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Welding solutions at their best…

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Welding consumables for the oil & gas industry


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Introduction

T-PUT welding consumables for the oil & gas industry

For many decades, T-PUT welding consumables have been successfully applied in the oil & gas industry. Supported by experienced welding and metallurgical engineers, T-PUT welding consumables have a proven track record in a wide variety of field applications in various severe service conditions and environments.
T-PUT products faced the challenges and have demonstrated reliable performance all over the world in surroundings ranging from the arctic conditions in Alaska and Siberia to the tough waters of the North Sea and from the dry heat in the Sahara to the extremes of the outback of Australia.

This brochure is intended to provide an overview of T-PUT welding consumables for applications in the oil & gas industry. In general the consumable selection is based on the required mechanical properties such as yield and ultimate tensile strength, low temperature impact toughness and CTOD values as well as corrosion resistance properties and last but not least, optimal weldability.
The T-PUT Phoenix, Union and Thermanit product ranges include consumables for the main welding processes:
SMAW, GTAW, GMAW, SAW and FCAW in the oil & gas industry.

Oil & gas industry overview


Source: BP

The oil & gas industry as such comprises of many individual industries that all have their specific applications, material groups and welding consumable requirements. In order to be able elaborate on the specific areas of application within the oil & gas industry it is necessary to break it down into the various stages of the value chain, related processes and welded constructions.

A first popular distinction is **Onshore and Offshore**. Onshore includes everything that takes place on land including the jetties, docking facilities as well as the loading and offloading facilities. Offshore includes mainly everything that takes place on open water. The confusion starts when storage facilities are now being constructed as floating stationary vessels offshore! The main focus of the brochure is the offshore part, although storage facilities are being discussed as well.

A second popular distinction is **Upstream and Downstream**. The major oil companies refer to upstream for everything "till it hits the refinery". This definitely includes the storage and transport facilities for crude oil & gas. Downstream would in this case be everything from the refinery itself and onwards.

For offshore activities the oil companies also refer to **Exploration and Production**. Exploration includes the discovery drilling (drilling rigs) and preparation for actual exploiting of the oil & gas wells whereas production (production platforms) refers

Onshore oil & gas:	
Storage	tanks, tank farms, spheres etc.
Process & Petrochemical	heaters, separators, dryers, condensers, hydrocrackers, coke drums etc.
Pipelines	cross country for long distance transport

to extracting and treating large volumes of oil & gas offshore before it is transported onshore via pipelines or ships.

This implies that offshore facilities include process equipment as separators, dryers and flair-stacks similar to applications in the petrochemical industry. Although this brochure is not specifically about the petrochemical industry, most base materials will be discussed as they play an important role in the oil & gas industry.
A further division can be made regarding applications and constructions in various stages in the complete process chain.

For the purpose of this brochure the major segments with related base material groups within the oil & gas industry are:
subsea, piping, structural, topsides, transportation and storage, process and petrochemical.

(see illustration at pages 14 – 15)

The 3 main base material groups for the oil & gas industry

An overview of the applicable base materials with corresponding welding consumables is given in the tables further on in this brochure.

Although the main content of this brochure is on offshore oil & gas, upstream and LNG, the full overview of the major segments with specific applications and constructions are listed in the following specific industrial areas within the oil & gas industry:

❶ Offshore oil & gas, upstream	
Subsea	wellhead systems, subsea templates, manifolds, risers, flowlines, umbilicals, pumps, valves etc.
Piping	pipelines, lay barge production or spooling, fire fighting systems etc.
Structural	fabrication of jackets, tension legs, floating platforms, gravity base structures etc.
Topsides	process equipment, piping and petrochemical equipment
Transportation	pipelines and ships

❷ Gas in general:	
Process equipment	separation, drying, cooling, liquefaction, gasification
Transportation	pipelines, carriers
Storage	tanks and spheres

❸ LNG (Liquefied Natural Gas):	
Process equipment	separation, drying, cooling, liquefaction, regasification
Tranportation	single & double walled pipelines, LNG carriers
Storage	onshore tanks & spheres and semi-submersibles

For this groups in the oil & gas industry the main base materials are:

① Un- & low-alloyed steels for oil & gas exploration, production and transportation

② Stainless steels and nickel alloys for oil & gas processing and storage

③ 3.5 to 9% Nickel steels for liquefied gas processing, storage and transportation

❶ Un- & low-alloyed steels for oil & gas exploration, production & transportation

Pipeline welding

Pipelines are nowadays commonly used for the transportation of all kind of liquids and gases. For the oil- and gas industry pipelines are an effective way for transporting these valuable mediums from one place to the other. As pipelines are used onshore, offshore and for covering long distances, they offer many benefits compared to other means of transportation. Although the concept of a pipeline looks quiet simple, in reality the total construction of a pipeline is much more than that. Looking at the aspect of welding pipelines there are various demands that a pipeline technically has to fulfil. Higher strength materials with thinner wall thickness, in combination with more stringent testing requirements are more or less becoming standard.

The importance of welding and thereby the function can not be valued high enough. It is the fundamental process in the construction of pipelines. The results of the welds are depending on factors such as base material, welding process and the right choice of welding consumables.

T-PUT started to develop welding consumables for pipeline construction many years ago. Through all these years of development and experiences the products of T-PUT meet the highest demands on quality of welding consumables for pipeline applications. T-PUT faces this challenge alongside the prominent pipelaying companies and consequently has achieved a world leading position in this segment with cellulosic and basic coated electrodes as well as with wires. The high requirements regarding mechanical properties including weld metal toughness are, for safety reasons, in the focus of our attention.

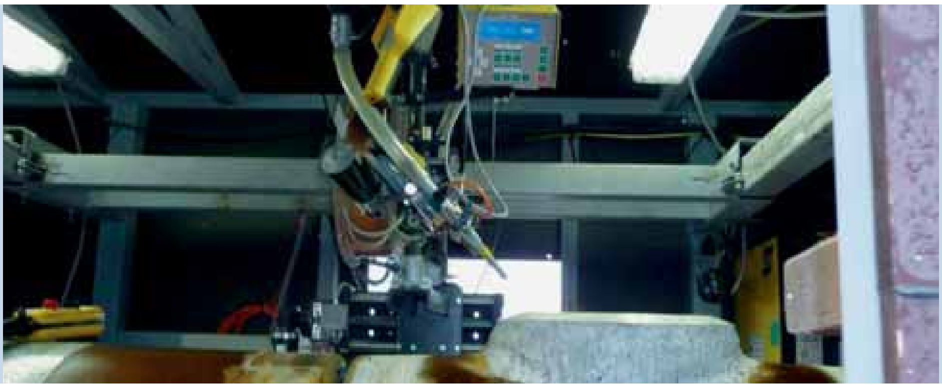
Not only the high quality standard plays an important role, but also the individual technical support and the flexible service for the benefit and the satisfaction of our customers.

The T-PUT consumables are world-famous both for onshore pipeline projects as well as for offshore subsea pipeline laying from barges, and pipelay vessels as thousands of kilometres of flowlines and steel catenary risers (SCR's) have already been welded with T-PUT welding consumables. The wide range of products, which is united in the brand name T-PUT are helpful in solving welding problems. The following overview shows typical applications with some for our welding consumables.

Structural applications

T-PUT offers a wide range of electrodes for girth welding of pipelines. All our cellulosic- and basic electrodes have excellent welding characteristics and therefore suitable for joining all common grades of pipe materials.

Solid- and flux cored wires, mostly with balanced alloying concepts are providing the optimum results of strength and toughness properties. T-PUT is supplying on large scale the most suitable wires for manual- and (semi) automatic welding.



The wire and fluxes produced by T-PUT are offering many combinations for submerged arc welding for prefab and double joint applications. All suitable combinations are fulfilling the highest demands on weldability, slag release and mechanical properties.

The T-PUT welding consumables for pipeline applications are successfully used worldwide. Due to the many years of experience the consumables of T-PUT will provide the best results for onshore and offshore pipeline constructions.

