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PRESS Construction and Structural Working Group

Structural Stainless Steels for Railroad Passenger Equipment

Abstract: This standard covers the minimum properties of austenitic stainless steels used in fabrication of passenger railroad equipment. Principal grades of structural stainless steels for railroad passenger equipment structural applications are the low-carbon types 201L, 20lLN, 301L and 301LN. Other austenitic, ferritic, and duplex stainless steels may be applied where justified by design considerations. This standard also includes requirements and precautions for forming, welding, and handling of the low-carbon stainless steels.

Keywords: austenitic stainless steel, ferritic stainless steel, duplex stainless steel, structural materials, welding

Summary: This standard was titled "Austenitic Stainless Steel for Railroad Passenger Equipment" in the previous publication of this document.

This standard describes the minimum acceptable properties of austenitic, ferritic, and duplex stainless steel sheet, plate, strip, bar, tubing, forgings, and castings to be used for structural parts in passenger railroad equipment. The described properties include chemical composition and mechanical properties.

This standard covers austenitic, ferritic, and duplex grades of stainless steel suitable for passenger railroad equipment structure; however, this standard is not intended to specify the acceptable applications of the various grades in a structure. The latter would normally be prescribed by the procurement contract for new or refurbished equipment. Therefore, application of the various grades of austenitic, ferritic, and duplex stainless steels covered by this standard shall be prescribed by the contract documents.

The standard also contains requirements for testing, forming, handling, and welding, and material test reports and certifications.

Foreword

The American Public Transportation Association is a standards development organization in North America. The process of developing standards is managed by the APTA Standards Program's Standards Development Oversight Council (SDOC). These activities are carried out through several standards policy and planning committees that have been established to address specific transportation modes, safety and security requirements, interoperability, and other topics.

APTA used a consensus-based process to develop this document and its continued maintenance, which is detailed in the manual for the APTA Standards Program. This document was drafted in accordance with the approval criteria and editorial policy as described. Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

This document was prepared by the Construction and Structural Working Group as directed by the Passenger Rail Equipment Safety Standards Planning Committee.

This document represents a common viewpoint of those parties concerned with its provisions, namely transit operating/planning agencies, manufacturers, consultants, engineers, and general interest groups. APTA standards are mandatory to the extent incorporated by an applicable statute or regulation. In some cases, federal and/or state regulations govern portions of a transit system's operations. In cases where there is a conflict or contradiction between an applicable law or regulation and this document, consult with a legal adviser to determine which document takes precedence.

This document supersedes APTA PR-CS-S-004-98, Rev. 2, which has been revised. Below is a summary of changes from the previous document version:

- Title changed to "Structural Stainless Steels for Railroad Passenger Equipment" from "Austenitic Stainless Steel for Railroad Passenger Equipment."
- Inclusion of structural stainless steels other than austenitic varieties into the scope.
- Wording changes to abstract.
- Addition of keywords ferritic stainless steel and duplex stainless steel.
- Former section 1, Overview, renamed to Summary.
- Former sections 1.1, Scope, and 1.2, Purpose, combine new section, Scope and purpose.
- Former section 2, References, moved to rear.
- Addition of Foreword. Changes to Documents section incorporated into Foreword.
- Update of participants and acknowledgments list.
- Introduction wording updated.
- Scope and Purpose section moved.
- Removal of section 3, Chemical Composition.
- Added new section 1, Alloy specification.
- Content of former section 4, Mechanical Properties, incorporated in new section 1.1, Standards for purchasing raw material.
- Former section 5.1, Dimensional tolerances, renamed to new section 1.2, Product tolerances.
- Former sections 5.3 renumbered to section 1.3.
- Former sections 5.4 renumbered to section 1.4.
- Former sections 5.5 renumbered to section 1.5.
- New section 2, Mechanical data/application added.
- New section 2.1, Typical alloys and uses, added.

