353 MA®

EN 1.4854
UNS S35315

C 0.05	Si 1.3	Cr 25	Ni 35	Others N, Ce

Design Features

The chemical composition of 353 MAis balanced to give an optimum combination of high temperature properties above 1000°C.

- **High scaling temperature, approximately 1175°C.**
- **High creep deformation and rupture strength.**
- **Good resistance to carbon and nitrogen pick-up in oxidizing as well as reducing atmospheres.**
- **Excellent resistance to erosion-corrosion.**

Applications

- Equipment in the cement, gasification, iron and steel, and power generation industries, and in heat treatment and thermal destruction plants:
- Burners.
- Cyclones.
- Damper and flap valves.
- Furnace inner hoods, muffles, and retorts.
- Heat treatment baskets, fixtures, and trays.
- Radiant tubes.
- Rotary kilns.

General Characteristics

Avesta Sheffield 353 MAis an austenitic heat resisting alloy with 35% nickel and 25% chromium. This alloy has been developed primarily for service at 1000°C and above, and is especially suitable for applications with high carbon and/or nitrogen activities.

The relatively high chromium content provides an excellent resistance against carbon and nitrogen pick-up under oxidizing conditions, while the high nickel content reduces the pick-up when no protective oxide layer can be formed. Under both conditions, the elevated silicon content of the alloy will enhance the performance.

Together with the Avesta Sheffield grades 153 MAand 253 MA, 353 MAmakes up a family of high temperature alloys which covers most property requirements over a wide temperature range. The common denominators of this family of MAalloys are:

- their alloying with rare earth metals (REM) which, together with high chromium and silicon contents, results in excellent oxidation resistance.
- their elevated carbon and nitrogen contents which contribute to the high creep and rupture strength.

Structure

353 MAis a fully austenitic alloy. The high nickel content and the addition of nitrogen give the alloy a high austenite stability. Due to the elevated contents of carbon and nitrogen, the structure will contain intergranular nitrides and carbides, especially after service in the temperature range 600–950°C. These precipitations will result in a reduced impact toughness at room temperature, but the ductility (tensile and bending) is nevertheless rather high. Temperature characteristics are shown in Table 2, page 2.

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.

Table 1

International steel numbers		Avesta Sheffield	Typical composition %					National steel designations, superseded by EN		
EN	ASTM	steel name	C	Cr	Ni	Si	Others	BS	DIN	SS
1.4878	321H	18-10Ti	0.05	17.3	9.2	0.5	Ti	321S51	1.4878	2337
1.4828	–	20-12Si	0.04	20	12	2.0	–	–	1.4828	–
1.4833	309S	23-13	0.06	22.5	12.5	0.5	–	309S16	1.4833	–
1.4845	310S	25-20	0.05	25	20	1.0	–	310S16	1.4845	2361
1.4818	S30415	153 MA™	0.05	18.5	9.5	1.3	N, Ce	–	1.4891	2372
1.4835	S30815	253 MA®	0.09	21	11	1.7	N, Ce	–	1.4893	2368
1.4854	**S35315**	**353 MA®**	**0.05**	**25**	**35**	**1.3**	**N, Ce**	**–**	**–**	**–**
–	N08330	Alloy 330*	0.05	19	35	1.0	–	–	1.4864	–
2.4816	N06600	Alloy 600*	0.06	16	72	0.3	–	–	2.4816	–
2.4851	N06601	Alloy 601*	0.10	23	60	0.3	Al	-	2.4851	–

* These alloys are not produced within the Avesta Sheffield Group.

INFORMATION 9835:2 SUPERSEDES INF.96106

TEMPERATURE CHARACTERISTICS

Table 2

	Temp. °C
Solidification range	1410 –1360
Scaling temperature in air	1175
Carbide/nitride precipitation	500 – 950
Hot forming	1150 – 980
Quench annealing	1100 –1150
Stress relief annealing (min. 0.5 h)	1010 –1040

Mechanical Properties

The proof strength and ultimate tensile strength of 353 MA are high at all temperatures. Design values are usually based on proof strength or tensile strength for constructions used at temperatures up to about 600°C. For higher temperatures the creep strength values of the material are applied.

