New Potentials for Composite Technologies in Buildings & Infrastructure
Joint Market and Technology Study

Markets and Applications | Materials | Production Technologies | Business Cases
Participants of the Market and Technology Study “Buildings and Infrastructure“

AZL Partner Companies

3M
AXIAmaterials
aliancys
AHLSTROM
armacell
covestro
CONIBILITY
BASF
AIREX
DU PONT
Evonik Industries
Huntsman
KARL MAYER
Mitsui Chemicals
Mubea
LG
KraussMaffei
Polynt
ThyssenKrupp
VELUX

External Companies

BOREALIS
BUFFA
exel composites
Karl Mayer
LG Hausys
REHAU
SGL Carbon Group
AZL – Market and Technology Study
Systematic Approach

Technology Push:
Next Generation Composite Technologies (materials, product design, production technologies)

Future Success of Composites in Buildings and Infrastructure

External Experts

Industry
Consortium of more than 25 companies

Experience of other markets

Varied Perspectives

University/Research

Pilot Projects

Composite Know-how

Market Requirements

Market Pull:
Future Challenges & Trends in Buildings & Infrastructure
AZL – Market and Technology Study
Systematic Approach

Kick-off Meeting
November 2016

1st Report Meeting
March 2017

2nd Report Meeting
July 2017

Final Report Meeting
September 2017

Stage 1
Questionnaire

Stage 2
Workshop (Buildings) Workshop (Infrastructure)

Stage 3
Workshop

Pilot Study
2 months

Technology/Market Study
2 months

Business Cases
2 months

Expert Keynote Speeches
Realized Proceeding
From 438 Components to 11 Highlights

- 2 Markets
- 20 Market Segments
- 27 Market Subsegments
- 438 Applications /Components
- 25 Detailed Analyses
- 11 Business Cases
Realized Proceeding
Market (sub-)segments

20 Market Segment Profiles:

Segment Description: Buildings and infrastructure require a wide range of renovation and maintenance activities during the whole lifecycle to ensure a proper performance.

- Highly increased "after market service" in the construction environment.
- Rigid and limited infrastructure that has to face high failure rates.
- New innovative solutions required to close an ever-greater gap of 1 to 1.5% per year.
- More opportunities to target customers based on big data analysis.
- Various available pricing levels in maintenance.

Market Intelligence: Building renovation and maintenance represent an ever-increasing share of the global market. In 2018, the European market alone is estimated to be worth over EUR 1 trillion.

- "Low service and complex production for machine equipment - establish leasing business in marine market.
- Remote solutions required.
- Direct negotiations.

Evaluation/Recommendation: Internationalization of developed countries is aging and needs new innovations to ensure the increasing functional properties. In Germany, the renovation industry is a high-volume and growth space for the new market sector.

Relevant Sub-segments: Insulations, Sandwich Panels, Road Railways, Architectural, Components, Insulations.

Segment Description: Infrastructure-related activities like retrofitting and maintenance are becoming more important in the global market.

- "Highly increased "after market service" in the infrastructure environment.
- Rigid and limited infrastructure that has to face high failure rates.
- New innovative solutions required to close an ever-greater gap of 1 to 1.5% per year.
- More opportunities to target customers based on big data analysis.
- Various available pricing levels in maintenance.

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- "Low service and complex production for machine equipment - establish leasing business in marine market.
- Remote solutions required.
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Evaluation/Recommendation: Internationalization of developed countries is aging and needs new innovations to ensure the increasing functional properties. In Germany, the renovation industry is a high-volume and growth space for the new market sector.

Relevant Sub-segments: Insulations, Sandwich Panels, Road Railways, Architectural, Components, Insulations.
Market Segmentation: Buildings – Key Segments

- **Residential**
  - Permanent
  - Temporary

- **Non-residential**
  - Industrial
  - Commercial
  - Office
  - Design and street furniture
  - Safety & Protection
  - Event buildings

- **Infrastructure**

- **Cross Functions**
  - Installation
  - Renovation
Market Segmentation:
Infrastructure – Key Segments

- Infrastructure
- Traffic Network
- Supply Network
- Cross Functions
  - Installation
  - Renovation

- Road/Rail
- Bridge/Tunnel
- Water constr.
- Filling Stations
- Traff. Settings
- Transportation
- Fluid Supply
- Solid Supply
- Communication
- Energy Supply
Cross function: Renovation

**Segment Description:**
The elements of buildings & infrastructure require a various amount of renovation and maintenance activities during the whole life cycle to ensure a proper performance.