Selection chart of filler metals for pipeline welding and structural application

Steel classification	Steel grades				
EN 10208-2	L210	L245MB	L290MB	L320MB	L360MB
DIN 17 172 StE	210.7	240.7	290.7 (TM)	320.7 (TM)	360.7 (TM)
API 5 L-92	A	B	X 42	X 46	X 52
Cellulosic covered electrodes for vertical down welding					
Phoenix Cel 70 Δ	■	■	■	■	■
Phoenix Cel 75 Δ			■	■	■
Phoenix Cel 80 Δ			■	■	■
Phoenix Cel 90 Δ					
Basic covered electrodes for vertical up welding					
Phoenix K 50 R Δ	■	■	■	■	■
Phoenix 120 K Δ	■	■	■	■	■
Phoenix SH V 1 Δ					
Phoenix SH Ni 2 K 90 Δ					
GTAW – solid rods and wires					
Union I 52	■	■	■	■	■
Union I 52 Ni					
Union I 1,2 Ni					
Union I 2,5 Ni					
Union I Ni1MoCr					
GMAW – solid wires					
Union K 52 S	■	■	■	■	■
Union K 56 S					
Union K Nova					
Union K Nova Ni					
Union Ni 2,5					
Union NiMo 80					
FCAW – flux cored wires					
Union TG 55 Fe	Metal cored wire ■	■	■	■	■
Union MV 70	Metal cored wire ■	■	■	■	■
Union TG 55 M	Rutile cored wire ■	■	■	■	■
Union RV 71	Rutile cored wire ■	■	■	■	■
Union TG 56 Fe					
Union TG 55 Ni					
Union RV Ni 1					
Union RV NiMo 80					
SAW – Special flux for double/triple jointing					
UV 421 TT*	■	■	■	■	■

*in combination with different wires Δ = Not sold under this product designation in North America.

Steel grades						Steel classification
	L385MB	L415MB	L450MB	L485MB	L 555 MB	EN 10208-2
	385.7 (TM)	415.7 (TM)	445.7 (TM)	480.7 (TM)	550.7 (TM)	DIN 17 172 StE
	X 56	X 60	X 65	X 70	X 80	API 5 L-92
Phoenix Cel 70 ∆	■	□	□	□		
Phoenix Cel 75 ∆	■	■				
Phoenix Cel 80 ∆	■	■	■	■	□	
Phoenix Cel 90 ∆			■	■	■	
Phoenix K 50 R ∆	■	■	□	□	□	
Phoenix 120 K ∆	■	■	□	□	□	
Phoenix SH V 1 ∆			■	■		
Phoenix SH Ni 2 K 90 ∆					■	
Union I 52	■	■				
Union I 52 Ni			■	■		
Union I 1,2 Ni			■	■		
Union I 2,5 Ni				■		
Union I Ni1MoCr					■	
Union K 52 S	■	■				
Union K 56 S		■	■			
Union K Nova		■	■			
Union K Nova Ni			■	■		
Union Ni 2,5			■	■		
Union NiMo 80					■	
Union TG 55 Fe	■	■	■			
Union MV 70	■	■	■			
Union TG 55 M	■	■				
Union RV 71	■	■				
Union TG 56 Fe			■ Metal cored wire	■		
Union TG 55 Ni			■ Rutile cored wire			
Union RV Ni 1			■ Rutile cored wire			
Union RV NiMo 80*				■ Rutile cored wire	■	
UV 421 TT*	■	■	■	■	■	

■ = for root-, hot-, filler- and cap-pass welding

□ = for root-pass welding only

❷ Stainless steels and nickel alloys for oil & gas processing and storage

1. Introduction

In corrosive environments such as in oil & gas applications, a specific level of corrosion resistance against high localised and uniform corrosion is usually required. Crevices, which in certain constructions cannot be avoided, can pose a serious problem in the presence of aqueous, high chloride containing solutions, such as seawater as well as SO_2 and particularly H_2S containing media. Additionally due to the increasing necessity of deepwater exploration, the mechanical requirements of materials applied in the oil & gas industry become increasingly important.

The corrosiveness of chloride containing media is increased through the salt content of aqueous media and other halogens, ions of alkali metals or sulphur. Furthermore the temperature of the above mentioned corrosive agents is important for sensitivity to localised attacks such as pitting and crevice corrosion and other high hazard corrosion mechanisms e.g. stress corrosion cracking (SCC), sulphide stress cracking (SSC) or galvanically induced hydrogen stress cracking (GHSC). Due to of the corrosion resistance requirements, amongst others identified by H_2S contents in oil & gas applications, corrosion resistant alloys (CRA's) such as 13 Cr, 316 L, 22 % Cr duplex (DSS), 25 % Cr super duplex (SDSS) and 6 % Mo super austenitic stainless steel as well as Ni-alloys have to be considered. Figure 1 shows a listing of common CRA's in the oil & gas industry.

The pitting and crevice corrosion of stainless steels can be determined by standardised laboratory tests such as ASTM G 48 in ferric chloride solutions. In this test, a test specimen will be examined in 10 % FeCl3 testing solution at a constant temperature for a defined time. After this time period the temperature will be incrementally increased. Each test run must be evaluated by visual examination.

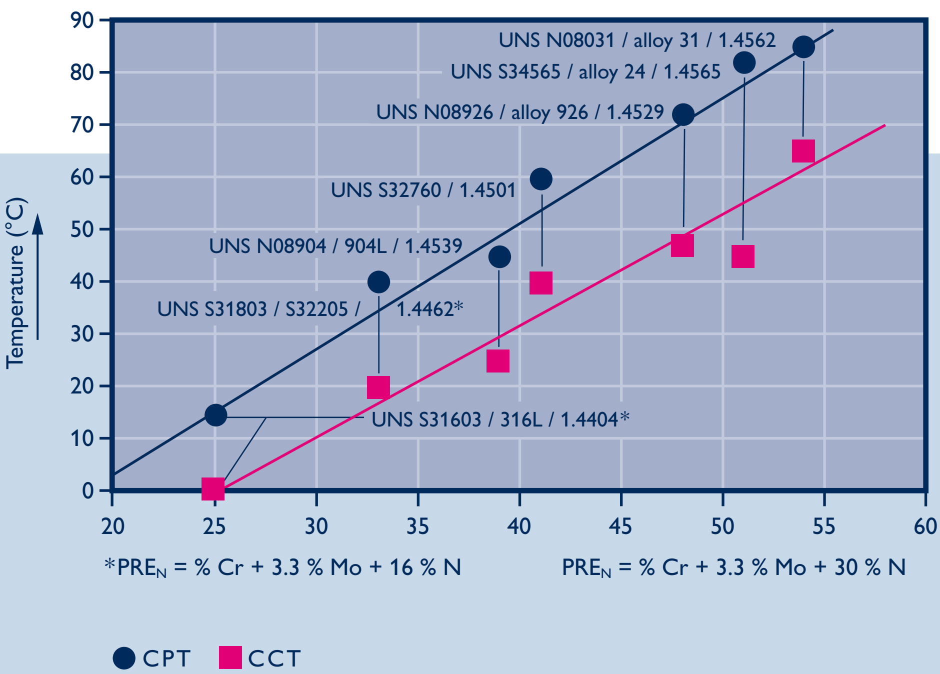


Figure 1

The critical pitting (CPT) or crevice corrosion temperature (CCT) is defined as the temperature at which the first corrosive attack occurs.

As an indicator for localised corrosion of CRA's, pitting resistance equivalent formulas (PRE or PREN) were established and often defined as follows: PRE_N = % Cr + 3.3 % Mo + (16 or 30 % N)
The nitrogen factors of PRE_N depend on the austenitic-ferritic or fully austenitic structure.
The pitting resistance equivalent was developed predominately for aqueous chloride containing media.
Figure 1 gives an overview of the CPT / CCT values for various DSS / SDSS and austenic parent metals.

2. Martensitic and supermartensitic stainless steel (13 Cr SMSS)

Because of the highly restricted welding behaviour of martensitic stainless steels the utilisation of such materials in the oil & gas business was of minor acceptance. Nevertheless, economic reasons and good mechanical properties lead to the development of low carbon and Ni alloyed martensitic stainless steels with drastically improved welding behaviour.
Thus and in comparison to previously discussed material selections for oil & gas applications, the SMSS, for example (UNS S41500), are very cost effective alternatives to low-alloyed mild steels and duplex steels in consideration of corrosion resistance, mechanical properties and weldability. The low carbon content of max. 0.02 % C causes the improved weldability. Furthermore, Ni contents of 3.5 to 6.0 % enhance the austenitic structure and decrease the martensite start temperature. Tempering of the martensitic structure at approx. 620 °C is leading to the reformation of the finely dispersed austenitic structure.
Therefore, the impact toughness of SMSS is 3–4 times superior to martensitic 13 Cr steel. Mechanical properties with YS > 600 MPa, UTS > 800 MPa and elongation > 10 % makes this stainless steel attractive for the production of oil & gas components in comparison with duplex stainless steels.
(see Figure 2 on page 12).

Nevertheless due to the susceptibility for SCC in H_2S containing environments the SMSS can be used for instance for flowlines if the media is characterised as sweet till slightly sour. Typical applications for SMSS in oil & gas are seamless or longitudinally welded pipes and fittings. The production of longitudinally welded pipes can be carried out by using the SAW process for example with matching filler metal Thermanit 13/06 Mo. Based on this filler metal selection a PHWT must be considered. By using the DSS / SDSS filler metals Thermanit 22/09 (AWS A5.9 ER2209) root layer and Thermanit 25/09 CuT (AWS A5.9 ER2594) filler and final pass, a PWHT is not required.