- New **Table 1**, Stainless Steel Alloy Uses, added.
- Former section 5.2 moved to new section 2.2.
- New **Table 2**, Stainless Steel Surface Finishes, added.
- New section 2.3, Static Design, added.
- New section 2.4, Mechanical Connections, added.
- Former section 5.6.5 renamed to new section 2.5, Fatigue design.
- New section 2.6, Material strength and FEA modeling considerations, added.
- Former section 5.6 renumbered to new section 3.
- .1 renumbered to section 1.3.
- Former section 3.4 renumbered to section 1.4.
- Former section 3.5 renumbered to section 1.5.
- Former section 3.2, moved to new section 2.2.
- New section 3.1, Arc welding, added.
- Former sections 5.6.1, 5.6.2 and 5.6.3 removed.
- Former section 5.6.4 renamed to new section 3.2, Resistance welding.
- New sections 3.3, Resistance welding, 3.4, Welding to carbon steel, and 3.5, Welder qualifications, added.
- Former section 5.7 renumbered to new section 3.6.
- Former section 5.8 renumbered to new section 3.7.
- New sections, Related APTA standards, Abbreviations and acronyms, and Document history added.
- New appendix A (informative): Commentary, added.
- Former annex A, Recommended Practice for the Handling of Austenitic Stainless Steel, renamed new appendix B (informative): Corrosion prevention.

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Introduction

This introduction is not part of APTA PR-CS-S-004-98, "Structural Stainless Steels for Railroad Passenger Equipment," formerly "Austenitic Stainless Steel for Railroad Passenger Equipment."

This standard covers chromium, chromium-manganese-nickel and chromium-nickel stainless steel sheet, plate, strip, bar, tubing, forgings and castings for welded fabrication of structural parts in passenger rail vehicles. It was developed to help ensure the quality of steel used in the fabrication of passenger rail equipment.

This standard applies to all:

- railroads that operate intercity or commuter passenger train service on the general railroad system of transportation; and
- railroads that provide commuter or other short-haul rail passenger train service in a metropolitan or suburban area, including public authorities operating passenger train service.

This standard does not apply to:

- rapid transit operations in an urban area that are not connected to the general railroad system of transportation;
- tourist, scenic, historic or excursion operations, whether on or off the general railroad system of transportation;
- operation of private cars, including business/office cars and circus trains; or

- railroads that operate only on track inside an installation that is not part of the general railroad system of transportation.

Scope and purpose

This standard is limited to the application of austenitic, ferritic, and duplex stainless steel alloys for construction of passenger rail equipment car bodies. It makes specific recommendations for alloys that are suitable for this application and provides specific cautions against the use of unsuitable alloys. It is intended to formalize the properties of austenitic stainless steels used for passenger railroad equipment for use by railroad vehicle builders, component fabricators and suppliers, railroad vehicle refurbishers, and passenger and commuter railroad operating authorities.

This standard is based on conservative industry practices and references other industry/trade association standards that are currently valid. Standards from other jurisdictions—e.g., EN, JIS—are deemed acceptable. However, these alloys should be used in conjunction with their respective design standards—i.e., no mixing between different national standards. Also, availability of alloys and/or replacement alloys that can be procured in North America, especially for repairs, should be a consideration. This document makes extensive use of existing standards for stainless steels that are published by the American Society for Testing and Materials (ASTM). In case of conflict between this standard and a referenced specification, the more stringent requirement shall prevail, including any national standards that may apply.

Some materials covered in this standard, because of their alloy content and specialized properties, may require special care in their fabrication and welding. Specific welding procedures are of fundamental importance, and it is presupposed that all parameters will be in accordance with approved methods capable of producing the desired properties in the finished fabrication.

The values stated are in English units. Metric units are provided for reference only. Metric units may be used by agreement between the railroad operating authority and the vehicle builder, along with the steel mill.

Structural Stainless Steels for Railroad Passenger Equipment

1. Alloy specification

1.1 Standards for purchasing raw material

The chemical and physical properties of recognized alloys are listed in the ASTM standards cited in the References section at the end of this document. Use of the ASTM standards is preferred for ordering raw material in mill run quantities because these standards include information that facilitates procurement in North America. ASTM A480/A480M provides information on ordering.

