URANUS 52N+

FORMING and WELDING PROCEDURES

THE PRODUCT

UR 52N+ is a super duplex stainless steel with 25 % Cr and a PREN value higher than 40. The minimum guaranteed yield strength is 550 MPa which allows the designer to reduce thickness of equipments.

The molybdenum and nitrogen contents have been optimized in order to obtain the best corrosion resistance properties even for the heaviest plates. Its high nitrogen addition improve the structure stability particularly in HAZ (Heat Affected Zone).

Copper addition increases the corrosion resistance, particularly in sulfuric acid media.

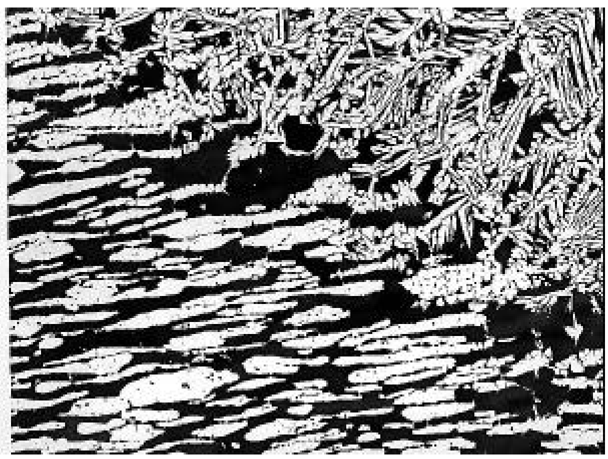
UR 52N+ is a cost efficient grade designed for offshore, marine, phosphoric acid and pollution control equipments.

<u>URANUS 52N+ answers to the following standards</u> :

EURONORM................ 1.4507 - X2 Cr Ni Mo Cu N 25.6.3
AFNOR........................ Z3 CNDU 25.07 AZ
DIN............................... W. Nr 1.4507
ASTM........................... UNS S32520

<u>Chemical analysis of URANUS 52N</u>

C	Cr	Ni	Mo	N	Others
.030	25	6.5	3.5	0.25	Cu ≥ 1.5
PREN = [Cr %] + 3.3 [Mo %] + 16 [N %] ^{3} 40					



Microstructure of UR 52N+ HAZ welded joint

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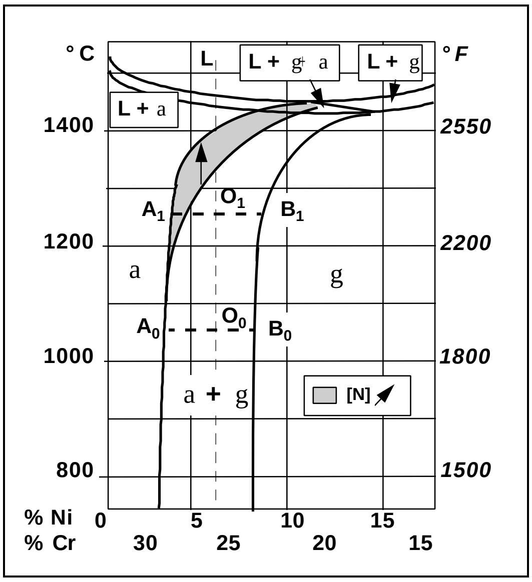
USINOR GROUP

METALLURGY

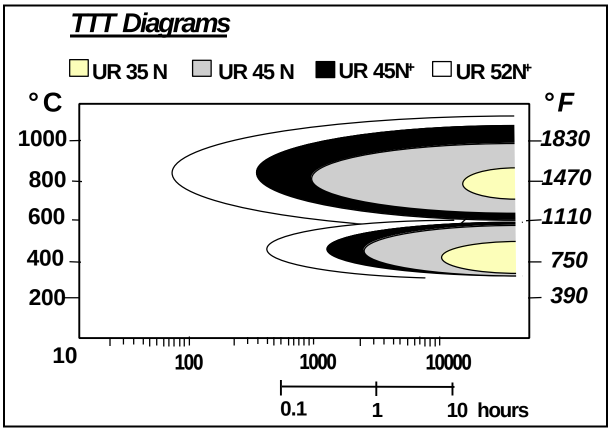
URANUS 52N+ has roughly equivalent volume fractions of ferrite and austenite (slightly more austenitic). This is obtained by work-hardening, followed by solution annealing + water quenching, and involves the simultaneous control of the chemical composition and annealing temperature. The figure shows a schematic isoplethal section of the Fe-Cr-Ni diagram, for an iron content of 68%. The proportions of each of the phases and their respective compositions are indicated for a given alloy analysis and annealing heat treatment.