Base material	UNS-no.	SMAW	GTAW	GMAW	FCAW	SAW	
						wire	flux
13 % Cr	S41500	Thermanit 22/09 Thermanit 25/09 CuT			–	Thermanit 22/09	Marathon 431

3. Duplex (22 Cr) and super duplex (25 Cr)

Base material	UNS-no.	SMAW	GTAW	GMAW	FCAW	SAW	
						wire	flux
22 % Cr Duplex	S31803 S32205	Thermanit 22/09			Thermanit 22/09 (PW)	Thermanit 22/09	Marathon 431
25 % Cr Super Duplex	S32760	Thermanit 25/09 CuT			–	Thermanit 25/09 CuT	Marathon 431

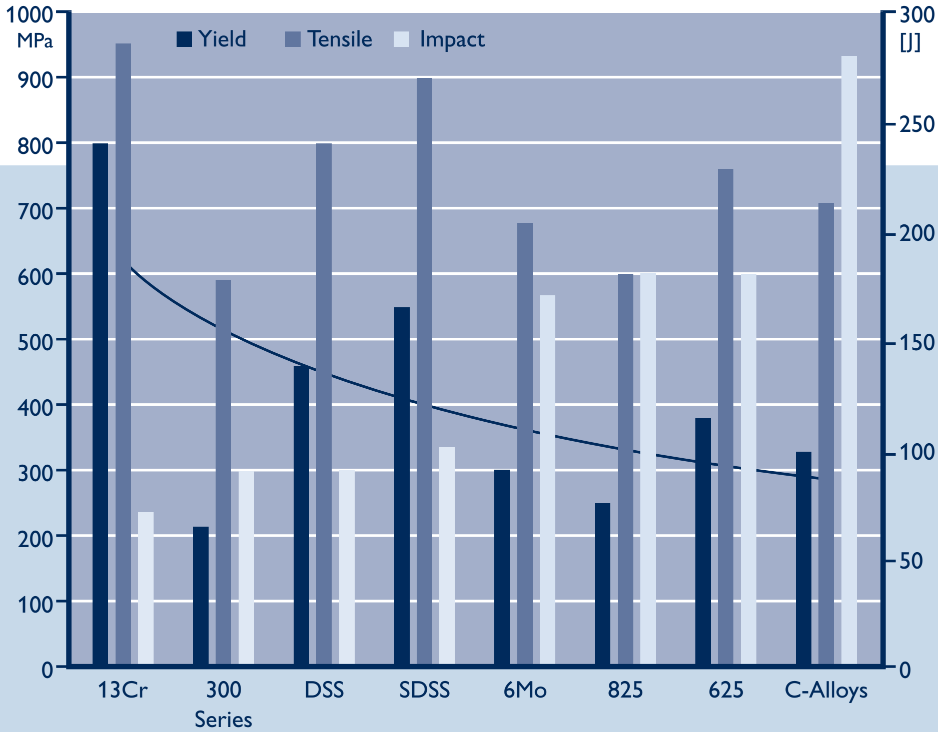


Figure 2

Duplex stainless steels DSS (UNS S31803) and super duplex stainless steels SDSS (UNS S 32760) are widely used in oil & gas or offshore installations. The chart shows the typical mechanical properties of 22/05 DSS (UNS S31803) and 25/07 SDSS (UNS S32750). In both cases the micro structure is ferritic-austenic with each phase accounting for roughly 50 % of volume.
The increased chromium content of approx. 25 % Cr requires an addition of austenite-forming elements like nickel or nitrogen. Particularly nitrogen is very effective in increasing the thermal stability of the microstructure to avoid the formation of undesired sigma-, or chi phase and mechanical properties by solid solution strengthening.

Heat treatments like solution annealing should be carried out at approx. 1050 °C (DSS) up to 1120 °C (SDSS) which is nearly comparable to solution annealing requirements of austenitic materials. Particularly SDSS have superior mechanical properties compared to the above mentioned standard stainless steels with tensile strength above 800 MPa.
Due to excellent wet-corrosion resistance and mechanical properties, these materials are often selected for seawater systems like pipes, flanges and fittings as well as for process systems, e.g. shell & tube heat exchanges, separators and underwater equipment like flowlines and risers, etc.

4. Austenitic and super austenitic (6 Mo)

Base material	UNS-no.	SMAW	GTAW	GMAW	FCAW	SAW	
						wire	flux
304L	S30403	Thermanit JE Spezial	Thermanit JE-308L Si		Thermanit 308L-PW	Thermanit JE-308L	Marathon 431
316L	S31603	Thermanit GE-316L			Thermanit 316L-PW	Thermanit GE-316L	Marathon 431
Super Austentic (6 Mo)	N08028 N08926 N08031 etc.	Thermanit Nimo C 276 Thermanit Nimo C 24			–	Thermanit 625	Marathon 431

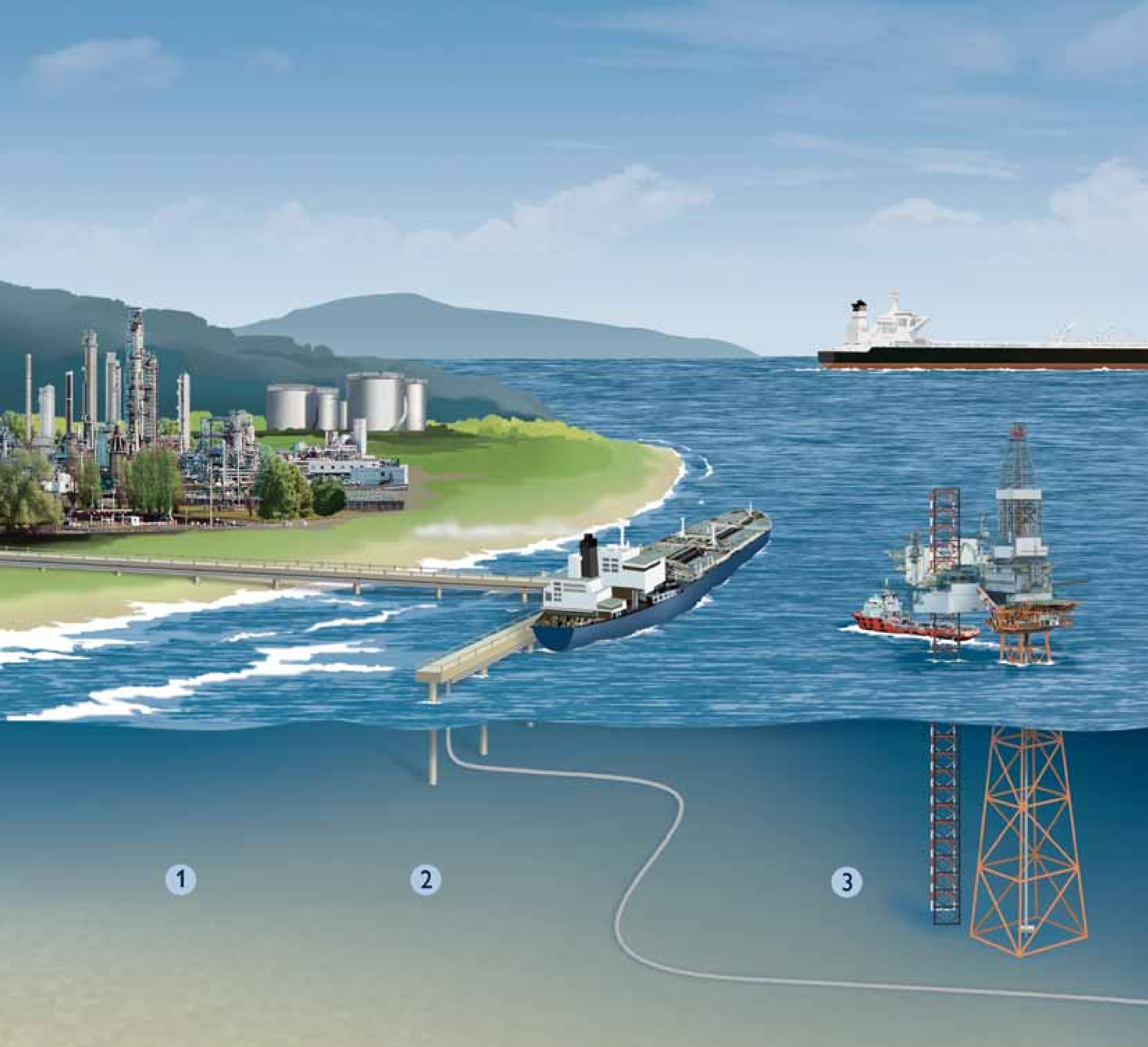
Austenitic parent metals out of the SS 300 series like AISI 316L (UNS S31603) or SS 316Ti (UNS S31635) are characterised by good workability e.g. machining, bending and welding usually without post weld heat treatment. Particularly due to the good welding behaviour, all kinds of fusion welding processes are applicable. Nevertheless, care should be taken concerning the heat input to minimise the risk for hot cracking as a generic problem of austenitic materials as well as the required corrosions resistance.
In case of standard stainless steels matching filler metals like extra low carbon (ELC) types such as Thermanit GE-316L Si (AWS A5.9 ER316LSi) or in case of stabilised parent metals the Nb-alloyed filler metal Thermanit A Si (AWS A5.9 ER318 mod) should be considered.