Mechanical properties are shown in Tables 3–4. Avesta Sheffield is using EN 10095 data when applicable. Data refers to transverse specimens of sheet and plate with a thickness of up to 30 mm.

No elevated temperature tensile properties are given due to scarcity of data.

MECHANICAL PROPERTIES
(MINIMUM VALUES)

Table 3

			20°C
Proof strength	$R_{p0.2}$	N/mm²	300
	$R_{p1.0}$	N/mm²	340
Tensile strength	R_m	N/mm²	650
Elongation	A_5	%	40
Hardness	HB	max	210

High Temperature Corrosion

The high temperature corrosion resistance of a material is in many cases dependent on the material's ability to form a protective oxide layer. Under reducing conditions, when such a protective coating is not formed, the corrosion resistance is determined by the alloy content of the material.

Aconsiderable amount of data is available from tests on the oxidation resistance of 353 MAin air. For other types of corrosion, however, test results are still rather limited. For the time being, only a short time corrosion test programme has been carried out, and there are also some results reported from actual service applications.

OXIDATION

353 MAhas a very high resistance to oxidation. This is due to the high chromium and silicon contents and the REM addition, which restrain an excessive oxide growth. The oxide layer, which is thin and ductile, adheres strongly to the underlying alloy surface. Thus, the resistance against spalling due to cyclic temperature variations is improved.

Another effect of the high ductility and good adherence of the oxide layer is the high erosion resistance of the alloy.

Traditionally, the only commonly used measure of oxidation resistance has been the scaling temperature. At Avesta Sheffield, 45 hour oxidation tests with continuous weight measurements are used to determine this temperature. During these tests, the specimen is air cooled down to room temperature five times. The scaling temperature is defined as the lowest of the following:

- the temperature that gives a weight increase of 1.0 g/m² h.
- the temperature that is 50°C below the temperature which leads to a weight increase of 2.0 g/m² h.

CREEP STRENGTH (MEAN VALUES)

Table 4

N/mm²	550	600	650	700	750	800	850	900	950	1000	1050	1100°C
Creep strain												
RA 1/10 000	149	88	54	34	22	15	10.5	8	6	4.5	3.5	2.7
RA 1/100 000	86	52	33	21	14	9.7	6.9	5.1	3.9	3	2.3	1.8
Creep rupture												
Rkm 10 000	206	127	82	56	39	28	20	15	11	8	6	4.5
Rkm 100 000	129	80	52	36	25	18	13	9.2	6.7	4.8	3.5	2.7

Physical Properties

Table 5 below shows the physical properties of 353 MA at different temperatures.

Table 5

Typical values		20	200	400	600	700	800	900	1000	1100°C
Density	g/cm³	7.9	7.83	7.76	7.67	7.63	7.59	7.54	7.50	7.45
Modulus of elasticity	kN/mm²	190	180	165	155	150	140	135	130	125
Linear expansion	(20–T)x10⁻⁶/°C	15.3*	15.6	16.3	16.9	17.2	17.5	17.8	18.2	18.5
Thermal conductivity	W/m°C	11.3	14.0	17.0	20.0	21.5	23.0	24.5	26.0	27.5
Heat capacity	J/kg°C	450	505	555	600	615	630	645	660	670
Electrical resistivity	μΩm	1.00	1.07	1.14	1.20	1.22	1.25	1.28	1.30	1.32

* = 20–100°C

Based on this definition, the scaling temperature in air for 353 MAwas evaluated as being 1175°C. See Figure 1 which shows that, below 1200°C, 353 MAis superior to all other tested alloys.

