WELDING OF AVESTAPOLARIT HEAT RESISTANT GRADES

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Background

AvestaPolarit has developed a group of austenitic HT steels designed for temperatures up to about 1150°C. Welded constructions used at high temperatures, very often operate under varying temperatures and stresses. This variation will give focus on material properties such as thermal fatigue, toughness, creep properties, and oxidation resistance. For those applications, there is a great variety of stainless steels with different compositions. Austenitic steels used above 950 °C, all have high Cr contents and many have high Ni contents. To improve oxidation resistance, some of them are also alloyed with Al, Si, and Rare Earth Metals (REM). To increase strength and microstructural stability, they are also alloyed with nitrogen.
AvestaPolarit 153 MA is a variant of EN 1.4301 (AISI 304), with increased contents of Si, N and REM.(1) The maximum service temperature in dry air is about 1000°C.
AvestaPolarit 253 MA is more highly alloyed and the most suitable temperature range in dry air is 900-1100°C.
AvestaPolarit 353 MA is the most highly alloyed steel in this group. It has a significantly higher nickel content. The maximum service temperature in air is 1150°C. The high Ni content improves the resistance to nitrogen and carbon pick-up, especially when the atmosphere has a low oxygen content.
The steels AvestaPolarit 153 MA, 253 MA and 353 MA should be welded with specially designed matching filler materials to obtain optimum properties. The steels 153 MA and 253 MA are normally welded with 253 MA fillers. In cases were the welded construction is exposed to temperatures below 900°C a new developed filler Avesta 253 MA-NF, can be a better alternative, as discussed below.
This paper gives examples of welding procedures and weldment properties, and reviews about where those steels have been used successfully in the temperature range 650-1150°C. The paper will specifically highlight the use of welded austenitic stainless steels at 800-900°C, where there is a high risk of embrittlement due to formation of intermetallic phases.

Steel Grades and Filler Materials

AvestaPolarit HT special steels and developed filler materials are listed below.

Table 1. Steels

Steel	Chemical composition (%)			
AvestaPolarit EN	C	Cr	Ni	Others
153 MA 1.4818	0.05	18.5	9.5	Si N REM
253 MA 1.4835	0.09	21	11	Si N REM
353 MA 1.4854	0.05	25	35	Si N REM

Table 2. Filler materials

Filler	Chemical Composition (%)				
AvestaPol.Welding	C	Cr	Ni	Others	FN
253 MA	0.06	22	10.5	Si N REM	8
253 MA-NF	0.06	19	10	Mn N	0
353 MA	0.08	28	35	Mn N REM	0

Choice of Filler Material

When welding 153 MA and 253 MA parent materials, the fillers 253 MA or 253 MA-NF can be used. For service temperatures above 950°C, the filler 253 MA is a better choice. When welding 153/253 MA to carbon steels, AvestaPolarit 309/309L fillers are suitable alternatives. On the other hand, if creep is an essential criteria for the application, the use of a nickel- base filler might be a better alternative (AvestaPolaritWelding P10).
The matching filler material for the steel 353 MA is the one with the same name. This filler can also be used when joining 353 MA to carbon steel. If the dissimilar weldments is exposed to creep , P10 can be a better alternative. When joining 153/253 MA to AISI 310 or 304, the filler 253 MA can be used.
The filler 353 MA can be used when joining the steel 353 MA to other austenitic stainless steels

Weldability

The welding procedures used for welding high temperature constructions are in most cases not different from welding other high quality components. Austenitic stainless steels have, in general terms, very good weldability.
153 MA and 253 MA give, when the filler 253 MA is used, some ferrite in the weld metal. This prevents formation of hot cracks.
353 MA is however a fully austenitic steel and is highly alloyed with Si. The welding must for this reason be carried out with some care. It is better to weld in a way that the weld cap becomes convex instead of concave. One such practical example is a convex fillet weld. The heat input should in most cases be limited to about 1.0 kJ/mm to make it possible to avoid hot cracking.
The high nitrogen content increases the risk for pore formation. A too rapid cooling after welding also increases the risk. A too narrow joint and welding in overhead position might give the same result.

