Novel ductile steel fiber composites: opportunities and challenges

SIM User Forum
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Ghent

"NANOFORCE"

Next generation nano-engineered
Polymer-Steel/CNT Hybrids
Composites for structural applications today

**Advantages:**
- Lightweight
- Excellent strength and stiffness
- Good durability (fatigue life, corrosion, impact resistance)

**Problem areas:**
- Brittleness (due to fibers)
- Catastrophic failure without warning, material disintegration
- Weak out-of-plane properties
- Early onset of damage

![Graph showing stress-strain relationship](image)

\[ \text{stress} \quad \sim 2\% \quad \text{strain} \]

I. Taketa (PhD thesis, KU Leuven)
Next generation composites

Properties of interest:

- Ductile of pseudo-ductile behavior, gradual failure
- No sacrifice in other properties

Strategies to:

- Fiber hybridization (combination of two or more fiber types)
- Development/search for new fibers with intrinsic ductility

Steel has a unique combination of **Stiffness** and **Ductility**.

**Stiffness**: 200 GPa

~ = carbon fibres (> 230 GPa)

3x glass fibres (72 GPa), flax (60~70 GPa)

**Ductility**:

Failure strain adjustable without loss of stiffness

M. Callens (PhD thesis, KU Leuven)
Challenges for steel fibers

- High density (not for weight sensitive applications)
- High stiffness mismatch between the fiber and the polymer (200GPa vs 2 GPa) → debonding and cracks
- Irregular cross-section (due to bundle drawing) → additional stress concentrations
- Additional challenges (identified during the project)

Debonding in carbon fiber composite

M. Callens (PhD thesis, KU Leuven)
Engineering steel fiber composites

**Composite properties**

Tensile and compressive properties
- Impact resistance
- Fracture toughness
- Fatigue life
- Functional properties

**Matrix selection**
Epoxy, PA, PU, PP, nano-reinforced polymers

**Interface modification**
Plasma and wet chemistry treatments to tune interface strength (including nano-modifications)

**Composite production**
VARI, RTM, hot pressing, pre-pregging...

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Effect of the matrix
Effect of the matrix

Ductile polymers lead to higher failure strain of steel fiber composites

Composite failure strain is ± 50% for a ductile matrix

Failure of steel fibers in a brittle matrix

- Applied deformation
- Crack in the matrix
- Local necking of the fiber
- Local debonding
- Ductile fiber failure

M. Callens (PhD thesis, KU Leuven)
Failure in brittle and ductile matrices

Effect of the interface becomes important

Effect of the interface
Surface treatments

- Wet chemistry (Department of Chemistry, KU Leuven)
- Plasma process (VITO)
- Characterization of the interface strength (VUB)
- Effect on composite properties (UGent, KULeuven)

Different types of silanes, deposition parameters, aging, etc were studied.

Testing methodology

Transverse 3-point bending

Ghosh et al., Optimisation of wet chemical silane deposition …, Applied Surface Science, 2015

Da Ponte et al, Adhesion Improvement …, Plasma Processes and Polymers, 2014
Effect of surface treatments (1)

Wet chemistry treatments (Chemistry Department at KU Leuven)

Developed treatments perform better than those found on the market

Effect on composite failure strain

Effect of treatments on damage development

Damage development is hindered in composites with stronger interface

Other mechanical properties
In-plane properties of UD steel fibre composite laminates

Allaer et al, CSTE 2014

Longitudinal failure strain, $\varepsilon_{11t}^f$ (%) 
Transverse failure strain, $\varepsilon_{22t}^f$ (%) 
$19.15 \pm 0.52$
$0.312 \pm 0.004$

Low velocity impact properties of UD steel fibre composites

- More energy **absorbed** by steel fibre laminate configuration
  - Deformation energy → Plastic behaviour
    → Damage
- Damaged area ± equal for both materials
Penetration impact resistance

M. Callens, L. Gorbatikh, I. Verpoest, Effect of fibre architecture ..., Composite Structures (2014)
Hybrid steel fiber composites
Remaining challenges

- High density
- Low yield strength

Hybridisation with traditional fibres

An increase in strength comes at the expense of the failure strain → optimization is needed
Potential of hybridisation with steel fibres

Hybridisation with self-reinforced PP

- Increase the stiffness of self-reinforced PP
- Without sacrificing the toughness/impact resistance

M. Callens (PhD thesis, KU Leuven)
Conclusions and outlook

- Conclusions
  • Steel fibres \( \rightarrow \) composites with high strain-to-failure

- Ductility can be further improved through modification of:
  • Matrix and interphase
  Hybridisation offers opportunities
  • C- and G-fibres: additional strength, but loss in toughness
  • SRPP: no loss in toughness and higher stiffness than non-hybrid SRPP

- Outlook
  • Effect of the fibre diameter
  • Partially annealed fibres
  • Complex and dynamic loading (fatigue, open hole tension)
  • Multi-functionality
Thank You!