- Highly increased “after market service” in the construction environment
- Aged and limited infrastructure that has to face high future demands
- New innovative solutions required to close an invest gap of 1 tr USD per year
- More opportunities in predictive maintenance based on big data input
- Various available price levels in maintenance

**Market Intelligence:**

<table>
<thead>
<tr>
<th>Service/Material</th>
<th>bn USD (CAGR %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building maintenance service</td>
<td>169,2</td>
</tr>
<tr>
<td>Annualy global investment</td>
<td>2700</td>
</tr>
<tr>
<td>Thermal Insulation</td>
<td>23,53</td>
</tr>
</tbody>
</table>

**Evaluation/Recommendation:**
- Infrastructure in developed countries is aging and needs new innovations to assure the increasing functional properties.
- In Germany (example) the renovation sector has a higher volume and growth than the new constr. sector.

**Relevant Sub-segments**

- Reinforcements/Replacements
- Sewer renovation
- Machine equipment
- Scaffolds
- Insulations

**Resources data:**
1 – freedoniagroup.com
2 – marketsandmarkets.com
3 - prnewswire.com
4 - jindinglift.com

**Resources picture:**
1 – sp-reinforcement.de
2 – greystoneuk.com
3 - brogangroup.com
»Worldwide Market Study for Lightweight Applications«
Highlight-Segment Evaluation Portfolio

Key Parameters

- Production volume
- Entry barriers/risks
- Market Volume/growth/dynamic
- Willingness to pay for improvements or innovations
- Time-to-Market
  - Mass production possibility
- Technology Potential
  - Added value by composite usage
  - Superior to competing technologies

Evaluation of the sub-segments based on key parameters of the Market and the Technology Potential

<table>
<thead>
<tr>
<th>Market Potential</th>
<th>Technology Potential</th>
<th>Total Score</th>
<th>Production volume</th>
<th>Entry Barriers</th>
<th>Willingness to pay for innovation</th>
<th>Time-to-Market</th>
<th>Mass Production Possibility</th>
<th>Superior to Competing Technologies</th>
<th>Added Value by Composite Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>23 Housing</td>
<td>8.33 8.64</td>
<td>17.57</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>37 Reinforcements</td>
<td>8.33 8.69</td>
<td>17.02</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>36 Energy</td>
<td>8.64 8.33</td>
<td>16.97</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>40 Water systems</td>
<td>8.69 8.33</td>
<td>16.62</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50 Sewer renovation</td>
<td>8.64 8.33</td>
<td>16.97</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 Bridge</td>
<td>8.18 8.69</td>
<td>16.87</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>65 Prefabricated houses</td>
<td>8.33 8.33</td>
<td>16.66</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>24 City/street furniture</td>
<td>8.73 8.45</td>
<td>16.18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19 Business offices</td>
<td>9.39 7.26</td>
<td>16.65</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>12 Warehouse/logistics</td>
<td>8.18 8.45</td>
<td>16.63</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 Greenhouse/farming</td>
<td>8.18 8.33</td>
<td>16.51</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>66 Energy/Transportation</td>
<td>7.88 8.33</td>
<td>16.21</td>
<td></td>
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<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>25 City/street furniture</td>
<td>7.73 8.45</td>
<td>16.18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>51 Airport</td>
<td>7.42 8.69</td>
<td>16.11</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Market Potential Technology Potential Total Score
Realized Proceeding
Technology Trees

