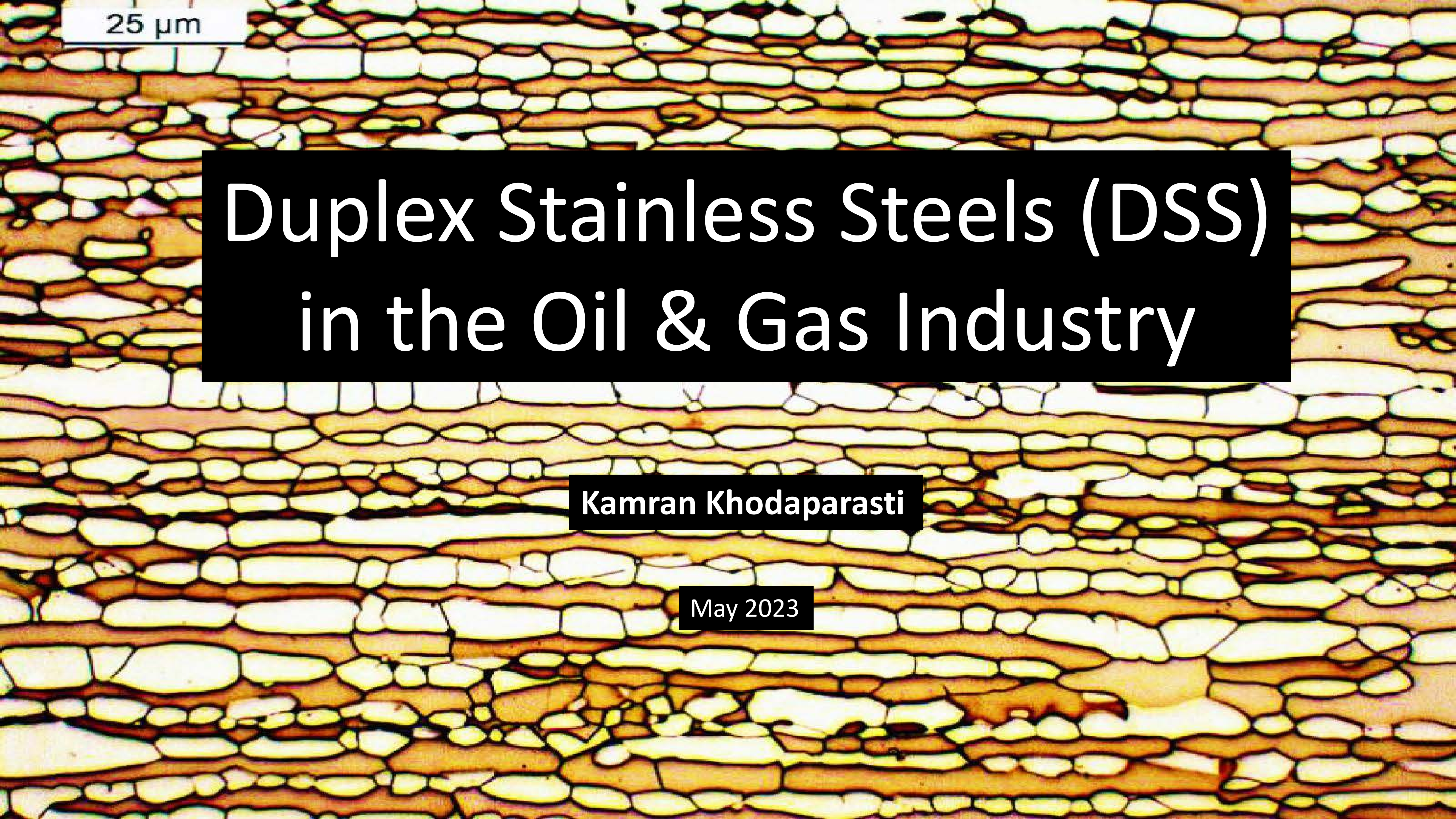


# Duplex Stainless Steels (DSS) in the Oil & Gas Industry

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# Education

1991 - 1996 **Shiraz University**
B.Sc., Materials Engineering - Metal Forming

1998 - 2001 **Shiraz University**
M.Sc., Materials Engineering - Characterization and Selection of Materials