The figure shows that the duplex microstructure solidifies in the ferritic phase and that the austenite forms only when the steel is cooling down. Over-heating (1150-1450°C - *2102-2642°F*) of a solution annealed, water quenched, plates (HAZ for example) of duplex steels may result in the formation of more ferrite which may retransform in austenitic when again cooling down. Too fast cooling rate may reduce this α-γ retransformation process and explain why welding consumables are over alloyed in nickel.

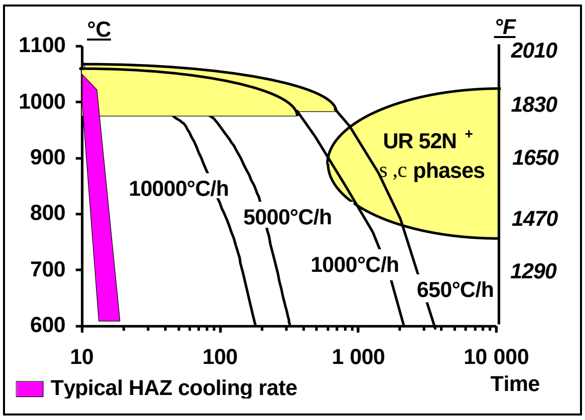


As regards the high temperature stability of the duplex structure, it is important to note the gamma stabilising action of nitrogen.

The TTT diagrams for the grades UR 35N, UR 45N, UR 45N+ and UR 52N+ here presented are conservative, and do not imply that the mechanical properties or corrosion resistance are modified as soon as the boundaries indicated are reached. This is particularly true for the low temperature ferrite hardening field. The TTT curves are mainly affected by molybdenum, chromium and tungsten additions.



Continuous cooling diagram shows that intermetallic phase transformation in duplex 52N+, and even more easily in UR 45N+ grade can be avoided by a control of the cooling rate which is obtained by a control of the heat input.



HOT FORMING

Hot forming is carried out between 1150 and 1000°C (*2102 - 1832°F*).
It should be kept in mind that ferritic-austenitic stainless steels have low strength at high temperatures. So, precautions must be taken to avoid possible deformations (wedging and support of pieces).

At temperatures below 1000°C (*1832°F*), embrittlement can appears due to intermetallic phase precipitations especially when material is strained.

After hot forming, a solution annealing heat treatment in the range 1080 - 1120°C (*1976 and 2018°F*) with water cooling is necessary.

COLD FORMING

Due to its higher yield strength, forces required for the cold forming of UR 52N+ are more important than for austenitic steels.
Edges will be grinded and surfaces (absence of scratches...) will be checked before cold forming.

For cold deformations higher than 20 %, an intermediate treatment is required (solution annealing between 1080 and 1120°C (*1976 and 2018°F*) with water cooling).
This heat treatment performed after cold forming is always required when the deformation exceeds 10%.

® ***Detailed recommendations for cold forming or bending of welded and unwelded duplex and super duplex plates are available upon request.***

MACHINING

Generally, the same technologies and tools can be used as for conventional stainless steels.

For drilling, high speed steel tools must preferently be used with a speed cutting of 10 to 15 m/min. The drilling speed depends on the hole diameter.

For machining with carbide tools, the cutting speed is the same as the cutting speed used for 316 L type austenitic steels.