27 Technology Trees

2 Markets

20 Market Segments

27 Market Subsegments

25 Applications / Components

10 Detailed Analysis

5 Business Cases

3 Technology Trees
Technology Trees

- Total amount of 27 Technology Trees
- Overview about 10 challenges of most relevant impact out of a catalogue of 40 possible challenges
- Break-down to component and application level
- Total scope of 438 different components and applications (100 expected!)
- Evaluation on component level based on three dimensions:
  - Product Usage
  - Production
  - Product Perception
- Participant voting to select 25 out of the 438 components
Realized Proceeding
From 438 Components to 10 Highlights

- 2 Markets
  - 20 Market Segments
  - 27 Market Subsegments
  - 438 Applications /Components
  - 25 Detailed Analyses
  - 11 Business Cases

Participant voting
Final Voting Results

<table>
<thead>
<tr>
<th>Feature</th>
<th>Votes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buildings</td>
<td>11</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>11</td>
</tr>
<tr>
<td>Both</td>
<td>3</td>
</tr>
<tr>
<td>Both</td>
<td>25</td>
</tr>
</tbody>
</table>
25 Detailed Analyses

Participant voting

Level 4

Level 5

25 Detailed Analyses

11 Business Cases

AZL Aachen GmbH in cooperation with Aachener Zentrum für integrativen Leichtbau – AZL
Realized Proceeding
Detailed Analysis

Detailed Analyses

- Total amount of 25 Detailed Analyses
- Objective of the Analyses:
  - Overview regarding market potentials
  - Overview of technology potentials
  - Insides about dimensions, materials and norms/standards
  - Requirements of the value chain
- Detailed Analyses outcome:
  - Evaluation regarding technology potentials
    - Manufacturing Capability
    - Improvement potential for the product
    - Improvement potential for the process
  - Evaluation regarding the market potential
    - Market volume and growth
    - Entry barriers
    - Potential margin
  - Value chain overview
### Description
Bar or mesh supporting the concrete structure against tensile stress impact

### Technology-related Information

<table>
<thead>
<tr>
<th>Possible Manufacturing Technologies</th>
<th>Substitutional Technologies/ Materials</th>
<th>Manufacturers (Top player)</th>
<th>Cross-Industry Potential</th>
</tr>
</thead>
</table>
| **Thermoplastic/Thermoset/Multi-Material:**<br> - Continuous Pultrusion Process<br> - Steel rebar with plastic coating | **- Hot roll forming for steel rebars**<br>**-**<br>**| Hughes Brothers<br> Schoeck International<br> Dextra Group<br> Pultron Composites<br> Kodiak Fiberglass Rebar Marshall Composite Technologies | **Suspension ropes**<br> **House protection**<br> **Elevator**

### Market-related Information

<table>
<thead>
<tr>
<th>Technological Feasibility</th>
<th>Market Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Manufacturing Capability</strong>&lt;br&gt; 0-5-10</td>
<td><strong>Production Volumes and Revenues</strong>&lt;br&gt; 0-5-10</td>
</tr>
<tr>
<td><strong>Mass Production Possibility</strong>&lt;br&gt; 0-5-10</td>
<td><strong>Future Market Potential</strong>&lt;br&gt; 0-5-10</td>
</tr>
<tr>
<td><strong>Potential for Improvement by Alternative Materials</strong>&lt;br&gt; 0-5-10</td>
<td><strong>Entry Barriers</strong>&lt;br&gt; 0-5-10</td>
</tr>
<tr>
<td><strong>Improvement by Alternative Manufacturing Technologies</strong>&lt;br&gt; 0-5-10</td>
<td><strong>Profit Margin</strong>&lt;br&gt; 0-5-10</td>
</tr>
</tbody>
</table>

### Graphs
- **Global Market FRP Rebar**: 2017-2022 CAGR
- **Revenue Forecast**: [Mio. €] 500-1,500
- **Rebars**
- **Suspension ropes**
- **House protection**
- **Elevator**
### Technological Feasibility

**Manufacturing Capability**
- Continuous production with known technologies
- Different fiber materials possible
- Production technologies for thermoplastic resins have to be improved

**Mass Production Possibility**
- Continuous production technology enables mass production
- Different fiber materials possible
- Flexible usage of the product for different applications (bar, mesh, preforms)
- Shorter cycle time required

