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WELDING SOLUTIONS FOR THE OFFSHORE INDUSTRY

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INTRODUCTION

HYUNDAI WELDING MEETS OFFSHORE INDUSTRY CHALLENGES

The world's energy consumption is astronomical and still increasing, fuelled by a growing population, developing regions, industrialisation and technological advancements. Energy demand is a dynamic aspect of the global energy landscape and can change – gradually or abruptly – due to policy shifts, technological breakthroughs, societal changes or unforeseen events. The (offshore) oil and gas industry is a sector that therefore constantly needs to adapt to changing conditions by balancing costs and improving operations.

Oil & gas exploration at sea plays a significant role in meeting the world's energy demand, as a substantial part is recovered from offshore fields. The variety of drilling platforms and associated equipment reflects the need to adapt to specific site conditions, water depths, technical requirements and economic considerations.

HYUNDAI WELDING has traditionally been involved in the offshore industry with dedicated filler materials designed for typical welding applications in the construction of fixed and jack-up platforms, floating production units and associated facilities. They cover all commonly applied offshore construction steels, pipeline grades and stainless and nickel-base alloys used in offshore oil & gas processing and are available for the entire scope of welding processes used.

Examples of welding consumables designed for use in offshore fabrication are Supercored 81MAG for manual flux cored arc welding and Superflux 787 for submerged arc welding. The weld metal of these filler materials meets high strength steel yield strength requirements as well as additional properties typical for the offshore industry; CVN impact toughness down to -60°C and CTOD at -10°C or lower. The chemical weld metal composition of both Supercored 81MAG and Superflux 787 (with wire EH12K) fulfills the NACE chemical weld metal requirements for applications in environments where sulphide-induced stress corrosion cracking may be a risk.