The method described above is a rapid way of determining the scaling temperature, but it does not allow predictions of the behaviour at lower temperatures and longer exposure times. In addition, the short time tests could result in a different ranking of alloys than a long time test. For that reason, longer time tests have been carried out by a US laboratory. Results from one of these have been plotted in Diagram 2 which shows that at 1150°C, the oxidation resistance of 353 MAis superior to that of similar grades and almost equivalent to (and sometimes even superior to) that of more highly alloyed grades.

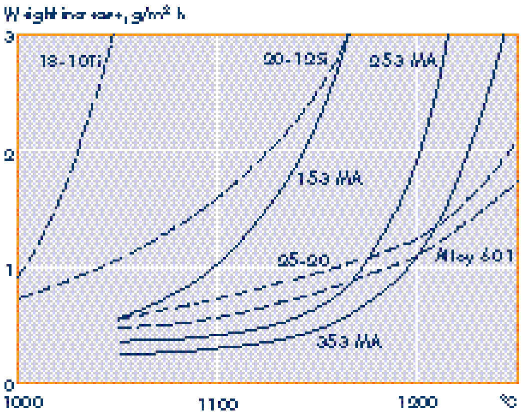

Fig. 1. Weight increase for 353 MAand some other grades after intermittent oxidation, 45h.

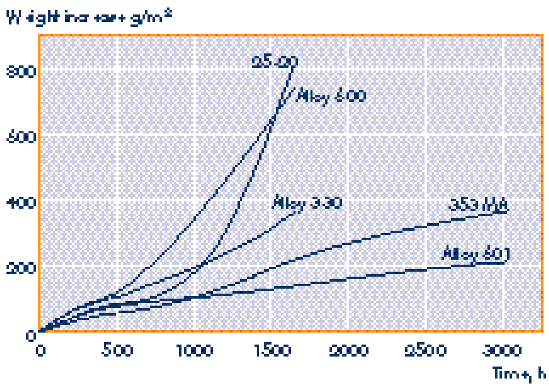

Fig. 2. Oxidation resistance test, recording weight increase versus time at a constant temperature of 1150°C. (Source: Rolled Alloys)

CARBON AND NITROGEN PICK-UP

In small amounts, both carbon and nitrogen will improve the mechanical properties of a material. However, excessive pick-up of either element will lead to embrittlement and reduced oxidation resistance – both caused by the precipitation of chromium carbides and/or nitrides in the grain boundaries.

Especially when subjected to fluctuating carburizing and oxidizing atmospheres, heat resistant alloys are at risk of carbon pick-up. This may be the case in carburizing furnaces or when oil residues are present on heat treated material. The risk of nitrogen pick-up is particularly great in furnaces working at high temperatures with oxygen-free protective gases consisting of cracked ammonia or other N_2/H_2 mixtures.

The resistance of an alloy to carbon and nitrogen pick-up can be improved by increasing the nickel content. In oxidizing environments, strong oxide formers such as chromium and silicon (and aluminium in carburizing but not nitriding atmospheres) are beneficial.

Service experience and some limited laboratory tests have thus shown that the ability of 353 MAto form a very protective oxide layer results in a resistance to carbon and nitrogen pick-up, which is equal or even superior to that of higher alloyed grades.

Under reducing conditions (often found e.g. in the petrochemical industry) an alloy with a higher nickel and/or silicon content must be selected.

SULPHUR ATTACK

Sulphur and sulphur compounds are often present in combustion gases and in different process gases. Ahigh chromium content and the addition of silicon, for example, will increase the resistance to sulphur attack, particularly under oxidizing conditions. Even small quantities of oxygen in the gas are sufficient to enable the formation of a protective oxide layer. Under reducing conditions, when no oxygen is present thus preventing the formation of an oxide layer, alloys with a high nickel content should be avoided. This is especially true for high nickel (>50%) and low chromium alloys. Ahigher chromium content (>25%) in materials containing nickel will increase the resistance to sulphur attack.