**Potential for Improvement by Alternative Materials**
- Lightweight design: 9 times lighter than steel
- Tensile strength: 3 times higher than steel
- Resistant to corrosion, alkalies, acids
- Low maintenance required
- Ease in transport and installation
- Similar thermal expansion compared to concrete
- Concerns about long term durability and bent stiffness

### Market Potential

**Production Volumes & Revenues**
- Addressed steel rebar market has a size of X bn USD (2017)
- FRP rebar market size of X mio USD (2017)
- APAC accounted for X% of the global construction (2015)
- Estimated operating time: 80-100 years

**Future Market Potential**
- Increasing market share of FRP rebars
- Expected CAGR of X% for steel rebar market
- Expected CAGR of X% for FRP rebar market
- Basalt fiber composites will grow with CAGR of X%
- China wants to invest more than X bn USD in Infrastructure until 2019

**Entry Barriers**
- Market dominated by steel solutions
- Various players and applications
- Performance driven market segment
- New engineering models required to use all benefits
- Confidence of customer is required for long term use

**Profit Margin**
- Low margin and low risks

---

### Detailed Description

**Rebar**

<table>
<thead>
<tr>
<th>Improvement by Alternative Manufacturing Technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pultrusion is a continuous production technology like hot rolling for steel rebars</td>
</tr>
<tr>
<td>Low production speed compared to benchmark (steel)</td>
</tr>
<tr>
<td>Complex profiles possible</td>
</tr>
</tbody>
</table>
Detailed Description

Rebar

Competence and Form Requirements

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Geometry &amp; Form</th>
<th>Material &amp; Performance</th>
<th>Norms &amp; Standards</th>
<th>Quality &amp; Safety</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>▪ Standard diameter size 2.5 mm – 41 mm; anchor bars up to 76 mm outside diameter</td>
<td>▪ Thin single bars; or connection of bars for meshes and form configurations (e.g. columns)</td>
<td>▪ Various fiber materials: Glass, Carbon, Basalt, Steel/galvanic steel, chemical resistant, High tensile strength, Thermoset and upcoming thermoplastic resins</td>
<td>▪ American Concrete Institute (ACI) guideline: 440.1R-06 - 440.7R-10</td>
<td>▪ Many guidelines including security factors for specific conditions</td>
</tr>
<tr>
<td>▪ Length theoretically not limited (continuous production)</td>
<td>▪ Hollow core anchor bars</td>
<td></td>
<td>▪ ISO 10406-1:2008</td>
<td>▪ No long term experience (Bridge 1982) – concerns regarding durability</td>
</tr>
<tr>
<td>▪ Standard length: 150 – 300 mm</td>
<td>▪ Different surface profiles bent bars</td>
<td></td>
<td>▪ JSCE, 1997 (Japan)</td>
<td></td>
</tr>
</tbody>
</table>

□ Standard diameter size 2.5 mm – 41 mm; anchor bars up to 76 mm outside diameter
□ Length theoretically not limited (continuous production) □ Standard length: 150 – 300 mm
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□ JSCE, 1997 (Japan) □ Many guidelines including security factors for specific conditions □ No long term experience (Bridge 1982) – concerns regarding durability
Value Chain Overview

Material Manufacturer
- Materials cost competitive to steel solution
- Chemical resistant
- Reasonable resin for further processing (e.g. thermoplastic for endless production)

Part Manufacturer
- Mass production feasibility
- Price depend on diameter (price per meter)
  - 4mm: 0.075 USD
  - 10mm: 0.390 USD
  - 16mm: 0.998 USD
  - 24mm: 2.245 USD
- Continuous and fast production possibility

Construction Companies
- Lightweight for better transportation and installation conditions
- Low maintenance effort
- Good connection possibility

Derived Requirements

<table>
<thead>
<tr>
<th>Material Systems</th>
<th>Manufacturing Technology</th>
<th>Additional Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material has to be cost competitive to benchmark steel (TCO/TLC)</td>
<td>Increased production speed</td>
<td>Regulations and standards for engineering and design to realize benefits and avoid issues</td>
</tr>
<tr>
<td>Small difference of thermal expansion compared to surrounding concrete</td>
<td>E.g. pultrusion can provide freedom of profile design. New designs can provide new benefits</td>
<td></td>
</tr>
<tr>
<td>High bending stiffness for small diameter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low thermal &amp; electrical conductivity</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
References