Welding Methods

General

153 MA and 253 MA can be welded with all methods normally used for standard austenitic stainless steels. For 353MA we recommend SMAW, GMAW and GTAW as the best choices.

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Welding Techniques

a. SMAW (Shielded Metal Arc Welding) / Repair welding

SMAW is the most versatile procedure. Direct current with the electrode connected to the positive pole is the preferred welding polarity.
The 253 MA-NF electrodes give a very good weldability in out of position situations. The electrode also has very good weldability in service-exposed materials.
253 MA AC/DC gives excellent weldability due to its rutile/acid coating.
The basic 353 MA has, typically for such a coating, a harder slag removal. The arc should be extinguished carefully to avoid end crater cracks. Finish the welding in the opposite welding direction, i.e, a slight back stepping before extinguishing the arc.
SMAW is the preferred method for repair welding. If the in service exposed construction must be welded, check the magnetism in the weld area first. If it is strongly magnetic, it could be a sign that there has been a strong carburisation or nitridation. This is normally a surface effect, which can and must be removed by grinding before repair welding. If there is only a weak magnetic effect, it might be a small carbon/nitrogen pick-up or an internal material property. In the latter case, the construction can be heat treated at above 1070°C before start of repair welding.

b. GMAW (Gas Metal Arc Welding)

When welding HT steels with GMAW, good welding equipment is necessary. Today, inverters with high frequency are mostly used. The use of synergic pulse makes the welding easier. The equipment shall have a specifically designed/programmed arc characteristic for those steels, and the possibility for infinitely variable current/wire speed and voltage. Low inductance is also an advantage. These HT steels have the best weldability if the Ar-shielding gas is mixed with about 30%He. An addition of small amounts of NO improves the weldability. This gives a nice looking cap. In some equipment, a shielding gas of Ar+30He+5CO_2 has shown good results. An alternative is to use pure Ar but the fluidity will then not be as good and the weld will have a high cap. When many beads are used in a joint, it is recommended to brush between beads to avoid loss of weldability. The welding parameters (Voltage;Current), are slightly higher for these HT steels compared to standard grades.
When welding 353 MA, it is recommendable to use a stringer bead technique. Maximum heat input shall be less than 1.0 kJ/mm. Some examples of welding parameters are given in table 3 below.

Table 3. Welding parameters for GMAW

Filler		Short Arc		Spray Arc	
	∅ mm	I (A)	U (V)	I (A)	U (V)
153/ 253 MA	0.8	100-140	17-22	-	
	1.0	120-150	16-24	200-240	25-29
	1.2	-		220-290	26-30
353 MA	1.0	70-140	17-22	180-220	25-29
	1.2	-		200-240	26-30

c. GTAW (Gas Metal Arc Welding)

GMAW of 153/ 253 MA can be carried out with or without filler. 353 MA should in most cases be welded with filler. Try to make the weld convex using excess of filler wire. This weld cap geometry minimizes hot cracking. For 353 MA it is important not to use too high heat input (< 1 kJ/mm). The shielding gas is normally pure argon.

d. SAW (Submerged Arc Welding)

For the steels 153 MA/ 253 MA the wire/flux combination 253 MA/ Flux 805 or Flux 801 can be used. SAW is not recommended for 353 MA because of the risk of hot cracking. Following welding parameters can be used;

Table 4. Welding parameters for SAW

∅ 2.4 mm	I= 320-400A	U=28-30V
∅ 3.0 mm	I= 400-550A	U=29-32V

e. Other welding methods (plasma, laser and resistance welding)

The AvestaPolarit high temperature grades 153 MA and 253 MA can be welded with in principle the same parameters as used for other ordinary austenitic stainless steels. The fully austenitic steel 353 MA requires special precautions. Due to the high nitrogen content in the steels, there might be a risk for pore formation.

