COLD-WORKED AUSTENITIC STAINLESS STEELS (CWASS) IN PASSENGER RAILCARS AND IN OTHER APPLICATIONS

Stainless Steel in Structures:
Fourth International Experts Seminar
6-7 December 2012, Ascot, UK

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AWS Committee on Structural Welding, S/C on Stainless Steel

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CWASS in passenger railcars and in other applications

- **INTRODUCTION**
- **PASSENGER CARS**
  - HISTORY
  - MATERIALS
  - WELDING
  - DESIGN
  - FABRICATION
  - QUALITY
- **OTHER APPLICATIONS**
- **CHALLENGES**
- **CONCLUSION**

Bombardier Overview

Corporate office based in Montréal, Canada

Workforce of 70 000 people worldwide

60 countries

76 sites

Revenues of $18.3 bn US

Listed on Toronto Stock Exchange (BBD)

For fiscal year ended January 31, 2011

CWASS in passenger railcars and in other applications

© Joseph-Armand Bombardier Museum

Joseph-Armand Bombardier (1907 – 1964)
Founder of Bombardier Inc.

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CWASS in passenger railcars and in other applications

(Joseph-Armand Bombardier Museum)

Auto-neige B-12 1941 Total of 7000 made

CWASS in passenger railcars and in other applications

(Bombardier)

What have the snowmobiles to do with stainless steel railcars?

Ski-Doo MX Z-REV Edition 007 (James Bond - Die another day)

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From snowmobiles to railcars

Bombardier plant, La Pocatière, Québec, Canada
1974: Montréal subway contract for 423 cars

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Bombardier plant, La Pocatière, Québec, Canada

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CWASS in passenger railcars and in other applications

(Arnaud Munoz)

Sunset over St-Lawrence River, La Pocatière, Québec, Canada

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Contract for 825 stainless steel subway cars for New York City: 1982

CWASS in passenger railcars and in other applications

(Hagley Museum & Library)

Edward Gowan Budd (1870 – 1946)

Founder of Edward G. Budd Mfg. Co.

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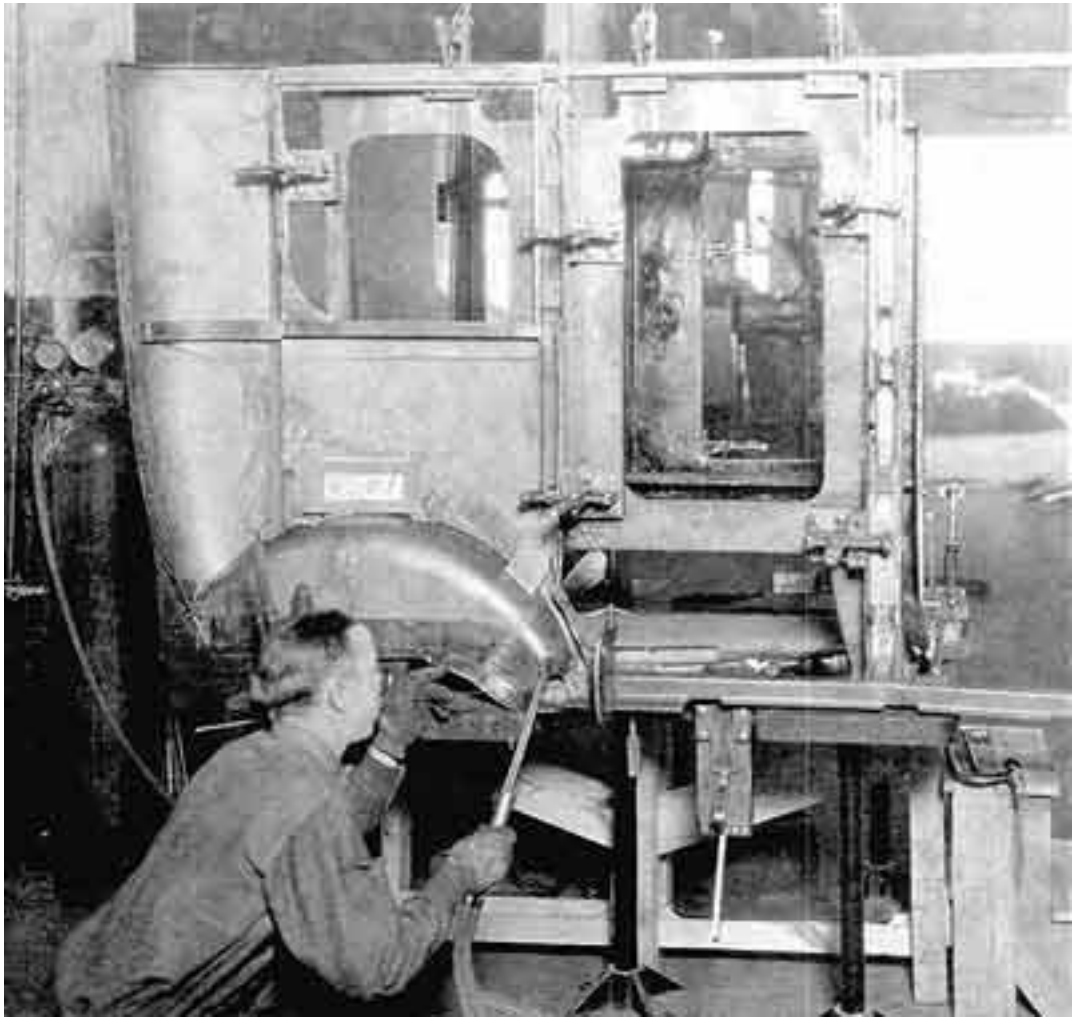
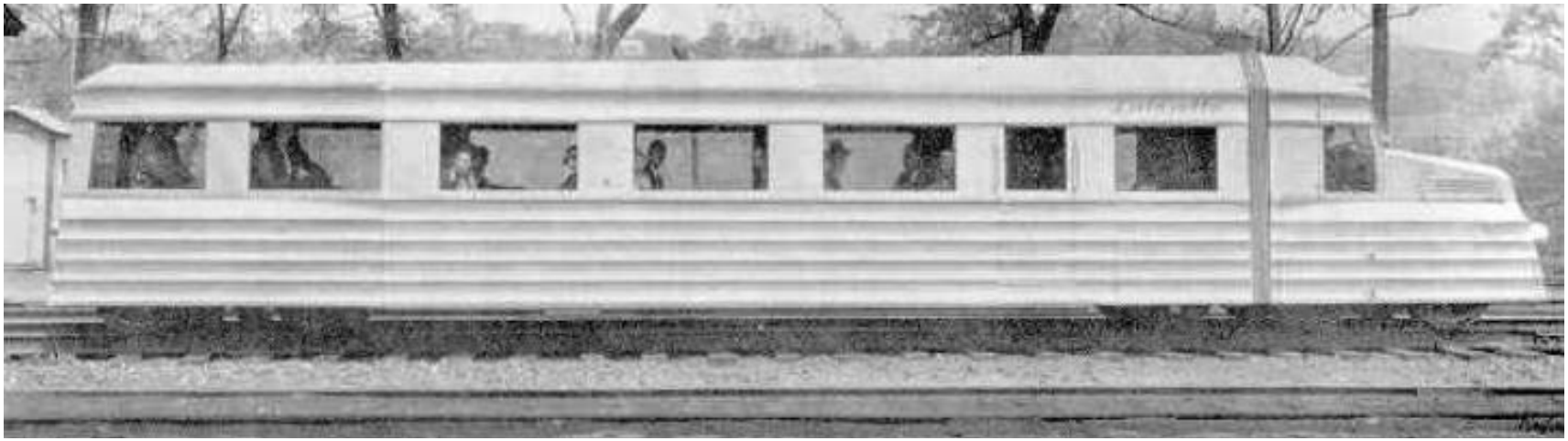


(Coachbuilt encyclopedia)

CWASS in passenger railcars and in other applications



Lafayette - self-propelled stainless steel rail vehicle on tires, 1932

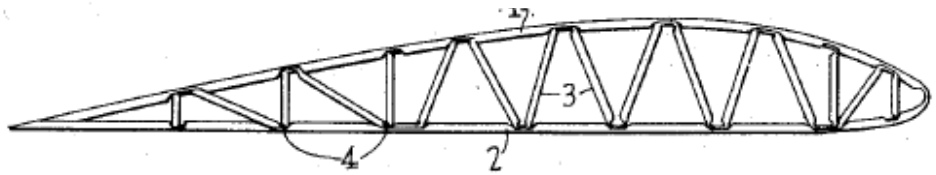
CWASS applied 80 years ago

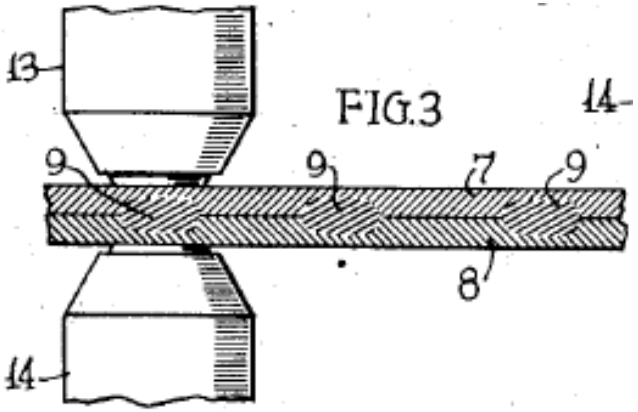
CWASS in passenger railcars and in other applications

