STEEL BASED COMPOSITES

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Steel-based composites: a long history

Composites can be made through the combination of different steels
Classification: scale and hybridation

- Scale
  - macrocomposite
    - High voltage cables (Fe/Al)
    - Composite pipes
  - mesocomposite
    - Damascus steels
    - Mesoscale multi-layer (steel/stainless)
    - Sandwich (steel/polymer)
    - Co-extruded (stainless/copper, copper/pearlite, Steel/magnesium)
  - microcomposite
    - Graded steels
    - Foams
    - Multiphase steels (pearlite, DP)
    - Dynamic composite (TRIP, TWIP)
    - micro-scale multilayer (Fe-Pt, Fe-Cu, Fe-Ag)

- Fully steel composites
- Steel based multimaterials

Main driving forces for steel based composites

Steel based for mechanical strength

Functionnal properties:
- thermal
- electrical
- magnetic
- chemical

Specific stiffness
Damage tolerance

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
- STAINLESS
- WELDING

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 cables => 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

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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 E/ρ ratio

• Results with TiB₂ reinforcement
  – With a extra-low-alloyed ferritic matrix + 12%vol. TiB₂
  – TiB₂ precipitation during the continuous casting
  – E = 245 GPa ρ = 7,32 g/cm³ ⇒ E/ρ +20%
  – YS = 240 MPa UTS = 530 MPa ⇒ YS/UTS = 0,45 (DP behaviour)
  – 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

\[ \varepsilon = \varepsilon_1 + \varepsilon_2 \]

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

\[ \frac{d\sigma}{d\varepsilon} = (1 - F) \frac{d\sigma_1}{d\varepsilon} + F \frac{d\sigma_2}{d\varepsilon} + \frac{dF}{d\varepsilon} (\sigma_2 - \sigma_1) \]
Recent contributions in hybrid and architectured steel-based solutions
Steel-Magnesium Composite
The main limitation for lightening with steel

- The performance of steel is very high concerning the strength especially including cost
- The situation for specific stiffness is less clear

- Specific stiffness is the same in tension for the main structural metals but less for steel in the case of bending
Why Fe-Mg system?

- Surprisingly Fe-Mg system has been poorly investigated

- Limitations of the composites developed with Al and Ti: formation of brittle intermetallics with iron

- Mg is lighter than Al or Ti

- Mg is immiscible with Fe => no intermetallic

- Limitation: due to the important difference of melting temperatures and the oxidation of Mg a process based on casting is not realistic
Repeated co-extrusion process

- Proposed for the first time by F.P. Levy in 1960
- A very simple principle
- Suitable to produce very fine scale multi-metallic composites
- Very successful applications to produce coils of supraconductors magnets based on Cu-Nb system (Large Hardron Collider, CERN, Switzerland)

First example of Cu-Fe system
Repeated co-extrusion process: application to Fe/Mg system

- Step 1: extrusion of the initial assembly to a diameter of 1 mm
- Step 2: annealing 600°C-2h
- Step 3: second extrusion of 31 firstly extruded bars embedded in a new steel tube

- Final volume fraction of Mg: 24% => density = 6.3
Microstructure

- Multiscale microstructure with highly serrated interfaces

Strain-Hardening Control by Architecture
Motivations

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

[Bouaziz, Mat. Sc. For. 2009]
Interest of corrugated reinforcement: numerical simulations (1)

[Bouaziz&al., Proc. MRS 2009]

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Interest of corrugated reinforcement (2)

- WH can even be an increasing function of strain!!
Experimental illustration of the concept (2): corrugated laser treatment

Référence

h/P=0.1 : Essai 1 (E1)

h/P=0.2 Essai 2 (E2)

h/P=0.3 Essai 3 (E3)

Martensite

DP 600 steel

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Microstructure
Tensile tests (1)
Tensile tests (2) : stress-strain curves

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

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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
General conclusions

• The manufacturing processes of architectured materials have now to be carefully investigated
• A rigourous definition of “architectured materials” is probably required