WELDING SOLUTIONS FOR LIQUID NATURAL GAS STORAGE TANKS AND CARRIERS MANUFACTURED WITH NICKEL STEEL

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The importance of LNG

Energy becomes a key topic for many countries, considering the energy transition and the necessity for low carbon emission energies, LNG becomes a key player on the energy market. Not only for topics on carbon emissions but also in terms of energy security, LNG brings accessible reserves to markets where gas was not accessible before. In addition, new regulations on sulfur emission for marine applications have driven the shipbuilding industry in considering more and more LNG as a cleaner fuel.

The technology for LNG is well established since the 60s, with first LNG commercial shipments done from Algeria to France and UK and from Louisiana to Europe. Operations of liquefaction, transport and gasification have been optimized since then and several international engineering and contractors companies are reliable partners to countries having the desire to extend their energy sources portfolio. Sizes of LNG tanks and tankers have increased in order to reduce transportation and storage costs, with current typical gas storage tanks reaching more than 200.000 m^3.

voestalpine Böhler Welding is a reliable partner for high and nickel alloys consumables designed for the LNG industry since more than 20 years. We have been working with most of the specialized EPC, delivering high quality welding consumables to all continents: Europe, America's, Asia, Oceania and Africa.

LNG STORAGE TANKS

NICKEL STEELS

Different kinds of nickel steels will be found and will be applicable for applications with extremely low designed temperature. They are the material of choice for cryogenic applications when liquid gas has to be stored or transported.

Typical nickel steels – ASTM standard:

Plates	Nickel content	Impact testing T°	Typical liquid gas application
ASTM A645 grade A	5 % Ni	-140 °C	Ethylene
ASTM A645 grade B	5½ % Ni	-195 °C	Liquid natural gas
ASTM 553 type I	9 % Ni	-195 °C	Liquid natural gas

In between the 5 % and the 9 % nickel, we will find the A645 grade B, with nickel content slightly above the grade A but having mechanical properties similar to the ones of the 9 % Nickel.

Lowering the nickel content will have a direct impact on the material cost, reason of the attractiveness of that grade. Mechanical properties are achieved thanks to a double heat treatment of the steel during production.

Chemical analysis – ASTM:

	C	Mn	Si	Ni	Cr	Mo
A645 Grade A	0.13	0.3-0.6	0.2-0.4	4.8-5.2	-	0.20-0.35
A645 Grade B	0.13	0.9-1.5	0.15-0.3	5.0-6.0	0.10-1.00	0.10-0.30
A553 Type I	0.13	0.90	0.15-0.40	8.50-9.50	-	-

Mechanical properties – ASTM:

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ASTM 553 type I	9 % Ni	-195 °C	Liquid natural gas

The first steel of choice for LNG containment tanks will then be the 9 % Ni showing excellent fracture toughness at cryogenic temperatures. Typically, the ASTM A553 type I steel will be selected.

Nevertheless, with the current high pressure on the nickel costs (check www.lme.com for current values), several engineering companies have been considering the grade ASTM A645 grade B, containing a lower amount of Nickel, in the range of 6 %, making that steel about 10% cheaper than the standard A553 and keeping the same mechanical properties.

Two of the main design codes for cryogenic tanks are the API 620 and EN 14620.

For design temperatures below -165 °C, the material has to be tested at -196 °C and meet the below minimum requirements:

	Testing Temperature	Min Energy Absorption (longitudinal – transverse)*	Lateral Expansion
Grade A	-140 °C	27 J-22 J	Min. 0.38 mm
Grade B	-195 °C	27 J-22 J	Min. 0.38 mm
A553 Type I	-195 °C	34 J / 27 J-27 J / 20 J	Min. 0.38 mm

Typical Charpy impact tests are done on transverse specimens for which API requires a minimum of 27J at -196 °C for a 10 x 10mm specimen.

In addition to the minimum requirements of the API 620 code, engineering are using safety factors, very often requiring a minimum value of 55J or even 70J.

WELDING CONSUMABLES FOR NICKEL STEEL WELDING

The selection of appropriate welding consumable will be done based on the requirements of the mechanical properties of the weld metal but not only. Indeed, the welding operations will have an influence on the mechanical properties of the heat affected zone of the base material as well as on the diluted weld metal. Due to this influence, the application standards will require WPQR to prove the conformance of the procedure against design standards.

Nickel base alloys will be selected to perform the welding operations.

Key products for A553 Type I and A645 grade B welding:

Ni Steels Selection		Process	Welding Consumables	Classification AWS	Classification EN ISO
Steel Grade	UTS MPa [ksi]				
X8Ni9 A553 Type I	690-830 [100-120]	SMAW	**Thermanit 620**	ENiCrMo-6	E Ni 6620
X8Ni9 A553 Type I	690-830 [100-120]	SAW	**Thermanit NiMo C276 + Marathon 104**	ERNiCrMo-4	SA FB 2 AC
X8Ni9 A553 Type I	690-830 [100-120]	FCAW	**FOXcore 625-T1**	ENiCrMo3T1-4	Ni 6625 P M21 2

Mainly three welding processes are considered for the welding operations of the containment tank. The submerged arc process will be used to weld the horizontal joints – 2G position – when the stick electrode or flux cored wires will be used for the vertical ones.

