Composite decks of concrete glued to timber
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INTRODUCTION

Timber composite decks and structures are gaining a market niche in many parts of Europe. In the past, the connection between timber and concrete has been effected with mechanical means such as with screws and bolts. In 1996, researchers from the Research and Development Department of the Swiss School of Engineering for the Wood Industry (SWOOD) and from the chemical firm SIKA AG, Zurich, came up with the idea of achieving the connection with glue. For the practical development of this idea they invited the well-known Swiss timber construction firm Häring AG to join in the research activities. Fig. 1 shows how the project was organised between the partners.

The structural advantages seemed obvious: an adhesive connection distributes the shear forces and avoids the unfavourable concentrated forces which occur when mechanical connectors are used. A glued connection would eliminate the relative movement between timber and concrete: the increased bending stiffness would decrease deflections. Then again, there was the promise of economic feasibility because of the simplification of the work: no drilling of holes for screws, no need for indentations in the timber. Thanks to advances in the adhesive industry, the “wet” manufacturing process was envisaged, with the liquid concrete being poured directly on the adhesive applied to the wood surface. The industrial partners decided to prefabricate composite elements with a width of about 1m in the workshop in order to shorten construction time and to avoid water applications on site.

PROJECT TEAM

For the tests and for future construction purposes, the partners agreed to use only materials from their factories:

- Timber: only glulam of Swiss standard quality FA or B from the factories of Häring AG would be used.
- Concrete: Self Compacting Concrete (SCC), developed by SIKA AG. This concrete type is relatively new in Europe. Thanks to special chemical additives, SCC is self-compacting. No vibrators would be needed, thus eliminating fears that the glue might be physically pushed to the sides of the surface of the timber. The compressive strength of SCC is very high, however it exhibits a higher creep rate than normal concrete.
- Adhesive: Sikadur®-T35LVP, a two-component, thixotropic product of SIKA AG on an epoxy-resin basis.

HINTS REGARDING CONSTRUCTION DETAILS

The partners agreed to prefabricate all future elements because the adhesive sets after only about 45 minutes. After the glue has been spread over the surface of the timber the concrete must be poured within 45 minutes. Fig 2 shows some

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phases of the production of the unreinforced tests specimens. It is clear that for practical use in future the engineer may need to provide for a minimum of steel bars according to the standards of the country involved.

Fig. 2: Production sequences of the test specimens

The elements will be about 1m wide. After production in a factory they will need to be transported to the building site and placed on supports prepared beforehand. They must then be connected together in order to stiffen the structure and also to provide a smoke impervious deck in case of fire. The figs. 3 and 4 show 2 possibilities to connect 2 elements on the longer side, these are:

- with classical mechanical connectors
- with glue

Plan:

Fig. 3: Timber-Concrete-Composite elements connected with steel bars (left), and with adhesive (right)
With regard to fire, the question of the temperature profiles inside the timber was of particular interest. According to SIKA AG, the glue loses its adhesion properties at temperatures exceeding about 65°C. Fortunately, prior research in the field of temperature profiles and charring rate of wood provides the necessary information (fig. 5) for the deck design with respect to the desired fire resistance.

- Fire resistance F30: Timber thickness at least 40mm
- Fire resistance F60: Timber thickness at least 70mm
- Fire resistance F90: Timber thickness at least 100mm

**Fig. 5: Temperature profiles in a timber member in the case of an ISO standard fire at the underside: left according to Fontana/Frangi, right according to Kordina/Meyer-Ottens.**

**STRUCTURAL PERFORMANCE OF GLUED TIMBER CONCRETE COMPOSITE DECKS**

All decks in buildings bear the loads through bending. Most international codes demand the analysis of the load-bearing behaviour at ultimate limit state (ULS) and at service state (SLS). Loading tests for the new product were planned accordingly. The structural performance was checked with calculation models.

The calculation of the structural behaviour was based on the classical theories for composite structures such as commonly used for steel-concrete-composite structures. Zero slippage was assumed: the glue was expected to give 100% bondage. The material properties were partly taken from the values listed in the Swiss code of practice (SIA-Normen). Some of the material properties were determined directly in special tests, or, in the case of the adhesive, from the technical documentation of SIKA AG.

The adhesive used was SIKADUR®-T35LVP, a thixotropic, 2-component adhesive on epoxy-resin basis. Preliminary tests had shown that this adhesive would be particularly good for connecting wet concrete and timber. In all tests glulam type B according to the Swiss codes was used. Two concrete types were used: normal concrete B35/25 and self levelling concrete SCC. Fig. 6 lists the material properties which were used to calculate the theoretical structural performance.

**Fig. 7** shows a sketch of the test arrangement and the corresponding internal forces. The test specimens were all 6.0m long; the effective span was 5.7m. The tests were carried out at the Engineering School at Yverdon.