Operation	Tool	Lubrication	CONDITIONS					
			Depth of cut		Feed		Speed	
			mm	*inch*	mm	*inch*	m/min	*feet/min*
Turning	High speed steel	Cutting oil	6	*0.23*	*0.5*	*0.019*	15-20	*49.2-65.6*
			3	*0.11*	0.4	*0.016*	23-28	*75.5-91.9*
			1	*0.04*	0.2	*0.008*	30-35	*98.4-114.8*
	Carbide	Dry or cutting oil	6	*0.23*	0.5	*0.019*	75-85	*246.1/278.9*
			3	*0.11*	0.4	*0.016*	90-100	*295.3-328.1*
			1	*0.04*	0.2	*0.008*	110-120	*360.9-393.7*
Parting off	High speed steel	Cutting oil	Blade width		Feed			
			1.5	*0.06*	0.03	*0.0012*	23-28	*75.5-91.9*
			3	*0.11*	0.04	*0.0016*	24-29	*78.7-95.1*
			6	*0.23*	0.05	*0.0020*	25-30	*82.-98.4*
Drilling	High speed steel	Cutting oil	Drill Ø		Feed			
			1.5	*0.06*	0.25	*0.0010*	10-14	*32.8-45.9*
			3	*0.11*	0.06	*0.0024*	11-15	*36.1-49.2*
			6	*0.23*	0.08	*0.0031*	11-15	*36.1-49.2*
			12	*0.48*	0.10	*0.0039*	11-15	*36.1-49.2*
Milling /profiling	High speed steel	Cutting oil			Feed			
					0.05/0.10	*.002/.0039*	12-22	*39.4-72.2*

HEAT TREATMENT

UR 52 N+ is delivered in the solution annealed and water quenched conditions (1080/1120°C - *1976/2018°F*).

The chemical composition of UR 52N+ is optimised in order to obtain after heat treatment nearly a 50 α / 50 γ microstructure.

These solution annealing conditions must be respected for final or intermediate heat treatment in case of forming and when a solution annealed or a stress relieved treatment is required after welding.

All other heat treatments, particularly the one with holding time or with slow cooling in 300 to 1000°C (*572-1832°F*) range must be avoided. Heat treatments at 400°C (*742°F*) used for dimensional stability of austenitic stainless steels are not acceptable for UR 52N+.

WELDING

Welded joints preparation

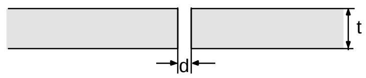
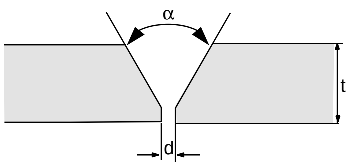
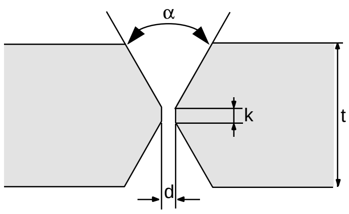
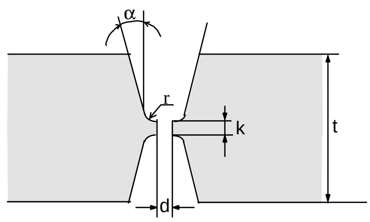
The joint must be designed in such a manner that the penetration weld could be realised without an excessive dilution of base meta or a Burn through. Groove type must be designed in order to have a good gaseous shielding protection (GTAW, GMAW, PAW, FCAW) ; a good accessibility for welding guns in the bottom of the joint must be obtained.

Some examples of welded joints preparation, are presented on the following tables which can be used for the butt welding of UR 52N+ (different plate thicknesses).

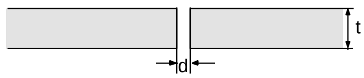
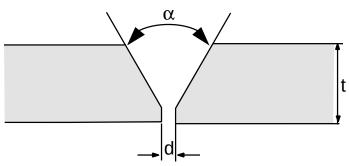
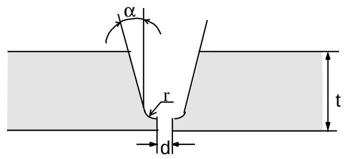
Grooving will be realised by machining or thermal cutting (oxy-acethylenic gas with iron powder or plasma) followed by grinding to eliminate oxyded and heat-affected zones.

As for all others stainless steels, the welding zone will be carefully cleaned with unchlorided solvent in order to eliminate grease or paint marks.