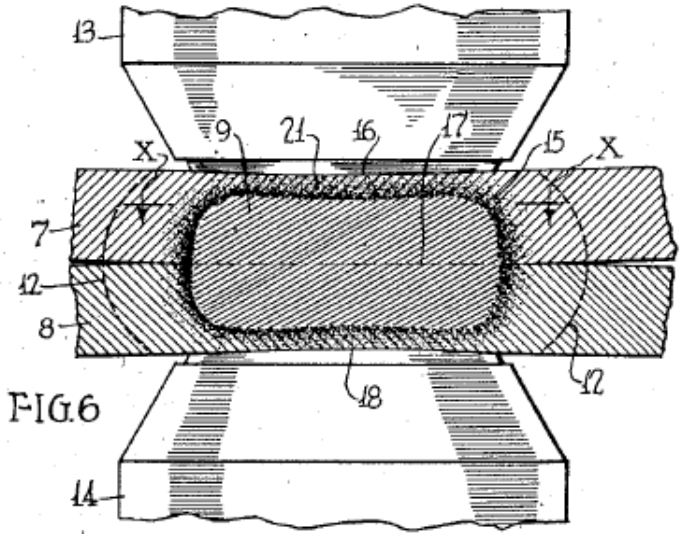
Jan. 16, 1934. E. J. W. RAGSDALE 1,944,106

METHOD AND PRODUCT OF ELECTRIC WELDING

Original Filed Aug. 20, 1932







“Shotweld”: short-time resistance spot welding process

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CWASS in passenger railcars and in other applications

(Hagley Museum & Library)

Zephyr train

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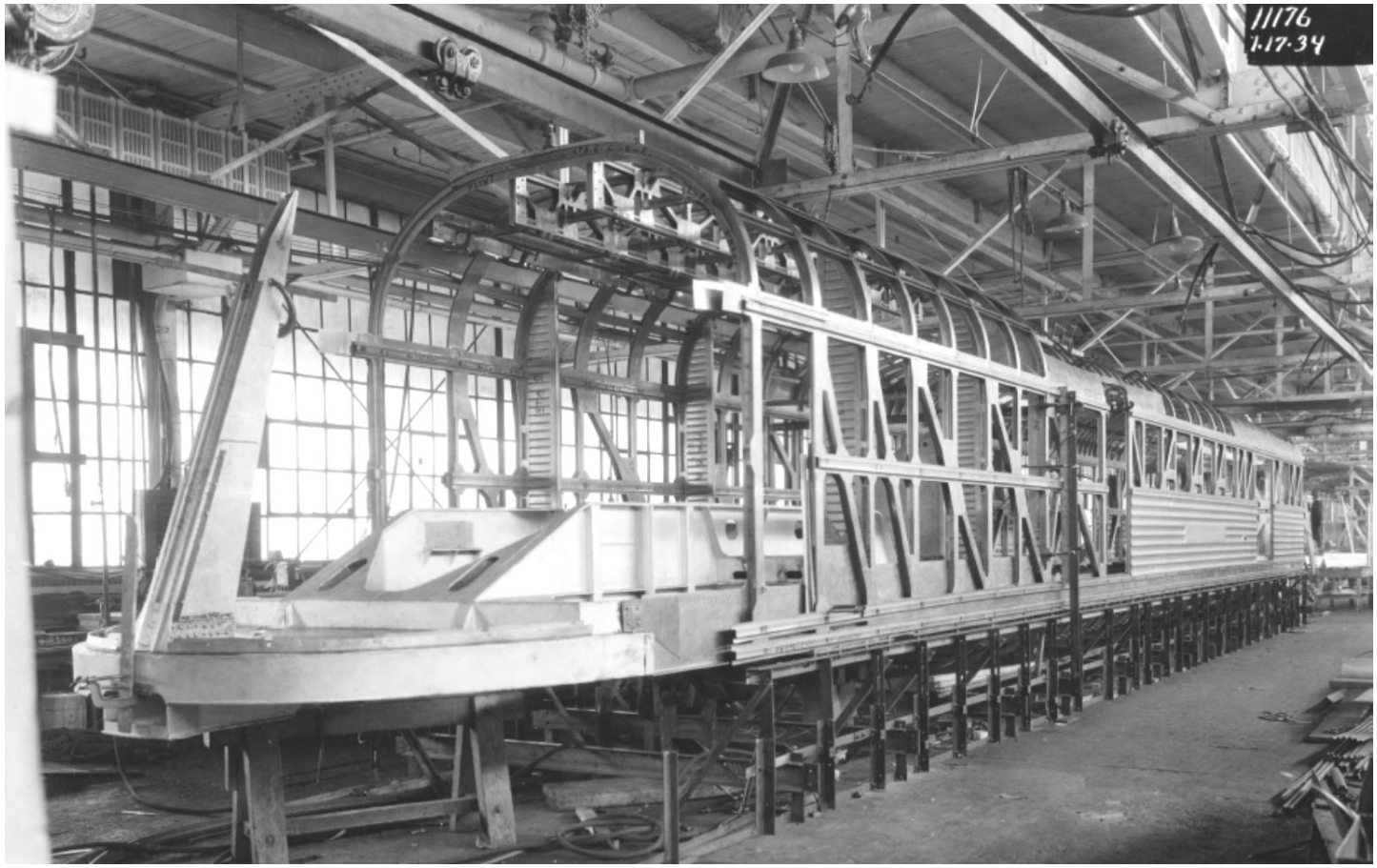
CWASS in passenger railcars and in other applications



(Hagley Museum & Library)

Zephyr in production

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CWASS in passenger railcars and in other applications

(Hagley Museum & Library)

CWASS in passenger railcars and in other applications

Non-stop ride Denver – Chicago: 1633 km, average 124 km/h, max 181 km/h

Arrival at Chicago World's Fair, May 26, 1934

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Pullman, USA

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CWASS in passenger railcars and in other applications

Japan 1962 (Budd's license)

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CWASS in passenger railcars and in other applications

Japan now

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India

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Australia: about 2000 stainless steel cars, 80% of the total passenger railstock

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Sweden

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CWASS in passenger railcars and in other applications

(Nickel Institute)

Eurotunnel shuttle. The locomotive is of the standard size.

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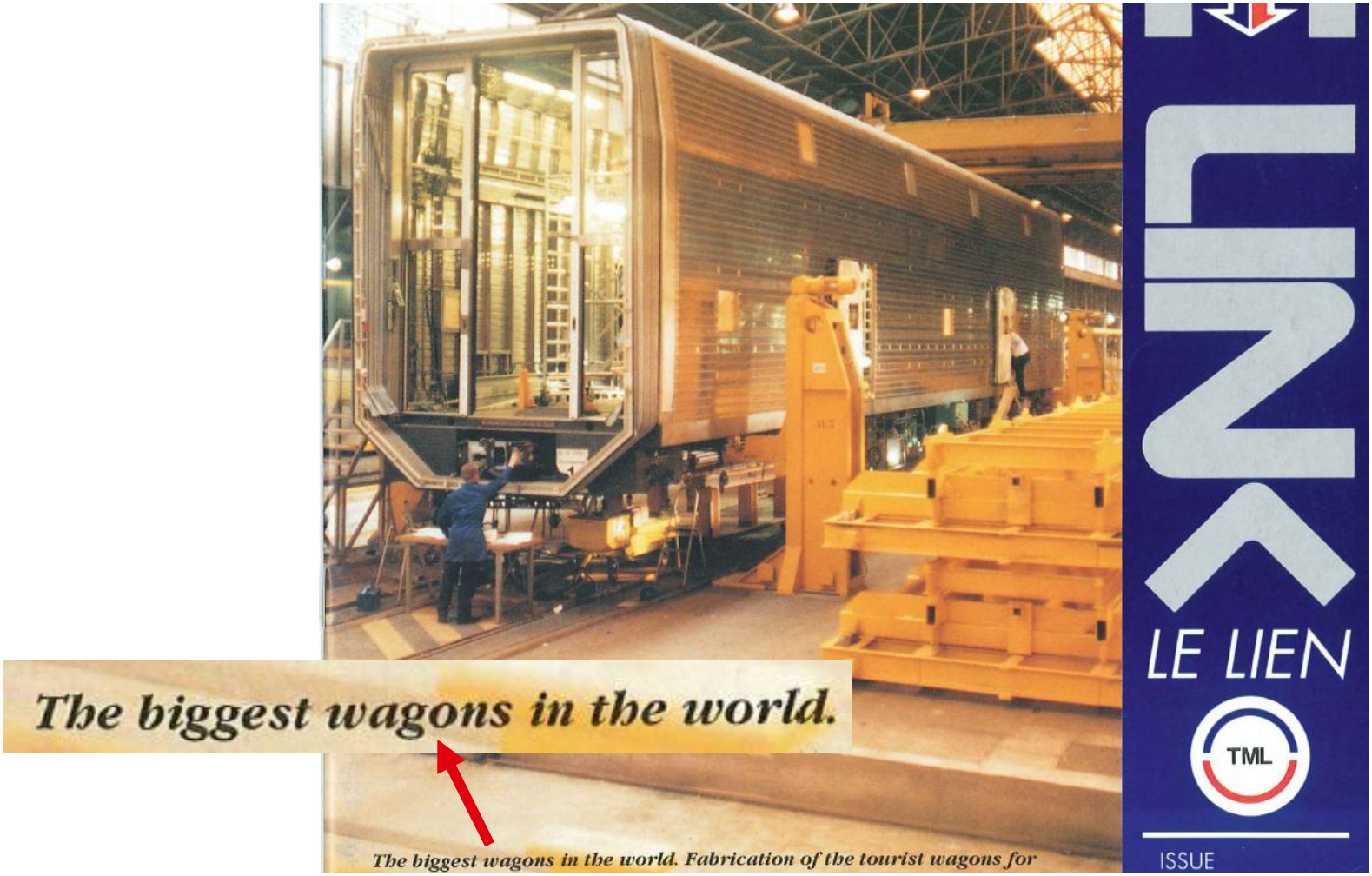

