Product standards and approvals

Approval
Arbetarskyddsstyrelsen

TKN
Plate, sheet, strip, bar, forgings for pressure vessels (Swedish Pressure Vessel Code)

NGS 1605
Nordic Rules for application of the non-standard steel Avesta 254 SMO (plate, sheet, strip, bar and forgings for pressure vessels)

DnV Rules
Avesta 254 SMO sheet and plate for use in offshore structures

VdTÜV WB 473
Austenitischer Walz- und Schmiedestahl X2 CrNiMo-CuN 20 18 6. Blech, Band, Schmiedestück, Stabstahl für Druckbehälter

TÜV Wien WB 182
Austenitischer Walz- und Schmiedestahl X2 CrNiMo-CuN 20 18 6. Blech, Band, Schmiedestück, Stabstahl für Druckbehälter

ASTM A167
Stainless and heat resisting CrNi steel, plate, sheet, strip

ASTM A182/ASME SA-182
Forged or rolled alloy-steel pipe flanges, forged fittings, and valves and parts for high temperature service

ASTM A193; ASTM A194
Alloy and stainless steel bolts and nuts for high pressure and high temperature service

ASTM A240/ASME SA-240
Heat resisting Cr and CrNi stainless steel, plate, sheet, strip for fusion-welded unfired pressure vessels

ASTM A249/ASME SA-249
Welded austenitic steel boiler, superheater, heat exchanger and condenser tubes

ASTM A269
Seamless and welded austenitic stainless steel tubing for general service

ASTM A276
Stainless and heat resisting steel bars and shapes

ASTM A312/ASME SA-312
Seamless and welded austenitic stainless steel pipe

ASTM A351/ASME SA-351
Steel castings, austenitic, for high temperature service

ASTM A358/ASME SA-358
Electric fusion-welded austenitic CrNi alloy steel pipe for high temperature

ASME SA-403
Wrought austenitic stainless steel piping fittings

ASTM A409/ASME SA-409
Welded large diameter austenitic steel pipe for corrosive or high temperature service

ASTM A473
Stainless and heat resisting forgings

ASTM A479/ASME SA-479
Stainless and heat resisting steel wire, bars and shapes for use in boilers and other pressure vessels

ASTM A743; ASTM A744
Castings, iron-chromium, iron-chromium-nickel for general and severe service

ANSI B31.1
Power piping

ANSI B16.34*
Valves, flanged and butt welding ends

NACE MR0175
Sulphide stress cracking resistant material for oil field equipment

EN 10088

*application to be approved

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...ntra AB, Västerås 1996.

STAINLESS AND HEAT RESISTING STEELS

254 SMO® UNS S31254

a 6% Mo steel with very good corrosion resistance in environments containing halides, especially in seawater

C	Cr	Ni	Mo	Others
0.01	20	18	6.1	N, Cu

Information 9596; supersedes inf. 9512

General

Avesta Sheffield 254 SMO is an austenitic stainless steel which due to its high molybdenum content possesses very high resistance to pitting and crevice corrosion. The steel grade was developed by Avesta Sheffield for use in halide-containing environments such as seawater. 254 SMO also shows good resistance to uniform corrosion and, especially in acids containing halides, this steel grade is superior to conventional stainless steels.

254 SMO is a registered trademark of Avesta Sheffield AB.

Characteristic properties

The high levels of molybdenum in particular but also of chromium and nitrogen endow 254 SMO with extremely good resistance to pitting and crevice corrosion. The addition of copper provides improved resistance in certain acids. Furthermore, due to its relatively high nickel content in combination with the high levels of chromium and molybdenum 254 SMO possesses good resistance to stress corrosion cracking.

Even highly alloyed stainless steels have a very limited applicability in environments which contain halide ions, e.g. chloride, bromide and fluoride solutions. For this reason it has often been necessary to use expensive materials such as nickel based alloys or titanium for these environments. 254 SMO was developed with a view to offering a less expensive alternative.