Joint preparation

Welded constructions used in alternating temperatures often require welds with full penetration to avoid cracking due to thermal fatigue. This means that the joint shall be prepared for full penetration welds. Weld defects associated with incomplete penetration are the most common reason for failures in HT-equipments. To make full penetration possible, the joint angle needs to be somewhat greater and sometimes the land should be smaller than, for example in 304 materials. The reason for these differences is the lesser penetration due to high nitrogen contents in the steels. The plates shall be tacked with sufficient gap to secure full penetration. If the joint bevel angle is large, nitrogen porosity can also be minimized.

Weld Metal Properties

General

A new welded HT construction has, as a rule higher room temperature (RT) proof strength in the weld than the wrought material. Elongation and impact toughness are however lower. At higher temperatures, strength is falling for both weld and parent material. The influence of aging is small up to about 550°C. At higher temperatures, elongation and reduction of area can be significantly lower after aging.The welded joints give lower creep strength than the parent material. This differences is accounted for in most design codes.
The scaling/oxidation resistance of the welds is the same as for parent material up to about 750°C. At higher temperatures the welds give more oxidation up to the maximum recommended application temperatures.
In flue gases different amounts of sulphur, nitrogen and carbon are often present. Formation of sulphides will be detrimental because this will increase HT corrosion. Excessive pick-up of nitrogen and carbon may give an embrittling effect. The weld additionally also often has a geometrical deviation which is negative from the stress concentration point of view. 253 MA welds contain ferrite to avoid hot cracking. This ferrite might also increase embrittling.

Results with the filler AvestaPolaritWelding 253 MA-NF

Customer application

There has been an interest to produce hot water for district heating purposes as well as steam for production of electricity. One of the first Pressurized Fluidised Bed Combustion plants (PFBC) has been constructed and built in Stockholm, Sweden. In accordance with the plant owner's desire, the plant was made to be so compact that it could be located in the centre of Stockholm. By this idea, hot water could be distributed with a minimum of energy loss. The environmental effects should also be minimized. The compact construction is working at a temperature of 750-850°C. The working pressures are designed to 20 bar.
Due to the design, some parts (cyclones, pipes) were in direct contact with the exhaust gases. The temperature/stresses in those parts, made austenitic stainless steel necessary. AvestaPolarit 253 MA parent material was selected for its good creep and erosion resistance. It was well known from the beginning that this temperature might create some embrittlement in the structure. After some years, cracks were found in the 253 MA welds. An investigation showed that the ferrite in the weld metal had transformed into sigma phase. The customer then asked AvestaPolaritWelding to develop a new filler which shall not be sensitive to this temperature range. It was also desired that this electrode should have a good weldability for exposed materials maintenance welding.
The commercial name of this new developed product is AvestaPolarit Welding 253 MA-NF, see table 2.
By decreasing Cr content, and by balancing the chemical composition, the new fully austenitic filler 253 MA-NF was designed to give a weld metal with a good weldability and a stable microstructure at service temperatures of

700-850 °C. Below, some of the documented weldments properties found during the laboratory investigation are shown.

Oxidation properties

At temperatures below 900-950°C the oxidation properties do not normally cause any problems. Compared to the parent metal and the 253 MA AC/DC filler, welds with the 253 MA-NF filler have a lower Cr content. This will give a lower oxidation resistance. In Fig 1 it is shown that 253 MA-NF gives a greater mass change compared to the 253 MA welds. A higher mass change means a higher oxidation rate. However, below 950°C, the oxidation is sufficiently slow. Within AvestaPolarit, the internal interpretation is that if the mass changes (due to oxidation) is lower than about 1.2 mg/cm², this indicates that the material has a satisfactory oxidation resistance.

