Application of Timber-lightweight Composite Structures for Building Construction

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ABSTRACT: The main objective of this paper is to show the benefits of using timber-lightweight composite structures for the more widespread practical applications in buildings.

The advantages of using timber-lightweight composite structures, concerning constructive aspects, economy and structural behavior will be illustrated by the presentation of the results of several research projects of Institute of Architectural Sciences, Department of Structural Design and Timber Engineering.

KEYWORDS: Timber-lightweight concrete, wood chip concrete, building construction, binder

1 INTRODUCTION

Timber-lightweight (wood chip) concrete composite structures represent a recent technique used both in existing timber structures and in new constructions for strength and stiffness upgrading.

Advantages of composite timber-lightweight (wood chip) concrete structures can be found in facts that the load bearing capacity of e.g. floors can be doubled and its out-of-plane stiffness improved more times.

Serviceability conditions are better satisfied. Sound insulation and fire resistance are improved. Vibrational effect in the buildings due to concrete decreases and the self-weight of the whole structure is less than self-weight concrete type structure or steel type structure for the same constructional work.

The advantages of using timber-lightweight composite structures, concerning constructive aspects, economy and structural behavior will be illustrated by the presentation of the results of a number of current research projects of Institute of Architectural Sciences, Department of Structural Design and Timber Engineering.

The composite of cement and wood-particles has been developed about 80 years ago and found its application in non-load-bearing building materials such as insulating boards. More recent applications concern wood-concrete bricks for formwork.

Wood was the first principal component of bearing systems in olden times, often completed by heavy layers of earth, plaster or other mineral materials to provide noise prevention and fire protection.

The upcoming concrete technology later conducted to heavy monolithic floor systems. Since 1980s, the idea of connected wood-concrete systems has been developed in Europe as an alternative to the European heavy concrete floors and to the North-American light wood floors (Fig. 1).

![Fig. 1: Wood-concrete floor system development by D. Molard and W. Winter](image-url)

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The research projects have three aims

1. Combining timber and concrete in a new type of composite material and using the best properties of both materials, the high tensile strength of timber and the high compressive strength of concrete, depending on different building conditions,

2. Design concepts for load-bearing timber-lightweight concrete structures. This innovation applies to both, development in materials and building elements, as well as design approaches,

3. Provide practical, well presented information for designers and architects in a comprehensive handbook.

2 SHEAR STIFF CONSTRUCTIONS

In order to develop a multi-layer shear wall and shear stiff floor system composed of lightweight wood-concrete, the lightweight wood-concrete composites, the adhesives as well as the connection between these components and the timber sections were investigated with respect to strength, reduced dead load, fire safety, thermal performance and environmental consideration.

This technology involves the addition of wood material such as chips, saw dust, residual or recycled wood as permanent aggregate in concrete.

Timber-lightweight concrete composite systems form a low-cost solution to renovate existing timber floors. The increased stiffness and strength are such that higher floor loads are permissible or decreased deflections are obtained. The structural behavior of timber-lightweight concrete composite members is governed by the shear connection between them.

The key objective of the research projects is to provide and facilitate new possibilities for timber-lightweight concrete structures in construction. The use of timber-lightweight concrete products is to be supported and stimulated by comprehensive and scientifically robust background data, which is presented in user-friendly and adapted tools for engineers.

The lightweight wood-concrete construction systems allow:

- Use of wood both as permanent formwork and as concrete reinforcement;
- Reduction of the dead load and increasing the thermal insulation;
- Minimization of the dimensions of the timber and concrete components;
- Creation of environmental-friendly construction made of renewable resources;
- Reduction of energy consumption by using low-energy materials and energy-efficient systems.

Reductions in concrete and reinforcing steel quantities were two of the advantages that directly impact overall construction costs.

In respect of reduction of the dead load and increasing the thermal insulation as well as minimization of the dimensions of the shear stiff constructions an aim of the research projects was to develop innovative shear stiff systems. These were optimized by the variation of construction layers and their geometry (Fig. 2 and 3).

Fig. 2: variation of floor construction systems [1]

Fig. 3: Timber wood chip concrete wall

It included design concepts, feasibility studies and performance assessments as well as the optimization of manufacturing methods of the components in order to improve the overall performance. To achieve relevant results compatible to industrial applications following issues were evaluated:

- Strength tests and evaluation of the physical properties of the lightweight wood-concrete,
- Design of wall and floor components made of lightweight concrete connected to timber sections,
- Development of various sets of prototypes for testing,
- Shear and bending tests of the prototypes,
- Analysis of the experimental results to develop design concepts,
- using recycled wood particles and new additives
- Optimization of the manufacturing methods,
- Studies regarding the ecological impact,
- Evaluation of the thermal and sound insulation behavior.

The results provide a marketable component system for buildings that optimally uses timber sections and lightweight wood-concrete [2].
This technology provides statically and energy-efficient components for low-energy constructions. Such products support rapid-assembly construction methods which use prefabricated dry elements to increase the efficiency of the construction (Fig. 4). Wood-based alternatives to conventional concrete or masonry construction also open opportunities to reduce the carbon emissions [3].