(TML Link)

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MATERIALS

Element % wt.	Stainless Steel Grades			
	Allegheny (Budd) 18-8	304 (ref.) (1.4301)	301L (1.4318)	201LN (1.4371)
C	0,12	0,08	0,03	0,03
Cr	17,0 min	18,0-20,0	16,0-18,0	16,0-17,5
Ni	7,0 min	8,0-10,5	6,0-8,0	4,0-5,0
Mn	0,2-2,5	2,0	2,0	6,4-7,5
Si	0,2-1,5	0,75	1,0	0,75
Cu	0,5	-	-	-
N	-	0,10	0,20	0,25

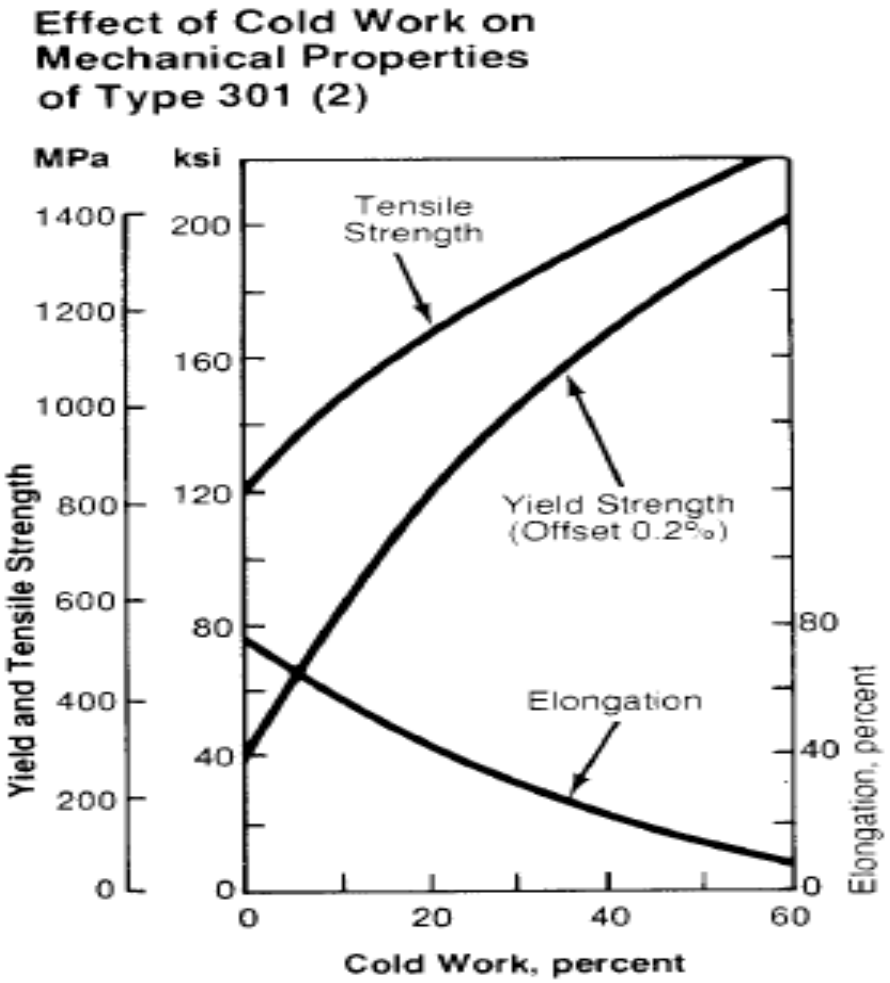
Maximum contents, unless otherwise specified.

Mechanical Properties

Cold working: significant increase in strength;

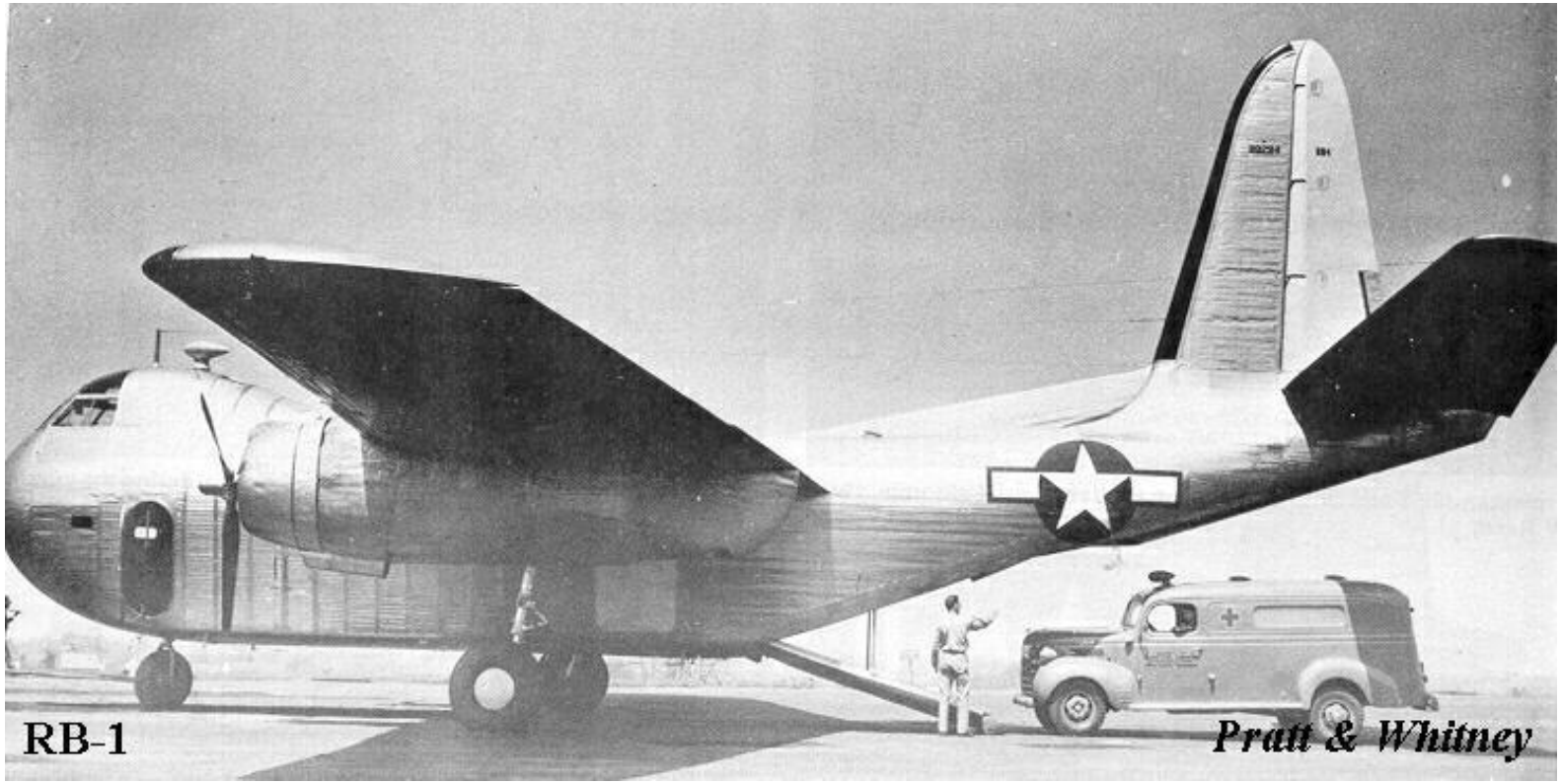
ASTM A 666, EN 10088-2

Passenger railcars fabrication is the principal application area for CWASS.



Nickel Institute Publication 9014

CWASS in passenger railcars and in other applications



(Wikipedia)

CWASS have a high strength-to-weight ratio = lightweight materials.

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CWASS in passenger railcars and in other applications

RB-1 Conestoga, PIMA Museum, Tucson, AZ

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CWASS in passenger railcars and in other applications

RB-1 Conestoga, PIMA Museum, Tucson, AZ

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CWASS in passenger railcars and in other applications

(Nickel Institute)

CWASS are strong and ductile = good crashworthiness

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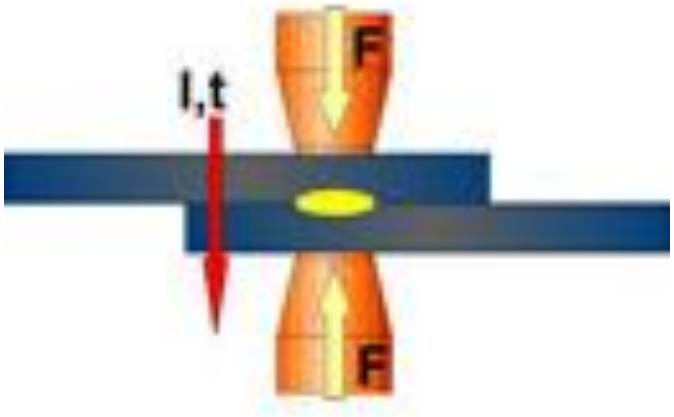
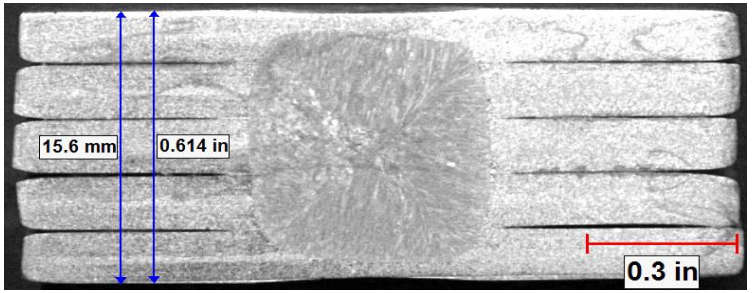
WELDING PROCESSES

Resistance spot welding



Austenitic stainless steels: a perfect material for resistance welding:

- High electric resistivity
- Low thermal conductivity
- No gamma-alpha transformation – ductile welds and HAZ.