EN and JIS standards are acceptable, provided that ASTM equivalents are noted in case of repairs, which can be compared using EN 15510 and/or UNS HS-1086.

Mechanical properties of austenitic stainless steel sheet, strip and plate in annealed condition shall conform to the requirements of ASTM A240/A240M, with Table 2 listing the mechanical properties of the most frequently used stainless steels in passenger rail vehicle structural applications.

Mechanical properties of austenitic stainless steel sheet in the cold-rolled (temper-rolled) condition shall conform to the requirements of ASTM A666, with Table 3 listing mechanical properties for tension tests of specimens taken in the transverse direction.

Because cold-worked stainless steel is highly anisotropic, properties taken in the longitudinal direction or determined by compression testing can be significantly different and shall be addressed by special agreement between the producer and purchaser. Also, adjustments of specific properties to meet formability requirements may be made by special agreement between the producer and purchaser.

1.2 Product tolerances

The dimensional tolerances of stainless steel sheet, strip and plate shall be in accordance with ASTM A480/ A480M, or as otherwise agreed to by the railroad operating authority and the vehicle builder, along with the steel mill. It is recommended that rolled materials be held to the minimum acceptable thickness within the allowable tolerance to the extent possible where it is desirable to minimize structure weight.

1.3 Material test reports and certifications

Material test reports and certifications shall be in accordance with ASTM A480/A480M.

An intergranular corrosion test in accordance with ASTM A262 shall be required for each heat of austenitic stainless steel. Following provisions of A262, material may be accepted to Practice A of A262. Material shall be rejected only by application of Practice E of A262.

1.4 Handling

Austenitic stainless steel sheet and coil shall be packaged for shipment to protect the finished surface. Coils shall have paper or protective separator placed on the finished surface as the coil is wound. Recommended practices for handling and protection of stainless steel are discussed in Appendix A.

1.5 Forming

Bending, forming and metal working shall be performed on tooling that has been cleaned and is free of iron particles and slivers. Formed parts shall have smooth radii and be free of cracks, creases, or stretcher strains, as demonstrated by visual inspection. An appropriate bend radius should be used based on material properties to avoid cracking and/or other defects.

2. Mechanical data/application

2.1 Typical alloys and uses

TABLE 1
Stainless Steel Alloy Uses

Grade	Type	Uses
201	Austenitic	• Used in structural applications in construction of side walls and roof. • Good corrosion resistance and can be easily resistance welded and laser welded. • Not recommended for arc welding; use 201L, 201LN instead.
201L, 201LN	Austenitic	• Used in structural applications in construction of underframes, side frames and roof. • Good corrosion resistance and can be easily resistance welded, and laser welded.
301	Austenitic	• Used in underframes, up to 1/2 hard for higher strength. • Can be resistance welded; not suitable for arc welding. • Recommend 301L, 301LN or dual-certified 301/301L.
301L, 301LN	Austenitic	• Used when arc welding required.
304	Austenitic	• Used for brackets, formed shapes; suitable for resistance welding. • Not recommended for arc welding; recommend 304L or 304LN.
304L, 304LN	Austenitic	• Good corrosion resistance; used for interior finishing and low-stress areas. • Available in greater thicknesses than 201L/201LN and 301L/301LN.
316	Austenitic	• Not recommended due to arc welding issues; recommend 316L.
316L	Austenitic	• Used in higher-corrosion areas, standing water, roofs, kitchens, and washrooms. • Can be arc welded.
2205	Duplex	• Used in high-stress areas (e.g., end underframe) due to high strength and high corrosion resistance. • Can be arc welded, but loss of strength at welds. • Higher cost than austenitic stainless steels.
4XX	Ferritic	• Not typically used in passenger rail, but in freight rail and automotive. • Contains no nickel but chromium; ideal in slightly corrosive environments. • Not susceptible to stress corrosion cracking like austenitic. • Group 1 (grades 409, 410, 420): Least expensive, lightly corrosive applications. • Group 2 (grade 430): Most common of 4XX; can replace 304. • Group 3 (grades 430Ti, 439, 441): Better weldability than 430.

