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SUSTAINABLE REUSEABLE TIMBER-CONCRETE COMPOSITE STRUCTURAL FLOORING SYSTEM

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ABSTRACT: The objective of this study is to enhance the reusable performance and efficiency of timber-based composite floor systems. To this end, a comprehensive investigation is conducted into combinations of various composite materials and the numerous types of connections that can be used to create these systems. This paper presents the overarching structural design concept, accompanied by the results of manufacturing research. Its primary objective is to offer a preliminary understanding of the ongoing structural research endeavors. The objective of the studies is to develop application-optimized multi-layered structural composite floor systems, with a special focus on the joint design of the various connection types between the coupled composite layers. The extent of interrelationships in the development of complex optimized system solutions can be shown, taking into account structural, economical, and resource efficiency on overall component level. Furthermore, the study aims to derive design criteria that are instrumental in the implementation of composite floor systems. The findings of the research project are poised to present successful technical solutions and concepts for reuse and recycling in timber construction.

KEYWORDS: Timber, timber-concrete composite, connection, sustainability, reuse

1 – INTRODUCTION AND MOTIVATION

In the context of the mounting significance of large-volume timber construction in European metropolitan areas, a study is underway to ascertain the potential for enhancing the utilization of timber in a circular manner, as well as in conjunction with alternative building materials. In Austria, there has been a notable increase in the market share of timber construction over the past twenty-five years. However, in relation to the total residential construction sector, the proportion of timber construction in Austria averaged 3 % in 2019, exhibiting a modest upward trend.

This relatively low percentage indicates that, although multi-story timber housing has emerged in Austria, it remains a niche market. Nevertheless, given the discernible trend observed in recent years, there is considerable potential for a substantial increase in the percentage of timber-built structures [1].

1.1 RESEARCH QUESTIONS

In this context, the Department of Structural Design and Timber Engineering (ITI) at the Vienna University of Technology (TU Wien), in collaboration with the Institute of Timber Engineering and Wood Technology, Graz University of Technology and H.U.T. Innovation Ltd., has developed a multi-layer floor system that integrates prefabricated concrete with timber sections, leveraging the strengths of both materials. The integration of timber-hybrid elements aligns with contemporary architectural imperatives and stands to augment the utilization of timber in construction. A critical examination of the reusability and reutilization of timber components, both primary (initial use) and secondary (reused), reveals their integration with building materials. The foundational principle underlying this investigation is the substantial advancements witnessed in the field of manufacturing. The integration of composite technologies and mixed construction solutions, when utilized in a sustainable manner, can ensure the continuity of timber's use beyond the life cycle

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of a building. Consequently, various composite constructions are being developed and evaluated for their structural implementation and environmental optimization. Through the strategic integration of these technologies, it is feasible to attain a construction-optimized design that exhibits enhanced resource efficiency, manifested at both the component level and the level of the overall structure.

2 – TECHNICAL DESCRIPTION

The KLAGX TCC system represents an advanced solution for hybrid structural elements that combine timber and concrete through a mechanical connection. This system, as evaluated in the European Technical Assessment ETA-24/1172 [2], is based on the integration of several carefully engineered materials designed to function in unison under structural loads. This paper provides an in-depth technical description of each constituent material and its associated performance criteria, grounded in applicable European Standards and norms.

The KLAGX TCC system, a dowel-type fastening solution designed for timber-concrete composite floor comprises self-tapping, fully threaded screws made of steel, which are inserted into timber elements at an angle of ±30° (Figure 1) through special concrete connectors. These connectors are manufactured from low-shrinkage, pressure-resistant concrete.

The connector is manufactured from a pressure-resistant, low-shrinkage special concrete, which ensures:

- Dimensional stability during curing and in-service use
- Long-term compatibility with the timber base and embedded steel elements
- Resistance to cracking due to internal stresses and environmental exposure

The connector's geometry, shown in Figure 2 is specifically designed to:

- Ensure proper angular installation of the screws
- Distribute shear loads evenly into the concrete
- Maintain consistent edge and spacing tolerances for anchorage performance

This connector is considered non-load-bearing in itself but is essential to the functioning of the system as a whole.