Joint design for Butt welding from both sides

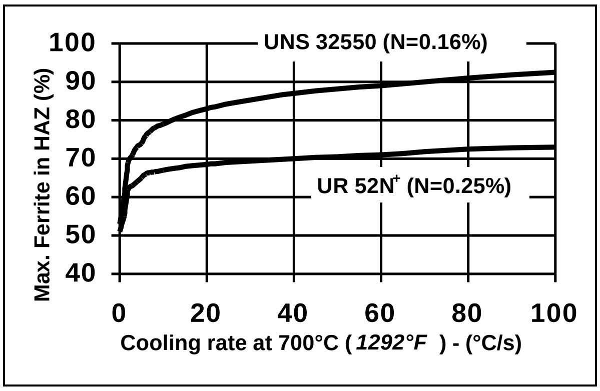
GROOVE	Process	Thickn. th(mm)	GAP d (mm)	ROOT k (mm)	BEVEL a (°)
	GTAW	3 - 5	1 - 3	-	-
	GMAW	3 - 6	1 - 3	-	-
	SMAW	3 - 4	1 - 3	-	-
	SMAW	4 - 15	1 - 3	1 - 2	55 - 65
	GTAW	3 - 8	1 - 3	1 - 2	60 - 70
	GMAW	5 - 12	1 - 3	1 - 2	60 - 70
	SAW	9 - 12	0	5	80
	SMAW	> 10	1.5 - 3	1 - 3	55 - 65
	GMAW	> 10	1.5 - 3	1 - 3	60 - 70
	SAW	> 10	0	3 - 5	90
 R=6--8mm	SMAW	> 25	1 - 3	1 - 3	10 - 15
	GMAW	> 25	1 - 3	1 - 3	10 - 15
	SAW	> 25	0	3 - 5	10 - 15

Joint design for one-sided butt welding

GROOVE	Process	Thickn. th(mm)	GAP d (mm)	ROOT k (mm)	BEVEL a (°)
	GTAW GMAW SMAW	< 3 < 3 < 3	0 - 2 0 - 2 0 - 2	- - -	- - -
	SMAW GTAW GMAW SAW	3 - 15 2.5 - 8 3 - 12 4 - 12	2 - 3 2 - 3 2 - 3 2 - 3	1 - 2 1 - 2 1 - 2 1 - 2	60 - 70 60 - 70 60 - 70 70 - 80
 r = 6-8 mm	SMAW GTAW GMAW SAW	12 - 60 > 8 > 12 > 10	1 - 2 1 - 2 1 - 2 1 - 2	2 - 3 1 - 2 2 - 3 1 - 3	10 - 15 10 - 15 10 - 15 10 - 15

General welding conditions

- **Welding metallurgy**



SMAW Process
Effect of the cooling rate on maximal ferrite content in HAZ

As for other ferritic-austenitic stainless steels, the weld metal of 52N+ has a whole ferritic microstructure when solidifying.

Due to high increase of temperature range (1150-1450°C - *2102-2642°F*) the HAZ may also increase its ferrite content by $\gamma \rightarrow \alpha$ transformation.

It's only during cooling that a part of the high tempe-rature ferrite retransforms into austenite, giving to the weld a ferritic-austenitic microstructure.

Consequently, the ferrite content in HAZ and in weld metal is directly linked to the cooling rate as indicated on the above graph.

If the cooling rate is too high, microstructure is too ferritic.
For 52N+, moreover, too low cooling rates could cause a beginning of ferrite transformation into intermetallic phases. This has also to be avoided since intermetallic phase precipitations reduce the corrosion resistance properties and the mechanical properties.

To obtain the best as-welded microstructure of weld, the optimal cooling rate must be ensured by a strict control of the heat input and interpass temperatures. A minimum and maximum value of the heat input is then recommended for each welding procedure. Typical data are provided here after. More specific informations are provided when requested.

- **Pre-heating**

Preheating of UR 52N+ is not necessary, and not recommended.
Preheating acts mainly on cooling rate at low temperature. Therefore, preheating is not very efficient for the transformation the ferrite into austenite which happens at high temperature while slow cooling rate may result in deleterious phase precipitation processes.

- **Interpass temperature**

Too high interpass temperatures decrease the cooling rate so that intermetallic phases, nitride or carbide precipitations are likely to occur.

The maximum allowed interpass temperature for UR 52N+ weldings is 150°C (*302°F*).

- **Heat input**

For a given thickness of plate, welding process and a welding configuration, the cooling rate is inversly proportionnal to the heat input which is calculated accordingly to the following relation :

$$HI_{(kJ/mm)} = \frac{I_{(A)} x U_{(v)}}{W_{S(mm/min)}} x \frac{60}{1000}$$

I and U are read on welding machine, W_s is the welding speed of the gun or the welding electrode.