2.2 Surface finish

Surface finish shall be in accordance with ASTM A480/A480M or as otherwise agreed to by the railroad operating authority and the vehicle builder, along with the steel mill.

Sheets and coils shall be produced in continuous passes, with surface finish within limits agreed to by the railroad operating authority and vehicle builder, along with the steel mill.

Typical finishes for sheet are shown in **Table 2**.

TABLE 2
Stainless Steel Sheet Surface Finishes

Finish	Description/Uses
No. 1	• Hot rolled, heat-treated, and pickled. Rough surface. • Used in hidden areas, e.g., underframe, sidewall framing.
No. 2B	• Cold-rolled, heat-treated, light cold-roll finish. • Bright surface, most common. • When corrugated often specified with an 80-grit finish.
No. 2D	• Cold-rolled, heat-treated. Dull surface. • Common finish used for structural and hidden areas.
TR	• Work hardened. Bright surface. • Cold-worked for higher strength, i.e., 301 1/4 hard. • Common finish used for structural and hidden areas.
No. 4	• General-purpose polished finish, one or both sides. • Produce by mechanical polishing or rolling. • Average surface roughness may be up to 25 µin. • A skilled operator can blend this finish. • Typical for interior and exterior finishes.
No. 8	• Mirror finish. Produced by polishing with progressively finer abrasives, then with buffing. Can be blended using buffing. • Used for specialized finishes.

2.3 Static design

Static design is covered by AISC Design Guide 27, which refers to AWS D1.6/D1.6M, or alternately by EN 15085-3, which refers to Eurocode 3 (EN 1993-1-9).

See Appendix A for further information.

2.4 Mechanical connections

Mechanical connections are covered by AISC Design Guide 27. Eurocode 3 is satisfactory and covers mechanical connections in fatigue in EN 1993-1-9.

See Appendix A for further information.

2.5 Fatigue design

Fatigue design in welded stainless structures shall be as per AWS D1.1/D1.1M, per EN 1993-1-9, British Standard BS 7608, and the vehicle builder’s design standards, or as otherwise agreed by the railroad operating authority and the vehicle builder.

See APTA PR-CS-S-034-99, “Design and Construction of Passenger Railroad Rolling Stock,” and Appendix A for further information.

2.6 Material strength and FEA modeling considerations

For car body design guidelines, refer to APTA PR-CS-S-034-99.

See Appendix A for further information.

3. Welding

3.1 Arc welding

Arc welding for sheet and plate stainless steels, including welder qualification, shall be as per AWS D1.6/D1.6M.

Fusion welding of cold-worked stainless steels tends to soften or anneal the weld heat-affected zone (HAZ). The annealed strength should be used unless justified by testing.

3.2 Resistance welding

Resistance welding shall be performed as per AWS D17.2/D17.2M Class B for structural welds.

3.3 Laser welding

Laser welding shall be performed as per AWS C7.4/C7.4M, Process Specification and Operator Qualification for Laser Beam Welding.

3.4 Welding to carbon steel

Arc welding of carbon steel to stainless steel shall be performed as per AWS D1.6/D1.6M.

The heat-affected zone hardness shall not exceed 400 on the Vickers hardness test.

3.5 Welder qualifications

All fusion welding shall be performed by welders qualified to AWS B2.1, D1.1, D1.3, D1.6, or ASME Section IX requirements and in accordance with approved welding procedure specifications that conform to AWS D1.1¸ D1.3, D1.6 and D15.1/D15.1M requirements, or equivalent standards approved by the purchaser.

3.6 Pre- and post-weld heat treatment

Pre- and post-weld heat treatments are not typically applied to the stainless steels covered by this standard and shall not be required, except as necessary for a particular approved application or approved welding procedure qualification.

