Industeel

ArcelorMittal

CryElso® 9Q

Steel for Pressure Equipment designed for extra low temperature service

CryElso®9Q is an alloyed steel grade containing 9% nickel intended for the fabrication of Liquefied Natural Gas storage tanks and welded pressure vessels designed for extra low temperature service.
CryElso®9Q is a Quenched and Tempered grade, to provide better tensile and toughness properties.
CryElso®9Q is manufactured via the electric arc furnace basic process, with dephosphorisation, followed by ladle refining with desulfurisation and vacuum degassing in order to provide reproducible chemistry, clean and homogeneous steel.
The use of special steelmaking practice provides high cleanliness combined with optimised chemical composition.

CryElso®9Q produces an excellent toughness at very low temperature and very good crack arrest properties.
CryElso®9Q has been extensively supplied for LNG storage tanks projects worldwide. CryElso®9Q is recognised by all the world-renowned engineering companies as a steel grade suitable for the construction of very safe Liquefied Natural Gas storage tanks.
It is further optimised for use in pressure vessels applications, cryogenic piping and ship board storage systems.

® CryElso is an Industeel Trademark

Standard

EN 10028-4 ..... X7Ni9 (1.5663)
EN 10028-4 ..... X8Ni+QT680 (1.5662)
ASTM/ASME ..... A/SA 553 Type I (UNS K81340)
JIS G3127 ..... SL9N590Q

Multiple certification is possible. Please enquire

Heat treatment

Water Quenching and Tempering treatment.
Heating at 820 °C minimum before quenching and tempering at 570 °C minimum.

Chemical analysis

Chemical analysis is guaranteed as per Table I hereunder.

Table I	C (%)	Mn (%)	Si (%)	P (%)	S (%)	Ni (%)	Cu (%)	Cr (%)	Mo (%)	Al (%)	Nb (%)	V (%)
Heat analysis	≤0.06	0.30/0.80	≤0.30	≤0.005	≤0.002	8.70/9.30	≤0.15	≤0.10	≤0.08	≥0.020	≤0.010	≤0.010
Product analysis	≤0.08	0.25/0.85	≤0.35	≤0.007	≤0.003	8.60/9.40	≤0.18	≤0.13	≤0.10	≥0.015	≤0.013	≤0.013

Tensile properties

One transverse tensile test specimens is sampled at both ends from each Quenched and Tempered plate.
Guaranteed tensile properties are given in Table II

Table II	$R_{p0.2}$ (MPa)	R_m (MPa)	$A_{5.65\sqrt{So}}$ (%)	A_{50} (%)
5 ≤ t ≤ 50 mm	590 mini	690 / 820	18 mini	20 mini
50 mm < t ≤ 100 mm		680 / 820		

Impact properties

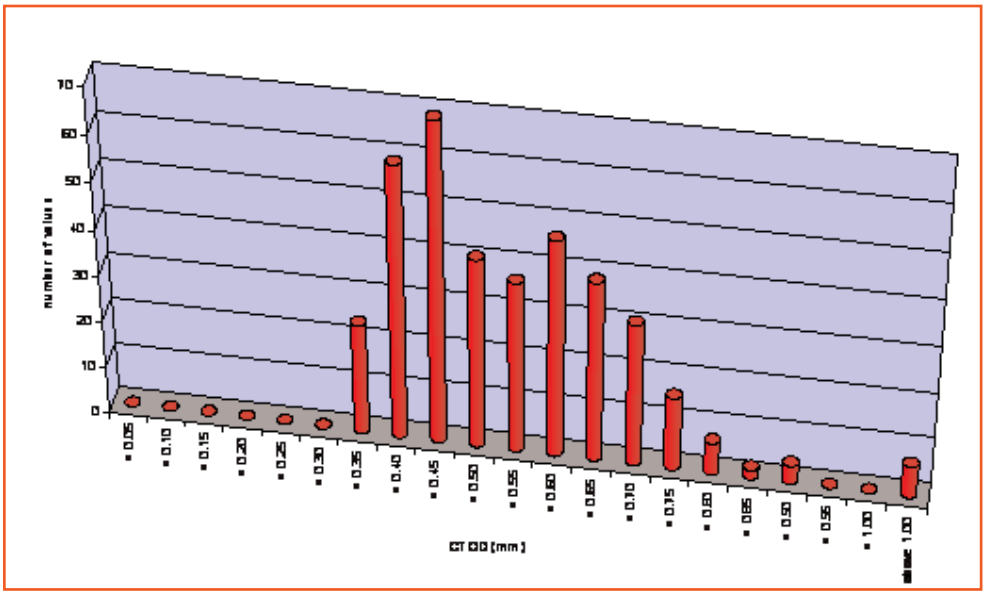
One set of three transverse Charpy V-Notch impact test specimens is sampled at one end from each Quenched and Tempered plate. More specimens can be extracted according to requirements.
Guaranteed impact properties are given in Table III. As far as possible in relation with plate thickness, the largest sample size is being used.