Rebar

1. marketsandmarkets.com/PressReleases/steel-rebar.asp (06/2017)
2. gminsights.com/pressrelease/fiber-reinforced-polymer-frp-rebars-market (06/2017)
4. compositeworld.com/ (06/2017)
5. compositeworld.com/produktsiya/stekloplastikovaya-armatura.html (06/2017)
6. Composites in Infrastructure - Building New Markets; E. Marsh; 2000
7. Nonconventional Concrete Technologies - Renewal of the Highway Infrastructure; National Materials Advisory Board; 1997
11. americanfiberglassrebar.com/designmanuals.aspx (06/2017)
12. iiic.org/publications/code-references/ (06/2017)
13. Durability issues of FRP rebars in reinforced concrete members; Francesca Ceroni; 2006
14. pinnacledrilling.ca/featured-products/anchor-bar/ (06/2017)
15. Combar - Schöck pricelist, 2017
Final Voting Results

Final Participant Votings
Realized Proceeding
Business Cases

11 Business Cases

Rebar
Executive Summary

AZL recommendation:
Material combination and an alternative process chain using a Catenary press for continuous production: material price remains a major driver
Technical innovation: development by AZL: Catenary press process analysis and optimization production
Expected economical potential: high
Expected economic potential: high
Realized Proceeding

Business Cases

- Total amount of 11 Business Cases
- Objective of the Business Cases:
  - Status quo analysis (product, process chain)
  - Overview regarding market potentials
  - Improvement suggestions considering product and production process (technology)
  - Product costs analysis
- Business Case outcome:
  - Market overview
  - Analysis state of the art product specification
  - Analysis state of the art process specification
  - Improvement proposal regarding product design
  - Improvement proposal regarding the process design – proposal of novel process designs
  - Cost calculations using the costing software OPLYSIS
- Evaluation of the composite solutions considering technological and economical potentials
Rebar

Executive Summary

Status Quo Process Chain – Hot Rolling Steel Rebar

<table>
<thead>
<tr>
<th>Process/Product data</th>
</tr>
</thead>
<tbody>
<tr>
<td>mio</td>
</tr>
<tr>
<td>€/unit</td>
</tr>
<tr>
<td>s/unit</td>
</tr>
</tbody>
</table>

Unit length 6m

Addressed Challenges of Status-Quo Process

- Competitive market price
- Improved mechanical properties
- Better failure type

Process/Product Comparison Process 1&2

- Part costs: - 4.5%
- Production speed: + 300%
- E-modulus: + 260% (Hybrid to GFRP)

AZL recommendation:

Material combination and an alternative process chain using a Caterpillar-press for continuous production; material price remains a major driver

- Technical Innovation developed by AZL: Caterpillar-press process enables fast simultaneous production
- Expected technological potential: high, Expected economic potential: high

Evaluated Process 1

- Pultrusion/Braiding
- Cutting

Evaluated Process 2

- Conti-RTM Press/Double Belt Press
- Cutting

Novel AZL Proposal
Rebar
Market Summary

Production volumes and revenues
- Addressed steel rebar market has a size of X bn USD (2017)\(^1\)
- Steel rebar market estimates a CAGR of X%\(^2\)
- FRP rebar market size of X mio USD (2017)\(^2\)
- FRP rebar market estimates a CAGR of X%\(^2\)
- APAC accounted for X% of the global construction (2015)\(^2\)
- Estimated operating time: 80-100 years

Current market scenario against competitors
- Already established in specific market areas
- Often used in cases of obvious technical benefits:
  - Chemical aggressive environment
  - Electrical, thermal and magnetic insolation
    (Energy plants – inductivity)
  - Lightweight construction

Profit margin
- Extremely cost driven market – high volume and low margin

Estimate Time-to-market
- Short time to market – well known production technology and easy product specifications
# Rebar - Market Summary