The cross sections of the specimens tested in the first series at Yverdon are listed in fig. 8. All specimens had a width of 1.000m. In the test series B1 with 3 specimens SCC was used: the concrete had the same thickness of 105mm as the timber. In the test series B2 normal concrete B35/25 was used. Two of the three specimens had the same measurements as in the test series B1. The third specimen had a reduced concrete thickness by mistake because not enough concrete was prepared. The odd specimen was tested anyway.
The deflection of the beams at mid-section was measured (mean of two values), as well as the slippage between the concrete and the timber at both beam ends. In all 3 specimens of the test series B1 8 devices were placed around the beam axis in order to measure the strains in both concrete and in the timber (fig. 10).

Fig. 9: Cross sections and concrete types used for the tests in Yverdon

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The structural performance was checked with calculations. Fig. 11 shows that the calculation agreed quite well with the measured results. The strain line across the cross section remained linear even with increasing loading. The tests also confirmed the calculated prediction that failure would be caused by the timber reaching the failure strain of 3.82‰.

Fig. 11: Strain lines in the cross sections of the different test specimens: comparison of theory and measurement.

Fig. 12 also shows a good agreement between the measured and calculated values for the deformation behaviour, because the corresponding force-deflection lines are quite parallel.

In fig. 13 the theoretical failure loads are compared to the actual values attained in the tests. The agreement is very good. In the case of the test specimens with self levelling concrete, the theory predicted timber failure. When normal concrete with a lower strength was used, the calculations predicted that the concrete would fail under compression. Both predictions were confirmed by the tests, and there was also quite good agreement between the theoretical values and the measured ones.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Concrete</th>
<th>Theoretical Values</th>
<th>Test results</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Failure load</td>
<td>Failure mode</td>
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<tr>
<td>B1.1</td>
<td>SCC</td>
<td>360kN</td>
<td>Timber under tension</td>
</tr>
<tr>
<td>B1.2</td>
<td>SCC</td>
<td>386kN</td>
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</tr>
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<td>B1.3</td>
<td>SCC</td>
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</tr>
<tr>
<td>B2.1</td>
<td>B35/25</td>
<td>190kN</td>
<td>Concrete in compression</td>
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<tr>
<td>B2.2</td>
<td>B35/25</td>
<td>300kN</td>
<td>Concrete shear force</td>
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Fig. 13: Failure loads and cases of failure: comparison theory/measurement
LONG-TERM DEFORMATIONS

According to the Swiss codes of practice, apart from the ultimate load state, the service limit state should also be analysed. In the latter case the deformations are particularly important. For building decks the following condition for long-term deflections is often the most relevant for the design:

\[ w_1 + w_2 + w_4 \leq w_{adm} = \frac{\text{Span}}{250} \]

With:  
- \( w_1 \) = super-elevation of structure
- \( w_2 \) = long-term deflection under permanent loads
- \( w_4 \) = short-term deflection under service loads

The calculation of the elastic deflections is relatively simple. However, shrinkage and creep of the concrete and of the timber will result in additional long-term deformations. In the Swiss codes of practice, simplified rules have been advanced for the different materials which permit an estimation of these additional deflections. Unfortunately, there are as yet no well-defined rules for estimating the long-term deformations of timber-concrete-composites. It was therefore necessary to make some simple assumptions in order to develop a calculation model. Structural timber is usually well-dried before use (about 12% moisture content) but modern heating techniques may cause wood to dry to about 8%. For common spans of housing, this variation has little influence on the long term deformation of timber concrete composite decks. It was therefore assumed that the long-term behaviour of the composite elements would mainly depend upon the behaviour of the concrete component. Using the standardised material properties in the Swiss codes, simple calculation models were developed to estimate the long-term deflections. The calculation approaches used are illustrated in figs. 14 and 15.

![Fig. 14: Calculation model for deflections due to concrete shrinkage](image)

![Fig. 15: Calculation model for deflections due to concrete creep](image)

Two test specimens were manufactured in June 1998. After 5 days one specimen was subjected to a constant load; the second specimen was loaded after 13 days. The experiment is illustrated in fig. 16. In fig. 17 the measured deflections are...
compared with the values calculated with the models mentioned above. There is quite good agreement. Interestingly, it appears that most of the long-term deformation is caused by the shrinkage of the concrete: creep plays a relatively minor rule.

Cross-section:  

Test principle:

Sketch

Engineering principle:
F = 11.12 kN
\( g = 4.76 \text{kN/m} \)

Shear forces

Bending moment

\[ M_{\text{max}} = 78.0 \]

**Fig. 16**: Experiment to test the long-term deflections of a timber-concrete-composite deck

**Fig. 17**: Comparison of the measured long-term deflections with the calculated values
CONCLUSION

The test results have confirmed the theoretical expectations: there is no slippage between concrete and timber when the composite deck is glued together with the proposed adhesive. The short-term and long-term structural behaviour can be predicted quite well with the calculation models presented. In a few specimens, the failure load was below expectation because the glue did not function as well as expected. Preliminary studies indicate that this might have been due to the presence of grease on the timber surface. This problem is under study for a practical solution. The system of gluing timber to the concrete is very promising because of the improved structural performance in comparison to timber-concrete-composite decks which rely on mechanical connections. The possibility to prefabricate elements also promises economic benefits. Research is not yet complete, but the system has a future.

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