Table III	Test temperature	Energy absorption		Lateral expansion	Shear fracture
		Average for a set	One specimen for a set	Each specimen	
10 x 10 mm specimen for plate thickness 10 mm and above	-196°C	100 J mini	75 J mini	0.64 mm mini	75% mini
10 x 7.5 mm specimen for plate thickness 7.5 mm to 9.99 mm		75 J mini	56 J mini		
10 x 5 mm specimen for plate thickness 5 mm to 7.49 mm		50 J mini	38 J mini		

Upon request, for thickness 16 mm and above, Drop Weight test may be carried out according to ASTM E 208. Acceptance criteria is double No Break at -196°C. Testing frequency shall be agreed upon. Industeel can also supply previous qualification records.

Crack arrest properties

Tests at service temperature have been extensively performed.
CryElso®9Q possesses a high resistance against brittle fracture initiation. All the recorded CTOD values are higher than 0.30 mm. In the figure below, a statistical distribution for 383 test results is provided for tests carried out between -170°C and -163°C.



Residual magnetism

CryElso®9Q is guaranteed to be free of residual magnetism exceeding 50 Gauss.

Internal soundness

CryElso®9Q is guaranteed to be free of lamination, porosity and inclusions exceeding the acceptance criteria of EN 10 160 class S1E2.

Upon special request ultrasonic examination can be carried out and more severe criteria can be guaranteed.

Surface condition

CryElso®9Q is supplied in the shot blasted condition. A protective paint coating can be applied. Please enquire. CryElso®9Q is guaranteed to be free of any injurious surface defects. Upper and lower surfaces are visually checked before shipment. Inherent surface imperfections are being checked according to the Acceptance criteria of EN 10163, class B, sub class 2.

Stamping

CryElso®9Q is stamped in accordance with the relevant standard ASTM, EN or JIS.

All plates are low stress die-stamped for traceability directly after rolling and before any heat treatment. This procedure contributes to removing eventual crack-starting risks. No underthickness is produced by this procedure.

Cold forming

CryElso®9Q is suitable for cold forming operation up to a very high level of deformation such as 33% (example of a bending on a mandrel with a diameter that equals two times the plate thickness).

In case of very high deformation level, before cold forming, light grinding of edges in order to obtain a bright metal finish is mandatory.

- If cold deformation does not exceed 5%, no further heat treatment is needed.
- If cold deformation exceeds 5%, but is less than 10%, a Stress Relief heat treatment can be applied according to the following recommendation.

Recommended Stress Relief Treatment

Heating rate	according to furnace capability
Soaking temperature	570°C ± 10°C
Soaking time	2 min/mm of thickness with a minimum of 20 minutes
Cooling rate	in still air

- If cold deformation exceeds 10%, the mechanical properties are to be regenerated by Quenching and Tempering. Soaking time and temperature are mentioned on the Mill test certificate.

Hot forming

CryElso®9Q is suitable for hot forming operation. A temperature not exceeding 1150°C is recommended.

After hot forming, the mechanical properties must be regenerated by Quenching and Tempering. Soaking time and temperature are mentioned on the Mill test certificate.

Cutting

Shear cutting or sawing may be applied. Also, gas cutting or plasma cutting can be used.
After a light grinding in order to obtain a bright metal finish, the Heat Affected Zone hardness is guaranteed below 360 HV 10. Less than 0.2 mm metal removal is needed to achieve this. The low carbon martensite which is produced in the Heat Affected Zone remains very tough with low hardness increase, even in the non-tempered condition.

Welding conditions

CryElso®9Q can be welded using all usual welding processes such as GMAW, GTAW, SMAW and SAW.
Usual Heat Input, typically in the range from 1.0 kJ/mm to 3.0 kJ/mm, can be used. Unless the construction is heavily restrained, preheating is not necessary. Inter-pass temperature shall be limited to 150 °C maximum.

Unless the construction is heavily restrained or unless mandated by some rule, Post Weld Heat Treatment is not necessary. If for any reason Post Weld Heat Treatment has to be carried out, the following parameters apply.