The table hereafter, shows the heat input ranges for some welding processes which can be used to weld UR 52N+.

Welding process	Heat inputs used for UR 52N+ (kJ/mm)
SMAW	0.4 to 1.4
Pulsed GMAW	0.4 to 1.4
GMAW	0.5 to 1.7
SAW	0.3 to 1.4
GTAW - PAW	0.6 to 2.2

However, the best results are obtained for more occurate heat input ranges determined by the welding parameters, including plate thickness, welding process, welding type (butt or filet weld).

→ ***Optimum heat input ranges calculated from welding parameters of the user are communicated on request by Marketing Department of CLI.***

As a general guide, the lowest heat input are recommended for the welding of the thinner plates.

- **Post-heating**

Post-heating is not recommended and even dangerous when temperature exceeds 290°C (*554°F*).

- **Hot straightening**

Hot straightening is not used for UR 52N+ insofar as any maintain at a temperature > 290°C (*554°F*) could deteriorate the microstructure and corrosion resistance of this duplex.

Welding processes

As indicated in the table hereafter, most of welding processes can be used to weld URANUS 52N+.

Welding processes for Duplex and Superduplex	**With filler metal**	**Without filler metal***
Industrial processes	- SMAW - SAW - FCAW - GMAW - Pulsed GMAW - GTAW - PAW	- GTAW - PAW
Processes not very used or being studied	- ESW	- LW - EBW - RW - FW

* A solution annealing heat treatment after welding or nitrogen addition in welding gas is recommended

The only restrictions concern welding processes without filler material for which it is difficult or impossible to counteract the loss of nitrogen content in molten metal by a nitrogen addition in the welding gas.

In this case, a solution annealing post-welding heat treatment of UR 52N+ allows to obtain a correct microstructure and satisfactory corrosion resistance of the weld metal.

- **Shielding metal arc welding**

This process can be used from a thickness of 3 mm. Rutile, basic-rutile or basic type of covered electrode are available to weld UR 52N+.

The highest levels of toughness and the highest capacities of deformation are obtained with basic covered electrodes. These basic electrodes will preferably be used if the weld should support strong deformation (heads forming) or if the weld should have a good level of toughness at low temperature.

The choice of electrode diameter will take into account the recommended heat input range. The weld will be made with stringer beads (the width of weave s-hould not exceed twice the electrode diameter).

When a covered electrode is used to make the root pass, a backing shielding gas, as used for GTAW, is recommended. In the opposite case, the penetration will be finily grinded.

In all cases, the welder will hold a short arc to avoid an atmospheric nitrogen pick up which leads to an unacceptable level of porosities, for an already nitrogen al-loyed duplex weld metal.

- **Submerged-arc welding**

This welding process is used for flat position with thickness of plate from 10mm.

Basic flux leads to the best toughness and ductility in weld metal whereas rutile flux gives an easier removal of slag and often a lower sensibility to porosity. Small filler diameter (often Ø 2,4 mm) will be chosen to respect recommended heat inputs (Nevertheless, that SAW thermal efficiency is very high, ≈ 1).

For a given heat input, the choice of welding parameters I, U, Ws is important. The use of both moderate amperage and low welding speed (Ws < 45 cm/min) reduces strongly the risk of shrinkage voids or porosities which could be unacceptable according to the most often used specifications of compactness (X-Ray exams ASME VIII for instance).

Too fitted passes (backing pass after gouging and too narrow grinding) must be avoided. Width of bead should always be higher than its depth.

- **<u>Flux cored arc welding</u>**

There are two types of flux cored wires to weld UR 52N+:

- Metallic cored wires (without mineral powders) can be used with solid flux or with shielding gas (particularly GTAW),
- Mineral flux cored wires can be used with GMAW and Ar+CO_2 18% shielding gas.

The high shielding gas activity and the rutile type of the cored wires lead to rather low resilience levels but acceptable for applications at room or higher temperature.

Those mineral flux cored wires give a good compactness of weld metals. Their pitting corrosion resistance measured by ASTM G48A test is the same as the corrosion resistance obtained with others welding processes.

- **<u>Gas metal arc welding and pulsed GMAW</u>**

These semi-automatic or automatic welding processes are used for thicknesses of 3 mm or more.

