Architectural and technical high-quality façades made from sandwich panels

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Architectural and technical high-quality façades made from sandwich panels

1. Introduction
2. Experimental and numerical research
3. Architectural façade detailing
4. Prospects
Architectural and technical high-quality façades made from sandwich panels

1. Introduction
   • Motivation
   • State of the art
   • German research project

2. Experimental and numerical research

3. Architectural façade detailing

4. Prospects
Motivation

- Economic advantages of sandwich panels lead to their dominant application for industrial buildings.

- Due to a low architectural quality, sandwich panels have not been used for public-office- and multi-storey buildings.
Motivation

- Minor acceptance of architects and builders due to:
  - Only uniaxial overall design of façades with long continuously manufactured sandwich panels
  - Structural detailing as well as joining and fixing do not meet architectural demands
State of the art

- Traditional fixing of sandwich panels:
  - Direct fixing
    (+) Flexible screw position
    (-) Weakening of thermal insulation
    (-) Visible screw heads
  - Indirect / hidden fixing
    (+) Improved appearance
    (-) Reduction of load capacity
State of the art

- Due to production conditions continuously produced sandwich panels have got only two longitudinal profiled panel sides
  - Joining of transversal panel edges by simply adding necessary components, e.g. end plates
  - Details with low architectural quality

Joining detail with low architectural quality

Corner detail with low architectural quality
State of the art

- Possible improvements by modular design and single-part production of sandwich panels
  - Overall optimization of panels as well as joining and fixing according to functional, mechanical and aesthetical demands

- Sophisticated façade design by using the Hoesch Matrix system based on:
  - Individual single-part production
  - Optimized detail solutions for joining, openings, bottom, corner, ..
  - Mineral wool core material to ensure fire protection
German research project

- Due to different reasons Hoesch Matrix was not able to prevail on the market:
  - Use of mineral wool as core material only
  - Complex manufacturing process
  - Design limitations
  - …

- Research objective:
  - Development of design- and construction methods for multi-storey building façades made from sandwich panels that will also satisfy architectural needs
  - Scientific investigations on innovative fixing methods and the overall structural behaviour of sandwich panels depending on different boundary conditions

- Parallel industrial progression of Hoesch Matrix and other architectural façade systems
German research project

- Duration: 28 month (11/2012 to 02/2015)

- Research departments:

- Subsidised by and in cooperation with:

- Industrial partners:
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1. Introduction
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   • Global load bearing behaviour
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Global load bearing behaviour

- Modular design of modern sandwich panel façades leads to biaxial load bearing behaviour

⇒ In total 35 tests have been performed to analyse the load bearing capacity of sandwich panels depending on different support conditions:

Sandwich façade with higher architectural quality and small length ratio (Example: Kingspan Benchmark)

Two side supported test specimen (longitudinal direction)

Two side supported test specimen (cross direction)

Four side supported test specimen
Global load bearing behaviour

- Test setup:
  - Controlled displacement (2 mm/min)

  Modular steel frame system to figure two- or four side line support
  Special air cushion at the bottom to obtain a uniformly distributed load
  Upside down setup to achieve a simple arrangement / rearrangement of the specimen

Test setup with mounted foam core sandwich panel
Global load bearing behaviour

- **Test parameters:**
  - Load type: uniformly distributed load
  - Support type: two- or four-sided line support (40 mm width)
  - Panel size: 90 cm x 90 cm (profiled edges removed)

- **Varied parameters:**
  - Face layer thickness: 0.5 mm / 0.6 mm
  - Face layer profiling: flat / profiled
  - Core material: polyurethane / mineral wool

- **Measurement:**
  - Six inductive displacement sensors
  - Ten strain gauge strips
Global load bearing behaviour

- Test series No.1 - tested parameters:
  - Core material: polyurethane
  - Core thickness: 60 mm
  - Face layer profiling: none
  - Face layer thickness: 0.5 mm / 0.5 mm

- Support types:
  - uniaxial
  - biaxial

Test specimen with uniaxial line support
Test specimen with biaxial line support
Global load bearing behaviour

- Test series No.1 - results: (uniaxial)
  - Foam core shear failure with minor dispersion of results
  - Results corresponding with calculated values
Global load bearing behaviour

- Test series No.1 - results: (biaxial)
  - No global panel failure
  - Local plastification at line supports which is corresponding with FE-Simulation results

- Front view test specimen at the end of the test
- Detail: local plastification at line supports
- FE-Simulation results plot: face layer stress (ANSYS 14.0)
Global load bearing behaviour

- Test series No.1 - comparison of support conditions: ![condition](image)

- Load-displacement-curve

  - Increase of load capacity due to four-sided support and biaxial load transfer above 70%
  - Biaxial tests failure is probably caused by local stress at line supports
  - Does local failure occur when increasing the panel size?