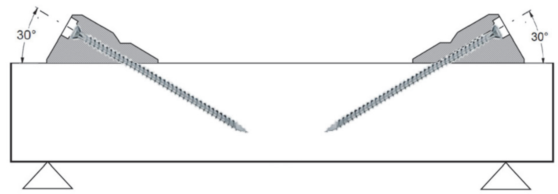

Figure 1. KLAGX TCC system applied on timber [2]

Placement of Concrete Connectors

The KLAGX concrete connectors, precast from a low-shrinkage, pressure-resistant mix, are placed at prescribed positions and spacing intervals (Figure 3):

- **Inclination**: ±30° relative to the timber axis
- **Minimum spacings**:
  - Along the grain (a_1): 150 mm
  - Perpendicular to grain (a_2): 55 mm
  - End distance ($a_{3,t}$): 50 mm
  - Edge distance ($a_{4,c}$): 40 mm

The connectors ensure correct alignment and embedment of screws and facilitate predictable load transfer.

The system is suitable for different types of base materials, including sawn timber (EN 14081-1 [3]), glued laminated timber (EN 14080 [4]), laminated veneer lumber (EN 14374 [5]), and cross-laminated timber, provided they comply with a relevant European Technical Assessment.

The core of the KLAGX TCC system is the set of self-tapping, fully threaded screws used to establish shear-resistant connections between timber members and the concrete component.

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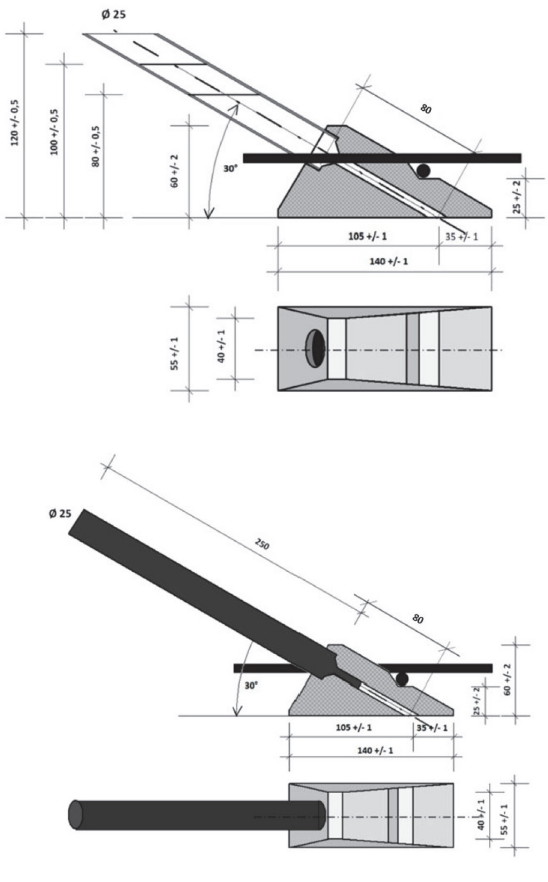

Figure 2. KLAGX TCC system connector's geometry [2]

The screws are made from hardened carbon steel and must conform to mechanical performance and corrosion protection criteria defined in:

- **ETA-12/0373** [6] for RAPID® screws
- **ETA-11/0190** [7] for ASSY® plus VG screws

The steel exhibits high tensile strength and durability under compressive and shear loading, with the following essential parameters:

- **Nominal diameter**: 10 mm
- **Head diameter**: 18.5 mm (90° countersunk)
- **Threaded length**:
  - Softwood: ≥ 60 mm
  - Hardwood: ≥ 32 mm
- **Length range**: 120 mm to 400 mm
- **Corrosion protection**: Zinc coating or equivalent as per the referenced ETAs
- **Shear resistance (Fv,k)**:
  - RAPID screws: ≤ 43.3 kN
  - ASSY screws: ≤ 39.0 kN

The screws are embedded at an angle of ±30° into the timber through the concrete connector, which influences both mechanical interlock and stress distribution.

2.1 PERFORMANCE CRITERIA

The system may incorporate permanent formwork from timber-based panels compliant with EN 13986, and a foil may optionally be used to prevent water leakage. The final composite slab includes precast reinforcement concrete (steel bars or steel fibers) with a minimum thickness of 70 mm according to EN 206 and EN 14889-1 (Figure 3). It is intended for load-bearing applications in building construction and ensures mechanical interconnection between timber and precast concrete layers.

The KLAGX TCC system is engineered for static and quasi-static load-bearing applications, excluding fatigue loading. It is designed for use in service classes 1 and 2 as defined in EN 1995-1-1 (Eurocode 5), addressing typical indoor and covered outdoor conditions.