## Competitive Technologies/ Materials

<table>
<thead>
<tr>
<th>FRP Solutions</th>
<th>Steel</th>
<th>Stainless Steel</th>
<th>Epoxy-coated Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tensile strength:</strong></td>
<td>N/mm²</td>
<td>N/mm²</td>
<td>N/mm²</td>
</tr>
<tr>
<td>&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Weight per meter:</strong></td>
<td>kg/m (GFRP)</td>
<td>kg/m</td>
<td>N/m</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>E-modulus:</strong></td>
<td>45 000 – 120 000 N/mm² (GFRP-CFRP)</td>
<td>210 000 N/mm²</td>
<td></td>
</tr>
<tr>
<td><strong>Price:</strong></td>
<td>$/meter</td>
<td>$</td>
<td>$/meter</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Average price for Stainless Steel 304 Reinforcing Bar</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Alibaba: $/meter)</td>
<td></td>
<td>(Alibaba: $/meter)</td>
</tr>
</tbody>
</table>

## Standard dimensions
- Length: m
- Diameter: mm (EU), mm (US)

### Major drivers of FRP
- Corrosion resistance, lightweight and high tensile strength

### Major drawbacks of FRP
- Higher price and lower pressure strength

## Competitive Technologies/ Materials

<table>
<thead>
<tr>
<th>GFRP (Schöck)</th>
<th>Steel</th>
<th>Stainless Steel</th>
<th>EC-Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price per meter (Ø 25 mm)</td>
<td>€¹³</td>
<td>€¹²</td>
<td>€⁶</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>€¹²</td>
</tr>
</tbody>
</table>
Rebar - Status-Quo Analysis

Current Process Properties

Reheating
- Steel billet is charged into a reheating furnace
- Billet obtains the rolling temperature

Rolling Process
- Three stage hot rolling process
  - 1st step roughing mill
  - 2nd step in an intermediate mill
  - 3rd step finalization mill

Finishing
- Finishing and surface profiling

Quenching
- Controlled cooling process

Cooling
- Cooling out in cooling bed

Cutting
- Cutting in customer related lengths
- Bundling and transport of rebar bundles

Required machine components
- Furnace
- Roughing mill
- Intermediate mill
- Finishing block
- Cooling bed
- Finishing facilities

Major potentials for improvement
- Lower energy consumption
Reinforcement
- Creels of fiber roving for unidirectional strength
- Woven fiberglass mats provide multidirectional reinforcement

Wet out
- Fiber reinforcements are impregnated by a resin; typically a thermoset resin

Preforming
- The endless reinforcements are arranged near the final shape in a preform

Curing
- The fiber roving are pulled through the heated die; getting its final shape and the resin is curing out

Profiling
- Adding a surface profile for a improved connection to the surrounding concrete

Cutting
- The result is a continuous product which can be cut into pieces of individual lengths

Required machine components
- Pultrusion production line

Major potentials for improvement
- Production speed
- High pulling forces
- Material costs
Rebar

Product alternative – Hybrid rebar

**Major Applications**
- All concrete application where a reinforcement is required. Typical applications are situations in an aggressive chemical environment in combination with high mechanical stresses. (salt water or construction of traffic infrastructure)

**Addressed Challenges**
- Low modulus of elasticity
- Brittle failure type
- High costs compared to traditional reinforcements
- Corrosion resistance

**Benefits and drawbacks**
- Chemical protection of the steel core
- Usage of specific material strengths
- Different behavior of materials threatened the material connection (inner stresses)

**Material properties**
- Combination of two materials to use the specific benefits of the materials
  - Steel solution for better price and higher E-modulus
  - Good tensile stress properties of the FRP material
  - A better brittle failure type

**Focused unit dimensions**
- Length: 6m
- Diameter 25mm
- Steel core: 17.3mm (47.9 vol. %)

**Description**
Rebar with steel core and FRP coating to combine the specific benefits of both solutions. Different form and material combinations are feasible.
Rebar

Types of hybrid bars

A: B: C: D:

Table 4. Results of tensile tests for specimens (Case A–D)