3.7 Post-fabrication cleaning

All surface contamination such as free iron, oil, and crayon marks, as well as welding discoloration and weld spatter, shall be removed before delivery of the fabricated stainless steel structure.

The cleaning processes shall be in accordance with ASTM A380/A380M and A967. Practice A, B or C of ASTM A967, or other such similar procedure as agreed to by the vehicle builder and railroad operating authority, should be used to demonstrate that the stainless steel is free of iron contamination.

Related APTA standards

APTA PR-CS-S-034-99, "Design and Construction of Passenger Railroad Rolling Stock"

References

Watter, M., and Lincoln, R.A., "Strength of Stainless Steel Structural Members as Function of Design," Allegheny Ludlum Steel Corporation, Pittsburgh, Pennsylvania, 1950.

American Society of Civil Engineers (ASCE):
ASCE 8-02, Specification for the Design of Cold-Formed Stainless Steel Structural Members

American Institute of Steel Construction (AISC):
AISC Design Guide 27: Structural Stainless Steel

ASTM International:
ASTM A240/240M, Standard Specification for Chromium and Chromium-Nickel Stainless Steel Plate, Sheet and Strip for Pressure Vessels and for General Applications
ASTM A262, Standard Practices for Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steels
ASTM A276, Standard Specification for Stainless Steel Bars and Shapes
ASTM A370, Standard Test Methods and Definitions for Mechanical Testing of Steel Products
ASTM A380/380M, Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment, and Systems
ASTM A480/A480M, Standard Specification for General Requirements for Flat-Rolled Stainless and Heat-Resisting Steel Plate, Sheet, and Strip
ASTM A484/A484M, Standard Specification for General Requirements for Stainless Steel Bars, Billets, Shapes, and Forgings
ASTM A511, Standard Specification for Seamless Stainless Steel Mechanical Tubing and Hollow Bar
ASTM A666, Standard Specification for Annealed or Cold-Worked Austenitic Stainless Steel Sheet, Strip, Plate, and Flat Bar
ASTM A743/A743M, Standard Specification for Castings, Iron-Chromium, Iron-Chromium-Nickel, Corrosion Resistant, for General Application
ASTM A967, Standard Specification for Chemical Passivation Treatments for Stainless Steel Parts

American Society of Mechanical Engineers Code (ASME Code)
ASME Section IX, Welding, Brazing, and Fusing Qualifications

American Welding Society (AWS)
AWS B2.1, Standard for Welding Procedure and Performance Qualification
AWS C1.1/C1.1M, Recommended Practices for Resistance Welding
AWS C7.4/C7.4M, Process Specification and Operator Qualification for Laser Beam Welding
AWS D1.1/D1.1M, Structural Welding Code—Steel
AWS D1.3/D1.3M, Structural Welding Code—Sheet Steel
AWS D1.6/D1.6M, Structural Welding Code—Stainless Steel
AWS D15.1/D15.1M, Railroad Welding Specification for Cars and Locomotives
AWS D17.2/D17.2M, Specification for Resistance Welding for Aerospace Applications
AWS 10.18, Guide for Welding Ferritic/Austenitic Duplex Stainless Steel Piping and Tubing
AWS A4.2, Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Ferritic-Austenitic Stainless Steel Weld Metal

British Standards (BS):
- BS 7608:1993, Code of Practice for Fatigue Design and Assessment of Steel Structures

European Standards:
- EN 1993-1-4, Eurocode 3, Design of steel structures
- EN 10027-1, Designation systems for steels - Part 1: Steel names
- EN 10088-1, Stainless Steels - Part 1: List of stainless steels
- EN 10088-2, Stainless Steels - Part 2 Technical delivery conditions for sheet/plate and strip of corrosion resisting steels for general purposes
- EN 10204, Metallic products: Types of inspection documents
- EN 10307, Non-destructive testing - Ultrasonic testing of austenitic and austenitic-ferritic stainless steel flat products of thickness equal to or greater than 6 mm
- EN 10349, Steel castings - Austenitic Manganese Steel Castings
- EN 13835, Founding - Austenitic cast irons
- EN 15085-2, Railway applications - Welding of railway vehicles and components - Part 2: Requirements for welding manufacturer