INDUSTRY INFORMATION

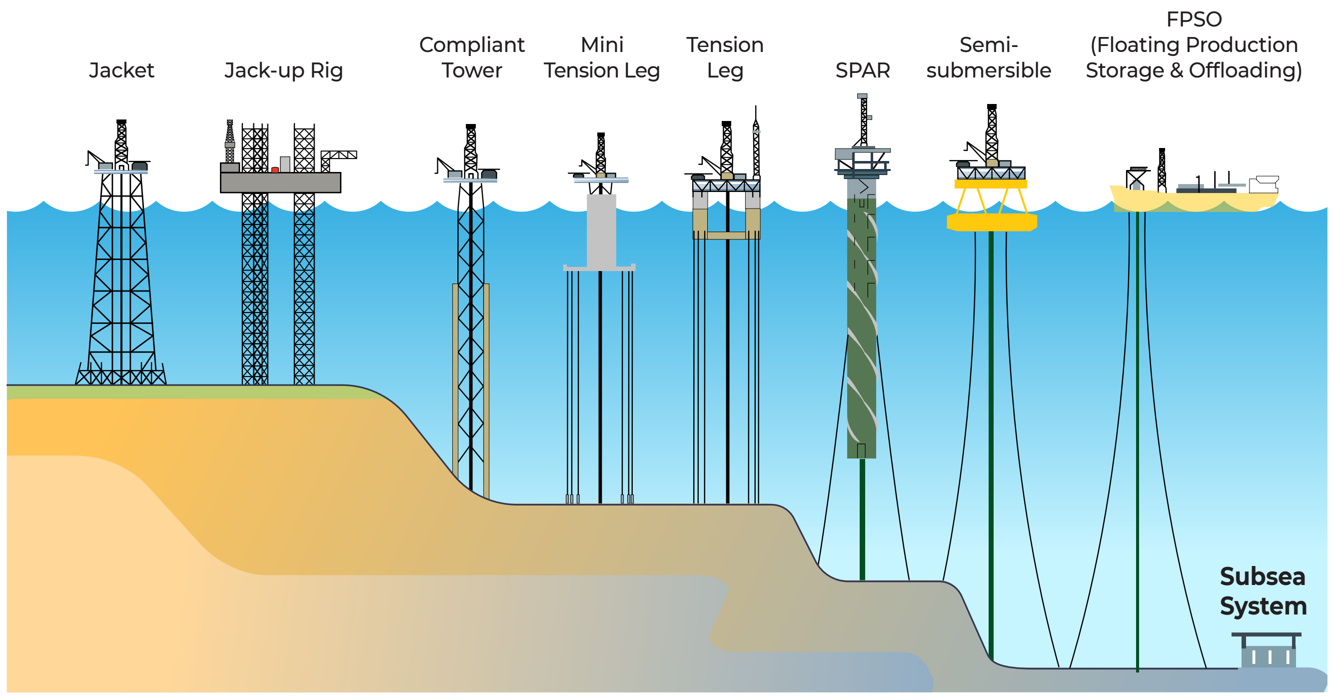
OFFSHORE OIL & GAS PRODUCTION TO REMAIN CRUCIAL FOR DECADES

The Covid-19 pandemic, as well as recent geopolitical conflicts, have made energy security dominate international policy agendas. It has undoubtedly accelerated the ongoing transition to clean energy technologies to counteract global warming to a point where today's investments in renewable energy are exceeding those in fossil fuels. In its 2023 report – Analyses and forecast to 2028 – the international energy agency IAE – sees "peak oil looming at the horizon". Demand for combustible fossil fuels is predicted to peak already by the end of the current decade, due to wide scale electrification and improved efficiencies. At the same time, environmental government policies in the developed world, such as the European "green deal", aim at CO_2 neutrality in 2050 and beyond, while developing areas like China, India, Brazil and Africa have to provide welfare to massive populations. Oil and gas from offshore and other locations will be needed for many decades to come, until renewables can fully power the world.

The offshore industry had to balance costs when oil and gas prices initially plunged during the pandemic. Prices and profits recovered during 2021 and later, which has had a positive impact on offshore exploration and production activities. This has enabled further investment in cutting edge technologies such as automation, robotics and digitalization to improve operations, reduce human error and optimize resource utilisation. Meanwhile an increased societal focus on renewable energy and sustainable practice has encouraged some companies to step into green projects such as wind energy and green hydrogen generation.

Global upstream oil & gas investment is expected to grow at a moderate pace, of which the offshore industry will take up a major part, due to the availability of abundant resources and improved technologies to produce from fields at greater depth, especially with floating production storage and offloading vessels (FPSO's). New activities are planned in established fields in the Middle East, Africa and Europe, while major new discoveries off the coast of Brazil, Guyana and Suriname will boost investments in the offshore industry worldwide.

OFFSHORE STRUCTURE PLATFORMS AND TYPES



Offshore oil & gas exploration platforms are installed on the seabed and utilized to explore and extract oil and gas reserves that are located off the coast and beyond the reach of conventional onshore drilling techniques. They are immense structures that may be exposed to high waves, severe storms and even seismic forces, and receive unpredictable impact across their entire body. These conditions require critical welds to be defect-free and fulfill stringent mechanical requirements. The design of a platform primarily varies with the water depth to cover, but other considerations may have their effect on the structure as well, such as:

· Cost and economics/ exploration vs production or both
· Environmental conditions like wave impact, wind force and sub-zero temperatures
· Characteristics of the oil and gas reservoir
· Technological advancements
· Safety and environmental regulations

The **jacket platform** is one of the most common types of fixed platforms and is typically deployed in shallow to intermediate water depths, ranging from around 30 to 350 meters. The term jacket refers to the structural framework that supports the platform and resembles a steel jacket or skeletal structure.

The **jack-up platform** or mobile offshore drilling unit (MODU) is the mobile version of the jacket platform. The hull can float to be towed to a drilling location and jacked-up above the water surface to create a stable platform for drilling operations.

The **compliant tower** is a narrower type of jacket platform for deeper water- up to 700m depth.

Tension leg (TLP) and **SPAR (single, large diameter cylinder)** are floating platforms permanently held in place by tensioned vertical tendons connected to the sea floor by pile-secured templates. They are designed for operation in deep to very deep water.

Semi-submersibles and **FPSO's** are mobile, floating vessels for very deep water operation. They are anchored above the well by means of mooring lines and use dynamic positioning to maintain their location. Floating Production, Storage and Offloading units are ship like vessels with on-board equipment for the treatment of crude oil and gas, including facilities for storage and offloading to carrier ships.