# Career Timeline

- **Sistan & Balouchestan University**
  Laboratory Expert and Instructor, 1996 - 1998
- **Niroo Research Institute**
  Researcher, Test Engineer and Laboratory Manager, 2002 - 2005
- **Moshanir Consultants**
  Senior Materials and Welding Engineer, 2005 - 2016
- **Nargan Co.**
  Senior Materials and Corrosion Engineer, 2016 – Present


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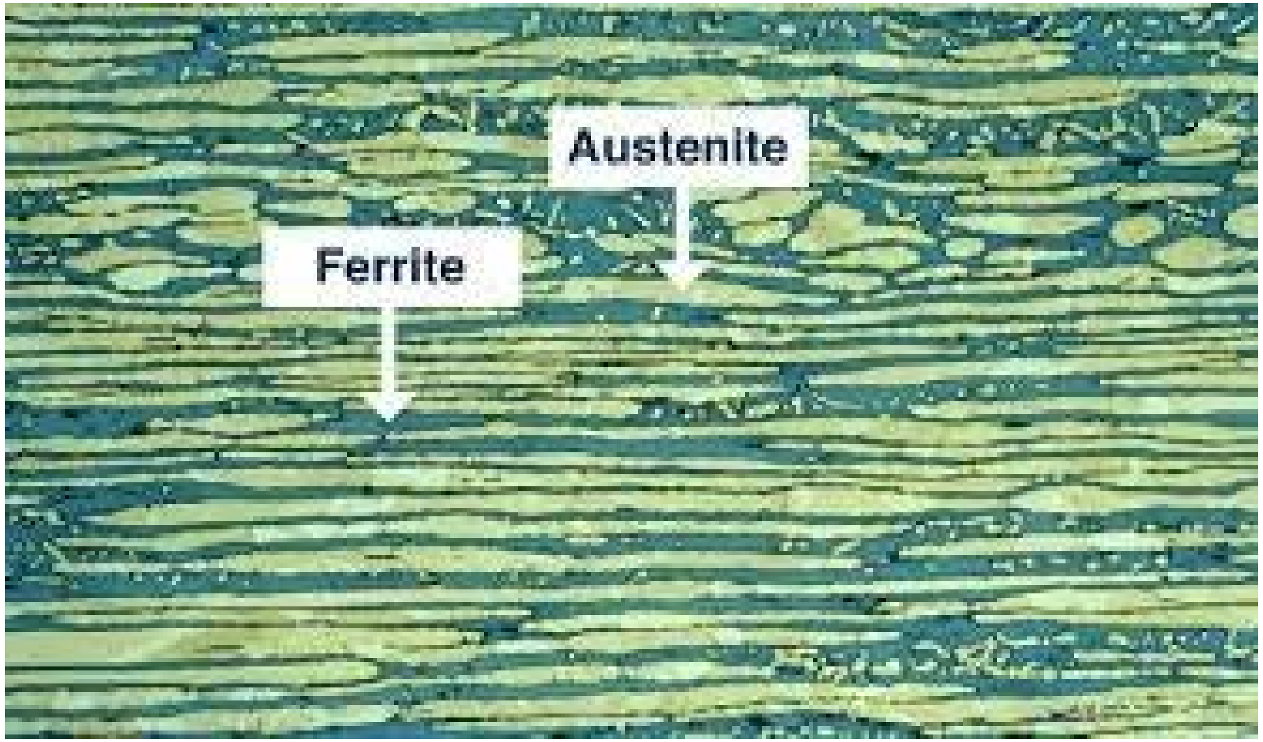
Duplex stainless steels (DSS) are finding increasing use in the refining industry, primarily because they often offer an economical combination of strength and corrosion resistance.