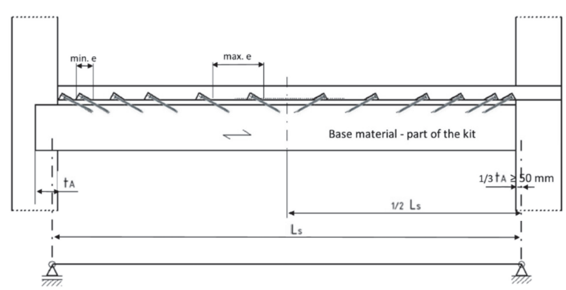

Figure 3. Principle structure of the timber-concrete composite floor [2]

2.2 PERFORMANCE CRITERIA

Mechanical performance, thermal behavior, dimensional stability, fire resistance, and environmental impact were assessed under EAD 130090-00-0303 [8]. Key essential

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characteristics and corresponding performance metrics include:

Mechanical Resistance: Verified shear strength values of up to 43.3 kN (RAPID screws) and 39.0 kN (ASSY screws).

Dimensional and Structural Stability: Compliance with EN standards, taking into account moisture-induced deformation, creep, and shrinkage.

Fire Safety: Classification A1 for steel and concrete; timber classifications vary according to the Declaration of Performance.

Thermal Properties: Assessed thermal resistance and inertia per component; no performance assigned for air permeability.

The KLAGX TCC system represents a robust solution for timber-concrete hybrid construction, offering reliable mechanical interlocking and enabling efficient, prefabrication-compatible assembly.

3 – EXPERIMENTAL SETUP

The research activities include conceptual feasibility studies on overall component level on the one hand, as well as accompanying experimental performance assessments on joint level on the other hand, in order to contemplate the overall performance of the structures along with the related design concepts.

The structural design idea of timber-concrete composite structural floor system is founded on the utilization of joints between the single prefabricated composite layers to reach an optimized reuseable application of each composite material. By the optimized use of composite materials on joint level as well as on overall component level, structural performance shall be increased. For this reason, various types of timber in combination with prefabricated concrete toppings coupled by various types of joints are being developed (Figure 4).

The casting of the precast reinforcement concrete structure occurs off site, before being placed (Figure 5).

The KLAGX TCC system provides a technically robust and modular solution for hybrid timber-concrete floor construction. Its installation process, while relatively straightforward, demands precise execution, qualified personnel, and strict adherence to technical guidelines (Figure 6). The comprehensive methodology outlined in ETA-24/1172 [2] ensures that, when installed properly, the system achieves optimal structural performance, longevity, and compliance with European standards.

Figure 4. Timber-concrete composite structural floor

Figure 5. Casting of the precast concrete structure

Figure 6. Installation process

3.1 EXPERIMENTAL INVESTIGATIONS

Based on general material properties, the interaction of composite layers can further be described as a function of the thereof resulting slip modulus respectively the shear transfer of the used composite joints. The bond behavior of flexible connected single layers thereby moves between a rigid and a non-rigid composite, essentially depending on the configuration of the contemplated connection. For this reason, the essential experimental research, as the general basis of the conceptual feasibility studies, also is focused on the exploration of the most promising joint typologies. Therefore, a broad spectrum of experimental performance assessments of various joint assemblies is executed by means of push-out shear tests and 4-point bending tests (Figure 7 center and right).

The test specimens were not conditioned in a standard atmosphere (according EN 408 [9]: air temperature 20 °C, relative humidity 65 %) subsequent to incoming inspection.

3.2 COMPRESSION SHEAR TESTS

The test series (a total of 10 test specimens) was carried out in accordance with EN 26891 [10] The measurement of the relative displacements of the timber and concrete components was carried out with two displacement transducers. As shown in Figure 7 left the transducers were located on the two narrow surfaces of the test specimens. To circumvent the potential impact of local imperfections on the assessment of stiffness, a hysteresis loop was employed (loading to a load level of 40 % of the estimated breaking load $F_{max,est}$, unloading to 10 % of $F_{max,est}$, loading until the sample failed). The test speed was selected with the objective of ensuring that the test time from the onset of the second rising branch of the hysteresis to the estimated breaking load fell within 300 s ± 12 s.

At the time of the test, the mean timber moisture content of the 10 test specimens was 11.4 %. A corresponding correction of the apparent density was made.

In nine out of ten test specimens of the series, failure of the screws due to pull-out was observed as the decisive cause of failure. In the statistical evaluation, the right-censoring of this data set was not considered separately.

The statistical analysis yielded an average failure load of $F_{max,mean}$ = 47.9 kN, accompanied by a coefficient of variation (CoV) of 6.05%. In accordance with the guidelines outlined in EN 14358 [11], the characteristic value is determined to be $F_{max,k}$ = 42.0 kN. The mean stiffness of the composite action between the timber and the concrete is $k_{s,mean}$ = 23.7 kN/mm.