The selection of the flux cored wire or the stick electrode will be mostly done based on the welding capabilities of the welders and the experience of the contractor with welding tractors. Indeed, when welding with flux-cored wires, the vertical up joints will be welded with automatic processes and tractors, allowing to drastically increase the welding productivity of the operation.

voestalpine Böhler Welding will support the contractor with the welding procedures qualifications of the above consumables as well as with welding equipment and mechanized automation.

Here below the typical chemistry of the all weld metal as well as the impact properties at the design temperature of -196°C:

Consumables	C	Mn	Si	Cr	Ni	Mo	Nb	Fe	W	Typical UTS all weld metal	CVN @ -196 °C
Thermanit 620	0.05	2.9	0.25	12.5	Bal.	5.9	1.2	4.8	1.4	700 MPa	90J
Thermanit NiMo C276 + Marathon 104	0.01	0.50	0.10	15.4	Bal.	16.0	-	6.0	3.7	720 MPa	110J
FOXcore 625-T1	0.02	0.3	0.5	20.7	Bal.	8.5	3.3	<1.0	-	750 MPa	90J

All these three welding consumables will be meet the most stringent market requirements in terms of toughness and ultimate tensile strength.

LIQUID NATURAL GAS CARRIER

LNG tankers will be used to transport the liquefied gas from the region of natural gas extraction and production to the country of utilization. Different designs are existing on the market and some of them are using nickel steels, as for the storage tanks.

Ultimate tensile strength, yield strength as well as impact toughness at design temperatures will be the key decision factors for the steel selection.

As an example, IGC/IGF codes are international standards for liquefied gas carriers. They are covering the LNG carrier vessels as well as vessels using LNG as fuel.

As for the storage tanks, design temperature is defining the impact test temperature:

PLATES, SECTIONS AND FORGINGS[1] FOR FUEL TANKS, SECONDARY BARRIERS AND PROCESS PRESSURE VESSELS FOR DESIGN TEMPERATURES BELOW MINUS 55°C AND DOWN TO MINUS 165°C[2] Maximum thickness 25 mm [3, 4]		
Minimum design temp. (°C)	Chemical composition[5] and heat treatment	Impact test temp. (°C)
-60	1.5 % nickel steel – normalized or normalized and tempered or quenched and tempered or TMCP[see note 6]	-65
-65	2.25 % nickel steel – normalized or normalized and tempered or quenched and tempered or TMCP[6, 7]	-70
-90	3.5 % nickel steel – normalized or normalized and tempered or quenched and tempered or TMCP[6, 7]	-95
-105	5 % nickel steel – normalized or normalized and tempered or quenched and tempered[6, 7 and 8]	-11 O
-165	9 % nickel steel – double normalized and tempered or quenched and temoered[6]	-196
-165	Austenitic steels, such as types 304, 304L, 316, 316L, 321 and 347 solution treated[9]	-196
-165	Aluminium alloys; such as type 5083 annealed	Not required
-165	Austenitic Fe-Ni alloy (36 % nickel) Heat treatment as agreed	Not required

Consequently, for LNG carriers, having a design temperature of -165 °C, only three base materials can be selected: austenitic stainless steels and 9 %-5 % nickel steels. Indeed, in addition to the table here above, the IGC code allows also special heat treated 5 % Nickel steel for design temperature down to -165 °C provided that the impact test are carried out at -196 °C.

For 9 % nickel steels, the same welding consumables as for the onshore tanks could be used. The main difference with the onshore tank welding is that carrier vessels are welded in shipyards, and their LNG tank are welded in roof covered workshops, allowing the use of welding processes not applicable on site welding of onshore tanks.

voestalpine Böhler Welding has developed a unique welding consumable for gas metal arc welding, austenitic stainless steel structure, designed for the welding of Nickel steels with impact testing requirements at -196 °C and minimum ultimate tensile strength at room temperature of 690 MPa. The main advantage of that solution against nickel alloys welding consumables is obviously the cost of the product, being a stainless steel.

Both A553 Type I and A645 grade B steels have been successfully welded with that innovative solution and both of them have met all standard mechanical requirements.

This innovative solid wire showed the following typical mechanical properties.
Tensile test was performed on transversal specimen. The welding consumables used had a wire diameter of 1.2 mm.