Japanese Industrial Standards:
- JIS G 4303, Stainless Steel Bars
- JIS G 4304, Hot-Rolled Stainless Steel Plate, Sheet and Strip
- JIS G 4305, Cold-Rolled Stainless Steel Plate, Sheet and Strip
- JIS G 4318, Cold Finished Stainless Steel Bars
- JIS G 4319, Stainless Steel Blooms and Billets for Forgings
- JIS G 4320, Cold-Formed Stainless Steel Sections

ISO Standards
- ISO 3506, Fasteners – Mechanical properties of corrosion-resistant stainless steel fasteners
- ISO 3651-2, Determination of resistance to intergranular corrosion of stainless steels – Part 2: Ferritic, austenitic and ferritic-austenitic (duplex) stainless steels – Corrosion test in media containing sulfuric acid
- ISO 9444-2, Continuously hot-rolled stainless steel – Tolerances on dimensions and form – Part 2: Wide strip and sheet/plate
- ISO 9445-2, Continuously cold-rolled stainless steel –Tolerances on dimensions and form – Part 2: Wide strip and plate/sheet
- ISO 13520 – Determination of ferrite content in austenitic stainless steel castings

NAVSEA:
- NAVSEA S9074-AQ-GIB -010/248, Requirements for Welding and Brazing Procedure and Performance Qualification

Abbreviations and acronyms

µin	microinch
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
AWS	American Welding Society
BS	British Standards
DoU	degree of utilization
EN	European (Norm) Standards
HAZ	heat-affected zone

ISO International Organization for Standards
JIS Japanese Institute of Standards
NAVSEA Naval Sea Systems Command
SCC stress corrosion cracking
UNS Unified Numbering System

Document history

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First published	—	—	—	March 26, 1998	March 17, 1999
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This document was retitled to its current title from “Austenitic Stainless Steel for Railroad Passenger Equipment” as part of Rev. 3. For all previous publications of this document prior to Rev. 3, unless otherwise indicated, this document was titled “Austenitic Stainless Steel for Railroad Passenger Equipment.”

Appendix A (informative): Commentary

Standards for purchasing raw material (Section 1.1)

ASTM standards are preferred, but EN and JIS standards are also acceptable.

Section 4 of ASTM A480/A480M contains information on ordering and can be used as a template for ordering EN and JIS stainless steels.

Handling (Section 1.4)

Stainless steel should be stored off the ground by cribbing with wood, stacked to promote draining and to prevent damage and contamination.

In shipping fabricated components, care should be taken that ordinary steel chains, tie-downs and banding do not come in contact with the stainless steel.

Forming (Section 1.5)

When processing stainless steel, care should be taken to ensure that all working surfaces of the forming equipment, layout tables and handling equipment are clean to avoid contamination of the stainless steel surface.

Processes involving stainless steel and carbon steel should be isolated from each other to avoid contamination of the stainless steel by iron oxide particles from the carbon steel.

Plasma arc and laser cutting or gouging should be the only acceptable methods for thermal cutting. All arc-cut edges should be ground to bright metal and free from moisture, oils, debris, etc., prior to welding.

All tools, such as wedges, lifting clamps and wire brushes used in contact with stainless steel should be stainless steel or other noncontaminating metal or material. Abrasives used on stainless steel, such as grinding wheels, flapper wheels and flexible abrasive discs, should not have been used previously on carbon steel.

Typical alloys and uses (Section 2.1)

Where arc-welded fabrication is required, only austenitic stainless steels with a carbon content below 0.030%, or with proven weldability that resists atmospheric corrosion (no sensitization in the weld heat-affected zone) shall be used.