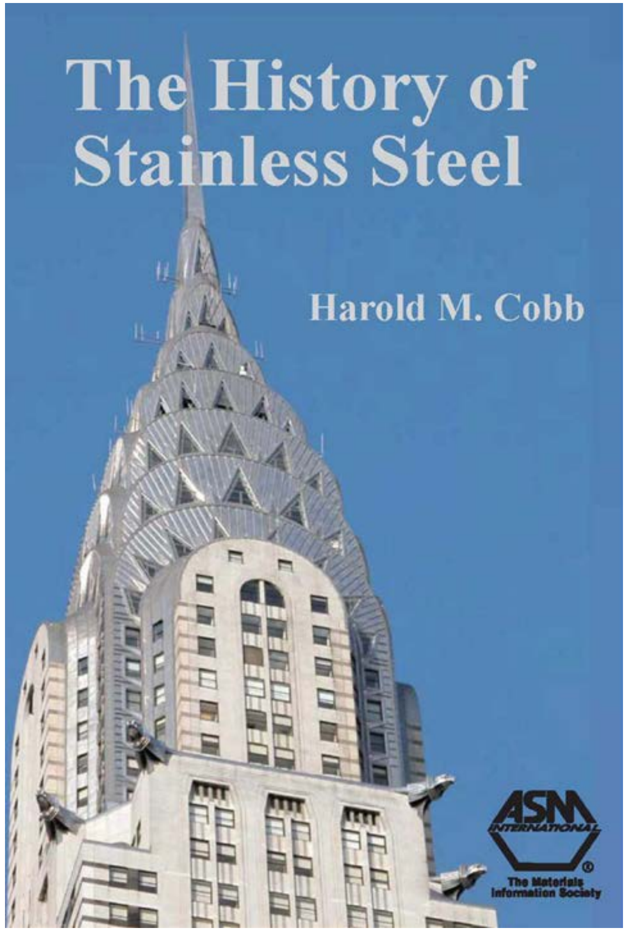
These stainless steels typically have an annealed structure that is generally half austenite and half ferrite, although the ratios can vary from approximately 35/65 to 55/45.



Most refinery applications where DSS are used are corrosive, and DSS or other higher alloys are required for adequate corrosion resistance.

However, some plants are also starting to consider DSS as a “baseline” material. They are using it in applications where carbon steel may be acceptable, but DSS have been shown to be more economical considering their higher strength and better long-term reliability.

DSS have existed since the 1930s. However, the first generation steels such as Type 329 had unacceptable corrosion resistance and toughness at weldments. Hence, the initial applications were almost exclusively heat exchanger tubing, particularly in corrosive cooling water services, and shafting or forgings.



In the 1980s, second generation DSS became commercially available which helped overcome the problems at the welds. These new grades had nitrogen additions, which along with improved welding practices designed for the DSS, led to the welds' mechanical (strength and toughness) and corrosion properties being comparable to the annealed base metal.

The DSSs most commonly used today in refineries include those with 22 %, 25 % and 27 % Cr. The 25 % Cr (super duplex grades) and 27 % Cr (hyper duplex grade) usually also contain more molybdenum and nitrogen, and so have higher PREN values than the 22 % Cr duplex steels.

DSSs are often used in lieu of austenitic SS in services where the common austenitic would have problems with chloride pitting or chloride stress corrosion cracking (CSCC).

Higher alloyed DSSs like super duplex and hyper duplex are an economic alternative to higher alloys with similar corrosion resistance.