- The short-circuiting transfer is used for low heat inputs and therefore for the lower plate thicknesses.
- The spray-arc transfer or axial transfer which is obtained with high amperage and voltage leads to a stable arc and high deposition rates.
- The pulsed arc transfer is obtained with special power sources. The current has its peak in the spray-arc transfer range and its low level in the short-arc transfer. This process allows to benefit of spray-arc advantages with reduced heat inputs and makes it possible to perform weldings in all positions

The UR 52N+ welding with GMAW process has been tested with the three transfer modes but the most used process is the pulsed GMAW.

The shielding gas composition is very important for duplex weldings when using GMAW or pulsed GMAW processes.

The shielding gas must avoid both nitrogen losses of weld metal and weld metal oxydation.

Some ternary gases (Ar+CO_2+N_2) or quaternal gases (Ar+CO_2+He+N_2) can be used for GMAW and pulsed GMAW welding of UR 52N+ (Sales references delivered on request).

The quality of the shielding g as must be stable. Flight of water cooled gun system or pick-up of atmospheric nitrogen are to be avoided since lack of compactness, *i.e.* porosities in the weld metal may then be created.

The use of welding speed inferior to 40 cm/min is adviced when a good compactness is required after X-Ray examination.

When GMAW is used to realise the root pass, the same backing shielding gas as for GTAW weldings is adviced.

▪ **Gas tungsten arc welding**

GTAW, manual or automatic is very used to weld UR 52N+ when the thicknesses of plates are lower than 15 mm. This is also the case to perform penetration passes before filling with SMAW or SAW processes.

The GTAW welding process leads to the purest weld metals (the lowest oxygen contents) and is the less sensitive to lack of compactness phenomenon.

GTAW process without filler material is used to weld very low thicknesses of plates (< 3 mm). The welding gas used must contain nitrogen addition.

The recommended shielding gas is a Ar 98%+N_2 2% mixture. More nitrogen additions can be used but can also lead to a deterioration of tungsten electrode. The nitrogen addition in the shielding gas is important to keep a satisfactory microstructure and corrosion resistance even when selected filler material is a nickel overalloyed grade.

The flow rate must be carefully set according to nozzle diameter and the use or not of a gas diffuser. Turbulence (too high flow rate) which can introduce atmospher in molten bath must be avoided

Moreover, the tungsten electrode extension can never exceed twice or three times its diameter, except when the torch has gas lens. In this case, an electrode length of about 20 mm can be used to resolve difficult accesses. If not, uncontrolled nitrogen addition in duplex or superduplex weld metal may occur. As a result, too low ferrite content and lack of compacity may be obtained.

A backing shielding gas is necessary and will be ensured by pure argon (Ar > 99,95%).

Welding will be realised with stringer beads and moderate thickness beads. Too thick passes are more sensitive to porosity (more difficult degasing).

Choice of filler materials and weld metal composition

Two types of weld metal compositions can be used to weld UR 52N+.

a) Mostly a 25% Cr, Ni, ferritic-austenitic product.
The pure chemical composition should be similar from this indicated below :

Elements

	C	S	P	Si	Mn	Ni	Cr	Mo	Cu	N_2
Mini %	0.015	-	-	0.300	0.500	9.6	25.0	3.60	-	0.220
Maxi %	0.035	0.015	0.025	0.750	1.500	10.2	27.0	4.00	1.50	0.250

b) A nickel alloy filler materiel with high chromium and molybdenum additions.

Two chemical compositions can be used :
- Alloy C22 type, E Ni Cr Mo 10 according to AWS or ASME,
- Alloy 59 type, SG Mo Cr 23 Mo 16 according to DIN.

The use of the second solution depends on the final application, and gives to the weld metal an increased corrosion resistance. Nevertheless, this weld metal has lower tensile properties than a super duplex weld metal.

® ***For these differents welding solutions, lists of filler materials* used to weld URANUS 52N+ can be obtained on request from CLI Marketing Department.***

****The supply of filler materials lists by CREUSOT-LOIRE INDUSTRIE doesn't take away responsability from supplier of filler material and fabricator who are totally in charge of their welding products quality.***

Wire/flux or wire/gas couples proposed by the filler material suppliers can't be separated without great problem regarding weld metal properties.

Covered electrodes and flux will be carefully dried in accordance with suppliers instructions.

Welding gas with hydrogen addition are not allowed for UR 52N+ welding.