From the point of view of corrosion in oil & gas applications the degree of utilization of standard stainless steels is small due to the low pitting-, crevice- and particularly SCC resistance. Typical applications for austenitic material are cable trays, stairs, walkways, elevators etc.

By reason of restricted corrosion resistance of austenitic steels super austenitic stainless steels were developed to bridge the gap between standard stainless steels and nickel alloys. The so-called 6 % Mo steels, e.g. alloy 926 (UNS N08926) or alloy 31 (UNS N08031), are showing an explicitly increased corrosion resistance under sour gas environments compared to standard austenitic wrought materials. Alloy 31 is approved according to MR 0175-2003 up to Level VI (175 °C, 3.45 MPa H_2S, max. 35 HRC in cold worked condition).

This outstanding corrosion resistance requires proper workmanship during fabrication as well as during the production of components. This is amongst others indicated by the heat treatment. In contrast to standard stainless steels (e.g. 1020 to 1120 °C), the highly chromium and molybdenum alloyed super austenitics require increased temperatures (> 1150 °C) that are well above the area where the formation of sigma-phase and other undesired precipitations can occur. Welding should be carried out by using over alloyed Ni-Cr-Mo filler metals e.g. Thermanit NiMo C 24 (AWS A5.14 ERNiCrMo-13) and preferably with GTAW, pulsed arc GMAW, or PAW procedures.
Typical applications for high alloyed stainless steels are longitudinal welded or seamless pipes for umbilicals and other components.

Orbital GTAW of seamless tubes by courtesy of "Westfalen AG"



Overview oil and gas – Exploration, Production and Transportation

① **Onshore:** process and petrochemical, storage facilities, pipelines

② **Upstream:** (off)loading jetty and pipelines

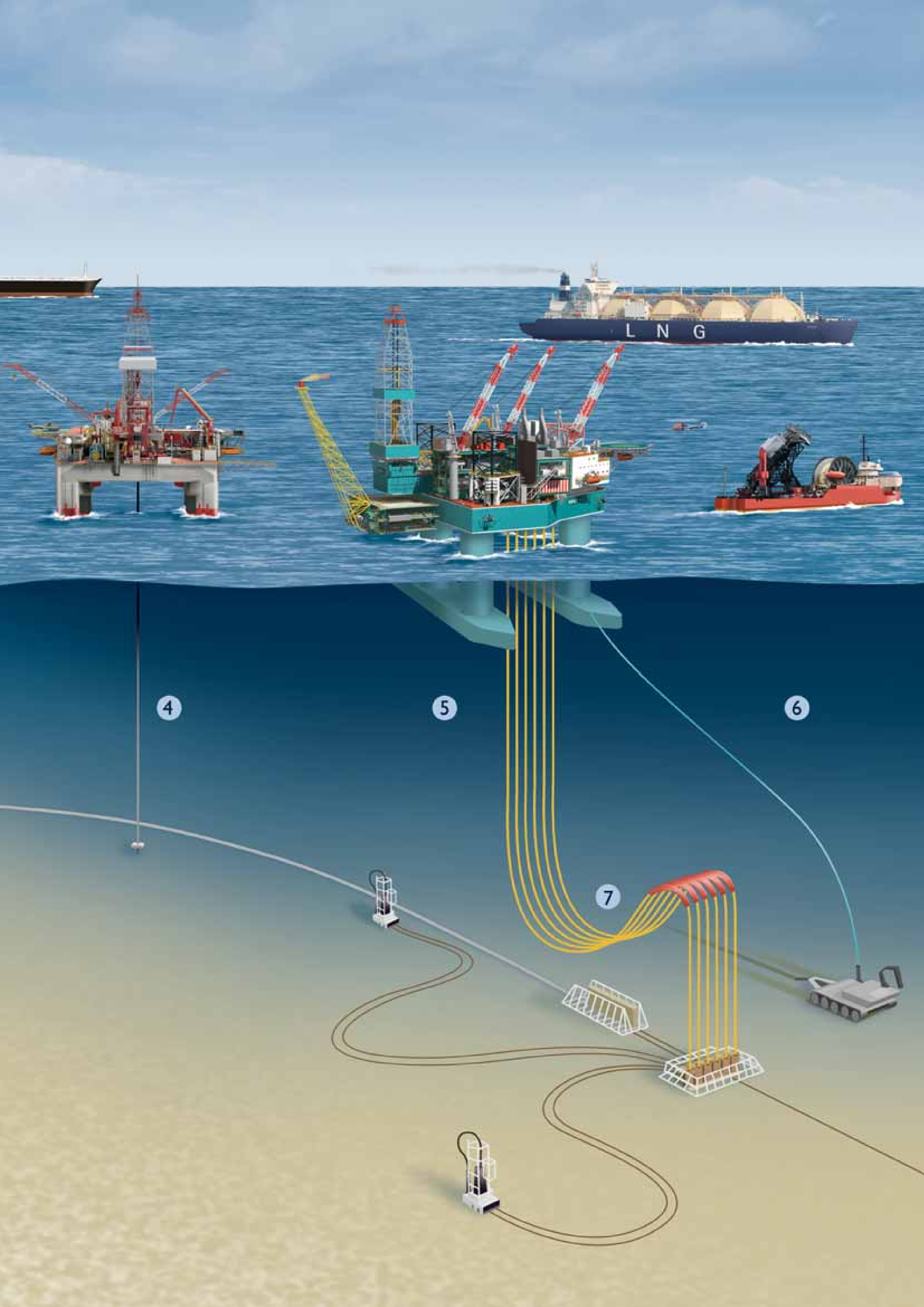
③ **Jack-up rig** with a jacket

④ **Tension leg platform** with a drilling rig

⑤ **Semi-submersible rig** and floating platforms

⑥ **Lay-barge** pipe-production and/or pipe-spooling

⑦ **Subsea:** wellhead systems, subsea templates, manifolds, risers, flowlines, umbilicals, pumps and ROVs (remotely operating vehicles)


LNG
4
5
6
7

2 Stainless steels and nickel alloys for oil & gas processing and storage

5.1 Alloy 825

Alloy 825 (UNS N08825) is a titanium stabilised fully austenitic material with addition of copper and molybdenum. With widespread use in oil & gas applications, it is characterised by good resistance to SCC by its high nickel content and shows also good resistance in oxidising and non-oxidising acids. On the other hand, the resistance to crevice and pitting corrosion is restricted due to its comparatively low molybdenum content. Typical examples for using alloy 825 are offshore product piping systems like tubes and components in sour gas service.

Instead of solid material e.g. for longitudinal welded pipes, alloy 825 is also often used as roll-bonded material for cladded components for oil field applications.

Due to the sensitivity to hot cracking of alloy 825, filler metals like Thermanit 625 (AWS A5.11 ENiCrMo-3, AWS A5.14 ERNiCrMo-3) will be commonly used as over-alloyed filler metal for GMAW, GTAW or SAW welding procedures.

Base material	UNS-no.	SMAW	GTAW	GMAW	FCAW	SAW	
						wire	flux
Alloy 825	N08825	Thermanit 30/40EW Thermanit 625	Thermanit 30/40E Thermanit 625		Thermanit 625 FD	Thermanit 625	Marathon 444
Alloy 625	N06625	Thermanit 625			Thermanit 625 FD	Thermanit 625	Marathon 444
C-Alloys	N10276 N06059 etc.	Thermanit Nimo C 276 Thermanit Nimo C 24			–	–	–

5.2 Alloy 625

Alloy 625 (UNS N06625) is a low carbon nickel-chrome-molybdenum alloy with additions of niobium. With regard to the mechanical properties of the so far discussed materials, alloy 625 has the highest yield and tensile strengths of the group of solid solution strengthened Ni-Alloys for wet corrosion services.

Alloy 625's resistance is excellent in a variety of corrosive media in the soft annealed condition and is superior to Alloy 825.

The soft annealing treatment leads to an increased resistance to intergranular corrosion compared to the solution annealed type.

For high temperature services up to 1000 °C the solution annealed condition and, if required, the grade 2 type of alloy 625 should be used because of the improved creep resistance. The coarser grain size compared to the soft annealed condition and carbon content of max. 0.05 % C is typically to increase the creep behaviour. Changes in temperature between 600 and 800 °C can lead to a precipitation hardening effect due to the formation of inter-metallic phases (γ', Ni3Nb) and should be avoided with respect to toughness requirements.

