Stainless Steel in Structures
Fourth International Expert Seminar
6-7 December 2012, Ascot

STAINLESS STEEL IN STRUCTURES IN VIEW OF SUSTAINABILITY

Barbara Rossi – Université de Liège, Belgium
1980-2007, World Population increased by more than 50% & global resource extraction by ~ 62%. About ½ of the forests that once covered the earth has disappeared. Human activity ➞ escalating impact on biodiversity of world ecosystems, reducing both their resilience and biocapacity.

IPCC : Intergovernmental Panel on Climate Change “Global warming is caused by increasing concentrations of greenhouse gases (GHG) produced largely by forest clearing and the burning of fossil fuels.” Many consequences: rise of sea levels, change of precipitation, expansion of subtropical deserts, retreat of glaciers, changes in agricultural yields…
Sustainable development

Sustainability (Latin *sustenere*) is the capacity to endure.

In 1987, the UN-sponsored Brundtland Commission released *Our Common Future*, a report that captured widespread concerns about the environment and poverty in many parts of the world.

It popularized the term *sustainable development*, which it defined as *development that meets present needs without compromising the ability of future generations to meet their own needs*.

It is usually related to “the three pillars”: sustainable development is at the intersection of social, environmental and economic development.
The construction sector is a vitally important sector manufacturing the built environment and putting in place a physical stock of facilities and infrastructure that determines our degree of freedom and flexibility for anything up to 100 years after construction” (Agenda 21, International Council for Local Environmental Initiatives ICLE).

- Estimated construction investment (EU 27 - 2011) : 1.208 billion €
- 9.6% of GDP
- 3.1 million enterprises (EU 27), of which 95% are SMEs with fewer than 20 operatives
- 14.6 million operatives representing 7% of Europe total employment
- 43.8 million workers in the EU depend, directly or indirectly, on the construction sector
The construction sector

Worldwide, 30-40% of all primary energy used in buildings is for operation (heating, cooling, electricity), entertainment and work equipment.

3 billion tonnes of raw materials – 40-50% of the total flow in the global economy – used in manufacture of building products.

30% of the world total number of lethal accidents happen on a construction site.

Responsible for 20% of the water use and 30-40% of global GHG emission in each country.

Construction and demolition waste = 30-50% of total waste generated in higher income countries.
Sustainable Construction – Stainless steel in buildings

Used for its aesthetic properties in minor building components than façades/roofing cladding or highly glazed systems, many possibilities of finishes, shape & grades...too many?
Sustainable Construction – Stainless steel in buildings

Example: LEED – U.S. Green building council

- « cool roof & façade systems » i.e. high Solar Reflectance Index
- powerful against air leakage/infiltration

But also (in summary for several systems)

- low roof runoff => valuable non-potable water
- high recycled content
- high recovery rate
- in-situ reuse of materials
- deal for upgrade of façades => Extension of life
- waste management on construction site
- robustness => fire

Int for:
- Material longevity & long-term appearance
- Subsequent low maintenance
- Off-site/dry construction
- No VOC emissions (points are awarded to materials with low VOC)
Sustainable Construction

Sustainability concerns the whole cycle of construction i.e. from raw material acquisition, through planning, design, construction and operation, to final demolition and waste management. This can be divided in stages, each of them equally important in regard to sustainability.
Sustainable Construction – Stainless steels opportunities

**Design stage:**
- Material avoidance ➤ slender, lighter
- Better knowledge of mech. prop. such as resistance to high temperature
- ➤ decrease embodied impacts
- Future adaptability: column free spaces/large spans allow flexible use of space

**Execution stage:**
- High degree of prefabrication & Dry/dust free construction ➤ Safer work conditions

**In-use stage:**
- Thermal point of view: high reflectivity, powerful against air leakage and infiltration, strength for highly glazed façade, easy installation of ren. energy system (development of coatings involving PV cells)
- ➤ decrease operational impacts
- Healthy indoor environment, odourless, hygienic...
- Reduced maintenance

**End-of-life stage:**
- Definitely recyclable
- No change in its properties
- Possible cleaning of façades
- Easily upgraded envelope (over-clad and over-roofed enveloppes ➤ reduce cool bridge and enhance...
Sustainable Construction – Stainless steels opportunities

**DESIGN**

- Importance of Embodied acts versus Operational impacts is ever – increasing in LCEA.
- Importance of materials avoidance in design and methodologies for inclusion cycling into LCA.

**DURABILITY**

- Corrosion resistance: stainless steel can sometimes be THE alternative.
  - Ex. rebar in concrete structures in corrosive environments (coastal bridges) or structures in atmospheres containing chlorides when regular cleaning is not possible.
- Fire resistance: austenitic stainless steel structural members retain their load-carrying capacity for a longer time than carbon steel equivalents thanks to higher strength and stiffness retention factors at temperatures above 500°C.
- Good energy absorption characteristics.

**ROBUSTNESS**

- Higher strength, lower thermal expansion, not prone to stress cracking, localised corrosion depends on the nickel content.
- Higher strength, for corrosion resistance enabling lighter structures.
  - 1.4162 lean duplex low nickel content.

**STAINLESS STEEL IN STRUCTURES – 4TH INTERNATIONAL EXPERT SEMINAR**

B. Rossi
Valuable research activities on the structural behaviour of stainless steel in sustainable construction - have been achieved in universities around the world” N. Baddoo

Material model ➤ Rasmussen, Mirambel & Real, Gardner, Talja & Hradil...

Section properties ➤ Quach, Gardner, Cruise, Jandera, Rossi...