Numerous field tests and extensive application experience show that 254 SMO has a high resistance to crevice corrosion in seawater at ambient and slightly elevated temperatures. Very few stainless steels possess this property.

254 SMO resists attack in acidic, oxidizing halide solutions that occur e.g. in pulp bleach plants and its resistance is such that the steel can often be ranked equal with the most resistant nickel based alloys and titanium.

Due to its high nitrogen content 254 SMO has higher mechanical strength than most other austenitic stainless steels. Like these 254 SMO is characterized by high ductility and impact strength as well as good weldability. The high molybdenum content of 254 SMO can lead to an increased oxidation rate at annealing and as a consequence a rougher surface finish after pickling than standard stainless steels. This has, however, no negative influence on the corrosion resistance of the material.

Super alloy welding consumables, designated Avesta P12 and P16 respectively, are used for welding and the weld metal thus produced has equally good corrosion resistance as the parent metal.

Abrasive contact with copper / brass items should be avoided in the manufacturing process. If these substances are present in metallic form on the surface, they can cause surface cracks in connection with welding, hot forming and heat treatment.

Chemical composition

The chemical composition of specific steel grades may vary slightly between different national product standards. The required standard will be fully met as specified on the order.

In order to provide constant reference to material tests previously carried out within the Group, the historical Avesta steel designations are used in this data sheet.

Table 1

Avesta Sheffield	EN	Chemical composition, %, typical values C	Cr	Ni	Mo	N	Others	Steel grades according to national product standars SS	DIN	ASTM	BS
17-12-2.5	1.4436	0.04	17	11	2.7	–	–	2343	1.4436	316	316 S33
17-14-4LN	1.4439	0.02	17	13	4.2	0.15	–	–	1.4439	S31726	–
904L	1.4539	0.01	20	25	4.5	–	Cu	2562	1.4539	N08904	904 S13
2205	1.4462	0.02	22	5.5	3	0.17	–	2377	1.4462	S31803	318 S13
SAF 2507™	1.4410	0.02	25	7	4	0.27	–	2328	–	S32750	–
254 SMO®	1.4547	0.01	20	18	6.1	0.20	Cu	2378	–	S31254	–
Ni-alloys		C_{max}									
Alloy G	–	0.05	22	44	6.5	–	Cu	–	2.4618	N06007	–
Alloy 625	–	0.10	21	60	9	–	Nb	–	2.4856	N06625	–
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Structure

254 SMO is annealed at 1150–1200°C to obtain an austenitic structure. In certain cases there may be traces of intermetallic phases (chi- and sigma phase) in the centre of the material. Normally, however, these have no influence on impact strength or corrosion resistance. When exposed in the temperature range 600–1000°C these phases can precipitate at the grain boundaries. If the recommendations given for hot forming, welding and heat treatment are followed, there will be no precipitation affecting the corrosion resistance.

Characteristic temperatures Table 2

	Temp. °C
Solidification range	1400–1325
Scaling temperature in air	1000
Hot forming	1200–1000
Quench annealing	1150–1200 water*)
Pressure vessel application	(–60)–400

*) 1120–1150 air / water for material in thicknesses below 2 mm

Mechanical properties

Mechanical properties for 254 SMO are given in Tables 3 and 4. Hot rolled plate in thicknesses 10–30 mm, transverse direction.

Mechanical properties Table 3

				20°C
Yield strength	$R_{p0.2}$	N / mm²	min.	300
	$R_{p1.0}$	N / mm²	min.	340
Tensile strength	R_m	N / mm²	min.	650
Elongation	A_5	%	min.	35
Hardness	HB		max.	210
Impact value	KCV	J / cm²	min.	120

Tensile properties at elevated temperatures Table 4

			50	100	200	300	400°C
$R_{p0.2}$	N / mm²	min.	270	235	195	175	160
$R_{p1.0}$	N / mm²	min.	305	270	225	205	190
R_m	N / mm²	min.	635	615	560	525	510

Physical properties

Table 5 shows typical properties for 254 SMO.