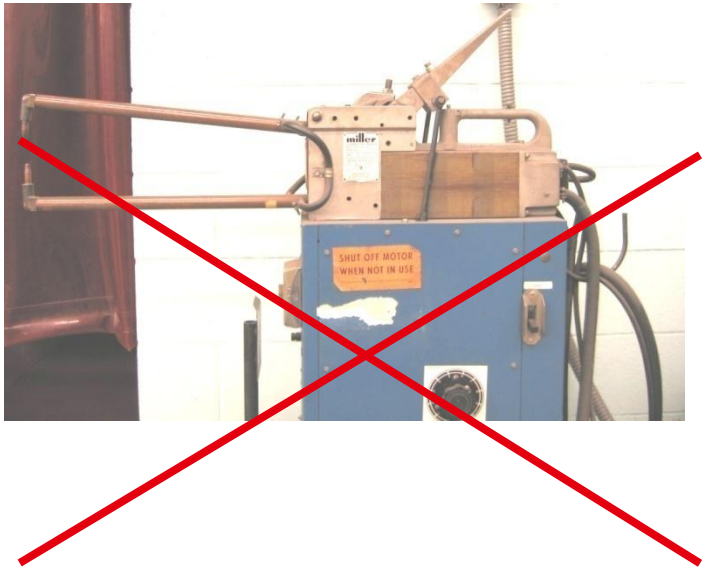


Total of 15,6 mm

- Possibility of welding multiple combinations and large thicknesses

CWASS in passenger railcars and in other applications

Equipment



Stationary - commercial

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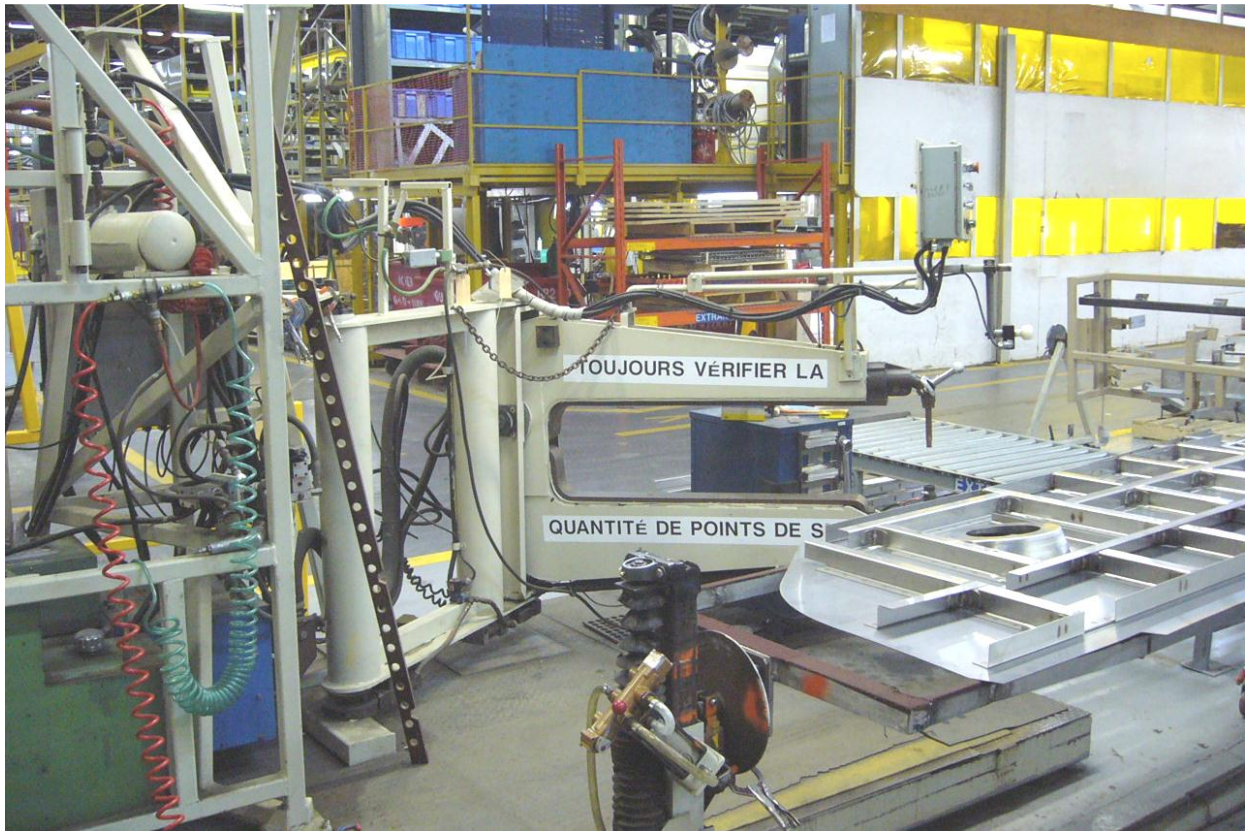
CWASS in passenger railcars and in other applications



Special equipment - large mobile gun for welding panels

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Gantry system for welding roof and side panels

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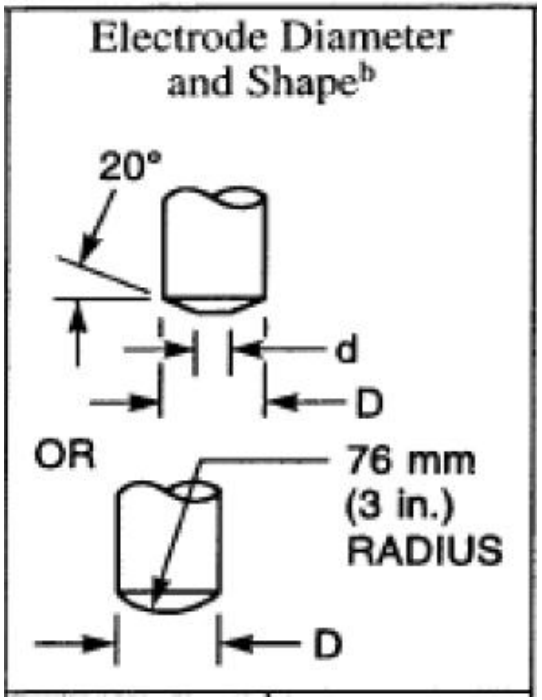
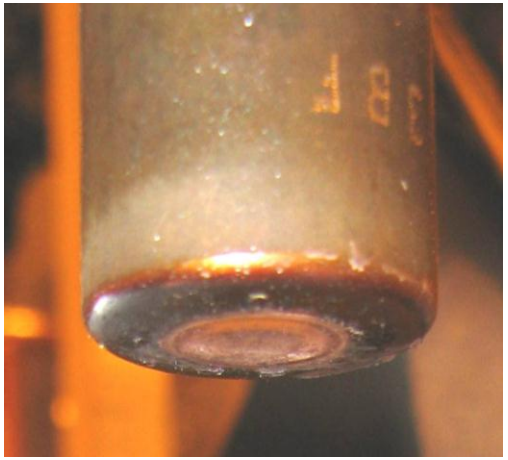
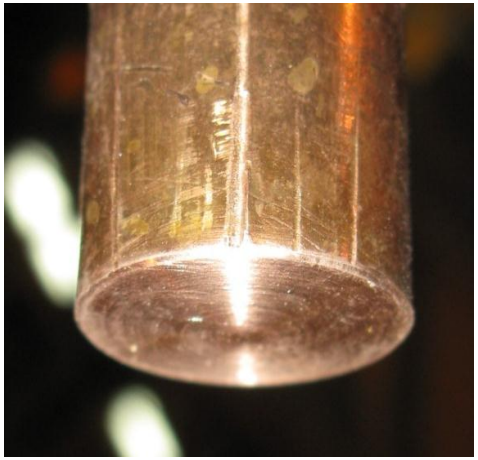
Electrodes