Fig. 4: Timber wood chip concrete composite floors

3 BINDER

The new binder which can be used instead of conventional cement for producing concrete allows combining the existing concrete tradition with the use of organic renewable resources.

This concrete made with special cements has some particular product properties [4]:

- low heat development
- After 28 days it has significantly higher strength values than comparable Portland cements (Fig. 5)
- massive saving of CO2 and NOx
- particularly dense concrete microstructure

Granulated blast furnace slag is used as the basic hydraulic component for producing this special cement. Sulfate activators and alkaline additives are used to promote the hydraulic properties.

It consists of granulated blast furnace slag, sulfate agents and special additives. The production of this type of blast furnace slag binder does not involve any burning process and therefore ensures a CO2 saving of up to 90 percent when compared with conventional cements and meets all the ecological requirements for the criteria of the Austrian Institute for Building Biology and Ecology (IBO) [4].

The IBO has set itself the objective of achieving health and environmental protection in the building and housing sector.

Since 1988 the IBO has awarded the IBO Seal of Approval on the basis of comprehensive testing for products that are distinguished by their qualities relating to housing hygiene and ecology. Building materials and interior fittings are examined holistically on the basis of comprehensive criteria that take the entire lifecycle of a product into account. If a product meets the strict building biology and building ecology requirements it is awarded the IBO Seal of Approval.

In contrast to conventional cements its production does not involve any burning process. This also means that no CO2 or NOx emissions are produced – apart from those associated with the generation of the requisite electrical power and with drying the granulated blast furnace slag.

This entails a CO2 saving of between 73 and 90%, depending on the cement use for comparison (CEM III/B to CEM I). Up to 160 tonnes of CO2 emissions are saved for every 1000 m3 concrete (Fig. 6).
The typical characteristic physical and chemical values of new binder 42.5 N aluminate-free found during testing in accordance with EN 196 [5, 6, 7 and 8] are listed in Table 1.

It can be seen that the increased sulfate content of 6.2wt.%, which is necessary for the sulfate activation, does not comply with requirements of EN 197-1 [9] for normal cements.

### Table 1: Typical characteristic physical and chemical values according to EN 196 [4]

<table>
<thead>
<tr>
<th>Properties</th>
<th>according to</th>
<th>values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive strength N/mm² 7 days</td>
<td>EN 196-1</td>
<td>19</td>
</tr>
<tr>
<td>Flexural strength N/mm² 28 days</td>
<td>EN 196-1</td>
<td>4.0</td>
</tr>
<tr>
<td>Loss on ignition % 28 days</td>
<td>EN 196-2</td>
<td>10.8</td>
</tr>
<tr>
<td>Water demand %</td>
<td>EN 196-3</td>
<td>29.8</td>
</tr>
<tr>
<td>Drying, part 1 mm</td>
<td>EN 196-4</td>
<td>3.2</td>
</tr>
<tr>
<td>Expansion mm</td>
<td>EN 196-5</td>
<td>0.2</td>
</tr>
<tr>
<td>Clinker strength</td>
<td>EN 196-6</td>
<td>0.05</td>
</tr>
<tr>
<td>Heat of hydration J/g</td>
<td>EN 196-8</td>
<td>0.08</td>
</tr>
</tbody>
</table>

The very low heat of hydration of 170J/g leads to a significantly lower temperature rise in the concrete compared to two ordinary cements, as is shown in Table 2 [4].

### Table 2: Heat of hydration according to OENORM B 3303 [10]

<table>
<thead>
<tr>
<th>Cement type</th>
<th>temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEM II/A 32,5</td>
<td>35°C</td>
</tr>
<tr>
<td>CEM I 32,5 C3A-frei</td>
<td>27°C</td>
</tr>
<tr>
<td>Slagstar 42,5 C3A-frei</td>
<td>9°C</td>
</tr>
</tbody>
</table>

This special cement is also the binder for self compacting concrete (SCC) layer and high performance concrete layer, which shall be used in stiff floor and roof structures (Fig. 7).

### 4 CONCLUSION

Timber-lightweight component as an ecological and sustainable building material has a lot of potential to be discovered.

Owners, contactors and architects benefit from well designed wood-based structures. The advantages of such constructions are:

- In case of earthquake the reduced weight is advantageous,
- The shear wall elements which are multifunctional as load bearing and stiffening and as façade elements are advantageous in ecological and economical reasons,
- Industrial prefabrication of load-bearing structure. With timber composite elements the use of the materials can be optimized in technical and economical terms and the connections can be executed in a simple way,
- Improvement of thermal insulation,
- Combination of light timber and lightweight wood-concrete construction with highly efficient thermal insulation and thermal storage,
- Near waste-free building design,
- Recyclability of all building components after service life.

### REFERENCES


**Fig. 7: Lightweight wood-concrete floors**