Corrosion resistance

Intergranular corrosion

254 SMO has a very low carbon content. This means that there is very little risk of carbide precipitation in connection with heating. The steel passes the Strauss test (ASTM A 262 practice E) even after one hour of sensitizing at 600–1000°C.

However, due to the high alloy content of the steel, intermetallic phases can precipitate at the grain boundaries in the above-mentioned temperature range (see under Structure). These precipitations do not involve a risk of intergranular corrosion in the corrosive media where this steel is used. Thus welding can be carried out without risk of intergranular corrosion. However, in hot concentrated nitric acid these phases can give rise to intergranular corrosion in the heat-affected zone.

Uniform corrosion

In a solution containing halides such as chloride, bromide or iodide ions conventional stainless steels can readily be attacked by localized corrosion in the form of pitting, crevice corrosion or stress corrosion cracking. In certain cases, however, the presence of halides can accelerate the uniform corrosion. This applies especially to cases where halides occur in non-oxidizing acids.

In *pure sulphuric* acid (Figure 1) 254 SMO is much more resistant than 17-12-2.5 (type 316) but is somewhat less resistant than 904L (N08904) in acids of high concentration. In *sulphuric acid contaminated with chloride ions* (Figure 2) 254 SMO shows the highest resistance. The high nickel content of 254 SMO ensures that the corrosion rate will not increase steeply if the temperature that is indicated by the curve for 0.1 mm / year is exceeded.

Stainless steels of the type 17-12-2.5 (316) cannot be used in *hydrochloric acid* due to the risk of localized and uniform corrosion. However, as appears from Figure 3, 254 SMO can be used in dilute acid at moderate temperatures. Pitting need not be feared in the zone below the borderline but crevices must be avoided.

Conventional stainless steels also have a limited range of resistance in *fluosilicic acid* (Figure 4) and *hydrofluoric acid* (Figure 5). 254 SMO, on the other hand, can be used within a relatively wide range of concentrations and temperatures.

More information about corrosion resistance in specific media can be found in the Avesta Sheffield Corrosion Handbook for Stainless Steels.

Physical properties Table 5

		20	100	200	300	400°C
Density	g / cm³	8.0	–	–	–	–
Modulus of elasticity	kN / mm²	200	195	185	178	170
Linear expansion 20–T°C	$x10^{-6}$ / °C	–	16	16	16.5	17
Thermal conductivity	W / m°C	13	14	15	17	18
Heat capacity	J / kg°C	500	520	540	555	570
Electrical resistivity	nΩm	850	900	950	1030	1100

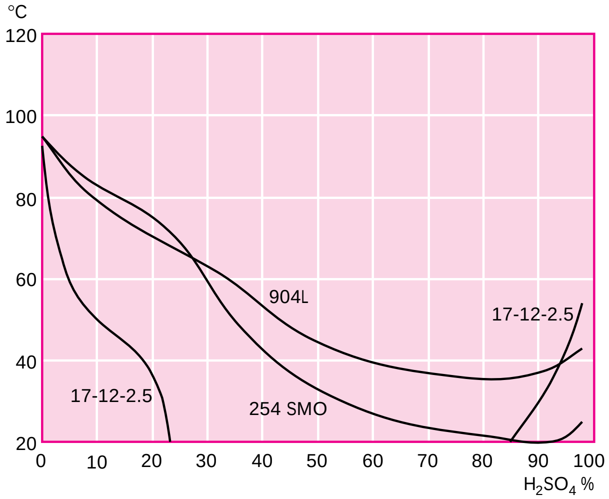

Fig. 1. Isocorrosion curves, 0.1 mm/year, in pure sulphuric acid.