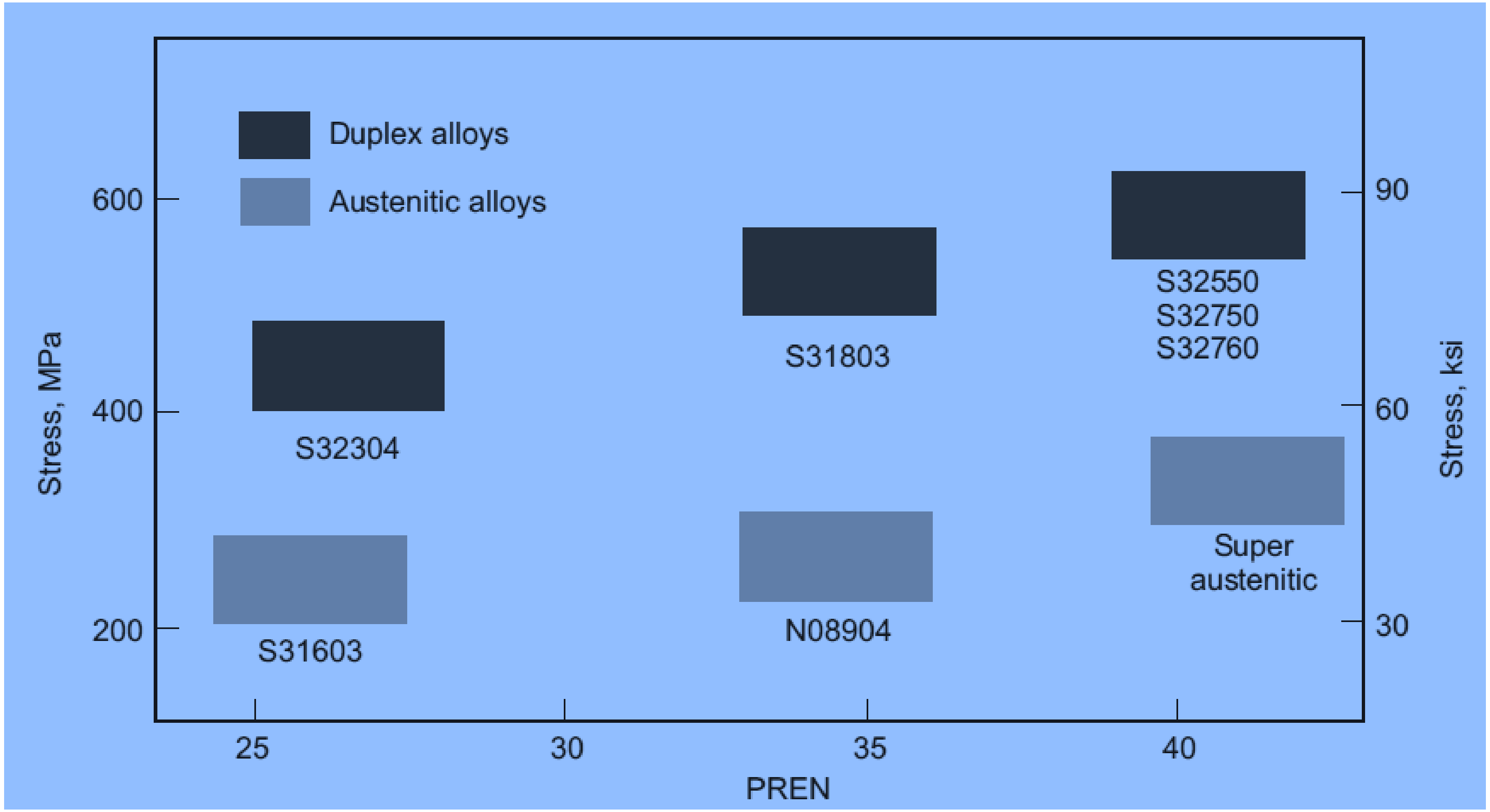
# Duplex Stainless Steels Specifications

| Product Form | ASME or ASTM Specifications |
|---|---|
| Plate, Sheet | SA-240 |
| Bar Products | SA-479, A276 |
| Pipe | SA-790, A928 |
| Tubing | SA-789 |
| Fittings | SA-815 |
| Forgings | SA-182 |
| Castings | SA-351, A890, A995 |
| HIP Products | ASTM A988 |
| Bolting | ASTM A1082 |
| Testing | ASTM A923, ASTM G48, ASTM A1084 |

# Mechanical Properties of Various Duplex and 316L

| UNS Number | Type | Tensile Strength, min | | Yield Strength, min | | Elongation min % | Hardness, max | |
|---|---|---|---|---|---|---|---|---|
| | | Mpa | ksi | Mpa | ksi | | Brinell | Rockwell C |
| S32304 | 2304 | 600 | 87 | 400 | 58 | 25.0 | 290 | — |
| S32101 | 2101 | 650 | 95 | 450 | 65 | 30.0 | 290 | — |
| S32202 | 2202 | 650 | 94 | 450 | 65 | 30.0 | 290 | — |
| S32003 | 2003 | 620 | 90 | 450 | 65 | 25.0 | 293 | 31 |
| S82011 (>5 mm) | 2102 | 655 | 95 | 450 | 65 | 30 | 293 | 31 |
| S82441 (≥10 mm) | 2404 | 680 | 99 | 480 | 70 | 25 | 290 | — |
| S31803 | — | 620 | 90 | 450 | 65 | 25.0 | 293 | 31 |
| S32205 | 2205 | 655 | 95 | 450 | 65 | 25.0 | 293 | 31 |
| S32550 | 255 | 760 | 110 | 550 | 80 | 15.0 | 302 | 32 |
| S32750 | 2507 | 795 | 116 | 550 | 80 | 15.0 | 310 | 32 |
| S32760 | Z100 | 750 | 108 | 550 | 80 | 25.0 | 270 | — |
| S32906 (≥4 mm) | — | 750 | 109 | 550 | 80 | 25.0 | 310 | 32 |
| S32707 [a] | 2707 | 920 | 133 | 700 | 101 | 25 | 318 | 34 |
| S31603 | 316L | 485 | 70 | 170 | 25 | 40.0 | 217 | 95 $R_b$ [c] |
| N08825 [b] | 825 | 586 | 85 | 241 | 35 | 30.0 | — | — |