Base material	Welding Position	UTS [MPa]	Fracture location	Average Impact toughness @-196°C
A553 type I	PA/1G	**716**	Weld Metal	82J
	PC/2G	**736**	Weld Metal	102J
	PF/3G	**727**	Weld Metal	96J
	PE/4G	**736**	Weld Metal	79J

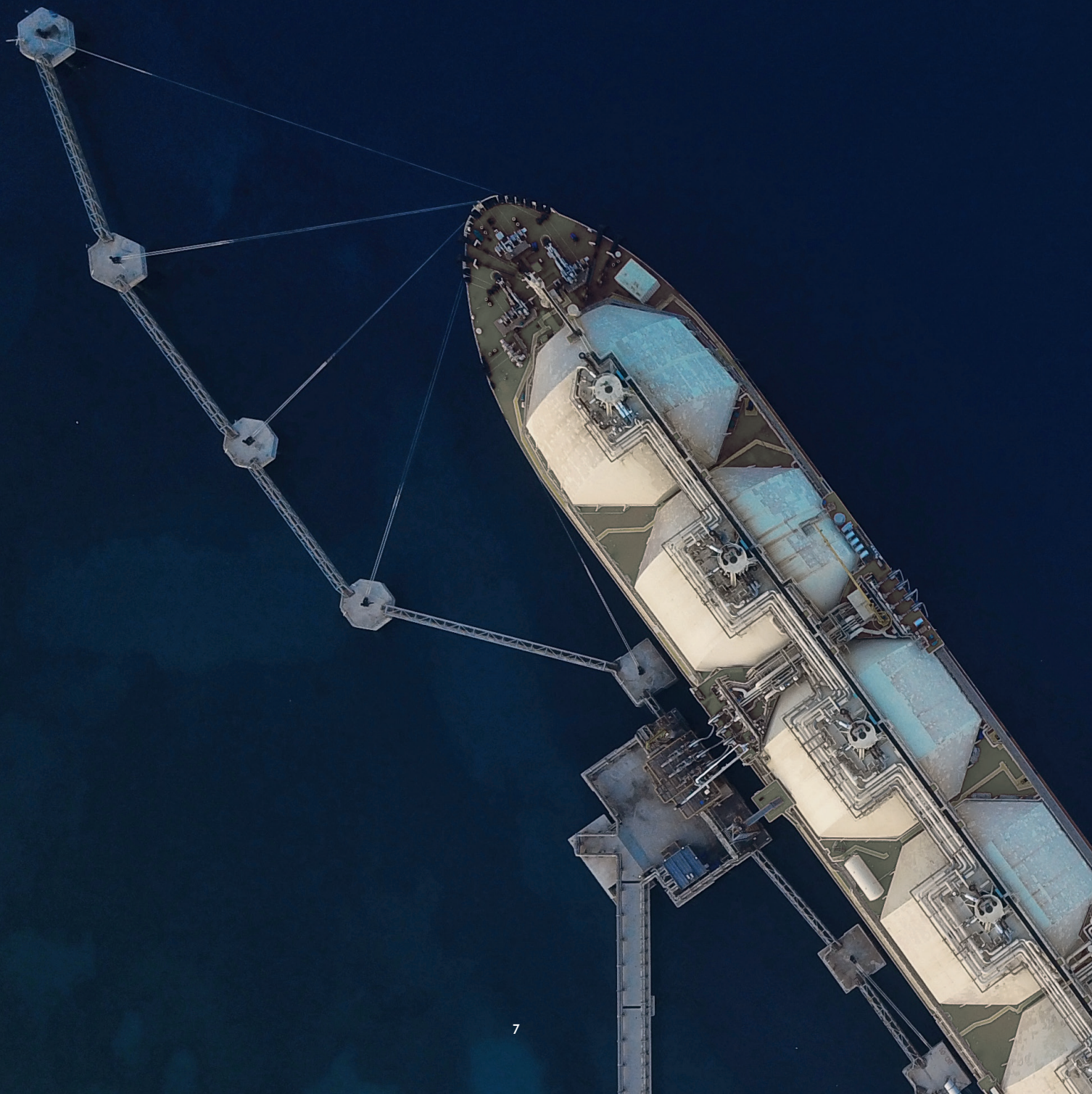
Base material	Welding Position	UTS [MPa]	Fracture location	Average Impact toughness @-196°C
A645 grade B	PA/1G	**724**	Weld Metal	**90J**
	PF/3G on ceramic backing	**719**	Weld Metal	**97J**
	PF/3G with back gouging	**745**	Weld Metal	**90J**

CONCLUSIONS

LNG is playing a big role in the energy transition and the infrastructure expansion is a continuously growing market for EPC and contractors.

The industry tries to meet the growing demand from countries having the wish to secure their energy supply and turn themselves into a stricter control of their CO_2 emissions.

voestalpine Böhler Welding has been a partner for the welding of LNG components since more than 20 years and we are closely following market demand and technical trends leading to innovations in welding solutions.



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