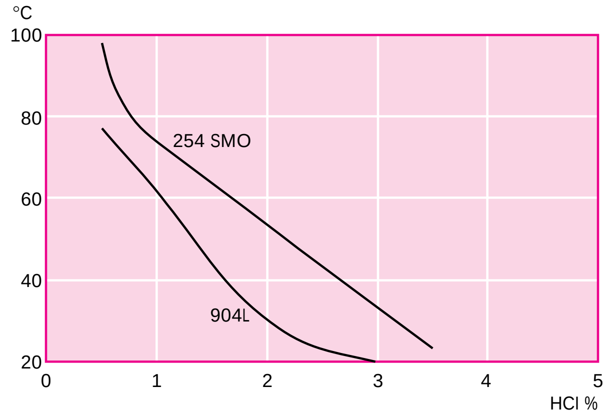

Fig. 3. Isocorrosion curves, 0.1 mm/year, in hydrochloric acid.

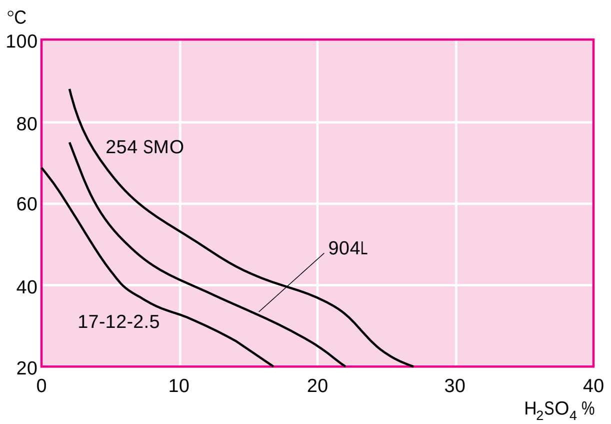

Fig. 2. Isocorrosion curves, 0.1 mm/year, in sulphuric acid containing 2000 ppm of chloride ions.

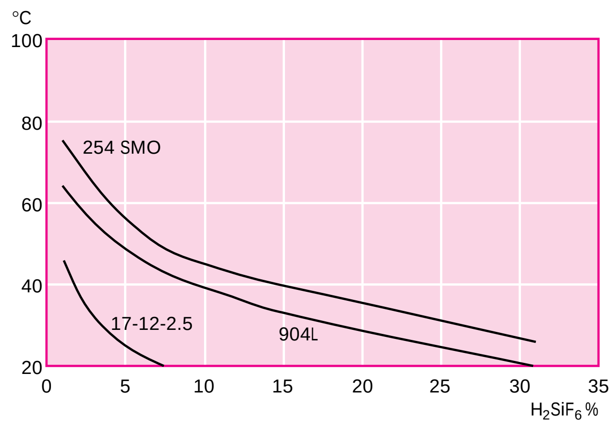

Fig. 4. Isocorrosion curves, 0.1 mm/year, in fluosilicic acid.

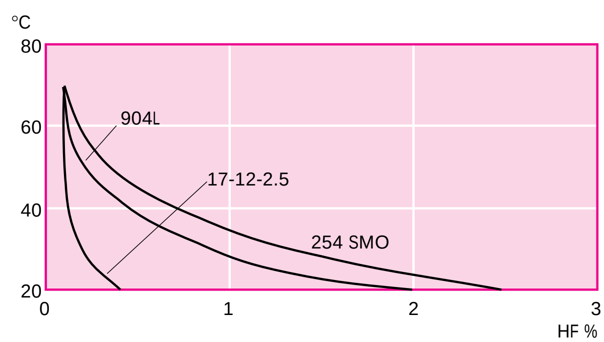

Fig. 5. Isocorrosion curves, 0.1 mm/year, in hydrofluoric acid.

Wet process phosphoric acid always contains corrosive impurities such as chlorides and fluorides. In cases where the acid has a high chloride content, 254 SMO, as appears from Table 6, is often more resistant than conventional stainless steels.

In strongly oxidizing acids, e.g. *nitric acid,* steels without molybdenum of the type 18-9 (304) or 18-10L (304L) are more resistant than molybdenum-containing steels. However, as appears from Table 7, 254 SMO can be the best material choice for mixtures of nitric acid and halides.