5.3 C-Alloys (Ni-Cr-Mo)

Among the nickel alloys the so called C-Alloys (Ni-Cr-Mo), e.g. Alloy 59, C-276, 22 or 686 CPT are eventually resistant to localised (pitting and crevice) and uniform corrosion as well as stress corrosion cracking.

An important factor concerning the corrosion resistance of the welded base materials is the thermal stability of the microstructure. Alloy 59 (UNS N06059) is the purest ternary alloy of the C-family, containing Ni, Cr, Mo and a small amount of iron. Due to this chemical composition alloy 59 shows excellent thermal stability compared to other Ni-Cr-Mo-alloys. The high requirements regarding thermal stability is caused by thermal loading during service as well as processing such as heat treatment or welding. Particularly the heat affected zone and the weld deposit are potentially susceptible to corrosive attacks. The Time-Temperature-Sensitisation diagram (Figure 3) shows that the sensitisation of standard nickel alloys, in the sense of 50 m intergranular corrosion criterion, measured according ASTM G 28 A, starts after approximately two hours. In the case of alloy C-276 (UNS N10276) the sensitisation starts already after a few minutes. Therefore, in practice, a post weld heat treatment (PWHT) e.g. of alloy 59 or 625 is usually not necessary. PWHT of large sections made of alloy C-276 could be necessary because of distinct lower thermal stability. This means resistance to the formation of precipitation or microstructures which increases a lower susceptibility for intergranular attack.

Due to the excellent thermal stability and corrosion resistance of Thermanit Nimo C24 weld deposit this welding consumable is appropriate for a wide range of C-alloy base materials as matching or over alloyed welding consumable.

In the case of GMAW welding multi component shielding gases are recommended to improve the wetting behaviour. Due to the same reason Argon-Hydrogen gas mixtures for GTA welding are recommended.

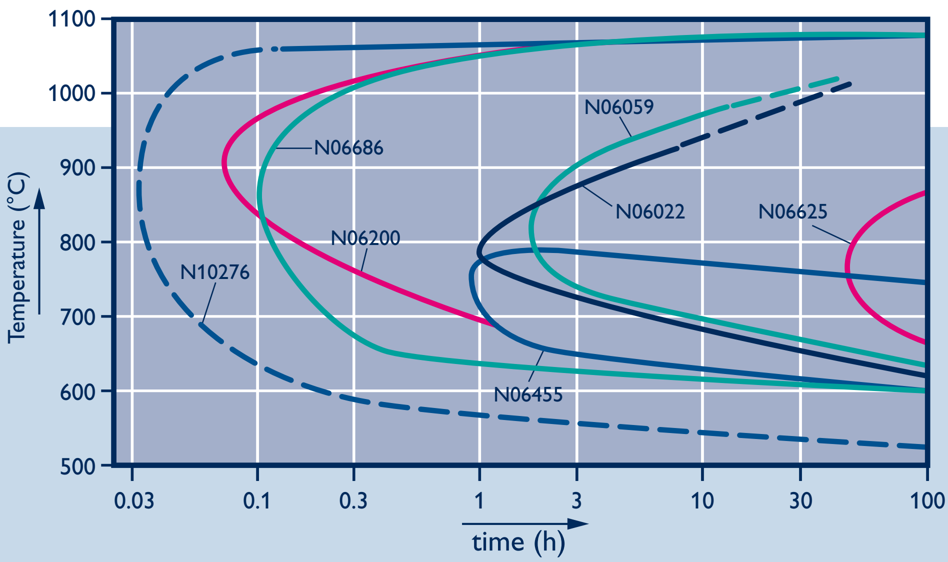


Figure 3

Time-Temperature-Sensitisation (TTS) diagrams of NiCrMo alloys when tested according to ASTM-G 28.
The lines indicate an intergranular penetration of 0.050 mm

❸ 3.5 to 9% nickel steels for liquefied gas processing, storage and transportation

Value chain for LNG


Source: Statoil

① Exploration and production

For the upsteam activities for exploration and production high quality material are required due to the extreme harsh enviroment conditions and the high mechanichal stresses.

② Liquefaction

The liquefaction train is the key part in the whole LNG chain. High investments are needed to built the gigantic systems with different components made from different materials.


Source: Statoil

③ Transportation

Transportation of LNG is the reason of the liquefaction. It is much more cost effective over long distance because of the reduction in volume after liquefaction.


Source: Enagas


Source: Statoil

④ Storage and regasification

Huge storage tanks with a capacity up to 200.000 m^3 are the main components on the import terminal. Big gas reserves are stored under cryogenic condition at –163 °C.


Source: Siemens

⑤ Downstream – Power stations

Gas fired Power stations are the key users for regasified LNG. Natural gas is the cleanest fossil energy source. It has a big contribution to the national energy supply.

⑤ Downstream – National gas grid

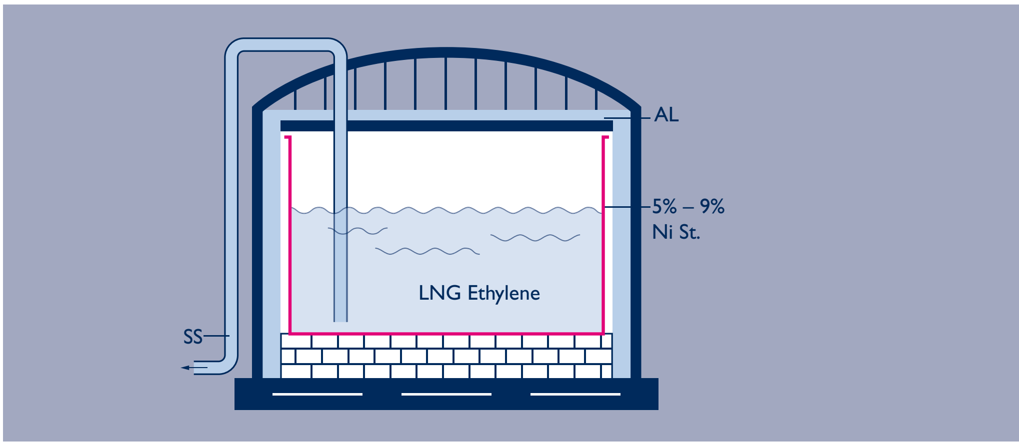
The national grid with its hundreds of kilometers of gas pipeline is the success factor to distribute the regasified LNG to millions of housholds for their local demand in heating systems and kitchens.

⑤ Decentralized gas stations

Decentralized gas stations are used in remote areas where the national grid is not available. Housholds and smaller entities are served by LNG trucks and sub stations. National grid serves in wide areas powerplants, big and small companies as well as household with regasified LNG to meet the energy demand. Gas fired power stations use regasified LNG to produce electric power and heat. They are the biggest comsumers of this kind of power source.

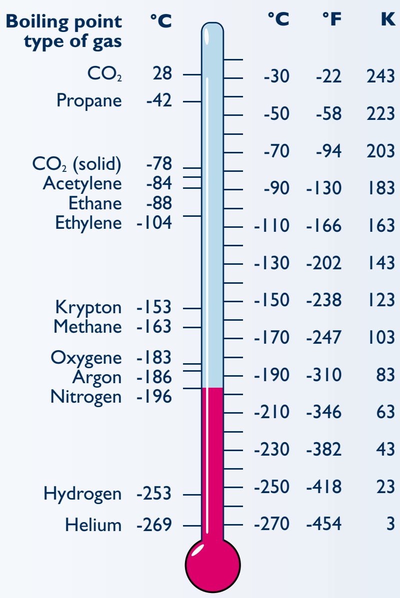
Cryogenic applications

The right choice of the welding consumables depends on the application, the base material and the specification. The Böhler Welding Group offers with its brand T-PUT a complete range of different high quality welding consumables. Some typical examples can be found in the following table. Our references prove a successful history in this application field. For further technical questions and requirement please contact our worldwide team of experts.



Base material	UNS-no.	SMAW	GTAW	GMAW	FCAW	SAW	
						wire	flux
3,5 % Ni	K32025	Phoenix SH Ni2 K 80 Δ	Union I 3,5 Ni		Thermanit 308 L-PW	Union S 2 Ni 3,5	UV 418 TT
5 % Ni	K41583	Thermanit 19/15*			Thermanit 316 L-PW	Thermanit 19/15	Marathon 104
5–9 % Ni	K81340	Thermanit 13/65 TTW 150	Thermanit 625		Thermanit 625 FD	Thermanit Nimo C 276	Marathon 104
		Thermanit 625 (FD)				Thermanit 625	Marathon 444

* also available for GMAW   Δ = Not sold under this product designation in North America.



Cryogenic applications can be found in many industries. It covers a temperature range of –70 °C to –269 °C. Typical media are liquefied Methane (LNG), Ethylene (Olefin), Ethane, Nitrogen and Helium. Beside these, refrigerated applications on a temperature range of 0 °C to –70 °C cover media like Propane, Propylene and Butane.