![Graph showing load-displacement curve with markers for additional increase, load increase, local failure, and measurement range exceeded.](image)
Global load bearing behaviour

- Test series No.2 - tested parameters:
  - Core material: polyurethane
  - Core thickness: 60 mm
  - Face layer thickness: 0.5 mm / 0.6 mm(p)
  - Face layer profiling
  - Support types:
  - Uniaxial (⊥)
  - Biaxial
  - Uniaxial (∥)
Global load bearing behaviour

- Test series No.2 - comparison of support conditions:

- Failure modes are comparable to test series No. 1
- Increase of load capacity due to four-sided support and biaxial load transfer about 45 % (70 % at test series No.1)
- Decrease of load capacity due to parallel profiling alignment
Global load bearing behaviour

- Test series No.2 - comparison of profiling alignment and face layer thickness:

<table>
<thead>
<tr>
<th>Profiling Alignment</th>
<th>Face Layer Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perpendicular (⊥)</td>
<td>0.6p/0.5</td>
</tr>
<tr>
<td>Parallel (∥)</td>
<td>0.5/0.5</td>
</tr>
<tr>
<td></td>
<td>0.6/0.6</td>
</tr>
<tr>
<td></td>
<td>0.6p/0.5</td>
</tr>
</tbody>
</table>

- Profiling perpendicular (⊥) to line supports: negligible influence of face layer profiling
- Profiling parallel (∥) to line supports: reduction of load capacity and rigidity due to

![Graph showing load bearing behaviour](image-url)
Global load bearing behaviour

- Test series No.2 - comparison of face layer thickness with biaxial support:
  - Profiled sandwich panel shows lowest load capacity and rigidity although face layer thickness (0.5/0.6p) fits between 0.5 and 0.6
  - Profiling parallel (∥) to line supports also reduces biaxial load capacity and rigidity

\[ F_u = 28 \text{kN} \]
Global load bearing behaviour

- **Summary:**

<table>
<thead>
<tr>
<th>Core material and thickness</th>
<th>Face layer profiling</th>
<th>Face layer thickness</th>
<th>Support condition</th>
<th>Ultimate load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyurethane d = 60 mm</td>
<td>no</td>
<td>0.5/0.5</td>
<td>uniaxial</td>
<td>18 kN</td>
</tr>
<tr>
<td></td>
<td>no</td>
<td>0.5/0.5</td>
<td>biaxial</td>
<td>31 kN*</td>
</tr>
<tr>
<td></td>
<td>yes</td>
<td>0.6p/0.5</td>
<td>uniaxial (\perp)</td>
<td>19 kN</td>
</tr>
<tr>
<td></td>
<td>yes</td>
<td>0.5/0.5</td>
<td>biaxial</td>
<td>28 kN*</td>
</tr>
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<td></td>
<td>yes</td>
<td>0.6p/0.5</td>
<td>uniaxial (\parallel)</td>
<td>13 kN</td>
</tr>
</tbody>
</table>

* additional increase?

