on the

Table 1
Mechanical and thermal properties of different materials.

	Glass (Soda-lime glass)	Softwood (S 10)	Steel S235
Density (kg/m^3)	2500	600	7850
Modulus of elasticity (N/mm^2)	70,000	11,000	210,000
Tensile strength (N/mm^2)	45	$\parallel$ 14 $\perp$ 0.5	235
Compressive strength (N/mm^2)	500	$\parallel$ 17–26 $\perp$ 4–6	235
Coefficient of thermal expansion (1/K)	9×10^{-6}	$\parallel$ 5×10^{-6} $\perp$ 35×10^{-6}	12×10^{-6}