Welding applications exist for instance in:

- Storage tanks
- Pipelines
- Valves and fittings
- Process equipments
- Vessels

Typical base materials are:

- Fine grain steel (CMn)
- Stainless steel
- 3.5 % Ni steel
- 5 % and 9 % Ni steel
- Aluminum

T-PUT History & Trade name

Welding consumables for all demanding industries

1873 – Foundation of the Westfälische Union AG for the iron and wire industry

1975 –
Thyssen Edelstahl AG, Bochum / Germany

1978 –
Thyssen Draht AG, Hamm / Germany

1870 –
Foundation of Gebr. Böhler & Co.
Vienna / Austria

1990 –
Thyssen Schweißtechnik GmbH
Hamm / Germany

1991
+ UTP

1992 + Fontargen
+ Soudokay

1996 –
Böhler Thyssen Schweißtechnik GmbH

a joint venture of the Böhler-Uddeholm AG and the Thyssen Stahl AG
2003 – 100 % owned by Böhler-Uddeholm AG

2004 –
Labelchange

Thyssen Brand changes into T-PUT

2007 –
Böhler Welding Group / New Group Logo

2007 –
Acquisition by voestalpine AG

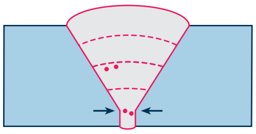
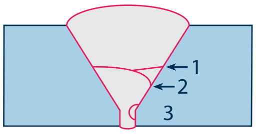
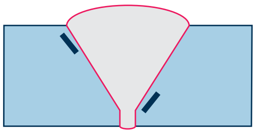
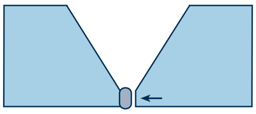
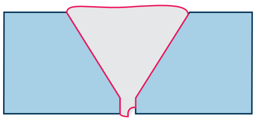
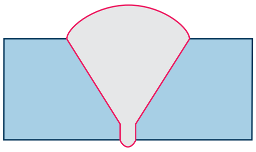
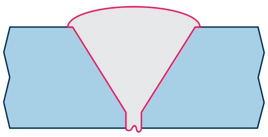
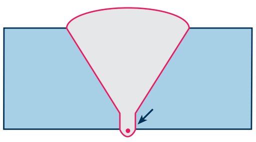
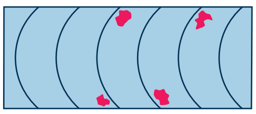
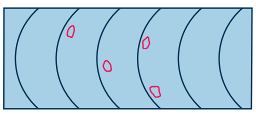
T-PUT – The Trade name

Trade name	Phoenix	Union	Thermanit
Alloy type	low and medium alloyed	low and medium alloyed	high alloyed
	SMAW covered electrodes	Gas welding – GTAW / rods and wires	Covered electrodes
		GMAW solid wires	GTAW welding rods
		Wire electrodes (SAW)	Wire electrodes (GMAW)
		Flux cored wires	Wire electrodes (SAW)
		Welding rods / bare wire electrodes (Al)	Flux cored wires

Wintershall platform L8-P4 (Dutch North Sea)

Source: Wintershall

Trouble-Shooting-Solutions

Defects		Causes	Measures for avoiding defects
Slag inclusions mainly occur in groove faces and in stringer bead areas (waggon tracks)		■ root pass poorly ground ■ incorrect electrode handling ■ insufficient cleaning between passes ■ too low current	■ grind root pass sufficiently before welding hot pass ■ improve electrode handling ■ clean each layer with rotary wire brush ■ increase current
Lack of fusion (cold laps) 1. interpass 2. side wall 3. root		■ current too low ■ insufficient melting of groove faces ■ groove faces contaminated and/or oxidized	■ control welding parameters, adopt them to the electrodes and welding positions ■ clean groove faces properly
Underbead cracks in the hardened HAZ		■ induced by hydrogen, stresses, hardened structure	■ preheat base metal to favor hydrogen effusion, increase heat input ■ avoid moving pipe string ■ welding of the hot pass immediately after finishing the root pass
Cracks caused by mechanical stresses observed in the stringer bead region		■ moving of pipe string during welding of the root pass ■ edge offset too great, resulting in reduced root cross section and increased risk of crack formation	■ avoid moving pipe particulary during welding of the root pass ■ control edge offset in relation to the relevant standards
Undercut mainly observed in the root pass and cover passes		■ current too high ■ incurrent handling	■ adopt current to the electrode diameter
Excess reinforcement		■ incurrent handling	■ adopt current to the joint width
Sagging stringer bead (suck back)		■ current too high ■ incorrect joint preparation, root gap too large	■ adopt current to the joint width
Piping (hollow bead)		■ root gap too narrow, no sufficient degassing ■ chemical composition of base metal: pittings are favored by high Al-contents	■ increase root gap width, min. width 1mm ■ if trouble continues, use smaller electrode diameter. Steels with an Al-content of 0.04% should be welded with root gap width of 1.5 mm
Porosity visible on the surface		■ base metal overheated (increased risk in thin wall pipe) ■ too low moisture content of electrode coating ■ excessive and uncontrolled weaving	■ adopt electrode diameter and current to pipe all thickness ■ keep electrodes in closed containers ■ max. weaving 3 x electrode stick diameter
Pinholes not visible on the surface		■ too low or too high moisture content in the coating ■ delayed deoxidization process in weld deposit	■ control storage ■ control welding parameters, reduce burn-off rate

Approvals

TÜV
Verband des Technischen Überwachungsvereins e.V.

DB
Deutsche Bahn AG

CE-Zertifikat über die werkseigene Produktionskontrolle
EN 13479

ABS
American Bureau of Shipping

Seproz, Ukraine

BV
Bureau Veritas

Statoil

GAZPROM
Russland

GL
Germanischer Lloyd

LR
Lloyd's Register of Shipping

DNV
Det Norske Veritas

ÖBB
Österreichische Bundesbahnen

The American Society of Mechanical Engineers
ASME III NCA 3800

Gaz de France

LRQA
DIN EN ISO 9001: 2000 – Qualitätsmanagementsysteme
ISO/TS 16949: 2002 – Qualitätsmanagementsysteme in der Automobilindustrie

LRQA
DIN EN ISO 14001: 2004 – Umweltmanagementsysteme

RR
Russian Maritime Register of Shipping

CWB
Canadian Welding Bureau

RINA
Registro Italiano Navale

UDT
URZEDU DOZURU TECHNICZNEGO, Warschau/Polen

VNIIST, Russland

You will find the current overview of our approvals on our homepage **www.t-put.com** (please download the product data sheet).