AWS C1.1 Specification





Material: alloyed copper

Large diameters, up to 25 mm

Spherical contact surface preferred

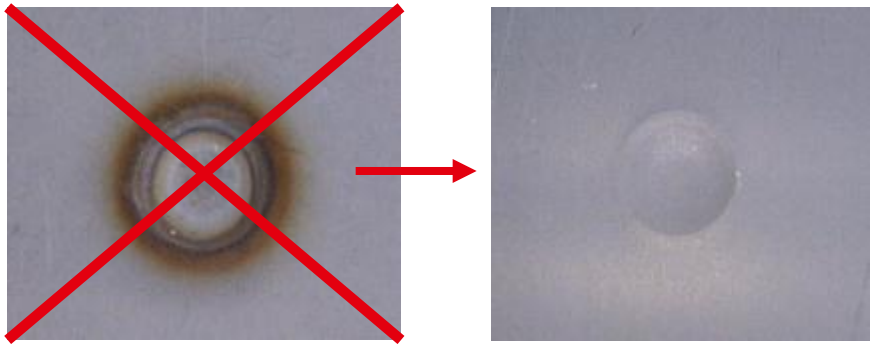
Regular cleaning and replacement

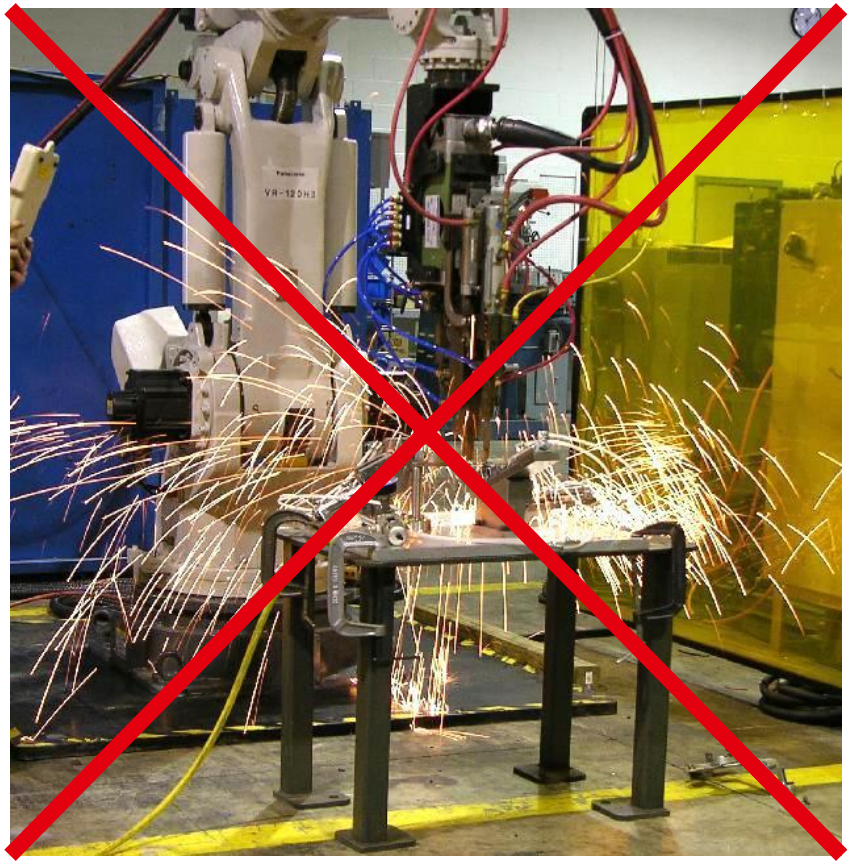
QUALITY

Every weld is important.

General requirements:

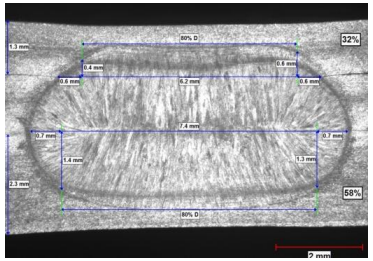
- **No nugget expulsion.**
- **Indentation: shallow and uniform.**
- **No heat tint at exposed surfaces.**



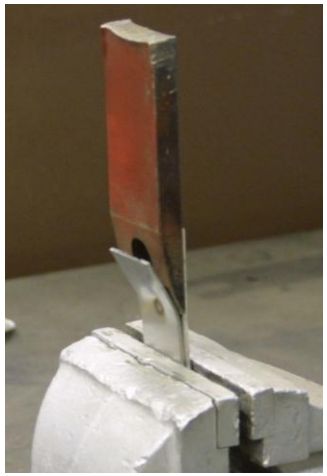


Welding Procedure Specifications

- Limits of nugget diameter, penetration and discontinuities.
- Qualification tests: tension, macros, chisel, torsion



Macrographic examination



Chisel test

Tension-shear test

Very strict production quality control

ARC WELDING

- GMAW (MAG, 135); GTAW (TIG, 141; mostly arc spot welds)
- Limited application
- Stainless to stainless and stainless to HSLA steels joints
- No metallurgical problems
- Challenges:
  - Distortion
  - Heat tint
  - Viscous molten metal
- Low heat input required

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Fumes extraction (Cr_{VI})

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LASER WELDING: XXIst century technology

- Process at the beginning in railcars fabrication
- No more spot welds indentations, high speed
- Major paradigm shift in design and fabrication
- Important challenges
  - If it works: great success
  - If it doesn't: major failure

DESIGN

Yield strength Stainless steels:

A666/EN10088-2

- **515/500 MPa**
- **700 MPa**

HSLA steels:

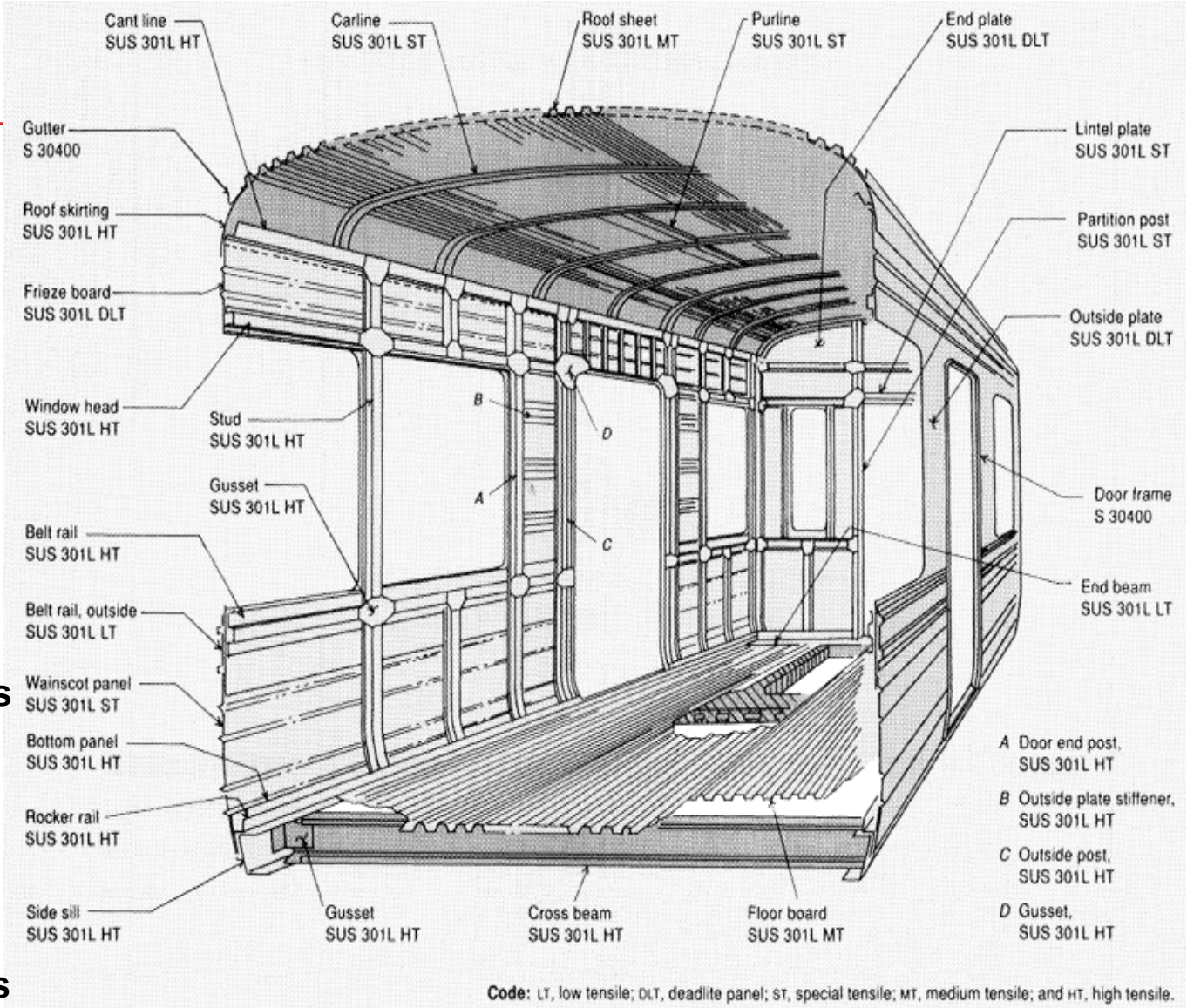
up to 700 MPa

Weight

- **St. Steel: 5-10 tons**
- **HSLA steel: 4-8 tons**

Carbody tests:

- **Compression**
- **Vertical load**
- **Diagonal jacking**
- **Hundreds of gauges**



Nickel Institute publication 14025

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Strength of welds

Resistance spot welds

- Tensile-shear strength: AWS C1.1, AWS D17.2

Arc welds

- Undermatching strength
- Joints properties established through testing

Undermatch has always been there.

It is accounted for in stress analysis.

Not a major design challenge – butt joints in tension are rare.