<table>
<thead>
<tr>
<th>Type</th>
<th>Tensile strength (MPa)</th>
<th>Improvements</th>
<th>Elastic modulus (GPa)</th>
<th>Improvements</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1035.9</td>
<td>1.00</td>
<td>49.6</td>
<td>1.00</td>
</tr>
<tr>
<td>B</td>
<td>970.4</td>
<td>0.94</td>
<td>53.7</td>
<td>1.08</td>
</tr>
<tr>
<td>C</td>
<td>876.2</td>
<td>0.85</td>
<td>98.3</td>
<td>1.98</td>
</tr>
<tr>
<td>D</td>
<td>956.1</td>
<td>0.92</td>
<td>129.2</td>
<td>2.60</td>
</tr>
</tbody>
</table>

Note: value for improvements were normalized to Case A

Experimental Investigation of Tensile Performance of GFRP-Steel Hybridized Bar, Dong-Woo Seo et al., 2016
Rebar

Examples for hybrid rebar production

Glass fiber

Steel

Asian 100

Schöck Combar

Pulltrall V-Rod

Glass roving

Braiding machine

Guide

Nozzle

Bobbins for deformation

Resin pool

Bobbins for clothing

Curing oven

Puller

Cut off saw

Finished GFRP rebars
Rebar

Alternative Process Chains

Pultrusion/Braidtrusion
- Continuous production of FRP rebar with steel core

Cutting
- Cutting of the continuous product into requested lengths
  - Unit length: 6 m

Conti-RTM Press/Double Belt Press
- Caterpillar press with profiled moulds
- Continuous and parallel production of several units

Cutting
- Cutting of the continuous product into requested lengths
  - Unit length: 6 m

Potential process improvements
- Increased process speed
- Parallel production of various units
- 3d surface profiles feasible

Potential product improvements
- Higher E-modulus
- Better brittle failure type
- High tensile strength

Main required machine components
- Pultrusion/Braidtrusion machine ca. €
- Cutting tool ca. €
- Double Belt Press/Caterpillar press ca. €
- Cutting tool ca. €

Process-related challenges
- Production speed
- Profile for better connection to surrounding concrete
- Injection speed and tightness
- High machine invest costs
Rebar Process 1
Production process proposal

Major Applications
- Application similar to standard applications of normal steel rebars. The composite layer protects the steel core. The hybrid material solution tries to combine the benefits of both materials and to avoid specific issues.

Addressed Challenges
- Continuous production technology
- Integration of shape for good connection to surrounding concrete

Benefits and drawbacks
- Integrate the steel rebar in the FRP production process
- Chemical protection of the steel core
- Still low production speed

Material properties
- Good tensile and pressure resistance
- Good impregnation ability

Description
Pultrusion/Braidtrusion process of the thin FRP with an integration of the low cost steel rebar solution
Rebar Process 1

Oplysis Process Chain Overview: Results

<table>
<thead>
<tr>
<th>Cycle Time Reached [s]</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Output [Parts]</td>
<td></td>
</tr>
<tr>
<td>Part Cost [€]</td>
<td></td>
</tr>
<tr>
<td>Material Cost [€]</td>
<td></td>
</tr>
<tr>
<td>Operating Cost [€]</td>
<td></td>
</tr>
<tr>
<td>Total Investment [€]</td>
<td></td>
</tr>
</tbody>
</table>

**Process information**

**Process Durations**

- Duration per unit PS 1:
- Output per cycle: 1 unit
- Duration per unit PS 2:

**Material Costs:**

- Steel rod: €/kg
- Glass fiber (E-CR): €/kg
- Vinyl ester: €/kg

**Material consumption per unit (6m Rebar):**

- Steel: kg
- Glass fiber: kg ( )
- Vinyl ester: kg

Assumptions for process chain modelling and analysis are based on literature research and expert interviews.
Rebar Process 1
Scale-up: Rebar - Pultrusion

Scaling steps at 134,640 units
+1 Unit of Pultrusion Machine
+1 Unit of Worker
Rebar Process 1
Cost Analysis

Part Costs vs. Material Price

The effect of the material price variation on the total part costs

Vinyl ester (Resin) costs: €/kg
Glass fiber costs: €/kg
Steel rod costs: €/kg

Part Costs vs. Process Duration
(Production Speed)

A variation of the production speed affects the costs per unit:

Start duration: s/unit (speed: 
Min. duration: s/unit (speed: 
Max. duration: s/unit (speed: 

[Graphs showing cost variations with material price and production duration]
Rebar Process 2
Production process proposal

Description
Caterpillar press with parallel linear die shape for continuous rebar production. Installation of surface profile in one process feasible.