LABORATORY TESTING

In an extensive high temperature corrosion test programme, the short time (<100 h) performance of 353 MAhas been investigated in various corrosive environments. The purpose of this programme was mainly to investigate the mechanisms for initial corrosion attacks. Although the results for 353 MA are promising, they should not be used to draw too far-reaching conclusions concerning the alloy's performance under more service-like conditions and for longer periods.

The testing in carburizing (reducing) and alternating carburizing/oxidizing atmospheres showed that 353 MA was superior to all other alloys tested, including the nickel base Alloy 601. Under nitriding and reducing conditions, the corrosion resistance of 353 MAwas equal to that of alloys of a similar composition, but slightly inferior to that of Alloy 601.
In a sulphidizing-oxidizing gas, 353 MAwas one of the better alloys tested, despite its rather high nickel content.

Fabrication

Any chemical compounds used to facilitate fabrication, e.g. lubricants, coolants, and pickling pastes/solutions, should be removed before the construction is put to service. Preferably, compounds containing sulphur and/or halogens should be avoided altogether.

COLD FORMING

Forming should be carried out at room temperature whenever possible. Higher deformation forces than for conventional stainless steels are required, due to the higher strength of the alloy.

HOT FORMING

If hot forming or forging is necessary, the work piece should be heated uniformly throughout its section to a starting temperature of 1100 –1150°C. The finishing temperature must be above 900°C. Overheating and excessive hold times should be avoided to minimize grain growth and to prevent grain boundary burning. No forming or bending should be performed in the low ductility temperature range, 650–950°C.

MACHINING

High alloy heat resisting grades, such as 353 MA, are generally more difficult to machine than conventional stainless steels. Due to its higher strength and alloy content, 353 MArequires higher cutting forces and causes more rapid tool wear.

For further information about machining data, see "Machining guidelines for 353 MA" which can be obtained on request.

WELDING

In order to take full advantage of the beneficial properties of 353 MA, all constructions in this alloy should be welded with matching filler metal, which is available as covered electrodes and welded wire. Recommended welding methods are SMAW, GTAW and GMAW, while SAW should be avoided. Typical values for the chemical compositions of the weld metals are given in Table 6.

WELD METAL (TYPICAL VALUES) *Table 6*

	C	Si	Mn	Cr	Ni	N	Other
Covered electrode	**0.08**	**0.5**	**1.5**	**28.0**	**35.0**	**–**	**–**
Welding wire	**0.05**	**0.5**	**1.5**	**27.5**	**34.5**	**0.16**	**REM***

*Rare Earth Metals

More detailed welding instructions are given in a special brochure "Guidelines for the welding of Avesta Sheffield 353 MA®", which is available from Avesta Welding, tel. +46 226 815 00 or telefax +46 226 815 75.

ANNEALING

For most high temperature applications, constructions in 353 MAneed no annealing after forming or welding. Residual stresses and work hardening from severe forming operations may be reduced by annealing at 1010 –1040°C, long enough to ensure a uniform metal temperature, followed by rapid air cooling or water quenching to temperatures below 425°C.

Products

HOT ROLLED PLATE AND COIL

Dimensions according to Avesta Sheffield's manufacturing programme.

COLD ROLLED SHEET, PLATE, AND COIL

Dimensions according to Avesta Sheffield's manufacturing programme.

WELDED STAINLESS TUBES AND PIPES

Manufactured by AST (Avesta Sandvik Tube AB), Sweden.

WELDING CONSUMABLES

Manufactured by Avesta Welding AB, Avesta, Sweden.

PRODUCT STANDARDS

EN 10095
Heat resisting steels and nickel alloys (Implementation 1998/99).

ASTM A167
Stainless and heat-resistant chromium-nickel steel plate, sheet and strip.

ASTM A240/ASME SA-240
Heat-resisting chromium and chromium-nickel stainless steel plate, sheet and strip for pressure vessels.

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