FABRICATION – primary parts

Cutting

- Straight cuts: guillotines
- Complex shapes: mostly laser, sometimes plasma

Bending and forming

- Easy bending and roll-forming even in cold worked condition (700 MPa yield: R = 2t in both directions

Constant care

- Avoidance of contamination and scratches

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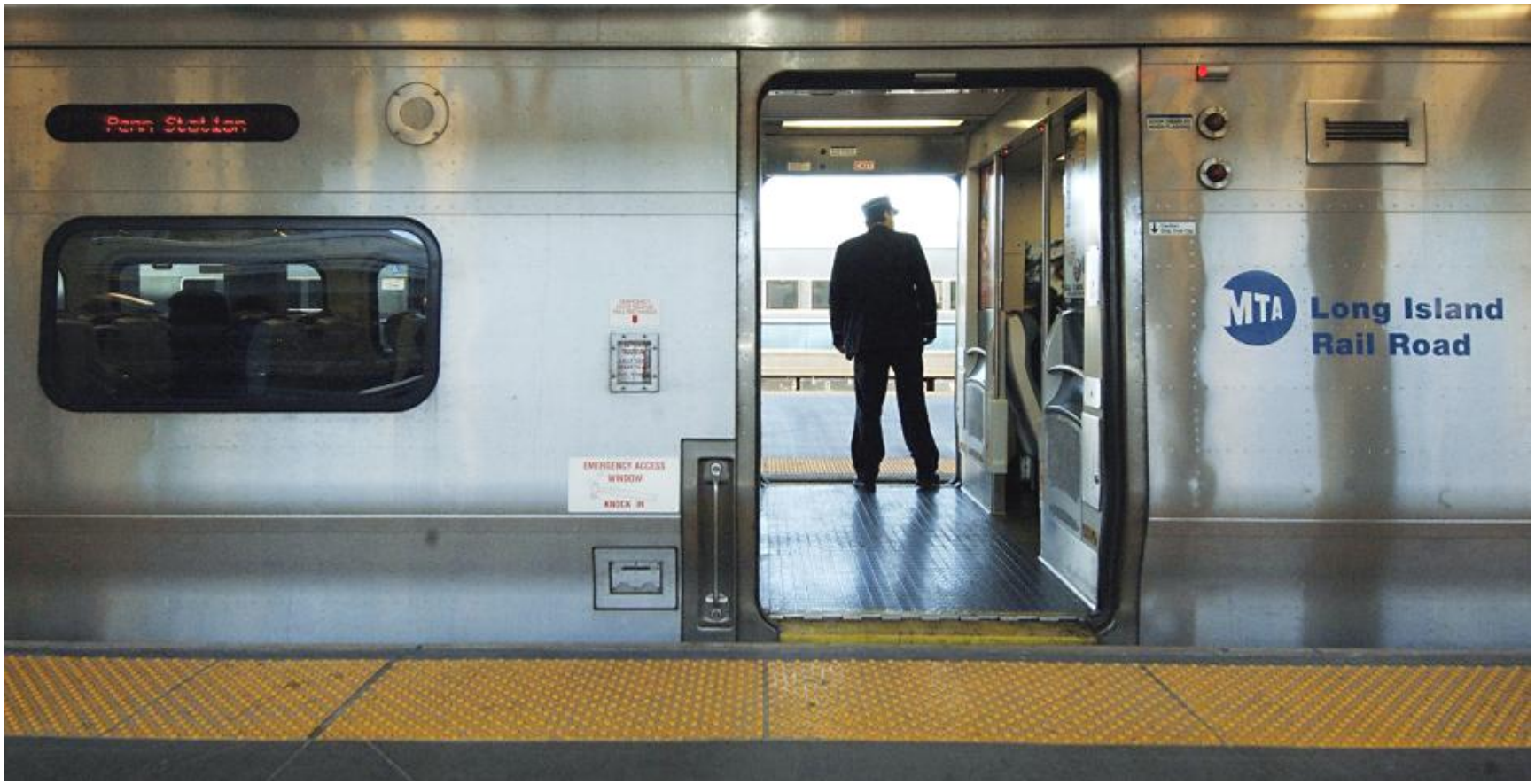
Nice clean shiny objects; one smaller, the other quite large…

CWASS in passenger railcars and in other applications



Final station

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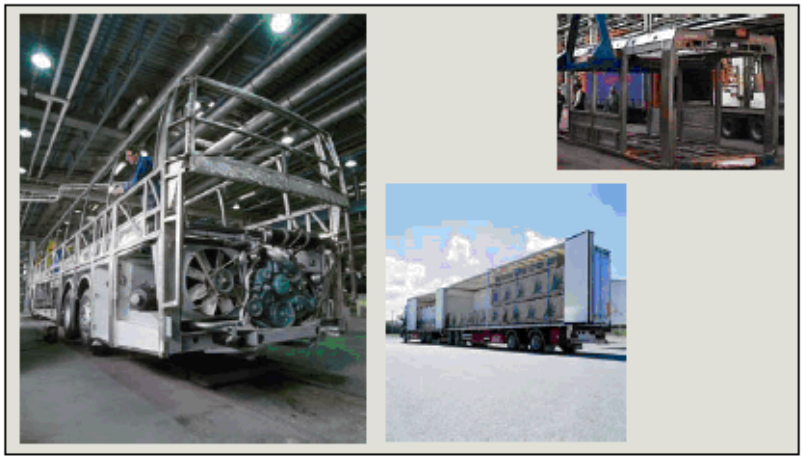
CWASS in passenger railcars and in other applications

Welded HSS: TIG, laser, high frequency

Stalatube Oy

CWASS in passenger railcars and in other applications



Pekka Yrjölä, Finnish Constructional Steelwork Association, INSAPTRANS presentation / Stalatube Oy

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Longwood Gardens, Pennsylvania, USA/ Stalatube Oy

CWASS in passenger railcars and in other applications

Lighting poles, 201LN (1.4318), Millerbernd Mfg. Co., USA

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CWASS in passenger railcars and in other applications

Beer keg: high-strength 304 (1.4301)
Aperam

CWASS in passenger railcars and in other applications

Outokumpu/Nordic Tank

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CWASS in passenger railcars and in other applications

Outokumpu/Briab

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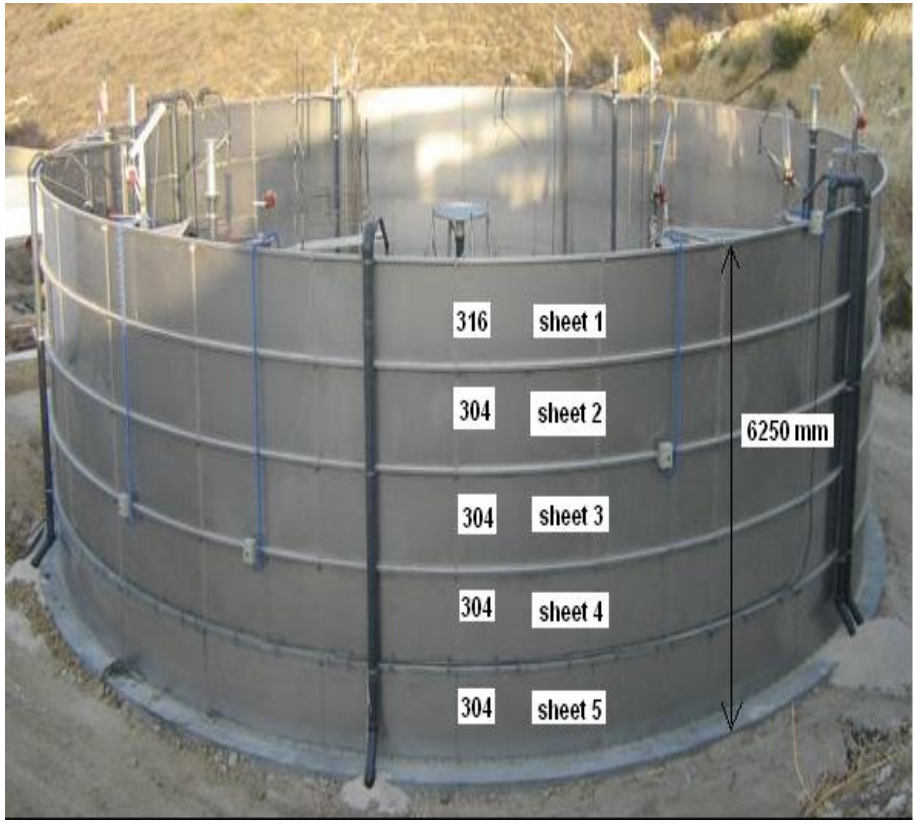
CWASS in passenger railcars and in other applications

ISO standard tank container, about 1800 kg of 316 steel

(Wikipedia and ref. Groth)

CWASS in passenger railcars and in other applications



The circumference of the fermenter: +/-100 m.

The upper ring: 316 (corrosive vapors).

CWASS, Re = 530 MPa instead of 275 MPa.

Quantity reduced from 17 ton to 11.5 ton.

Material cost reduced by 40%.

Aperam

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Ford Tudor 1936 (Wikipedia)