Source: Shell

T-PUT – Welding consumables for the oil & gas industry

Brand name	EN ISO • EN		EN ISO • EN		AWS	
1 Un- & low-alloyed steels for oil & gas exploration, production and transportation						
SMAW						
Phoenix Cel 70 ∆	2560-A	E 42 2 C 25	2560-B	E 4310 A	A5.1	E6010
Phoenix Cel 75 ∆	2560-A	E 42 2 C 25	2560-B	E 4910 P1	A5.5	E7010-P1
Phoenix Cel 80 ∆	2560-A	E 46 3 C 25	2560-B	E 5510 P1	A5.5	E8010-P1
Phoenix Cel 90 ∆	2560-A	E 50 3 1 Ni C 25	2560-B	E 5710 G	A5.5	E9010-G
Phoenix K 50 R ∆	2560-A	E 42 3 B 32	2560-B	E 4916 AU	A5.1	E7016
Phoenix 120 K ∆	2560-A	E 42 5 B 32 H5	2560-B	E 4918-1 AU	A5.1	E7018-1
Phoenix SH V 1 ∆	2560-A	E 50 6 Mn 1 Ni B 42 H5	2560-B	E 5518-GA	A5.5	E8018-G
Phoenix SH Ni 2 K 90 ∆	• 757	E 55 5 2 NiMo B 42 H5	–	–	A5.5	E10018-M
GTAW						
Union I 52	636-A	W 42 5 W3Si1	636-B	W 49A 5 W6	A5.18	ER70S-6
Union I 52 Ni	• 1668	W 50 5 W3Ni1(mod)	–	–	A5.28	ER80S-G
Union I 1,2 Ni	636-A	W 46 6 W3Ni1	–	–	A5.28	ER80S-G
Union I 2,5 Ni	636-A	W 46 8 W2Ni2	–	–	A5.28	ER80S-G
Union I Ni1MoCr	16834-A	W 55 6 ZMn3Ni0,9MoCr	–	–	A5.28	ER100S-G
GMAW						
Union K 52-S	• 440	G 42 4 M G3Si1	–	–	A5.18	ER70S-6
Union K 56-S	• 440	G 46 2 C G4Si1/ G 46 4 M G6Si1	–	–	A5.18	ER70S-6
Union K Nova	14341-A	G 46 5 C G0/ G 42 4 M G0	–	–	A5.18	ER70S-G
Union K Nova Ni	14341-A	G 46 4 C G3Ni1/ G 46 5 M G3Ni1	–	–	A5.28	ER80S-G
Union Ni 2,5	14341-A	G 50 8 M ZG2Ni2	14341-B	G 57A 8 M GN5	A5.28	ER80S-Ni2(mod.)
Union NiMo 80	• 12534	G Mn3Ni1Mo	–	–	A5.28	ER90S-G
FCAW						
Union TG 55 Fe	17632-A	T 46 4 M M 1 H5	17632-B	T555T15-1MA-H5	A5.18	E70C-6MH4
Union MV 70	17632-A	T 46 4 M M 2 H5/ T 42 3 M C 2 H5	17632-B	T555T15-1MA-H5/ T494T15-1CA-H5	A5.18	E70C-6MH4
Union TG 55 M	17632-A	T 46 4 P M 1 H10/ T 42 2 P C 1 H5	17632-B	T555T1-1MA-H10/ T494T1-1CA-H5	A5.20	E71T-1MJH8/ E71T-1CH8
Union RV 71	17632-A	T 42 2 P M 1 H5/ T 42 2 P C 1 H5	17632-B	T494T1-1MA-H5/ T494T1-1CA-H5	A5.20	E71T-1MJH4/ E71T-1CH4
Union TG 56 Fe	• 758	T 46 6 1 Ni MM 2 H5	–	–	A5.18	E70C-GMH4
Union TG 55 Ni	17632-A	T 50 5 1 Ni P M 1 H5	17632-B	T556T1-1MA-N2-H5	A5.29	E81T1-Ni1MJH8
Union RV Ni 1	17632-A	T 50 6 1Ni P M 1 H5/ T 46 5 1Ni P C 1 H5	17632-B	T556T1-1MA-N2-H5/ T555T1-1CA-N2-H5	A5.29	E81T1-Ni1MJH4/ E81T1-Ni1CJH4
Union RV NiMo 80	18276-A	T 62 4 1,5NiMo P M 2 H5	18276-B	T695T1-1MA-N2M2-H5	A5.29	E101T1-K3M JH4
SAW						
UV 421 TT	14174	SA FB 1 65 DC H5	–	–	–	–
UV 421 TT + Union S 2	14174-A	S 35 4 FB S2	–	–	A 5.17	F7A6-EM12
UV 421 TT + Union S 3 Si	14174-A	S 46 5 FB S3Si	–	–	A 5.17	F7A8-EH12K
UV 421 TT + Union S 2 NiMo 1	14174-A	S 50 6 FB SZ2Ni1	–	–	A 5.17	F8A8-ENi1-Ni1
UV 421 TT + Union S 3 NiMo 1	14174-A	S 55 6 FB S3Ni1Mo	–	–	A 5.17	F9A8-EG-F3
2 Stainless steels and nickel alloys for oil & gas processing and storage						
SMAW						
Thermanit 22/09	• 1600	E 22 9 3 N L B 2 2	–	–	A5.4	E2209-15
Thermanit 25/09 CuT	• 1600	E 25 9 4 N L B 2 2	–	–	A5.4	E2553-15(mod.)
Thermanit JE Spezial	• 1600	E 19 9 L B 2 2	–	–	A5.4	E308L-15
Thermanit GE-Spezial	• 1600	E 19 12 3 L B 2 2	–	–	A5.4	E316L-15
Thermanit 625	14172	E Ni 6625 (NiCr22Mo9Nb)	–	–	A5.11	ENiCrMo-3
Thermanit 30/40 EW	14172	E Ni 8025 (NiCr29Fe30Mo)	–	–	–	–
Thermanit Nimo C 24	14172	E Ni 6059 (NiCr23Mo16)	–	–	A5.11	ENiCrMo-13

∆ = Not sold under this product designation in North America.

AWS		Mat. No.	C	Si	Mn	Cr	Mo	Ni	N	Cu	W	YS MPa	TS MPa	Temp. °C	ISO-V J	Shielding gas EN ISO 14075
SMAW																
A5.1M	E4310	–	0.14	0.18	0.55	–	–	–	–	–	–	420	510	–40	28	–
A5.5M	E4910-P1	–	0.15	0.20	0.60	–	–	–	–	–	–	420	530	–30	28	–
A5.5M	E5510-P1	–	0.16	0.20	0.85	–	–	0.20	–	–	–	460	550	–30	47	–
A5.5M	E6210-G	–	0.18	0.20	0.85	–	–	0.75	–	–	–	530	630	–40	47	–
A5.1M	E4916	–	0.06	0.55	0.95	–	–	–	–	–	–	420	510	–30	47	–
A5.1M	E4918-1	–	0.07	0.35	1.20	–	–	–	–	–	–	420	510	–50	47	–
A5.5M	E5518-G	–	0.07	0.25	1.50	–	–	0.95	–	–	–	500	580	–60	50	–
A5.5M	E6918-M	–	0.06	0.25	1.40	–	0.45	1.80	–	–	–	580	690	–50	47	–
GTAW																
–	–	–	0.08	0.85	1.50	–	–	–	–	–	–	440	560	–50	50	I1
–	–	–	0.06	0.70	1.50	–	0.08	0.90	–	–	–	500	590	–50	80	I1
–	–	–	0.10	0.70	1.40	–	–	1.30	–	–	–	470	600	–60	47	I1
–	–	–	0.08	0.60	1.00	–	–	2.35	–	–	–	480	620	–80	47	I1
–	–	–	0.08	0.50	1.60	0.27	0.40	0.90	–	–	–	600	710	–60	55	I1
GMAW																
–	–	–	0.07	0.85	1.50	–	–	–	–	–	–	450	540	–40	50	M31
–	–	–	0.08	1.05	1.65	–	–	–	–	–	–	450	550	–20	50	C1
												480	580	–40	60	M21
–	–	–	0.06	0.75	1.55	–	–	–	–	–	–	440	570	– 40	50	C1
												480	600	–40	65	M21
–	–	–	0.06	0.70	1.50	–	–	0.90	–	–	–	470	560	–40	45	C1
												500	590	–40	80	M21
–	–	–	0.08	0.60	1.00	–	–	2.35	–	–	–	510	620	–70	47	M21
–	–	–	0.09	0.65	1.55	–	0.40	1.10	–	–	–	550	640	–40	50	C1
FCAW																
–	–	–	0.06	0.60	1.40	–	–	–	–	–	–	460	560	–40	47	M21
–	–	–	0.05	0.60	1.50	–	–	–	–	–	–	460	560	–40	50	M21
–	–	–	0.05	0.45	1.35	–	–	–	–	–	–	460	560	–40	80	M21
–	–	–	0.06	0.40	1.30	–	–	–	–	–	–	420	520	–40	27	M21
–	–	–	0.06	0.60	1.40	–	–	0.90	–	–	–	460	560	–60	50	M21
–	–	–	0.06	0.45	1.40	–	–	0.90	–	–	–	500	560	–50	47	M21
–	–	–	0.06	0.40	1.40	–	–	1.00	–	–	–	500	560	–60	47	M21
–	–	–	0.07	0.45	1.40	–	–	0.30	1.50	–	–	620	700	–40	47	M21
SAW																
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	0.10	0.10	1.00	–	–	–	–	–	–	400	510	–40	47	–
–	–	–	0.10	0.30	1.70	–	–	–	–	–	–	460	550	–60	47	–
–	–	–	0.11	0.10	1.00	–	0.25	0.90	–	–	–	500	560	–60	47	–
–	–	–	0.12	0.10	1.60	–	0.60	0.95	–	–	–	560	640	–60	47	–
SMAW																
–	–	≈1.4462	<0.04	0.50	0.90	22.50	3.00	9.00	0.13	–	–	480	520	+20	50	–
–	–	≈1.4501	0.03	0.50	1.20	25.00	3.70	9.00	0.20	0.70	0.60	600	650	+20	70	–
–	–	1.4316	<0.04	0.30	1.00	19.50	–	10.0	–	–	–	320	350	+20	70	–
–	–	1.4430	<0.04	0.20	1.30	18.50	2.80	11.50	–	–	–	320	550	+20	70	–
–	–	2.4621	<0.04	<0.70	<1.00	21.50	9.50	Bal.	–	–	–	420	450	+20	75	–
–	–	2.4653	<0.03	<0.90	1.50	28.00	36.00	–	–	1.80	–	350	370	+20	50	–
–	–	2.4609	<0.02	0.10	<0.50	23.00	16.00	Bal.	–	–	–	420	700	+20	60	–