Major Applications
- Production technology for continuous production of straight rebars

Addressed Challenges
- Accelerate the production speed
- Simultaneous production of several rebars in one process step
- Decreased part costs

Benefits and drawbacks
- 3D formed die surface for better concrete connection
- Add-ons like clamps can be integrated in the continuous production process
- High investment for machinery compared to single pultrusion solution
- A lot of space for roving storage is required

Press Dimensions
- Length: 4m
- Width: 1.5 m
- Distance between rebar moulds: 25/50 mm
- Parts per cycle: 28

Material properties
- Good impregnation properties
- High viscosity resin

http://www.kraussmaffeigroup.com/media/files/kmnews/de/PM_EXT_2012_18.JPG
Rebar

Production process proposal

http://bradburygroup-puma.com/Products/Continuous-Lines/Polyurethane/GLP-Double-Belt-Press-and-Panel-Cut-Unit
Rebar Process 2
Production process proposal

Press elements
- Press length: 4000 mm
- Press width: 1500 mm
- Fiber bundles: 25 mm
- Edge distance: 50 mm

Caterpillar press

http://bradburygroup-puma.com/Products/Continuous-Lines/Polyurethane/GLP-Double-Belt-Press-and-Panel-Cut-Unit
Rebar: Process 2
Production process proposal

Pre-impregnated fiber roving

Steel core

3D surface profile
Integration of profiles and clamps etc. possible

Cutting Tool

Heating unit
Rebar: Process 2
O plysis Process Chain Overview: Results

<table>
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<td>Total Investment [€]</td>
<td></td>
</tr>
</tbody>
</table>

**Process information**

**Process Durations**
- Duration per unit PS 1:
- Output per cycle: 28 units
- Duration per unit PS 2:

**Material Costs:**
- Steel rod: €/kg
- Glass fiber (E-CR): €/kg
- Vinyl ester: €/kg

**Material consumption per unit (6m Rebar):**
- Steel: kg
- Glass fiber: kg ( )
- Vinyl ester: kg

Assumptions for process chain modelling and analysis are based on literature research and expert interviews.
Rebar Process 2
Scale-up: Double Belt Press

Scaling steps at 11,309,760 units
+ 1 Unit of Double Belt Press Machine
+ 1 Unit of Worker

Scaling steps at 22,619,520 units
+ 1 Unit of Double Belt Press Machine
+ 1 Unit of Worker

Scaling steps at 33,929,280 units
+ 1 Unit of Double Belt Press Machine
+ 1 Unit of Worker

Scaling steps at 45,239,040 units
+ 1 Unit of Double Belt Press Machine
+ 1 Unit of Worker
Part Costs vs. Material Price

The effect of the material price variation on the total part costs

Vinyl ester (Resin) costs: €/kg
Glass fiber costs: €/kg
Steel rod costs: €/kg

Invest Costs vs. Press Width

A variation of the press width affects the invest costs per press:

Start press width: mm
Min. width: mm
Max. width: mm
Rebar

Conclusion of the Evaluations

Product
- Hybrid rebars (steel-FRP) offer potential of higher elastic modulus and better brittle failure type compared to FRP solution
- Compared to steel rebar: high tensile strength and corrosion resistance
- Cost reduction against FRP rebar is expected

Production
- Two process chains have been evaluated:
  - Pultrusion/Braidtrusion
  - Continuous forming in caterpillar press (novel AZL proposal)
- Continuous forming in caterpillar press requires higher investments, but is expected to reach higher output rates (such a system has not yet been developed)
- Material price is still the main cost driver
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