Static design (Section 2.3)

Rail vehicle stainless steel structural components are generally manufactured from cold-formed stainless steel sheet (thickness ≤ 0.25 in. or 6 mm). Cold forming (or cold work) increases tensile strength but also introduces anisotropic mechanical properties in the material that shall be accounted for in design.

The most significant effect of cold forming is that while the tensile strength is increased, the compression strength remains unchanged. With increasing cold rolling (work hardening), this difference increases.

Member and panel instability can further reduce compressive strength versus tensile yield allowables commonly used in design. Other less significant but potentially important effects include the following:

- Differences in strength in the longitudinal and transverse directions.
- Stress-strain curves that are nonlinear at stresses below the engineering yield strength (possibly important for stability calculations.)
- Shear strength that is less than 0.56 times the longitudinal tensile strength for highly cold-worked sheet.

Design values and approaches for treating these effects may be found in references [1-5].

Arc welding cold-formed stainless steel causes strengths in the heat-affected zone to revert to those in the annealed condition. This effect is not significant for the resistance (spot) welding used to join stainless steel members. Ultimate strength values of resistance welds may be found in reference [6].

Mechanical connections (Section 2.4)

For stainless steel bolts, see AISC Design Guide for a comprehensive list. However, the most common ASTM standard used is ASTM F593. Under EN standards, there is ISO 3506.

Stainless steel bolts may be used in bearing-type connections only. Slip-resistant joints are prohibited, as galling could easily occur if torque is not carefully controlled.

Where higher-strength fasteners are required, carbon steel fasteners may be used with appropriate corrosion protection precautions.

Holes in stainless steel sheet or plate can be formed by drilling or punching, although punched holes are less suitable in aggressive environments (e.g., heavy industrial and marine environments) due to the related cold working and associated susceptibility to corrosion.

Huck produces a number of stainless steel fasteners that have been used extensively on stainless steel structures.

Strength values to be per manufacturer recommendations and shall include a check of the fastener failure and of hole elongation failure.

Reference:

- Euro Inox, “The Design Manual for Structural Stainless Steel”

Fatigue design (Section 2.5)

Welded connections generally control fatigue design.

AWS D1.1 uses the endurance limit approach, with stresses below a certain level, whereas EN 1993-1-9 uses the Palmgren-Miner rule for accumulative damage. Both approaches are acceptable.

References:

1. Watter and Lincoln
2. ASCE-8-02
3. EN 1993-1-4
4. Flabel
5. Mayville
6. AWS C1.1
7. AISC Design Guide 27
8. AWS D1.1

Material strength and FEA modeling considerations (Section 2.6)

The use of FEA for designing stainless steel car body structures shall be performed with careful consideration of instability. With cold work amplifying tensile and compressive yield allowables, there is a propensity to utilize very thin un-corrugated sheet. Commonly used FEA methods employing linear static analysis and yield-based allowables lead to underestimated degrees of utilization (DoUs) in such stainless steel car shells. Designers shall consider the use of reduced allowables to account for buckling per references [1] – [3]N, or equivalent client-approved methods. This is a preferred method, as FEA buckling analysis solutions, whether linear or nonlinear, often overestimate the buckling load.

For panels where shear buckling (semi-tension field) is expected, redistribution of load shall be considered in connection design and documented DoU.

References:

1. Bruhn
2. Flabel
3. AAR M-1001

Arc welding (Section 3.1)

Qualification of welding procedures is recommended, even though AWS D1.6 permits the use of prequalified welds. By qualification, the contractor demonstrates that the welds can be achieved, including the effective throat for partial joint penetration welds.

Low-carbon electrodes are recommended for use in arc welding to help prevent the formation of carbides. Low-carbon versions of stainless steel grades, i.e., 301L and 304L, are recommended for arc welding.

The use of 308L as a filler metal is recommended for austenitic stainless steels; however, satisfactory qualification of other filler metals is acceptable.