# Comparison of the Proof Stress and Pitting Resistance of Duplex and Austenitic SS



# Temperature Limits

ISO 21457  requirement for uncoated DSS in marine atmospheric environments

Type 22Cr  Maximum operating temperature 80 to 100 °C

Type 25Cr  Maximum operating temperature 90 to 110  °C

## EEMUA Publication 194

**Table 2 CRAs commonly used in subsea equipment**

| Generic Type | Common Name | UNS | Typical Composition | | | | Typical Properties, MPa[1] | | Typical Min Design Temp | PREN[2] / PREw (min) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Cr | Ni | Mo | Others | Min YS | Min TS | °C | |
| Austenitic Stainless Steels | 316L SS | S31603 | 18 | 12 | 2.5 | | 205 | 515 | −196 | 22.6 |
| | Nitronic 50 | S20910 | 20.5 | 12.5 | 2.25 | Mn, Nb, N | 380 | 690 | −196 | 28.6 |
| Super-austenitic Stainless Steels | 6Mo | S31254 | 20 | 18 | 6 | N | 300 | 650 | −196 | 42.2 |
| | 904L | N08904 | 21 | 25 | 4.5 | Cu | 220 | 490 | −196 | 32.2 |
| | Alloy (Sanicro) 28 | N08028 | 27 | 31 | 3.5 | Cu | 215 | 550 | −196 | 35.9 |
| Precipitation-Hardened Aust. SS | Grade 660 | S66286 | 15 | 25 | 1.25 | Al,Ti,V,B | 585 | 895 | −29 | 16.8 |
| Duplex Stainless Steels | Nitronic 19D | S32001 | 19.7 | 1.6 | 0.06 | Mn, N, Cu | 450 | 620 | −50 | 22 |
| | 22% Cr Duplex | S31803 | 22 | 5.5 | 3 | N | 450 | 620 | −50 | 30.5[6] |
| | 25%Cr Superduplex | S32550 | 25 | 5.5 | 3 | N | 600 | 760 | −50 | 32.2 [5] |
| | 25%Cr Superduplex | S32750 | 25 | 7 | 3.5 | N | 550 | 800 | −46 | 37.7[5] |
| | 25%Cr Superduplex | S32760 | 25 | 7 | 3.5 | N,Cu,W | 550 | 750 | −46 | 37.4[5] |
| | 25% Cr Superduplex | S32974 | 25 | 7 | 3.2 | N,Cu,W | 550 | 800 | -46 | 36.7[5] |

# Temperature Limits (Cont.)

NORSOK standard M-001

Table 10 – Metallic materials for pressure retaining purposes

| Material | Minimum design temp. °C | Impact testing required | Maximum operating temp. °C | | Notes |
|---|---|---|---|---|---|
| | | | Marine environment | Seawater | |
| **Carbon and low alloy steel** | | | | | |
| 235 | - 15 | | | | |
| 235LT | - 46 | Yes | | | 1 |
| 360LT | - 46 | Yes | | | |
| 3.5 % nickel steel | -101 | Yes | | | |
| **Martensitic stainless steels** | | | | | |
| SM13Cr | - 35 | Yes | | | |
| 13Cr | - 10 | | | | |
| 13Cr valve trim parts | - 29 | | | | 2, 3 |
| 13Cr4Ni | - 46 | Yes | | | |
| 13Cr4Ni double tempered | -100 | Yes | | | |
| **Austenitic stainless steels** | | | | | |
| Type 316 SS | -196 | Yes | 60 | | 4 |
| Type 6Mo SS | -196 | Yes | 120 | 20 | 4 |
| **Duplex stainless steels** | | | | | |
| Type 22Cr duplex SS | - 46 | Yes | 100 | | |
| Type 25Cr duplex SS | - 46 | Yes | 110 | 20 | |

# Sour Service Limits

## NACE MR0175/ISO 15156 Recommendations

includes some recommended limits of H2S partial pressures for the avoidance of sulphide stress cracking, as follows:

Duplex stainless steel (i.e. PREN/PREw 30 to 40 and Mo ≥ 2%): 0.10 bar (abs)

Super duplex stainless steel (i.e. PREN/PREw > 40 and < 45): 0.20 bar (abs).