Welding of URANUS 52N+ with other steels

URANUS 52N+ can be welded with carbon steels, others stainless steels or nickel based alloys.

Processes described for matching welding of UR 52N+ can be used insofar as a filler material can be used .

Superduplex, duplex or 309 L Mo type filler materials can be used to weld UR 52N+ with carbon steel or low alloy steels or with austenitic stainless steels.

To weld URANUS 52N+ with super austenitic steels or nickel alloys, nickel alloys filler materials with high chromium and molybdenum contents, but without niobium (E Ni Cr Mo 10 or SG Ni Cr 23 Mo 16) will be used.

These heterogeneous welds will be done with the same precautions than matching welds (respect of heat input range, drying of filler materials...).

Cleaning and Pickling and Passivation of welds

The cleaning of welded zones is made by mechanical or chemical methods.

Welds can be finily grinded and polished, sand-blasted or micro-beaded (products without iron particles).

Complementary or, instead of these mechanical methods, pickling can be made with the same fluonitric baths or pastes as for others stainless steels but with a longer time (twice longer than 316 L grade).

Tidy washing must be realised after pickling.

These operations must be realised with high security (ventilation, protective clothing and rubber gloves).

Ferrite determination

The control of ferrite content in URANUS $52N^+$ welds is very important insofar as a too high ferrite content in HAZ or weld metal leads to a too low tenacity, a low ductility and a lower corrosion resistance of the weld.

- **Calculation methods**

  The ferrite content in weld metal can be predicted from its chemical composition with using formulas and ESPY diagram (results in ferrite per cent) or these of diagram WRC 93 (results in Ferrite Number or FN).

  The others methods (SCHAEFFLER or DELONG) which don't take care of nitrogen or copper additions can't be used for UR $52N^+$ welds.

- **Measurement methods**

  The more usual measurement methods to determine ferrite content in weld metal are magnetic methods as ferritscope (results in % or FN) or magnegage (results in FN).

  These methods can’t be used for very localized measurement of ferrite content. For instance, in HAZ, metallographic grid method (ASTM E 562) with sufficient magnification (≥ 400 x) is the only one which gives a significant result.

- **Expression of results**

  The ferrite content results expressed with % or FN are not equivalent.

  In fact, there is a correlation between ferritscope or grid method results (F%), and those obtained by magnegage expressed in FN.

For ferritic-austenitic steels and in accordance with IIW II 1196-92, the relation between F% and FN values of ferrite is as follow :

$$F\ \% = 0{,}54\ FN + 9{,}7$$

- **Ferrite contents recommended in UR $52N^+$ weld**

  In lack of all required values by the user, the following values of ferrite content in UR $52N^+$ as welded weld metal should be obtained :

Welding processes	Localisation	Method	Ferrite %
SMAW - FCAW SAW	Weld metal	Espy	15 to 35
		Ferritscope	20 to 40
GMAW - GTAW PAW	Weld metal	Espy Ferritscope	15 to 50 20 to 60
All processes	HAZ	Point grid at ≥ 400 x	< 70

Inspection :
non-destructive testing and qualification tests of welds

If it's easy to weld UR 52N$^+$, advices given in this document make it to improve the properties of the welded structures.

The weldings must be carried out by personnel who is qualified for welding of steels or alloys used for severe corrosive medias.

About non-destructive testings, dye-penetrant testing and X-Ray inspection can be used without any problem.

On the other hand, ultrasonic control is more difficult to do and requires operators familiar with US control of stainless steels.

In addition to controls required by main international codes, ASME, CODAP EN 288, some more specific tests are often required to qualify duplex or super duplex welds.

Metallographic ferrite content measurement and ASTM G 48A pitting corrosion test in Fe Cl_3 solution are very often required. These tests are only carried out, by laboratories which are competent in ferritic-austenitic stainless steels.

Le Creusot Research Center is totally able to realise all specific testings of duplex and super-duplex welds.

NOTE

This technical data and information represents our best knowledge at the time of printing. However, it may be subject to some slight variations due to our ongoing research programme on corrosion resistant grades.

We therefore suggest that information be verified at time of enquiry or order.
Furthermore, in service, real conditions are specific for each application. The data presented here is only for the purpose of description, and may only be considered as guarantees when our company has given written formal approval.

Further information may be obtained from the following address.

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