- **Considerable increase of load capacity and rigidity due to biaxial load transfer**

- **Longitudinal face layer profiling causes slight decrease of biaxial load bearing behaviour**
Global load bearing behaviour

- Test series No.2 - numerical verification of results:
  - FE-Software ANSYS 14.0
    - Face layer: SHELL181
    - PUR-Core: SOLID45
  - FE-Simulation of experimental tests
  - Experimental tests to adjust FE-Simulation with exact material parameters

<table>
<thead>
<tr>
<th>Material parameter</th>
<th>Experimental result</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_c$</td>
<td>3.36</td>
</tr>
<tr>
<td>$G_c$</td>
<td>2.85</td>
</tr>
<tr>
<td>$f_c$</td>
<td>0.092</td>
</tr>
<tr>
<td>$f_y$</td>
<td>361</td>
</tr>
</tbody>
</table>

Tests performed to analyze material parameters
Global load bearing behaviour

- Test series No.2 - numerical verification of results:

- Gain of displacement due to face layer profiling of all-around line supported sandwich panels can be verified
Global load bearing behaviour

- Test series No.3 - tested parameters:
  - **Core material**
    - mineral wool (120 kg/m³)
  - Core thickness 50 mm
  - Face layer thickness 0.5 mm / 0.6 mm
  - Face layer profiling none
  - Support types:
    - core alignment typical (⊥)
    - biaxial
    - core alignment (‖)

Test specimen with mineral wool core and two sided line support

Test specimen with mineral wool core and four sided line support
Global load bearing behaviour

- Test series No.3 - comparison of core alignment with uniaxial support:
  - Load capacity and rigidity depend on the mineral wool core alignment

- Load capacity and rigidity depend on the mineral wool core alignment

Load [kN] vs. Displacement [mm]

- $F_u = 15\,\text{kN}$
- $F_u = 6\,\text{kN}$

Shear stress failure on test specimen with core alignment II

Huge deformation and low rigidity of test specimen with core alignment \perp

8kN: Measurement range exceeded
Global load bearing behaviour

- Test series No.3 - results four sided line support
  - No global panel failure
  - Local plastification at line supports

26kN: Measurement range exceeded

$F_u = 15kN$

Local plastification at line supports
Global load bearing behaviour

- Test series No.3 - comparison of support conditions: □ vs. □ vs. □

- No increase of rigidity in linear-elastic range due to biaxial support

- After reaching the uniaxial ultimate load capacity load reserves can be used

Additional load reserves

Similar results

```
F_u=15kN
F_u=6kN
```

Force [kN]

Displacement [mm]
Global load bearing behaviour

- Summary:

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<tr>
<td></td>
<td>no</td>
<td>0.5/0.5</td>
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<td>31 kN*</td>
</tr>
<tr>
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<td>yes</td>
<td>0.5/0.5</td>
<td>uniaxial ⊥</td>
<td>19 kN</td>
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<td>yes</td>
<td>0.5/0.5</td>
<td>biaxial</td>
<td>28 kN*</td>
</tr>
<tr>
<td></td>
<td>yes</td>
<td>0.6p/0.5</td>
<td>uniaxial II</td>
<td>13 kN</td>
</tr>
</tbody>
</table>

| Mineral wool                | no                   | 0.6/0.5             | uniaxial ⊥       | 15 kN        |
|                             | no                   | 0.6/0.5             | biaxial           | 15 kN*       |
|                             | no                   | 0.6/0.5             | uniaxial II      | 6 kN         |

- Polyurethane:
  - Considerable increase of load capacity and rigidity due to biaxial load transfer

- Mineral wool:
  - No increase of rigidity in linear-elastic range due to biaxial support

* additional increase?
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1. Introduction
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   • Demands for architectural façades
   • Openings for a solution
   • Overall façade design
4. Prospects
Demands for architectural façades

- Architectural design
  - Office- and multi-storey buildings have got representative character
  - Architects and builders should be free to design their individual concepts

- Economic demands
  - Cost effectiveness of sandwich panel façade should be obtained
Demands for architectural façades

- Thermal insulation and noise protection
  - High demands on construction physics (with rising trend)

- Modular design
  - Due to standardised interior construction grids public- and office buildings require façades which match this modular design
Openings for a solution

- **Major problem:** Joining the unprofiled sandwich panel edges
  - Request of architects: Equivalent joining of longitudinal and transversal edge

- **Additional request for façades with high architectural quality:**
  - Segmentation of façades (which leads to more transversal joints)
  - Huge amount of window surface in office- and multi-storey buildings
Openings for a solution

- 1\textsuperscript{st} approach:
  - Subsequent machining of transversal edges
    - Additional production step in an already highly optimized and efficient production process is necessary
  - Increased prices on the market