CWASS in passenger railcars and in other applications

1981 DeLorean DMC12 (Wikipedia)

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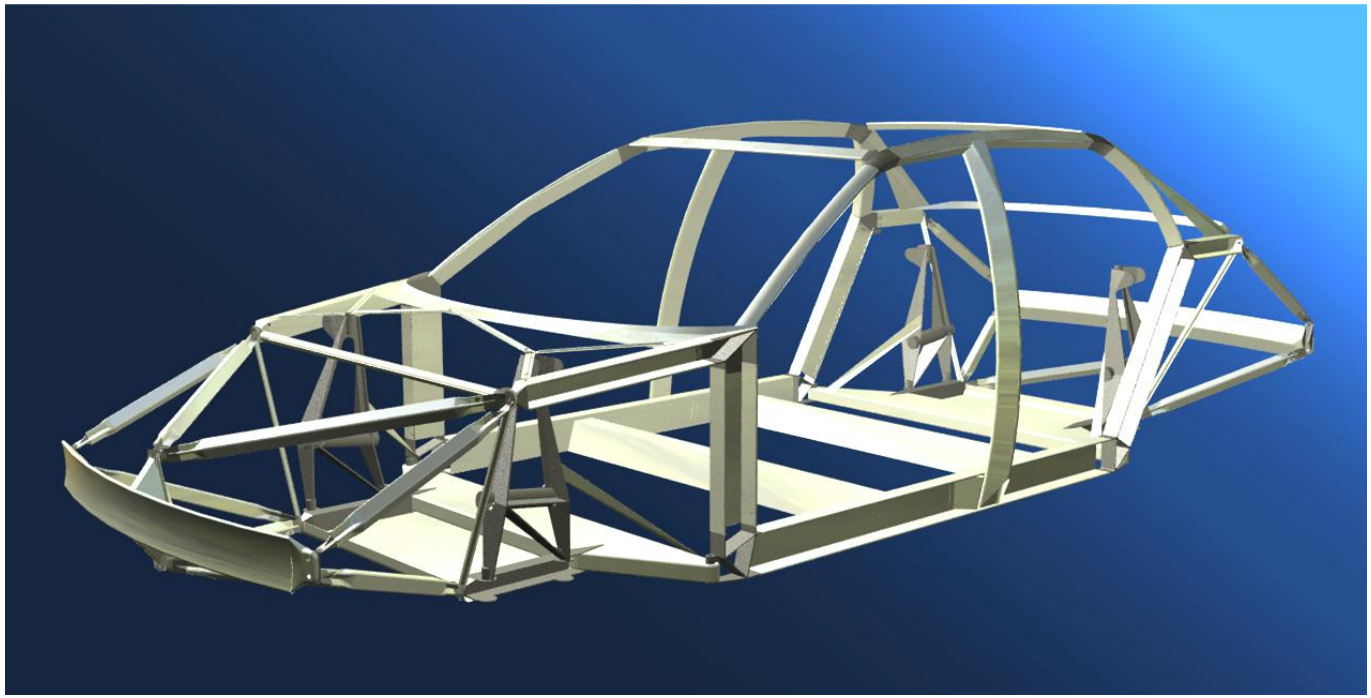
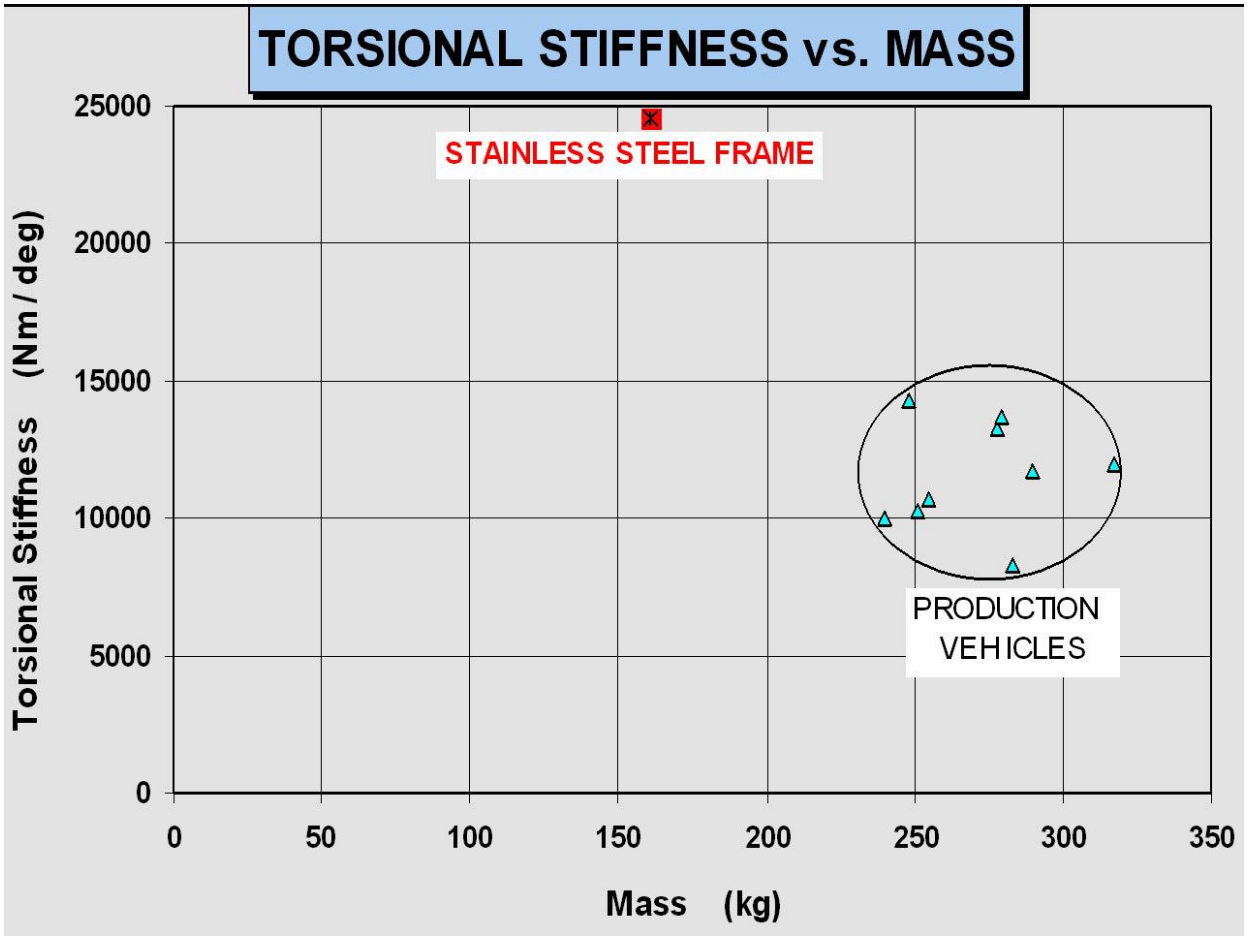


Modular Vehicle Frame, US Patent 5 882 064, Autokinetics, USA

Crashworthiness and cost: better than carbon steel body

CWASS in passenger railcars and in other applications



Modular Vehicle Frame, Autokinetics

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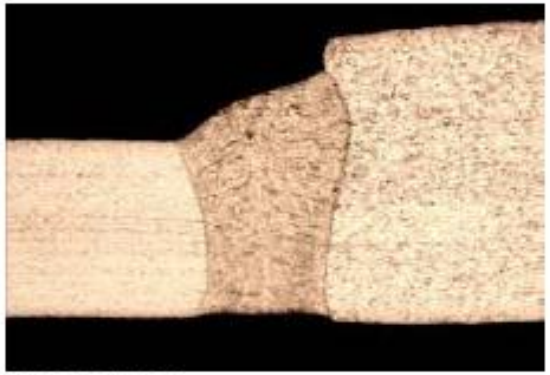
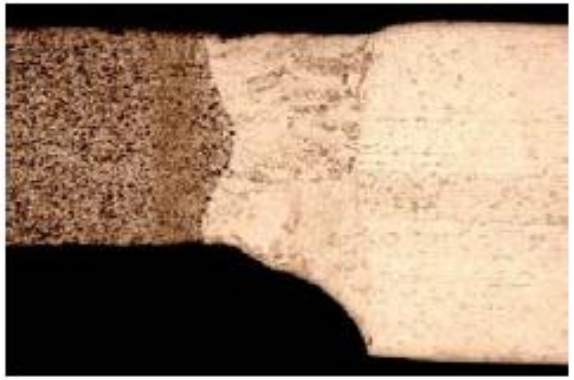
CWASS in passenger railcars and in other applications