Design of structural members: Inclusion of new grades in standards, DSM, CSM, GBT ➤ Lecce & Rasmussen, Becque & Rasmussen, Rossi & Rasmussen, Camotim, Gardner, Ashraf, Theofanus, Young...

New grades especially with low nickel content ➤ Baddoo, Cashell, Rossi, Young, Vellasco...

Behaviour under fire conditions ➤ Franssen, Lopes, Baddoo, Manninen, Gardner...
Test programme combined with existing measured stress-strain data on cold-formed stainless steel sections ➞ Predictive model for harnessing the strength increases in cold-formed sections as a result of plastic deformation during fabrication.

New DSM equations for distortional, local and local-overall buckling of stainless steel members in the low slenderness range based on existing DSM equations for stainless steel members.
Life cycle inventory of stainless steel products

- Stainless steel scrap content ~ 60%
- Stainless steel in buildings recovery rate > 90%
Recycled material replaces primary stainless steel ➪ save resources and decrease the environmental impacts

Easy to take into account during LCA using closed-loop recycling methodology i.e. end-of-life credits taken into account in the LCI

Important parameters:

- Recovery rate RR: global EOL RR ~90%
- Y: 1kg of scrap ➔ less than 1kg of material
- R : quantity of material produced
- k: ratio of scrap to scrap
- m: number of cycles n

"cradle to cradle": module D “Benefits and loads beyond the system boundary” in EN 15804 allows credits to be taken now for the eventual reuse or recycling of material in the future.
Life cycle inventory of stainless steel products

If $X_{\text{prim}} = \text{LCI for primary production}$
And $X_{\text{sec}} = \text{LCI for secondary production}$

1/ Total LCI
\[
\text{LCI} = X_{\text{prim}} + Y.(RR).X_{\text{sec}} + \ldots + (Y.(RR))^{n-1}.X_{\text{sec}}
\]

2/ Total mass of material produced
\[
M = 1 + Y.(RR) + \ldots + (Y.(RR))^{n-1}
\]

⇒ Total LCI per kg:
\[
X = \frac{\text{LCI}}{M} = \frac{(X_{\text{prim}}-X_{\text{sec}}).Q+X_{\text{sec}}}{(1-Y.RR)/(1-(Y.RR)^n)}
\]

where $Q = (1-Y.RR)/(1-(Y.RR)^n)$

If $n \rightarrow \infty$ :
\[
X = X_{\text{prim}} - Y \cdot RR \cdot (X_{\text{prim}}-X_{\text{sec}})
\]
cycle inventory of stainless steel products
cycle inventory of stainless steel products

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including remarks

Former times: not known & expensive material, difficult to specify, unusual mechanical properties not exploited to their maximum.

Today: combination of several intrinsic properties: strength, corrosion resistance, aesthetics, formability... making possible a more sustainable construction

› All in all: Lighter & more durable structures.

Overview of lifecycle analysis increasing importance of embodied impacts (material avoidance), LCC analysis & methodologies for EoL credits.

Minor building components, urban furniture (China, India...)

Façades and roofing cladding

Structural parts for highly glazed envelopes (tension rods, cabled stayed)

Connections for timber structures

Rebar

Masonry supports

Arches in bridges

What's next?
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Many thanks for your attention

Barbara Rossi – Université de Liège, Belgium
Recycling (in this case, recycling) usually involves secondary production steps. Recycling converts waste materials to new materials of lesser quality and reduced functionality.
Including remarks

Sustainable construction is more than what we have done so far

- Stable to current and future loading conditions
- Increase longevity of constructions with a wiser choice of materials (durability) and designs (future adaptability)
- Reduce our impacts with less operational impacts & greener materials
- Reduce costs on the basis of lifecycle cost analysis
Section properties

Test programme on 18 cross-section geometries (SHS, RHS & CHS) covering a range of stainless steel grades: austenitic (1.4301, 1.4571 and 1.4404), ferritic (1.4509 and 1.4003), duplex (1.4462) and lean duplex (1.4162) – and one structural carbon steel grade (S355J2H).

Combined with existing measured stress-strain data on cold-formed stainless steel sections.

Predictive model for harnessing the strength increases in cold-formed sections as a result of plastic deformation during fabrication.
Design of members using the DSM

Based on existing DSM equations for stainless steel members.

Conventional approaches propose a yield limit at the level $A \times \sigma_{0.2}$ to be used for slenderness values smaller than a threshold value.

Instead, a linear expression relating the cross-section resistance to the slenderness $\lambda$ is proposed.

A compression level equal to $\sigma_u$ is assumed to be attained as the slenderness approaches zero.

Underlying assumption: the material strength in compression is the same as the material strength in tension.
Design of members using the DSM

Reference test results ➔ stainless steel square, rectangular, channel and lipped channel cross-section columns

• *Distortional* – 186 points: Lipped channel with or without intermediate stiffeners made of austenitic 1.4301 (UNS30400) and 1.4318 (UNS30103) & ferritic 1.4003 (UNS41003) and 1.4016 (UNS43000) grades.

• *Local* (111 points) & *Local-Overall* (200 points): SHS, RHS, plain and lipped channel made of austenitic 1.4301 (UNS30400) and 1.4318 (UNS30103) & ferritic 1.4003 (UNS41003) and 1.4016 (UNS43000) grades.
Design of members using the DSM

Cross-section resistance, Local buckling

Four grades involved → four proposed modified DSM curves

- DSM
- Prop. DSM - 1.4301 [X]
- Prop. DSM - 1.4318 [x]
- Prop. DSM - 1.4016 [O]
- Prop. DSM - 1.4003 [°]
- Gardner/Kuwamura/Talja&Salmi 1.4301
- Kuwamura 1.4318
- Becque 1.4016
- Becque 1.4003