Note: See also tables A.24 & A.25

## EEMUA Publication 194

22% Cr Duplex stainless steel: 0.10 bar (abs) at pH 3.5 and higher

25% Cr Super duplex stainless steel: 0.25 bar (abs) at pH 3.5 to 4.5

0.50 bar (abs) at pH greater than 4.5.

Note: The limits for duplex stainless steel were largely developed for downhole tubing grades. For applications involving welding, further qualification for the field-specific conditions is recommended.

# Welding Requirements for Duplex Stainless Steels

## NACE MR0103/ISO 17495 Requirements

Fabrication and repair welds in all wrought and cast duplex stainless steels shall be produced using a welding procedure qualified by performing the following tests on specimens taken from the WPQT coupon(s) .

a) A hardness survey shall be performed in accordance with Annex C. The average hardness shall not exceed 310 HV, and no individual reading shall exceed 320 HV.

b) Metallographic ferrite measurements shall be performed in accordance with ASTM E562. The average ferrite content in the weld deposit and HAZ shall be within the range of 35 % to 65 %, with a relative accuracy of 10 % or lower.

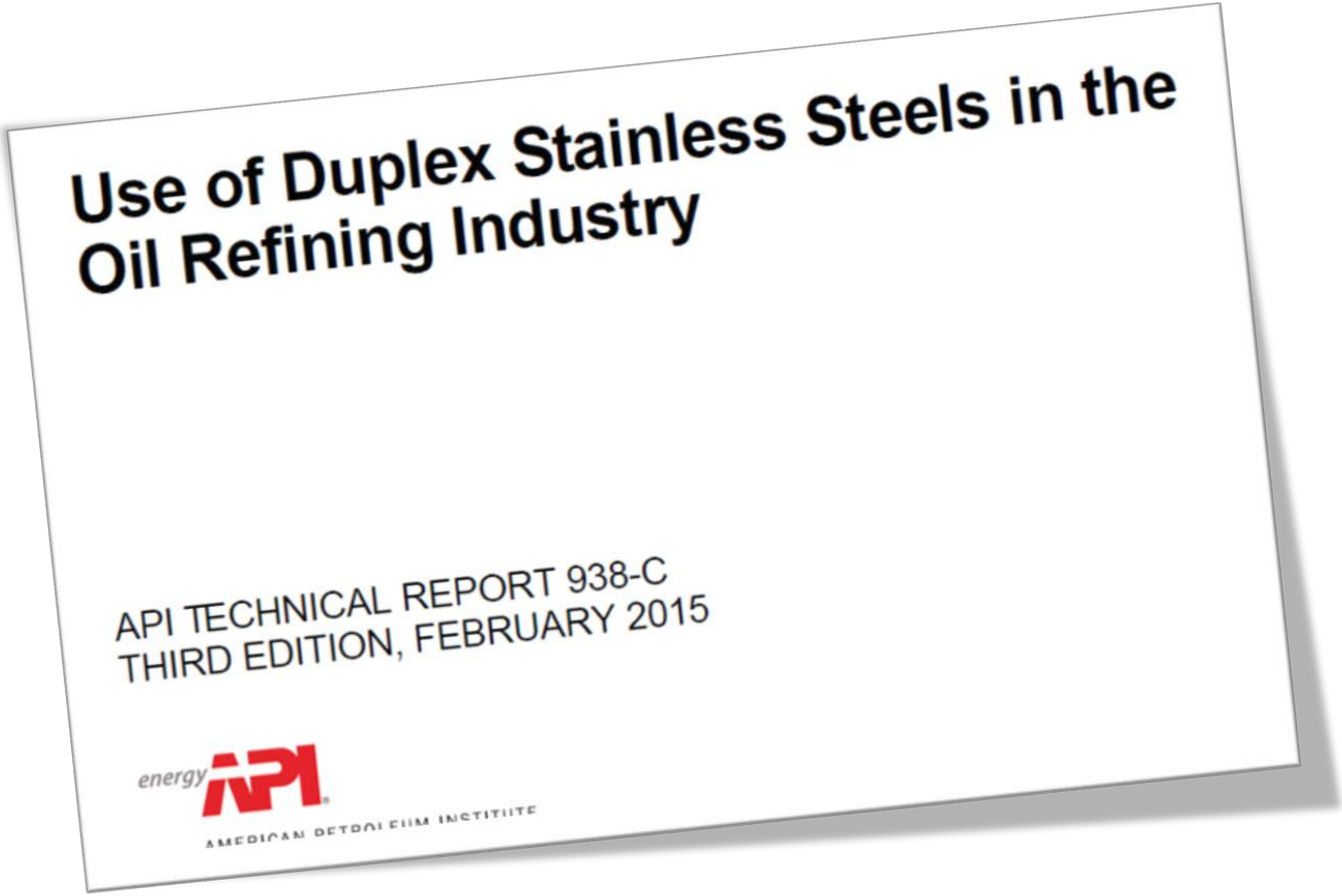
# Welding Requirements for Duplex Stainless Steels