H400-H400



HXT600X+Z-1.4318c

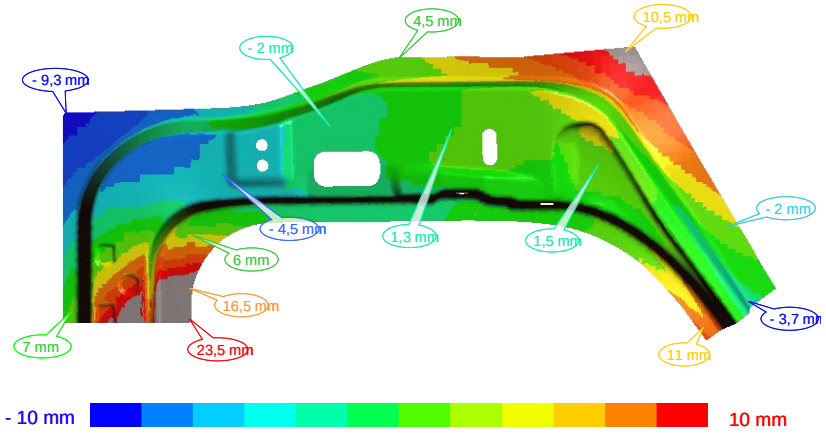
1.4318C1000 - DP600ZE

Next Generation Vehicle Project – Schuberth

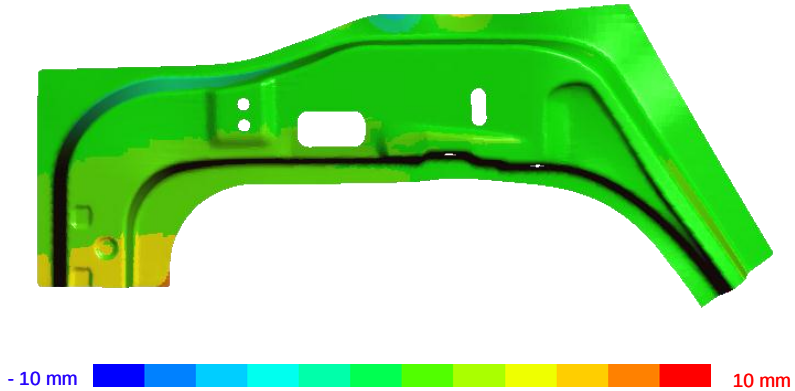
Laser-welded coiled blanks

CWASS in passenger railcars and in other applications

Original springback



Springback after die compensation



NGV Project - Aperam

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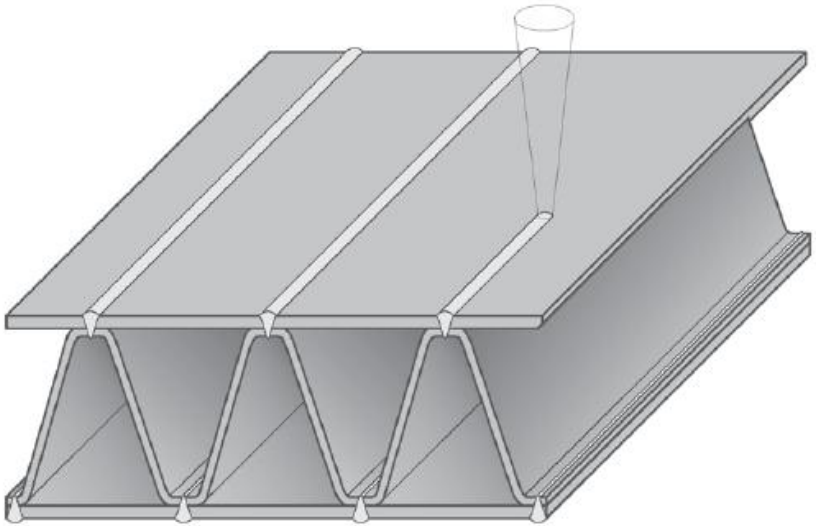
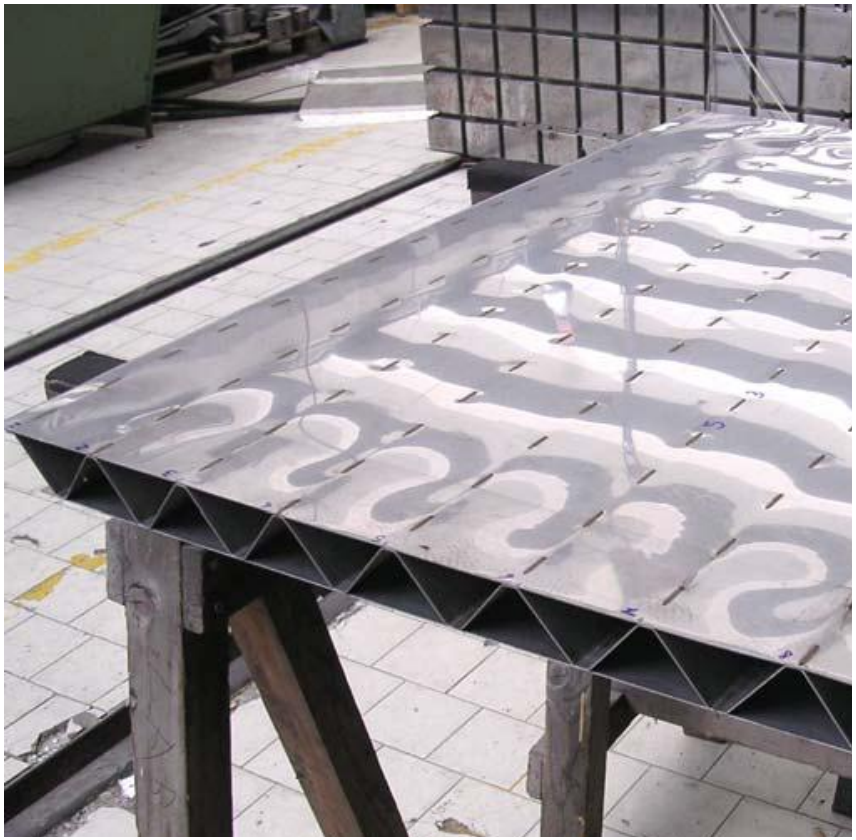
Eurobus (Italy)

CWASS in passenger railcars and in other applications

Sandwich Panels



Pennsylvania State University (LASCOR)



University of Pisa

Challenges for producers

- High competence is required to obtain exact mechanical properties.
- CWASS: leaner, lower price grades = small profit margin.
- Higher strength = lower weight = smaller quantity and sale value.
- Limited demand for CWASS = small fabrication volume.
- Lean duplexes as an alternative to CWASS for structures.

CWASS in passenger railcars and in other applications
Challenges and opportunities

- **User awareness**
- **Many potential CWASS users don't know these materials exist.**
- **In descriptions of stainless steels, mechanical properties of austenitics are those in the annealed condition.**

N.B. These austenitics are covered by ASTM A666 (CWASS Specification)

MECHANICAL PROPERTIES

The combination of a duplex structure and high nitrogen content provide significantly higher strength levels than 316L stainless steel. Often a lighter gage of [redacted] can be utilized to achieve the same strength levels of a 300 series fabrication. The resultant weight savings can dramatically reduce the material and fabrication costs of a vessel.

Table 1 – Tensile Properties Plate

	Ultimate Tensile Strength, ksi	0.2% Yield Strength, ksi	% Elong	Hardness Brinell
Alloy	**Min**	**Min**	**Min**	**Max**
[redacted]	94	65	30	290
304/304L	75	30	40	201
316/316L	75	30	40	217

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Marketing strategies – an example

- A large structure, typically of painted carbon steel, a lot of corrugated panels.
- The owner decided to use 1.4301 steel. Based on its nominal strength, thicknesses of 6 to 9 mm were required - too thick for corrugated parts.
- A stainless steel supplier sales team found a solution: lean duplex, stronger than 1.4301 – thickness reduction to 4 to 5 mm. Result: fabrication became possible, the weight was greatly reduced, and the total cost of material, too.
- Question: corrosion was not a problem, so why not CWASS, stronger and less expensive than duplex?

CWASS in passenger railcars and in other applications
Challenges and opportunities

Result

Some potential CWASS users select painted or zinc-plated carbon / low alloyed steel, duplex, or 12% Cr steel.

Remedy

CWASS promotion.

Example: INSAPTRANS project relative to buses and passenger rail vehicles.

Design / welding standards

- **EN 1993-1-4 Eurocode 3 for stainless steels: Re for austenitics only for annealed condition.**

  The highest Re = 350 MPa for 1.4318; Re = 230 MPa for 1.4301.

  For two duplex steels: Re = 420 MPa and 480 MPa.

  Values for CWASS: only if justified by complex testing.

- **EN 1993-1-4 through reference to EN 1993-1-8 *Eurocode 3 - Part 1-8: Design of joints,* imposes filler metal mechanical properties at least matching those of base metal.**

  Result: preference of users for duplex steels over CWASS, non-application of austenitics of Re in excess of the above limits even if only fillet welds are used.

CWASS in passenger railcars and in other applications
Challenges and opportunities

- **SEI/ASCE 8 *Specification for the Design of Cold-Formed Stainless Steel Structural Members* applies to CWASS covered by ASTM A666.**

  Groove welds: the design tensile strength = that of the annealed material. Higher values may be established by tests, simpler than EN 1993-1-4.

  Fillet welds: matching properties of filler metal are not required.
- **AWS D1.6 *Structural Welding Code - Stainless Steel* retains the above rules. For procedure qualification tensile test, the results may be below tensile strength of base metal, provided the design values are met.**
- **AS/NZS 1554.6 *Structural steel welding. Part 6: Welding stainless steels for structural purposes:* tensile test result shall be at least equal to the strength of base metal.**

Fatigue Provisions

EN 1993-1-4 refers to EN 1993-1-9 Eurocode 3 fatigue provisions.

The AWS D1.6 Code contains a caveat relative to thin-walled structures: load-induced distortion may affect the actual fatigue performance as compared to the nominal values.

Directionality and asymmetry of properties

- Mechanical properties of CWASS differ as a function of direction.
- For the longitudinal direction, the Euro Inox Design Manual for Structural Stainless Steel specifies the compression/tension yield strength ratio equal to 0.8. Higher values, especially for profiles, may be established by testing.

CWASS in passenger railcars and in other applications
Challenges and opportunities

- **Remedial actions and proposals**

  Application of actual material properties instead of standard ones (examples: Groth, Baddoo).

  Application of research results on CWASS sections: the design rules for the standard-strength sections also apply to sections made of high strength (i.e., cold-worked) steels. (examples: Gardner et al., Young).

  Introduction of the undermatch provisions for carbon and stainless steels into the Eurocode. Note: AWS D1.1 *Structural Welding Code - Steel* requires the match only for butt joints in tension:

Table 2.3
Allowable Stresses (see 2.6.4 and 2.16.1)

Type of Applied Stress	Allowable Stress	Required Filler Metal Strength Level
	CJP Groove Welds	
Tension normal to the effective area[a]	Same as base metal	Matching filler metal shall be used[b]
Compression normal to effective area	Same as base metal	Filler metal with a strength level equal to or one classification (10 ksi [70 MPa]) less than matching filler metal may be used.

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Butt joints strength

The actual joints strength in CWASS (Re and Rm) is less than matching but higher than permitted in standards.

Note: In structural aluminium alloys, butt joints strength is typically lower than that of base metal. This is accounted for in the design rules.

Remedy

- **A research project on CWASS fusion welds properties.**
- **Goal: Establishment of design properties of welds in CWASS and**
- **Revision of standards.**

CWASS in passenger railcars and in other applications
Conclusion

Cold-worked austenitic stainless steels have a long history. Their original application in passenger railcars is a vivid example of human genius reflecting vision, bold management, technical and aesthetical creativity, and an open mind. This legacy of Edward G. Budd and his companions is still alive and well: thousands of shiny stainless steel cars are still being produced every year. In this way, high strength stainless steels have proven their extraordinary potential. Other applications appeared, but many potential uses are still awaiting their turn. It is up to all of us, who are passionate about stainless steels, to bring this potential to its manifestation.

Thank you
for your attention