Fusion welds in austenitic stainless steels shall have a ferrite number in the range of WRC 4 to 10, according to AWS A4.2

Austenitic stainless steels have high thermal expansion and typically undergo a phase change from austenitic to ferritic and back again to austenitic upon cooling, causing distortion. The “tinkling” sound heard while cooling is the phase change back to austenitic. Care should be taken to avoid distortion.

Flame straightening is often used to “shrink” areas of distortion. However, this process needs to be closely controlled to avoid excessive temperatures, which can damage the base material.

Resistance welding (Section 3.2)

Resistance welding shall be in accordance with requirements of AWS D17.2/ D17.2M, Class B for structural welds and Class C for nonstructural welds. It is recommended that a more restrictive limit on indentation on visible structures than permitted by the standard be considered for improved appearance, as agreed to by the vehicle builder and railroad operating authority.

AWS D17.2 is preferred over AWS C1.1, which is only for guidance and not mandatory.

Welding to carbon steel (Section 3.4)

The use of 309L or 309LSi as a filler metal is recommended. However, satisfactory qualification of other filler metals is acceptable.

Minimize ring welds and other lap joints to carbon steel due to corrosion issues due to water and condensation.

Appendix B (informative): Corrosion prevention

Atmospheric corrosion

Stainless steels form a chromium oxide layer on the surface, often referred to as the passive film. Pitting or crevice corrosion can occur when there is a breakdown in this passive layer, especially with high moisture levels. Several environmental factors, such as temperature, rainfall, humidity levels, and the presence of chemicals, of which chlorides (from salts) are the most harmful, can accelerate the rate of corrosion. Coastal regions and cold-weather regions with level crossings or with streetcars will require stronger measures to reduce corrosion.

To help prevent corrosion, factors such as the base alloy, surface finish, direction and treatment can have an initial effect. Treatment can include paint finishes or passivation finishing, the latter requiring restoration after welding, since the heat from welding can affect the passivation layer, as well as cause discoloration.

Keeping the stainless steel clean with frequent washes and suitable cleaners (i.e., citric acid based) will help remove contaminants. Keeping areas dry will reduce the pitting element since ions need moisture to transfer electrons to oxidize the iron underneath. Do not use any bleach in the interior of the vehicles, as this is a major corrosion accelerant. (Aggressive cleaners can affect the chromium oxide layer, degrading the structure.)

When vehicles and equipment are being manufactured, it is important to ensure that carbon steel fabrication is *not* occurring in the same region (or building), as iron particles will seat themselves on the stainless steel and then start to rust once in contact with moisture.

Galvanic corrosion

Stainless steel is more noble than galvanized or uncoated carbon steel. Ideally, stainless steels and carbon should be separated by a nonmetallic barrier (e.g., mica, nylon) to avoid galvanic corrosion of the carbon steel, especially if the area of the stainless steel is large compared to the carbon steel (i.e., don't use carbon steel fasteners with stainless steel).

Ensure that moisture and/or rainwater does not accumulate, especially areas with both carbon and stainless steel. Wherever possible, the carbon steel and a portion of the stainless steel can be painted.

Stress corrosion cracking

Stress corrosion cracking (SCC) is a mode of attack due to a combination of repeated tensile stresses and a corrosive aqueous environment, typically chlorides or hydrogen sulfide. SCC typically initiates on the surface at welds, pits or on rough surfaces, and can cause cracking well below the normal critical stress intensity factor, sometimes as low as 1%. Thus, SCC can cause failures with extremely low stress levels.

Stainless steel welds are a typical source of SCC due to sensitization due to carbide formation at the grain boundaries with high carbon stainless steels, leading to intergranular stress corrosion cracking. Thus, the use of low-carbon alloys (i.e., 301L, 304L and 316L) are recommended where arc welding is used.

Duplex and ferritic stainless steels are less susceptible than austenitic steels. However, in all cases, exposed areas to the environment should be passivated and cleaned using products specific to stainless steel, as mentioned above. The use of bleach and ammonia-based cleaners is not recommended.