Rationalization of steel based composites

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Main driving forces for steel based composite

- Steel based for mechanical strength
- Functional properties: thermal, electrical, magnetic, chemical
- Specific stiffness
- Damage tolerance

Classification: scale and hybridation

Macro-composites: scale of the combination = scale of the component
Automotive applications

Pillar of a body in white for car industry made by laser welding of an HSLA (high-strength, low-alloy) steel with an ultra high-strength martensitic steel.
Other examples

HARDENED STEEL

WELDING

STAINLESS

strength/conductivity

hardness for piercing/corrosion
Meso-composites
Automotive applications

- Objectives: strong weight saving by specific rigidity improvement with other functions as low thermal and phonic conductivity
- Ways: light core sandwich with steel strips

- Rigidity is improved by 30%

[Usilight-ArcelorMittal]
Other examples

Steel/Aluminium high-voltage cable => strength/conductivity

Magnetic stainless: compatibility with all induction cooktops
Aluminium: heat conduction
Austenitic stainless steel: bio-compatibility
Toughness improvement
Micro-composites: static and dynamic
Multi-phase steels

Classical DP microstructure

Ultra-fine DP microstructure

<table>
<thead>
<tr>
<th>$f_a$</th>
<th>$d_a$</th>
<th>$d$ (µm)</th>
<th>Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.11</td>
<td>1.9</td>
<td>5.2</td>
<td>A</td>
</tr>
<tr>
<td>0.20</td>
<td>2.1</td>
<td>5.0</td>
<td>B</td>
</tr>
<tr>
<td>0.24</td>
<td>2.2</td>
<td>4.7</td>
<td>C</td>
</tr>
<tr>
<td>0.40</td>
<td>3.1</td>
<td>3.8</td>
<td>D</td>
</tr>
<tr>
<td>0.23</td>
<td>1.05</td>
<td>1.1</td>
<td>E</td>
</tr>
</tbody>
</table>
Steel matrix micro-composites

• Objectives :
  – Improved rigidity, weight reduction

• Ways :
  – Increase the Young modulus and decrease the density by the use of ceramic reinforcement (high volume fraction 10-20%) ⇒ increase \(\frac{E}{\rho}\) ratio

• Results with TiB₃ reinforcement
  – With a extra-low-alloyed ferritic matrix + 12%vol. TiB₂
  – TiB₂ precipitation during the continuous casting
  – \(E = 245\) GPa \(\rho = 7,32\) g/cm\(^3\) ⇒ \(\frac{E}{\rho}\) +20%
  – \(UE = 14\%\) \(TE = 21\%\) (good compromise UTS/TE)
Steel matrix composite Fe-TiB$_2$

Good resistance

Good ductility: not common for metal matrix composites

The resistance can be obviously improved using not only a pure ferritic soft matrix
Dynamic composites

316 stainless steel

TRIP effect:
high combination between strength and strain-hardening

Dynamic composites: a simple view

\[ \varepsilon_+ + \varepsilon_- = \varepsilon \]

\[ \sigma = (1 - F) \sigma_1 + F \sigma_2 \]

\[ \frac{d\sigma}{d\varepsilon} = (1 - F) \frac{d\sigma_1}{d\varepsilon} + F \frac{d\sigma_2}{d\varepsilon} + \frac{dF}{d\varepsilon} (\sigma_2 - \sigma_1) \]
Conclusions and prospects

– Driving forces for steel based composites have been determined
– A classification has been proposed based on the hybrid or not hybrid solution combined with the scale of combination
– This work show that meso-scale dynamic composite doesn’t exist
Strain-Hardening Control by Architecture
Motivations (1)

- Work-Hardening is one of the key properties controlling:
  - The formability (locus of necking)
  - Strain and stress fields at crack tip (toughness, tearing resistance)
- But WH decreases with strength

[Bouaziz, Mat. Sc. For. 2009]
Motivations (2)

Low carbon steels used in automotive industry
Motivations (3)

• Architecture could overcome the common limitations related to the combination of contradictory properties
  – density/stiffness
  – density/strength
  – stiffness/toughness
  – ...........

• But what about the strain-hardening?

• For Metal Matrix Composites, the usual shapes of reinforcement are particle or fiber
• Is it the best shape?
Interest of corrugated reinforcement: numerical simulations (1)

[Bouaziz&al., Proc. MRS 2009]
Interest of corrugated reinforcement (2)

- WH can even be an increasing function of strain!!
Experimental illustration of the concept (1): sandwich with corrugated core

- Efficient way to control WH by geometry (to be published)
Experimental illustration of the concept (2) : corrugated laser treatment

Référence

h/P=0.1 : Essai1 (E1)

h/P=0.2 Essai2 (E2)

h/P=0.3 Essai3 (E3)

[Bouaziz, scripta mat., 68, 2013]
Microstructure

Graph showing hardness (HV) vs position en x (mm)

Microscopic images with scale bars indicating 1 mm, 20 µm, and 100 µm.
Tensile tests (1)
Tensile tests (2) : stress-strain curves

- Corrugated thermal treatments by laser change the combination between strength and WH
Conclusions

• The WH can also be mastered by architecture (corrugated reinforcement for instance)

• The concept could be nicely applied to (collaboration with Y. Champion):
  – Metallic glasses
  – Nano-grained metals

• The manufacturing processes of architectured materials have now to be carefully investigated