Uniform corrosion in wet process phosphoric acid at 60°C — Table 6

Avesta Sheffield	Corrosion rate, mm/year
17-12-2.5	>5
904L	1.2
254 SMO	0.05

Composition in per cent: P_2O_5 54; HCl 0.06; HF 1.1; H_2SO_4 4.0; Fe_2O_3 0.27; Al_2O_3 0.17; SiO_2 0.10; CaO 0.20; MgO 0.70

Uniform corrosion in pickling acid at 25°C — Table 7

Avesta Sheffield	Corrosion rate, mm/year
17-12-2.5	>5
904L	0.51
254 SMO	0.31

Composition in per cent: HNO_3 20; HF 4.

Pitting corrosion

The resistance of stainless steels to pitting corrosion is improved by the introduction of higher levels of chromium, molybdenum and nitrogen. Many different methods are used to compare the resistance of these steels to pitting in chloride solutions. One of the most common methods is by determining the critical pitting temperature (CPT). This is the lowest temperature at which pitting occurs when the material has been exposed to a particular environment. Pitting can easily occur in oxidizing chloride environments. In laboratory conditions, it is possible to emulate oxidizing conditions by electrochemical means, using a potentiostat to give the steel a high potential. The CPT can then be determined by varying the temperature of the test solution and observing to see when pitting attacks occur. Using a specially designed test cell, known as the 'Avesta Cell', it is possible to eliminate the risk of crevice corrosion altogether, so that the CPT can be determined with a high degree of accuracy. Figure 6 shows some typical levels of CPT for different steel grades, obtained in a 1M NaCl solution.

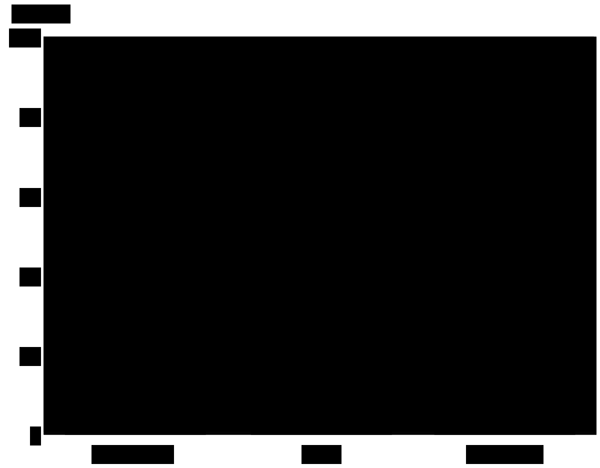

Fig. 6. Critical pitting temperatures (CPT) in 1M NaCl, as measured using the Avesta Cell. Typical values.

Crevice corrosion

The weak point of the conventional stainless steel grades is their limited resistance to crevice corrosion. As is the case with pitting, crevice corrosion occurs primarily under gaskets, deposits or fouling of various kinds. Figure 7 shows the resistance to crevice corrosion of different materials in a greatly accelerated test. The result is measured as the critical crevice corrosion temperature (CCT) at which crevice corrosion is initiated in this very aggressive solution. 254 SMO is superior to the other stainless steel grades.

Fig. 7. Critical crevice corrosion temperatures (CCT) in 6% $FeCl_3$ (MTI-2). PTFE blocks.

Crevice corrosion in seawater

Natural seawater contains biological organisms, which rapidly produce a mucous layer (biofilm) on a steel surface. This film increases the corrosion potential of the steel, which in turn increases the risk of crevice corrosion. This explains why natural seawater is more corrosive than sterile chloride solutions. Natural seawater is at its most corrosive between 25–30°C, whilst at 30–35°C the biofilm becomes less active. Tables 8 and 9 show the result of two tests in natural seawater. The welded samples had strongly tightened plastic washers, covering both weld and base material.