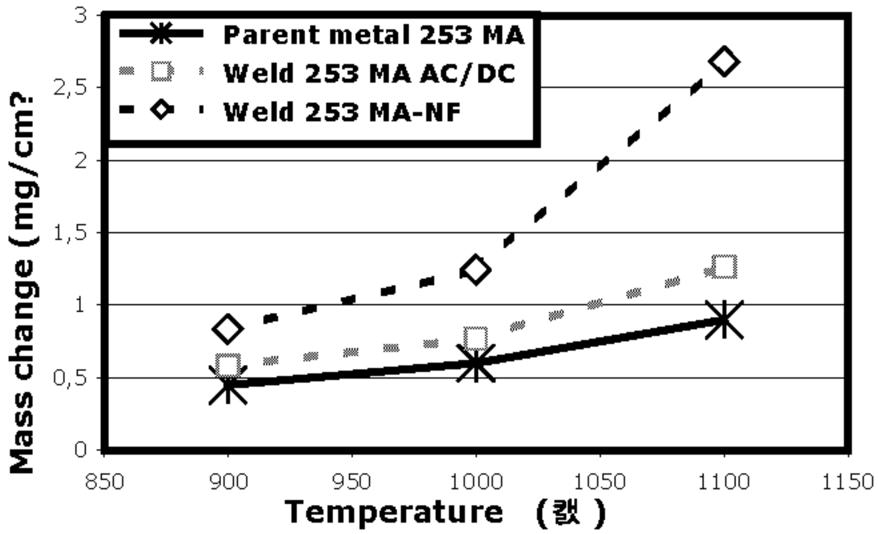

Fig. 1. Oxidation test results in dry air

Impact test results

The parent material 253 MA has high impact toughness in the delivery condition. When it was exposed to service temperatures of about 800 - 850 °C, the room temperature impact toughness decreased rapidly. The toughness of 253 MA AC/DC welds decreased even more rapidly. This effect can be seen already after one week. The welds were more or less insensitive to longer ageing times, as measured by impact toughness.

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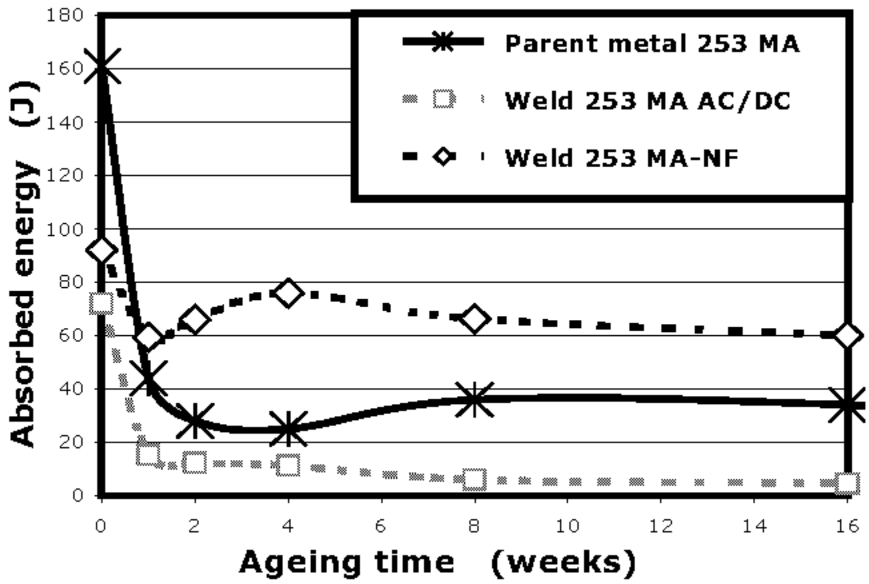

Fig. 2. Impact toughness at 20 °C after ageing at 840°C

Creep

Testing was carried out at 700, 850, and 900 °C. The creep strength results show that 253 MA-NF had about the same creep strength as welds with the standard filler 253 MA. The values are somewhat lower compared with the parent material 253 MA.

Practical experience

The use and experience of the new electrode, AvestaPolarit 253 MA-NF, has been very successful up to now after 3 years in the PFBC plant in Stockholm. At the yearly inspections, there have been no reports of cracking caused by embrittlement. The welders have also experienced an improved repair weldability. The earlier reported hot cracks found at annual inspections have disappeared with the use of this new electrode.