## NACE MR0175/ISO 15156 Requirements

The hardness of the HAZ after welding shall not exceed the maximum hardness allowed for the base metal and the hardness of the weld metal shall not exceed the maximum hardness limit of the respective alloy used for the welding consumable.

A cross-section of the weld metal, HAZ, and base metal shall be examined as part of the welding procedure qualification. The microstructure shall be suitably etched and examined at ×400 magnification and shall have grain boundaries with no continuous precipitates. Intermetallic phases, nitrides, and carbides shall not exceed 1.0 % in total. The sigma phase shall not exceed 0.5 %. The ferrite content in the weld metal root and unreheated weld cap shall be determined in accordance with ASTM E562 and shall be in the range of 30 % to 70 % volume fraction.

# Find more valuable information about DSS at:



**Use of Duplex Stainless Steels in the Oil Refining Industry**

API TECHNICAL REPORT 938-C
THIRD EDITION, FEBRUARY 2015

# API TR 938-C has four primary objectives

a) potential environment-related failure mechanisms and preventative measures to avoid them;

b) typical material specification requirements used by refineries;

c) typical fabrication specification requirements used by refineries;

d) examples of applications of DSSs within refineries.

# API TR 938-C table of contents

# Some Tips from API TR 938-C

ASME Section VIII requirements for impact testing for DSS base and weld metals are given in UHA-51(d)(3)(a), which requires testing of all DSSs thicker than 10 mm (3/8 in.) or those with an MDMT less than –29 °C (–20 °F).

ASME B31.3 requires testing of welds when the MDMT is less than –29 °C (–20 °F) and of base metals when the MDMT is below the minimum allowable temperature for the specific grade.

Maximum operating temperatures are limited by the susceptibility of the ferritic phase to 475 °C (885 °F) embrittlement and other embrittlement mechanisms.

Most Codes applicable to refinery equipment and piping limit the various DSS grades to between 260 °C to 340 °C (500 °F to 650 °F), maximum, to avoid these problems.

Welds are more prone to sigma formation than base materials, and hence, these temperature limits are especially important with welded components.

# Some Tips from API TR 938-C (Cont.)

**Table 5—ASME Code Maximum Allowable Temperatures**

| Grade | ASME Section VIII (Div. 1) °C (°F) | ASME B31.3 °C (°F) |
|---|---|---|
| S32304 | 316 (600) | 316 (600) |
| S32101 | 316 (600) Code Case 2418 | NL |
| S32202 | 316 (600) | NL |
| S32003 | 343 (650) Code Case 2503 | 343 (650) |
| S82011 | 343 (650) Code Case 2735 | NL |
| S82441 | 316 (600) Code Case 2780 | NL |
| S31803/S33205 (Note 1) | 316 (600) | 316 (600) |
| S32550 | 260 (500) | NL |
| S32750 | 316 (600) | 316 (600) |
| S32760 | 316 (600) | 316 (600) |
| S32906 | 316 (600) | NL |
| S32707 | 260 (500) Code Case 2586 | NL |

NOTE 1 NL = not listed.

NOTE 2 S32205 can use the design allowables for S31803 if the material is dual-certified.