Recommended Post Weld Heat Treatment

Heating rate	according to furnace capability
Soaking temperature	570°C ± 10°C
Soaking time	2 min/mm of thickness with a minimum of 20 minutes
Cooling rate	in still air

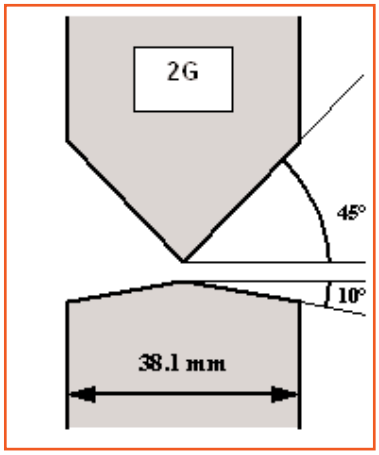
Please enquire for further recommendations on PWHT.

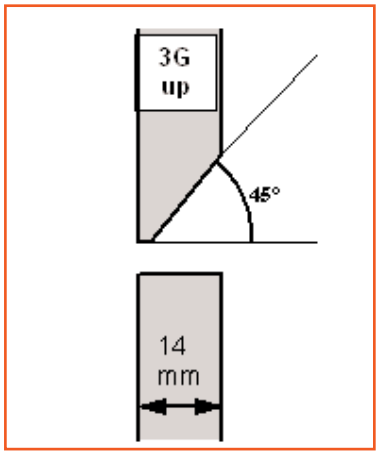
HAZ properties

Thanks to a very low carbon content, the structure in the Heat Affected Zone is a very tough martensite; even in the As-Welded condition. Hardness is limited to acceptable level and crack arrest properties give a full confidence in CryElso®9Q when properly welded with Heat Input in the range to 3 kJ/mm.

Tables IV and V give typical impact tests and CTOD tests results.

Examples have been selected in order:
- to cover the range from the first ring of thick shell and one of the last ring of thin shell
- to cover both welding processes SMAW 3G vertical up for the longitudinal seams and SAW 2G for the circumferential seams.





Other data is available upon request.

Table IV circumferential weld	38.1 mm - SAW (approx. 1.0 kJ/mm) - 2G position						
	Charpy V - Notch impact tests at -196°C				Tests at -163°C		
		Individual		Average			
Base Metal	205 J	165 J	185 J	185 J			
Weld Metal	127 J	121 J	118 J	122 J	δm : 0.716 mm	δm : 0.429 mm	δu : 0.458 mm
10° bevelled side							
Fusion Line (FS)	126 J	110 J	103 J	113 J	δu : 0.548 mm	δu : 0.481 mm	δu : 0.322 mm
FL + 2mm	252 J	304 J	288 J	281 J			
FL + 5 mm	186 J	182 J	180 J	183 J			
45° bevelled side							
Fusion Line (FS)	166 J	124 J	129 J	140 J	δu : 0.382 mm	δu : 0.309 mm	δu : 0.213 mm
FL + 2mm	180 J	202 J	154 J	179 J			
FL + 5 mm	174 J	174 J	194 J	181 J			

Table V longitudinal weld	14 mm - SAW (approx. 1.0 kJ/mm) - 3G up position						
	Charpy V - Notch impact tests at -196°C				Tests at -163°C		
		Individual		Average			
Base Metal	196 J	201 J	184 J	194 J			
Weld Metal	102 J	104 J	94 J	100 J	δm : 0.518 mm	δm : 0.563 mm	δu : 0.543 mm
Straight side							
Fusion Line (FS)	120 J	62 J	80 J	87 J	δu : 0.406 mm	δu : 0.458 mm	δu : 0.347 mm
FL + 2mm	330 J	358 J	358 J	349 J			
FL + 5 mm	214 J	224 J	202 J	213 J			
45° bevelled side							
Fusion Line (FS)	122 J	144 J	146 J	137 J	δu : 0.570 mm	δu : 0.614 mm	δu : 0.558 mm
FL + 2mm	162 J	192 J	144 J	166 J			
FL + 5 mm	180 J	196 J	208 J	195 J			

Filler materials

CryElso®9Q can be welded with metals of types Incoloy 625, Hastelloy C276 or other high-strength nickel base alloys. Table VI overviews some of the consumables classification.

