outokumpu
stainless steel & high performance alloys

# Special Stainless Steel Grades for Forgings

## General characteristics

Outokumpu Long Products offers a large variety of duplex and high performance austenitic stainless steel grades. A selection of commonly used steel grades for forgings is listed in Table 1. Outokumpu produces these grades as both rolled and forged billets, making us the perfect supplier for your forgings such as flanges, fittings and valves.

High performance austenitic and duplex stainless steels are best suited for forgings used in demanding environments. The selected grades can be positioned according to their corrosion resistance and mechanical strength as in Figure 1. High performance austenitic offers high corrosion resistance due to the high levels of chromium, nickel, molybdenum and nitrogen. For the duplex grades, the duplex microstructure contributes to high strength and improved resistance to stress corrosion cracking combined with a good resistance to localized corrosion.

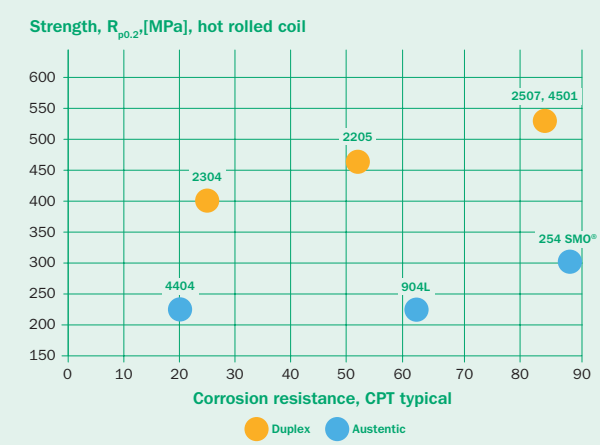


**Fig 1.** Positioning of the selected stainless steel grades. Grades 4845 and 4550 are high temperature grades and their wet corrosion resistance is not relevant, thus excluded from the figure.

## Chemical composition

The typical chemical composition of these grades is shown in Table 1. For full specification and ranges, see ASTM A182 or EN 10088.

**A selection of commonly used stainless steel grades for forgings and their typical chemical composition.** Table 1

| Outokumpu | EN | UNS | ISO | ASTM A182 | C | Cr | Ni | Mo | N | Others |
|---|---|---|---|---|---|---|---|---|---|---|
| 4404 | 1.4404 | S31603 | 4404-316-03-I | F316L | 0.02 | 17.2 | 10.1 | 2.1 | | |
| 904L | 1.4539 | N08904 | 4539-089-04-I | F904L | 0.01 | 20 | 25 | 4.3 | | 1.5Cu |
| 254 SMO® | 1.4547 | S31254 | 4547-312-54-I | F44 | 0.01 | 20 | 18 | 6.1 | 0.20 | Cu |
| 4550 | 1.4550 | S34700 | 4550-347-00-I | F347 | 0.05 | 17.5 | 9.5 | | | Nb |
| 4845 | 1.4845 | S31008 | 4845-310-08-E | F310 | 0.05 | 25 | 20 | | | |
| 2304 | 1.4362 | S32304 | 4362-323-04-I | F68 | 0.02 | 23 | 4.8 | 0.3 | 0.10 | Cu |
| 2205 | 1.4462 | S31803<br>S32205 | 4462-318-03-I | F51<br>F60 | 0.02 | 22 | 5.7 | 3.1 | 0.17 | |
| 2507 | 1.4410 | S32750 | 4410-327-50-E | F53 | 0.02 | 25 | 7 | 4 | 0.27 | |
| 4501 | 1.4501 | S32760 | 4501-327-60-I | F55 | 0.02 | 25.4 | 6.9 | 3.8 | 0.27 | W Cu |

# Hot workability

Both high performance austenitic and duplex stainless steels have excellent hot forming properties. However, a uniform temperature within the hot working temperature range for the whole forging is important in order to avoid differences in ductility and cracking in the cooler areas.

For the high performance austenitic grades, higher hot strength is expected compared to standard austenitic grades such as 4404. In some cases the forging equipment can be the limiting parameter. Longer heating times are also expected due to the lower thermal conductivity. However, for the high Mo-grades too long heating times might lead to scaling.

The duplex stainless steels might become soft at high temperatures. Therefore forging at too high a temperature might cause sagging and reduce structural stability.