⇒ Economic risk for the sandwich industry
Openings for a solution

- 2nd approach:

  - Design of frame structures which are surrounding sandwich panels and covering traditional joints

  ➔ Existing sandwich panels for industrial purpose can be used in new market segments using modular design

  ➔ Open new market segments with lower financial risk
Openings for a solution

- Frame structure surrounding sandwich panels
  - Option: Development of an “adapter-system” made from extruded aluminium
  - Cost-effective manufacture of complex shapes
    - Costs about 1,000 € to 5,000 € for each die (shape form) depending on the adapter shape
    - Costs for aluminium itself

Profiles with complex shapes made from extruded aluminium
Openings for a solution

- Frame structure surrounding sandwich panels
  - Improved option: modular “adapter-system”
    - Basic module matched with insets (slot, key, unprofiled edge, windows)
Openings for a solution

- Frame structure surrounding sandwich panels
  - Improved option: modular “adapter-system”

⇒ Basic module matched with insets
  (slot, key, unprofiled edge, windows)
Openings for a solution

- Frame structure surrounding sandwich panels
  - Improved option: modular “adapter-system”
  - Basic module matched with insets (slot, key, unprofiled edge, windows)
Openings for a solution

- Frame structure surrounding sandwich panels
  - Improved option: modular “adapter-system”
    - Disadvantage: increased assembly effort
    - Disadvantage: increased width and increased material consumption
Openings for a solution

- New development: individually matched “adapter-system”

  ➡️ Optimization of costs and on-site building process
Openings for a solution

- New development: individually matched “adapter-system”

- Optimization of costs and on-site building process

  Adapter: inner surface

  Packing made from extruded polyethylene (PE) for thermal insulation

  Adapter: exterior

  Adapter: cover cap

Individually matched “adapter-system” joint slot and key
Openings for a solution

- New development: individually matched “adapter-system”
  - Connection of inner surface and exterior with special rust-proof screws
    - Geared screw intake
    - Screw channel in PE-packing
    - Drilling adapter exterior at designated place
  - Individually matched “adapter-system” joint slot and key
Openings for a solution

- New development: individually matched “adapter-system”
  - Connection of inner surface and exterior with special rust-proof screws
    - Ultimate load about 3.0 kN each screw (tested)

➤ Approach: screw spacing about 25 cm
Openings for a solution

- New development: individually matched “adapter-system”

- Design variation (visible adapter width 10 cm, Sandwich panel thickness 16 cm):

  - Schematic: joint slot / key
  - Schematic: joint slot / unprofiled edge
  - Schematic: joint slot / window
Openings for a solution

- New development: individually matched “adapter-system”
  - Additional benefit:
    - Conformation of sandwich panel width to office building construction grids by adjusting the adapter size (width)
    - Two screw channels to ensure denseness
Openings for a solution

- New development: individually matched “adapter-system”
  - Design variation (visible adapter width 15 cm, Sandwich panel thickness 16 cm):
Openings for a solution

- Option: individually matched “adapter-system”
  - Additional benefit:
    - Integration of further details like corner, eave, ridge into the “adapter-system”
Openings for a solution

- Option: individually matched “adapter-system”
  
  - Additional benefit:
    
    - Installation of sandwich panels on existing façades with uneven surfaces like brickwork, ..
    
    - Option: Joining the adapter profile and an load bearing substructure inside the building
Overall façade design

- Case study:
  - Office building façade with industrial sandwich panels (vertically and horizontally adapter-mounted)
Overall façade design

- Design advantages of façades with adapter-mounted sandwich panels
  - Variable combination of sandwich panels and windows
  - Variable design possibilities with adapter front cover layout
  - Variable combination of sandwich panels with different appearance
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Prospects

- Global load bearing behaviour
  - Further experimental tests:
    - Variation of length/width ratio
      More knowledge of biaxial load bearing behaviour
  - Further numerical analysis:
    - Verification of experimental tests results
    - Parameter studies
      Extension of parameter range

FE-Analysis deformation plot
Prospects

- Architectural façade detailing
  - Optimization of the “adapter-profile” design layout
  - Research on the “adapter-system” load bearing behaviour
  - Further research on overall façade design
Acknowledgement

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Thank you for your attention.