Table VI	SMAW	GMAW	FCAW	SAW Wire + Flux
AWS	SFA 5-11 ENiCrMo-3 (625) ENiCrMo-4 (276) ENiCrMo-6	SFA 5-14 ERNiCrMo-3 (625) ERNiCrMo-4 (276)		SFA 5-14 ERNiCrMo-3 (625) ERNiCrMo-4 (276)
EN	ISO 14172 E Ni 6625 (625) E Ni 6276 (276) E Ni 6620	ISO 18274 S Ni 6625 (625) S Ni 6276 (276) S Ni 6620	ISO 14172 E Ni 6625 (625) E Ni 6276 (276) E Ni 6620	ISO 18274 S Ni 6625 (625) S Ni 6276 (276) S Ni 6620
JIS	Z3224 DNiCrMo-3 (625) Z3225 D9Ni-2	Z3332 YGT9Ni-2		Z3333 YS9Ni + FS9Ni-F YS9Ni + FS9Ni-H

Table VII lists a non-exhaustive list of suitable filler materials in alloy type 625:

Table VII	SMAW	GMAW	FCAW	SAW	
				Wire	Flux
ESAB	OK 92.45	OK Autrod 19.82		OK Autrod 19.82 SAW	OK 10.16
LINCOLN	Blue max NiCro 60/20	Blue max LNM NiCro 60/20		Blue max LNS NiCro 60/20	Blue max 2000
OERLIKON	Freezal 625				
T-PUT	Thermanit 625	Thermanit 625		Thermanit 625	Marathon 104
UTP	6222Mo	A6222Mo	AF6222Mo	UP6222Mo	FX UP6222Mo

Table VIII lists a non-exhaustive list of suitable filler materials in alloy type C276:

Table VIII	SMAW	GMAW	SAW	
			Wire	Flux
OERLIKON			Freezal S276	OP77
UTP	776Kb	A776	UP776	FX UP776

Table IX lists some other types of available nickel-based filler materials (ENiCrMo-6):

Table IX	SMAW	GMAW	FCAW	SAW	
				Wire	Flux
ESAB	OK 92.55				
LINCOLN	Blue max Nyloid 2				
OERLIKON	Freezal ENi9				
UTP	Soudonel D				
KOBELCO (other Hastelloy type)	NIC-1S	TGS-709S	DWN-70S	US-709S	PFN-3 or PFN-4

Applications

CryElso®9Q can be produced in thicknesses from 5mm up to 100mm ($^{3}/_{16}$" up to 4").

CryElso®9Q in 5 millimetres ($^{3}/_{16}$" with all-plus tolerance) is intended for bottom plates of Liquid Natural Gas and other cryogenic liquids storage tanks. 6 mm ($^{1}/_{4}$") is also available for that purpose.

The present trend is to increase the LNG storage tanks capacity up to 200 000 m^3, where thickness up to 55 mm ($2^{3}/_{16}$") is needed for the first rings of the shell. CryElso®9Q is already available in this thickness.

Safe crack arrest properties and very good mechanical properties are guaranteed based on an extensive welding research program on thick material. CryElso®9Q also finds further applications where cryogenic properties and limitation of weight are of importance, like LNG piping, pressure vessels and storage spheres, Floating LNG storage tanks, etc.

Prefabricated pieces

By special agreement, e.g. for Liquid Natural Gas storage tanks projects, prefabricated pieces can be delivered according to drawings.
The following operations can be done: bevelling, bending, rolling of shell to radius, cutting to shape, fabrication of stiffeners and annular plates, pre-welding.

Available sizes

In order to help designers, Industeel proposes the following standardized plate formats for CryElso®9Q for LNG storage tanks (Table X).

Table X Max. plate weight: 12.5 tonnes

Thickness (mm)	Width (mm)	Max. Length (mm)
5.00 to 6.99	1500 to 2000	12000
7.00 to 8.00	1500 to 2000	12000
	2500 to 3100	12000
8.01 to 9.99	2500 to 3100	13000
10.00 to 15.00	2500 to 3680	13000
15.01 to 50.80	2500 to 3680	16000

Other sizes may also be delivered, please enquire.
Plates of thickness above 50.80 mm thickness are also available on request.
Suggested thin plates sizes for the material aimed for the tank bottoms are adapted to high productivity yield as well as being "container-compatible", which helps avoiding unwanted deformations that can occur during handling.

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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 program on cryogenic 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.

All information in this brochure is for the purpose of information only. Industeel reserves the right to change its product range at any time without prior notice.

All Industeel facilities are ISO 9001, ISO 14001 and OHSAS 18001 certified.