### Recommended hot working and heat treatment temperatures

Table 2

| Steel grade | Hot working temperature range °C (°F) | Heat treatment temperature min/range °C (°F) |
|---|---|---|
| 4404 | 950-1250 (1740-2280) | 1040 (1900) |
| 904L | 1050-1300 (1920-2370) | 1050-1150 (1920-2100) |
| 254 SMO® | 1050-1300 (1920-2370) | 1150 (2100) |
| 4550 | 950-1250 (1740-2280) | 1050 (1920) |
| 4845 | 1050-1300 (1920-2370) | 1040 (1900) |
| 2304 | 1050-1250 (1920-2280) | 925-1050 (1700-1920) |
| 2205 | 1050-1250 (1920-2280) | 1020-1100 (1870-2010) |
| 2507 | 1060-1280 (1940-2330) | 1025-1120 (1870-2050) |
| 4501 | 1060-1280 (1940-2330) | 1100-1140 (2010-2085) |

# Heat treatment

After a forging operation, a heat treatment (solution annealing) is recommended for both high performance austenitic and duplex stainless steels. Suitable temperatures for heat treatment of forged products are presented in Table 2. For duplex stainless steels the chemical composition is balanced to give approximately equal amounts of ferrite and austenite in the solution-annealed condition. Heat treatment at higher annealing temperature gives higher ferrite content.

High performance austenitic and duplex stainless steels are sensitive to erroneous heat treatment and quenching. It is important, therefore, that the whole heat treatment load is given enough time, at the recommended temperatures, to dissolve any detrimental phases. The heat treatment operation should be followed by quenching in a liquid media to below 260°C (500°F) to avoid reformation of these detrimental phases that can, in worst case result in decreased corrosion resistance and mechanical properties.

The detrimental phases concerned are often sigma phase, nitrides and carbides. The formation of intermetallic phases such as sigma phase occurs in the temperature range 600-1000°C (1112-1832°F) and decomposition of ferrite occurs in the range 350-500°C (662-932°F) (475°C embrittlement). In Figure 2 and 3, the time and temperature for the formation of these phases are shown. The curves for the duplex grades (Figure 3) show the time and temperature where the impact toughness is reduced by 50% and the curves for the austenitics (Figure 2) show the time and temperature where unacceptable amounts of grain boundary precipitations have formed.

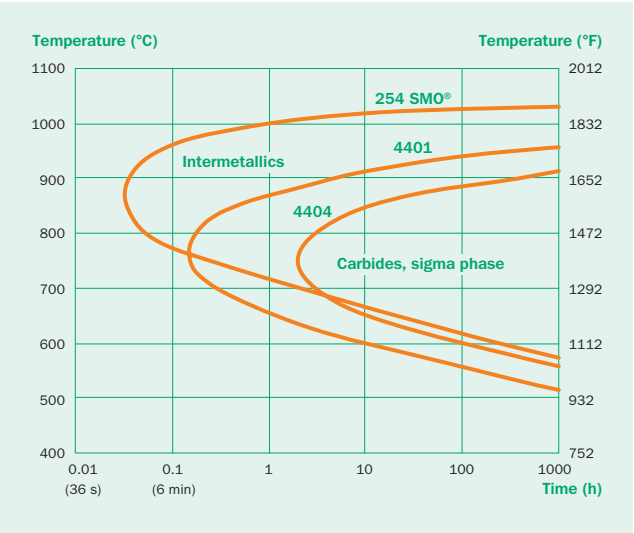


Fig. 2. TTT – curve for the austenitic grades.

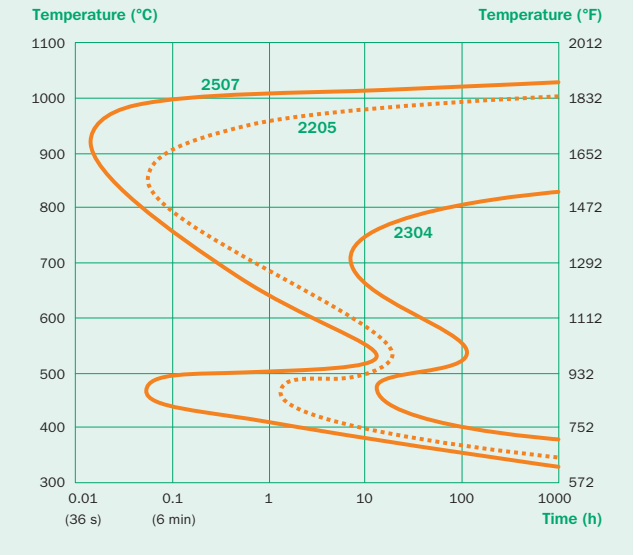


Fig. 3. TTT curve for the duplex grades.

# Machinability

Stainless steels are considered to be more demanding to machine than carbon steels. The rule of thumb is that the higher the alloy content is, the harder it is to machine. Figure 4 shows a relative comparison of the machinability of the selected stainless steel grades, using a turning operation with cemented carbide inserts. For recommended start values and inserts please review our machining guidelines which are available for most of the grades below.