Contrary to the conventional stainless steel grades, 254 SMO has an excellent resistance in natural seawater. In many seawater systems the water is chlorinated, mostly by use of hypochlorite, to avoid fouling. Hypochlorite and chlorine are strong oxidizers and

Crevice corrosion
in filtered Atlantic water — Table 8

Avesta Sheffield	No. of specimens attacked	Deepest attack, mm
17-12-2.5	3 out of 3	1.1
904L	3 out of 3	1.5
254 SMO	0 out of 15	0

Flow rate <0.1 m/s. 3 months at 25°C.

Crevice corrosion
in Atlantic water — Table 9

Avesta Sheffield	No. of specimens attacked	Deepest attack, mm
17-12-2.5	3 out of 3	>3
904L	3 out of 3	1.1
254 SMO	2 out of 12	0.09

The samples have been immersed in the sea for 18 months at ambient temperature (5–30°C).

higher levels than is normal in natural seawater, thus increasing the risk of crevice corrosion initiation further. Chlorinated water becomes more aggressive with increasing temperature. The highest chloride content which can be used without risking crevice corrosion in flange connections depends on temperature. Practical experience indicates that 254 SMO can be used for seawater handling systems at a residual chlorine content of 1 ppm and temperatures up to 30°C. However, much higher chlorine concentrations can be accepted if intermittent chlorination is used.

Stress corrosion cracking

Under unfavourable conditions stress corrosion cracking (SCC) can occur in all stainless steels, with the exception of those ferritic grades which are not alloyed with nickel or copper.

For austenitic steels the resistance to stress corrosion cracking increases with increasing nickel and molybdenum contents. One method to evaluate the resistance to SCC is the drop evaporation test (DET). In this test, a uniaxially stressed specimen is initially resistance heated, upon which a dilute sodium chloride solution (0.1M NaCl) is dripped at a rate of 6 drops per minute. The resistance heating is adjusted to allow each drop to evaporate completely before the next drop hits the specimen. Due to the cooling effect of the solution, the surface temperature of the specimen varies slightly around 100°C. The main purpose of the drop evaporation test is to simulate wetting/evaporation cycles often found in practical applications.

The recorded result is the time to fracture of the specimen. The threshold value of the stress which leads to fracture within 500 hours is determined and expressed as a percentage of the yield strength at 200°C for the steel grade. Figure 8 shows such test results for some stainless steels.

According to this test 254 SMO possesses very good resistance to stress corrosion cracking. However, the steel is not immune against this type of corrosion, it suffers attack in boiling 45% magnesium chloride

[redacted]

Fig. 8. Stress corrosion cracking (SCC) – Drop evaporation tests, threshold stresses. The white sections of the bars indicate the normal spread of results.

test procedure. Ferritic steels alloyed with nickel or copper, and ferritic-austenitic steels also fail in this test.

Sulphide stress corrosion cracking

Hydrogen sulphide may cause embrittlement in ferritic structures and sometimes also in heavily cold worked duplex and austenitic structures. When both hydrogen sulphide and chlorides are present in significant concentrations, the susceptibility to corrosion induced cracking of stainless steels is increased to some degree. Such sour environments are typically found in oil and gas production.

NACE standard MR0175-95 specifies the material requirements for resistance to sulphide stress corrosion cracking (SSCC) for equipment used in oil and gas production. In this standard 254 SMO (UNS S31254) is accepted in both annealed and cold worked condition to a maximum hardness level of 35 HRC. For common austenitic types like 304 and 316 a maximum hardness of 22 HRC is specified. Also, this standard does not allow cold working of the common types in order to increase mechanical strength.

Erosion corrosion

As distinguished from copper alloys, stainless steels have no real limitation as regards flow velocities in, for instance, seawater piping systems. For copper-nickel (e.g. CuNi 90/10), however, erosion corrosion can occur at velocities above 3 metres per second. In stagnant and flowing waters the copper alloys are attacked by sulphide contaminants from decomposition of organic and other matter. 254 SMO is not subject to these types of attack.