Brand name	EN ISO • EN		EN ISO • EN		AWS	
❷ Stainless steels and nickel alloys for oil & gas processing and storage						
GTAW						
Thermanit 22/09	14343-A	W 22 9 3 N L	14343-B	SS2209	A5.9	ER2209
Thermanit 25/09 CuT	14343-A	W 25 9 4 N L	–	–	A5.9	ER2594
Thermanit GE-316L Si	14434-A	G 19 12 3 L Si	14343-B	SS316LSi	A5.9	ER316LSi
Thermanit 625	18274	S Ni 6625 (NiCr22Mo9Nb)	–	–	A5.14	ERNiCrMo-3
Thermanit JE-308L Si	14343-A	G 19 9 L Si	14343-B	SS308LSi	A5.9	ER308LSi
Thermanit Nimo C 24	18274	S Ni 6059 (NiCr23Mo16)	–	–	A5.14	ERNiCrMo-13
Thermanit 30/40 E	18274	S Ni 8025 (NiFe30Cr29Mo)	–	–	A5.9	ER383(mod.)
GMAW						
Thermanit 22/09	14343-A	G 22 9 3 N L	14343-B	SS2209	A5.9	ER2209
Thermanit 25/09 CuT	14343-A	G 25 9 4 N L			A5.9	ER2594
Thermanit GE-316L Si	14434-A	G 19 12 3 L Si	14343-B	SS316LSi	A5.9	ER316LSi
Thermanit 625	18274	S Ni 6625 (NiCr22Mo9Nb)	–	–	A5.14	ERNiCrMo-3
Thermanit JE-308L Si	14343-A	G 19 9 L Si	14343-B	SS308LSi	A5.9	ER316LSi
Thermanit Nimo C 24	18274	S Ni 6059 (NiCr23Mo16)	–	–	A5.14	ERNiCrMo-13
Thermanit 30/40 E	18274	S Ni 8025 (NiFe30Cr29Mo)	–	–	A5.9	ER383(mod.)
FCAW						
Thermanit 22/09-PW	17633-A	T 22 9 3 N L P M 1/ T 22 9 3 N L P C 1	17633-B	TS2209-FB1	A5.22	E2209T1-4/E2209T1-1
Thermanit 308L-PW	17633-A	T 19 9 L P M 1/ T 19 9 L P C 1	17633-B	TS308L-FB1	A5.22	E308LT1-4/E308LT1-1
Thermanit 316L-PW	17633-A	T Z 19 12 3 L P M 1/ T Z 19 12 3 L P C 1	17633-B	TS316L-FB1	A5.22	E316LT1-4/E316LT1-1
Thermanit 625 FD	12153	T Ni 6625 B M21 2	–	–	A5.34	E NiCrMo 3 T1-4
SAW – wire						
Thermanit JE-308L	14343-A	G 19 9 L	14343-B	SS308L	A5.9	ER308L
Thermanit GE-316L	14343-A	G 19 12 3 L	14343-B	SS316L	A5.9	ER316L
Thermanit 625	18274	S Ni 6625 (NiCr22Mo9Nb)	–	–	A5.14	ERNiCrMo-3
SAW – flux						
Marathon 431	14174	SA FB 2 64 DC	–	–	–	–
❸ 3.5 to 9% nickel steels for liquefied gas processing, storage and transportation						
SMAW						
Phoenix SH Ni2 K 80 Δ	2560-A	E 42 6 3 Ni B 32 H5	–	–	A5.5	E7018-C2L
Thermanit 19/15 H	• 1600	E 20 16 3 Mn N L B 2 2	–	–	A5.4	E316L-15 (mod.)
Thermanit 13/65 TTW 150	14172	E Ni 6620 (NiCr14Mo7Fe)	–	–	A5.11	ENiCrMo-6
Thermanit 625	14172	E Ni 6625 (NiCr22Mo9Nb)	–	–	A5.11	ENiCrMo-3
GTAW						
Union I 3,5 Ni			–	–	A5.28	ER80S-Ni3(mod.)
Thermanit 19/15	14343-A	W 20 16 3 Mn N L	14343-B	SSZ316L	A5.9	ER316L(mod.)
Thermanit 625	18274	S Ni 6625 (NiCr22Mo9Nb)	–	–	A5.14	ERNiCrMo-3
SAW – wire						
Union S 2 Ni 3,5	14174-A	S2Ni3	–	–	A5.23	ENi3
Thermanit 19/15	14343	S 20 16 3 Mn N L	–	–	A5.9	ER316L(mod.)
Thermanit Nimo C 276	18274	S Ni 6276 (NiCr15Mo15Fe6W4)	–	–	A5.14	ERNiCrMo-4
Thermanit 625	18274	S Ni 6625 (NiCr22Mo9Nb)	–	–	A5.14	ERNiCrMo-3
SAW – flux						
UV 418 TT	14174	SA FB 1 55 AC	–	–	–	–
Marathon 104	14174	SA FB 2 55 AC	–	–	–	–
Marathon 444	14174	SA FB 2 AC	–	–	–	–

Δ = Not sold under this product designation in North America.

AWS		Mat. No.	C	Si	Mn	Cr	Mo	Ni	N	Cu	W	YS MPa	TS MPa	Temp. °C	ISO-V J	Shielding gas EN ISO 14075
GTAW																
–	–	≈1.4462	0.02	0.40	1.70	22.50	3.20	8.80	0.15	–	–	600	650	+20	100	–
–	–	≈1.4501	0.02	0.30	0.80	25.30	3.70	9.50	0.22	0.60	0.60	600	650	+20	80	–
–		1.4430	0.02	0.80	1.70	18.8.	2.8.	12.5.	–	–	–	380	420	+20	70	M12
–	–	2.4831	0.03	0.10	0.10	22.00	9.00	Bal.	–	–	–	460	500	+20	120	–
–		1.4316	0.02	0.90	1.70	20.00	–	10.00	–	–	–	350	570	–196	35	M12
–	–	2.4607	0.01	<0.10	<0.50	23.00	16.00	Bal.	–	–	–	450	700	+20	120	–
–	–	2.4656	0.02	0.20	2.60	29.00	4.30	36.00	–	1.80	–	350	380	+20	120	–
GMAW																
–	–	≈1.4462	0.03	0.50	1.60	23.00	3.00	9.00	0.14	–	–	510	700	+20	70	–
–	–	≈1.4501	0.02	0.30	1.50	25.50	3.70	9.50	0.22	0.80	0.60	650	750	–46	50	–
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	M12
–	–	2.4831	0.03	0.25	0.20	22.00	9.00	Bal.	3.60	–	–	460	740	–196	40	–
–	–	1.4430	0.02	0.80	1.70	18.80	2.80	12.50	–	–	–	380	560	+20	70	–
–	–	2.4607	0.01	0.10	<0.50	23.00	16.00	Bal.	–	–	–	420	700	+20	60	–
–	–	2.4656	0.02	0.20	2.60	29.00	4.30	36.00	–	1.80	–	350	550	+20	75	–
FCAW																
–	–	1.4462	0.03	0.80	0.90	22.70	3.20	9.00	0.13	–	–	600	800	–40	32	M21
–	–	1.4316	0.03	0.70	1.50	19.80	–	10.50	–	–	–	350	380	–196	32	M21
–	–	1.4430	0.03	0.70	1.40	18.10	2.10	12.50	–	–	–	350	560	–120	45	M21
–	–	–	0.05	0.40	0.40	21.00	8.50	Bal.	–	–	–	450	750	–60	32	M21
SAW – wire																
–		1.4316	0.02	0.60	1.70	20.00	–	10.00	–	–	–	320	550	–196	35	–
–	–	1.4430	0.02	0.80	1.70	18.80	2.80	12.50	–	–	–	380	560	+20	70	–
–	–	2.4831	0.03	0.25	0.20	22.00	9.00	Bal.	–	–	–	460	740	–196	32	–
SAW – flux																
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
SMAW																
–		–	0.05	0.25	0.85	–	–	3.50	–	–	–	430	520	–100	40	–
–		1.4455	<0.04	<0.50	6.00	20.00	3.00	16.50	0.18			430	650	–296	35	–
–		–	0.06	<0.50	3.30	13.50	6.00	Bal.	–	–	1.40	410	660	–196	60	–
–		2.4621	<0.04	<0.70	<1.00	21.50	9.50	Rest	–	–	–	420	450	–196	40	–
GTAW																
–		–	0.07	0.15	0.90	–	–	3.10	–	–	–	440	540	–100	47	I1
–		1.4455	0.03	0.50	7.50	20.50	2.80	15.50	0.18			430	650	–196	47	I1
–		2.4831	0.03	0.25	0.20	22.00	9.00	Bal.	–	–	–	460	740	–196	32	I1
SAW – wire																
–		–	0.09	0.15	0.90	–	–	3.30	–	–	–	–	–	–	–	–
–		1.4455	0.02	0.60	7.50	20.50	3.00	15.50	0.18	–	–	–	–	–	–	–
–		2.4886	0.01	0.08	0.30	15.50	16.00	Bal.	–	–	3.50	400	700	–	–	–
–		2.4831	0.03	0.25	0.20	22.00	9.00	Bal.	–	–	–	460	740	–196	40	–
SAW – flux																
–		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
–		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
–		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

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