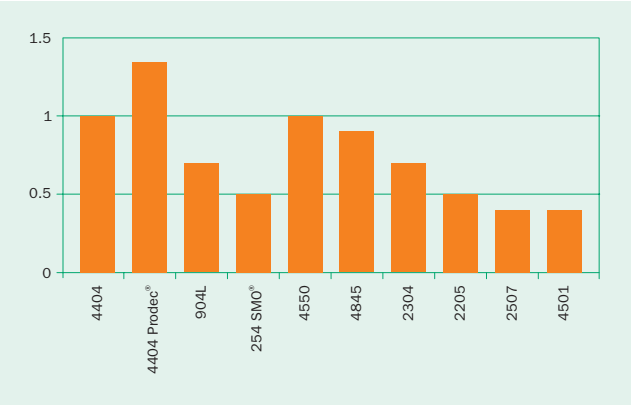


**Fig. 4.** Machinability index for the selected stainless steel grades.

# Corrosion resistance

The wet corrosion resistance of these stainless steel grades is shown in Figure 5, in relation to the localized corrosion caused by chlorides. Grades 4845 and 4550 are high temperature grades and their wet-corrosion resistance is therefore not relevant. The duplex and the high performance austenitic stainless steels offer a better resistance towards stress corrosion cracking (SCC) compared to standard austenitic grades, like 4404.

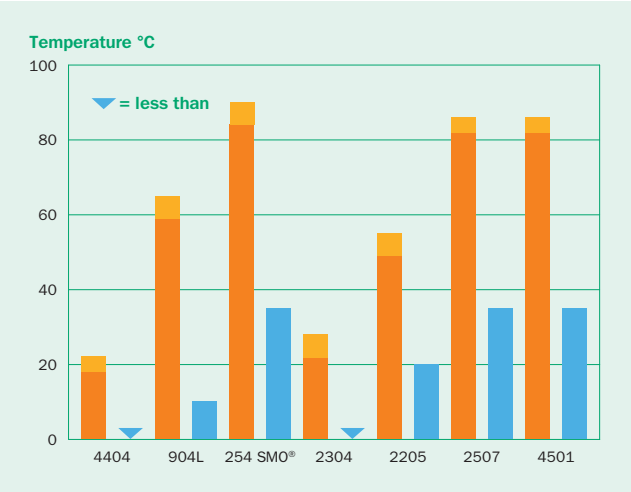


**Fig. 5.** Corrosion resistance of the stainless steel grades. Orange bars represent CPT (ASTM G150, min-max values), blue bars CCT values (ASTM G48 F).

# Mechanical properties

The expected mechanical properties of the final product are presented in Table 4. The duplex stainless steels have significantly higher mechanical strength than the corresponding austenitic grade with similar corrosion resistance.

**Mechanical strength according to ASTM A182** Table 3

| Steel grade | Min. proof stress, $R_{p0.2}$ MPa (ksi) | Min. tensile strength $R_m$ MPa (ksi) |
|---|---|---|
| 4404 | 170 (25) | 485 (70) |
| 904L | 215 (31) | 490 (71) |
| 254 SMO® | 300 (44) | 650 (94) |
| 4550 | 205 (30) | 515 (75) |
| 4845 | 205 (30) | 515 (75) |
| 2304 | 400 (58) | 600 (87) |
| 2205 (S31803) | 450 (65) | 620 (65) |
| 2205 (S32205) | 450 (65) | 655 (95) |
| 2507 | 550 (80) | 800 (116) |
| 4501 | 550 (80) | 750-895 (109-130) |

# Products

Outokumpu Long Products offers billets in rolled and forged condition from our mill Degerfors Stainless in Degerfors, Sweden. Dimensions, lengths and tolerances are seen in Table 5.

**Dimension program of rolled and forged billet[1]** Table 4

| Condition | Shape | Size (mm) | Length (m) | Tolerance (mm) |
|---|---|---|---|---|
| Rolled | Round | 75-210 | 3-12 | -0.5 to +3.5 |
| Rolled | Square | 75-200 | 3-12 | -0.5 to +3.5 |
| Forged | Round | 150-240 | 3-12 | ±5 |
| Forged | Square | 150-240 | 3-12 | ±5 |

[1]Where appropriate concast billet may be used. Larger sizes in rolled billet, from ingot, can be supplied upon request.

# Quality assurance

Our quality management system is approved to ISO 9001. Outokumpu Long Products takes complete responsibility for the quality of the products we supply from testing, selection and sorting of raw materials to pre-delivery inspection.

# Certifications

- ISO 9001 Technischer Überwachungs Verein-Nord (TÜV Nord)
- AD-2000-MerkblattW0 Technischer Überwachungs Verein-Nord (TÜV Nord)
- PED 97/23/EC Technischer Überwachungs Verein-Nord (TÜV Nord)

1525EN-GB:1. Centrumtryck AB Avesta, November, 2013.

# Working towards forever.

We work with our customers and partners
to create long lasting solutions for the tools
of modern life and the world's most critical problems:
clean energy, clean water and efficient infrastructure.
Because we believe in a world that lasts forever.



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