Galvanic corrosion

254 SMO is not affected by galvanic corrosion when connected to titanium in seawater. However, copper alloys are attacked, like carbon steel, when in contact with 254 SMO (or titanium). The galvanic attack is increased when the area of 254 SMO is increased in relation to the area of the copper alloy as illustrated by Figure 9. If the seawater is chlorinated the galvanic

[redacted]

Fig. 9. Galvanic corrosion of copper alloys in slow moving seawater at ambient temperature.

Fabrication

Hot working

Hot working should be carried out in the temperature range 1200–1000°C. Higher temperatures will reduce the workability. Fairly heavy scaling occurs at temperatures exceeding 1150°C.

To ensure dissolution of possible precipitations of secondary phases from the hot forming, the subsequent heat treatment should take place at min. 1150°C. The material should then be cooled as quickly as possible. A cooling rate that is too slow can result in reduced corrosion resistance.

Cold working

254 SMO possesses very good cold formability. Bending, pressing and other forming operations which are used in fabrication can be carried out without difficulty. Practical experience obtained from the pressing of heat exchanger plates has been very favourable. The steel work-hardens rapidly. This is demonstrated in Figure 10.

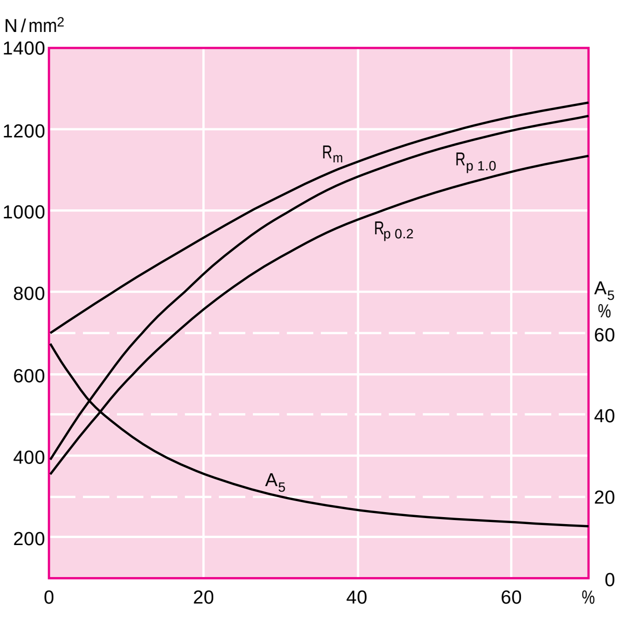

Fig. 10. 254 SMO work-hardening at cold rolling

Machining

Highly alloyed austenitic steels, such as 254 SMO, are generally more difficult to machine than conventional austenitic stainless steels such as 17-12-2.5 (type 316). 254 SMO requires higher cutting forces and causes more rapid tool wear than lower alloyed stainless steels, due to its higher strength and alloy content.

The relative machinability of 254 SMO compared to other stainless steels is illustrated by the machinability index in Figure 11. This index, which rises with increased machinability, is based on a compounded evaluation of test data from several different machining operations. It gives a rough indication of the machinability of different stainless steel grades in relation to that of 17-12-2.5 (type 316). It should be noted that the machinability index does not describe the relative difficulty of machining with cemented carbide or high speed steel tools.

[redacted]

Fig. 11. Relative machinability for some stainless steel grades.

Welding

254 SMO possesses good weldability. When delivered, sheets and plates in 254 SMO have a homogeneous composition. Remelting of the parent metal, such as during welding without filler metal, may cause microscale variations in composition for elements such as chromium, nickel and, particularly, molybdenum. This phenomenon occurs in all highly alloyed stainless steels. These variations may reduce the pitting resistance of the weld. GTA- and plasma-arc welding without filler metal should therefore be avoided. Avesta P12 and P16 welding consumables have a very high alloy type of composition, Table 10. These filler metals will give a weld with a pitting resistance comparable to the base metal.