3.3 FOUR-POINT FLEXURAL TEST

The test series was performed in accordance with EN 408 [9]. The measurement of local and global vertical displacements was conducted using displacement transducers of the local and global types, respectively. The measurement of horizontal joint displacement was facilitated (Figure 7 center and right). The location of the deformation measurements is illustrated in Figure 7.

In order to circumvent potential influences of local imperfections on the determination of stiffness, a hysteresis loop was employed in the tests (i.e., loading to a load level of 40 % of the estimated breaking load $F_{max,est}$, unloading to 10 % of $F_{max,est}$, loading until the sample broke). The test speed was selected with the intention of ensuring that the duration of the test commencing at the onset of the second rising branch of the hysteresis and culminating at the estimated breaking load-remained within 300 seconds ± 120 seconds.

The stress and deformation calculations for the specimen were based on the Euler-Bernoulli beam theory. The calculation bases relevant to the determination of the effective bending stiffness, designated as EI_{eff}, are delineated. These calculation bases were determined based on both local and global deformation measurements.

At the time of the test, the mean timber moisture content of the 3 test specimens was 13.5 %. A subsequent adjustment of the apparent density was conducted.

For all test specimens of the series, a (partial) failure of the connectors was observed due to shear stress, as indicated by an observable drop in load in the load-displacement relationship. However, this was followed by a further increase in load until the maximum test force was finally reached as a result of flexural tensile failure of the timber element.

The mean failure load is $F_{max,mean}$ = 104.6 kN, combined with a coefficient of variation (CoV) = 4.64 %. The characteristic value is calculated according to EN 14358 [11] to $F_{max,k}$ = 89.3 kN. The mean local effective bending stiffness is $EI_{eff,local,mean}$, which was determined to be 8,399 kNm². The corresponding global orientation parameter $EI_{eff,global,mean}$, was found to be 6,024 kNm².

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Figure 7. Push-out shear and 4-point bending tests on timber-concrete composite structural flooring system.

4 – DESIGN PROCESS

The KLAGX TCC system achieves high structural performance through the integration of rigorously specified materials. Each component—steel fastener, concrete connector, timber, and concrete slab—is selected and dimensioned in accordance with European standards to ensure long-term reliability, safety, and sustainability.

Design methodology may align with EN 1995-1-1 [12] and EN 1992-1-1 [13] and must reflect both initial and long-term structural states. Load transfer mechanisms account for composite action and are influenced by slip modulus, connection behavior, and moisture effects.

In the event that the separation between the screws exceeds 5 % of the distance between the moment origins, it is imperative that the installation of the screws be executed in a manner that is proportional to the shear force when smearing.

The potentiality for the formation of cracks in the concrete should be duly considered. In the absence of a more precise model, it is essential to consider only 70 % of the axial stiffness of the connected cross-section when calculating stresses and deformation.

The Eurocode-based design must verify limit states for both the **initial (t = 0)** and **long-term (t = ∞)** conditions. These values influence calculation of composite section behavior under both ultimate and serviceability limit states.

Design guidelines specify required timber member dimensions, connector spacing, edge and end distances, and deformation factors (k_{def}) for service classes 1 and 2.

The design uses deformation coefficients to account for long-term behavior (k_{def}) applied to material stiffness:

Table 1: Margin Settings

Material	Service Class 1	Service Class 2
Timber (sawn, GLT, LVL)	0.6	2.0
Cross-laminated timber	0.8	2.0
Concrete	2.5	2.5
KLAGX connection	0.6	4.0

5 – CONCLUSION

Hybrid timber-concrete composite structures have emerged as a sustainable and structurally efficient solution in modern construction. Among the most innovative systems supporting this construction typology is the KLAGX TCC system, a separable shear-resistant connector based on dowel-type fasteners. The system allows the integration of timber base elements and in-situ or prefabricated concrete slabs, offering structural rigidity, adaptability, and durability.

The meticulous specification of materials ensures consistent quality in prefabricated and site-cast applications and positions the system as a highly adaptable solution for hybrid construction in multi-story buildings, schools, public infrastructure, and more.

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A novel multi-layered composite floor system is developed and investigated. This paper illustrates the general structural design idea and the manufactural research findings associated with the introduced structural system and is intended to provide a first insight into related ongoing structural research activities. Potential assembling capabilities, as well as applied integrative system components are presented to cast light on the consisting system characteristics. Furthermore, first achievements with respect to the structural research activities can be presented. These include experimental as well as numerical investigations associated with the examined structural system.

Future research may focus on the lifecycle performance of the composite material interfaces, particularly in relation to environmental conditions, moisture cycling, and thermal dynamics. The adaptability of the KLAGX TCC system also offers promise for application in modular and circular construction contexts.

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