Examples where welded AvestaPolarit HT-Steels have been used.

	153MA	253 MA	353 MA
Cement industry			
Burner tubes, Kiln feed flanges, Cyclones	x	x	
Iron and steel industry			
Recuperators, Bell furnaces,		x	
Conveyor belts	x		
Rollers			x
Other Metal Industry			
Calcination furnaces,	x	x	
Muffles		x	x
Heat Treatment			
Fans	x	x	
Electric heating elements		x	X
Power and Heating			
Anchor bolts for fasteners for refractory materials	x	x	
Flame tubes, Fire tubes		x	

Discussion

When using stainless steel constructions in the temperature range where they normally are sensitised, great efforts must be made to select the most suitable parent metal and filler material. Factors to be taken into account include. strength, creep, ductility, oxidation resistance, reparability and weldability.
For the temperature range up to 950/1000 °C, the reduction of ductility is probably the factor causing the most problems. Loss of ductility by aging, combined with occurring microfissures/hot cracks, can substantially decrease the functional stability of the construction. In a thermal fatigue situation, such as in a PFBC power plant, this can be a disastrous phenomenon.
By balancing the contents of Cr, Si, Mn, and N, a weld metal with unique properties in the temperature range 650-900 °C has been obtained. The most important factor is to control the microstructural stability during long-term operation in this temperature range. The positive effect in 253 MA-NF welds could easily be demonstrated by studying the impact toughness as a function of ageing time.
For temperatures above 1000°C, oxidation resistance will be the most common problem. Sulphur present in the flue gas can be very detrimental to the oxide layer and can reduce the material service temperature range. This is specially pronounced under reducing gas conditions. To decrease this effect, cladding can be used on exposed areas. Overlay welding with 29Cr9Ni fillers(AvestaPolarit Welding P7) is sometimes used as a solution of the problem.
Carbon and nitrogen pick-up can also have an adverse effect on the construction stability. Solubility of these elements decreases with increased nickel content. If the weld is more embrittled than the parent material (153/253 MA), the 353 MA filler with higher nickel content might be a solution.
Embrittlement in parent material and weld metal can be further enhanced by the geometrical discontinuity in the fusion line. For this reason, a smooth grinding of the root/cap might also give an improvement.

Conclusions

- When welding HT steels, incomplete welds must be avoided. Chose the right joint type. Lack of adequate penetration is the most common cause of weld failures in service.
- AvestaPolarit HT steels can be welded as other austenitic stainless steels. It is also possible to weld them to other stainless steels as well as to mild steels and nickel-base materials.
- To obtain a defect free weld metal in AvestaPolarit 353 MA, the heat input should be lower than about 1.0 kJ/mm depending of material thickness and welding method.
- All AvestaPolarit HT grades have their specially designed fillers.
- The filler material AvestaPolaritWelding 253 MA-NF gives a weld metal with a much more stable microstructure at 650 - 900 °C and a higher toughness than the existing austenitic fillers.
- The 253 MA-NF welds have good oxidation resistance up to about 950/1000 °C, which is lower than for the established 253/353 MA fillers. However, the new filler is not intended for service temperatures above 1000 °C.
- Field experience in a PFBC carbon fired power plant shows good weldability with 253 MA-NF when repair welding.
- Field experience in the same plant shows a strong reduction in repair frequency after using 253 MA-NF
- SMAW gives the best results when repair welding HT steels.
- GMAW of AvestaPolarit HT grades should be carried out with modern inverters equipped with pulse facilities. Good weldability can be obtained by using a shielding gas mix of Ar and He

References

1. M. Segerbäck, B Ivarsson Avesta Sheffield AB , Rare earth metal alloyed high temperature grades, characteristic properties, applications and experience. Congress Stainless Steels´96 , Dusseldorf/Neuss

2. B. Holmberg, B Ivarsson AvestaPolarit, New SMAW filler material for medium high temperature applications. Stainless steel world, America 2002, Conference, Houston USA 12-14 Feb 2002