Welding consumables — Table 10

	Weld metal, typical composition, % C	Si	Mn	Cr	Ni	Mo	Nb
AVESTA P12							
Welding wire	0.03	0.25	0.2	21	63	9	3
Covered electrode	0.02	0.5	2	21	60	9	2
AVESTA P16							
Welding wire	0.02	0.2	0.5	23	60	16	–
Covered electrode	0.02	0.3	0.5	25	59	15	–

The following welding instructions should be observed:

1. The material may not be subjected to abrasive contact with copper/brass items. Penetration of copper/zinc into the grain boundaries can give rise to crack formation.
2. Avesta P12 or P16 welding consumables should be used for all welding methods. GTA- and plasma-arc-welding without filler wire should be avoided in cases where post-weld annealing is impossible.
3. Ignite the electrode in the joint since ignition burns beside the weld can give rise to corrosion attacks.
4. Weld with low heat input, i.e. small diameter filler metal. Weaving should be avoided in horizontal position. Do not use unnecessarily high amperages or thicker electrodes than necessary.
5. In multi-pass welding the workpiece should be allowed to cool to approx. 100°C before the next pass is welded.
6. If a welding pass is terminated too abruptly, so-called pipes or crater cracks can occur in this material just as in other austenitic steels. Such defects must be removed carefully by grinding. Pipe formation can be avoided if the electrode is moved backwards somewhat through the molten pool and lifted gently through the slag.
7. Ensure during GTA- and plasma-arc-welding that the filler wire is fed as continuously and as evenly as possible to avoid variations in composition.
8. Heat treatment is normally not necessary after welding. However, welding without filler metal should be followed by solution annealing at 1150–1200°C and subsequent rapid cooling in order to achieve the best possible corrosion resistance.
9. To ensure optimum corrosion resistance the welds should be cleaned, preferably by pickling.

Further information regarding joint designs, welding methods, etc., is found in the special pamphlet ''How to weld Avesta Sheffield 254 SMO'', Information No. 9556.

Applications

254 SMO has been supplied for the following applications, among others:

- Equipment for use in contact with seawater such as heat exchangers, cooling water pipes and similar components, even in cases where stagnant conditions can occur.
- Equipment at pulp bleaching plants, such as drums, vats and press rolls for filter washers, and pipelines for pulp and filtrate.
- Components in gas cleaning systems, e.g. in pulp and metallurgical industries, and in power stations.
- Tanks and pipelines for different chemicals with high halide levels.
- Equipment used for the distillation of tall oil.

Further information on the use of 254 SMO is given in reference lists, Inf. No. 92108, 9454, 9582.

Products

Hot rolled plate and coil

Dimensions according to Avesta Sheffield AB's manufacturing programme.

Cold rolled plate, sheet and strip

Dimensions according to Avesta Sheffield AB's manufacturing programme.

Bar and forgings

Delivered by Avesta Valbruna AB, Karlstad, Sweden.

Tube and pipe

Welded tube and pipe is manufactured by AST (Avesta Sandvik Tube AB), Fagersta, Sweden. Seamless tube and pipe is delivered by the licensees AB Sandvik Steel, Sandviken, Sweden, and Sumitomo Metal Industries Ltd, Japan.

Fittings

Welding fittings are manufactured by Avesta Calamo AB, Molkom, and Avesta ABE AB, Örnsköldsvik, Sweden. Threaded fittings and flanges are manufactured by Avesta Nords AB, Molkom, Sweden.

Wire rod

Wire rod is delivered by the licensed producer Fagersta Stainless AB, Fagersta, Sweden.

Wire

Cold drawn wire is delivered by the licensees Fagersta Stainless AB, Fagersta, Sweden and AB Sandvik Steel, Sandviken, Sweden.

Welding consumables

Covered electrodes as well as wire for automatic welding (GMAW, GTAW and SAW) of type Avesta P12 and Avesta P16 are produced by Avesta Welding AB, Avesta, Sweden.

Castings

More than 40 foundries are licensed to produce 254 SMO castings. They are located in the countries listed below. Addresses can be obtained from your nearest Avesta Sheffield representative.

Belgium	Japan
Canada	Norway
France	Spain
Germany	Sweden
Great Britain	USA
Italy	