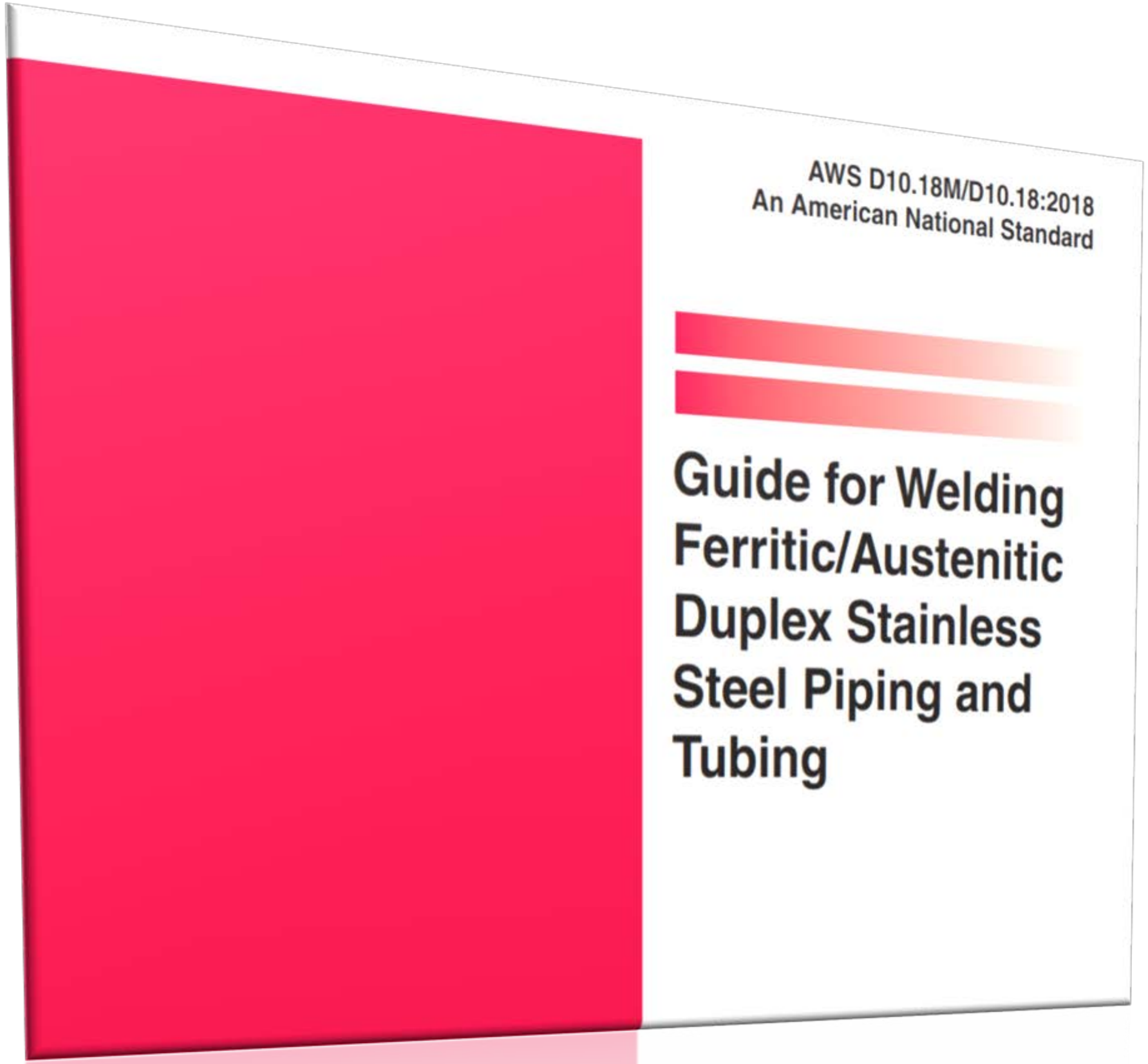
# Some Tips from API TR 938-C (Cont.)

**Table 9—Welding Consumables**

| Process | 22 % Cr | 25 % Cr (Note 1) | 27 % Cr |
|---|---|---|---|
| SMAW | SFA 5.4 E2209 | SFA 5.4 E2553, E2594, or E2595 | Not applicable |
| GTAW/GMAW | SFA 5.9 ER2209 | SFA 5.9 ER2553, or ER2594 | As recommended by alloy supplier |
| SAW | SFA 5.9 ER2209 with a flux designed for DSSs | SFA 5.9 ER2594 with a flux designed for DSSs | As recommended by alloy supplier |
| FCAW | SFA 5.22 E2209TX-X or EC2209 | SFA 5.22 E2553TX-X, E2594TX-X, EC2553, or EC2594 | Not applicable |

NOTE This table does not cover some of the specialized 25 % Cr alloys. The material manufacturer's (i.e. the alloy supplier's) recommendations on welding consumables should be followed.

# AWS D10.18 for welding



**This presentation was developed by Kamran Khodaparasti.**

**Publication date: May 2023**

**References:**

**API TR 938-C**
**ISO 21457**
**NORSOK M-001**
**EEMUA 194**
**NACE MR0175/ISO 15156**
**NACE MR0103/ISO 17495**
**Internet Documents**