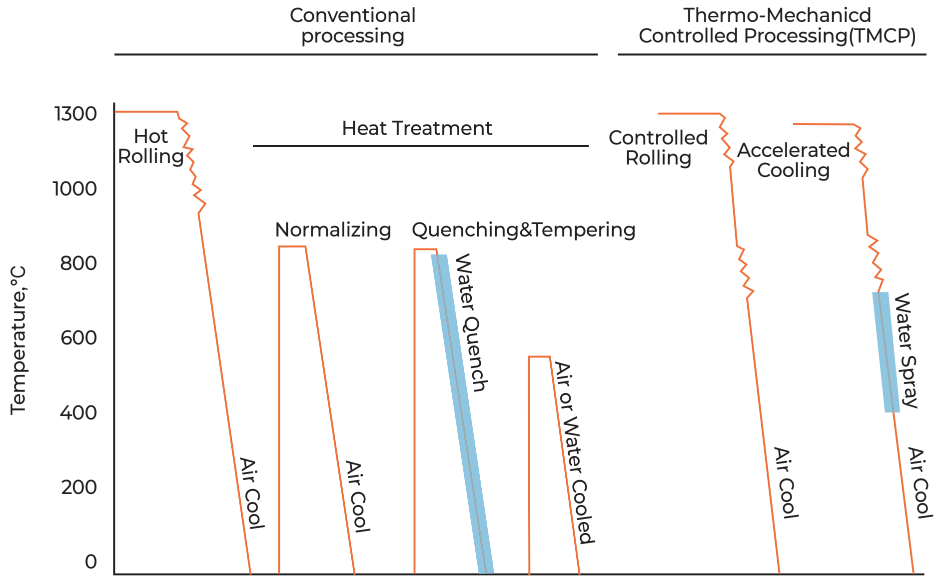
HIGH STRENGTH STEEL PRODUCTION METHODS

High strength steel derives its elevated strength from its micro structure. The elevated yield strength is obtained by grain size refinement achieved through recrystallization during the rolling process or by applying a heat treatment after rolling. There are three main production routes for high strength steel, see figure below.

Normalizing is a heat treatment at a temperature steel mills apply to refine the crystal structure of hot rolled steel. After cooling, the steel receives a heat treatment just above the point in the iron-carbon phase diagram where austenite is stable and recrystallization takes place. This process, followed by slow cooling, produces a fine and homogeneous ferritic-perlitic micro structure which increases the strength of the steel and improves its toughness properties. Steels are low carbon and with no alloying, so with excellent weldability.

Quenching and tempering is used to give rolled steel a hardened structure with high strength and good toughness. To obtain this structure, the steels are alloyed with elements such as Cr, Ni and Mo. The hot rolled steel is first reheated and held at normalizing temperature to obtain a finer micro structure through recrystallization and subsequently quenched to obtain a hard martensitic structure with elevated strength. Finally, the tempering treatment allows the precipitation of carbides which softens the matrix and improves toughness properties (bainitic structure). The obtainable high strength levels make them interesting for the offshore industry to save on material weight, thickness and welding costs, but their hardenability makes them more difficult to weld.

Thermo-mechanically controlled processing (TMCP) is a method to produce steel with a strength above normalized steel, but still with very good weldability. After hot rolling, the steel is cooled to around the normalizing temperature and rolled again. The combination of deformation and recrystallization results in a finer micro structure. Accelerated cooling, accompanied by precipitation hardening, is applied to establish the desired final micro structure and its strength and toughness levels. Steels have only minimal alloying and therefore good weldability.



Today, low and medium strength steel are exclusively manufactured by normalizing rolling or TMCP. Since these routes are not suited to produce sufficiently thick sections with elevated strength, Quenching & tempering is the standard production route for high strength structural steel.

STEEL GRADES FOR OFFSHORE FABRICATION

Offshore fabrication is the generic name for a variety of constructions related to the exploration, treatment, storage and transportation of oil and gas from offshore fields. In its widest sense it includes not only the various types of fixed offshore platforms, but also floating semi-submersibles and FPSO's, oil/LNG and LPG tankers and under water production equipment and pipelines.

Offshore constructions are generally large and complex steel structures fabricated from tubes, plates, pipes and profiles interconnected through welded joints. Use of high strength steel is widespread in offshore fabrication to save on material weight, thickness and welding costs. Use of grades with a guaranteed yield strength up to 690 MPa is common nowadays for specific platform components. At the same time, oil & gas exploration in deeper waters and colder climate zones has led to sharper toughness requirements. Guaranteed CVN impact toughness at -40 and even -60°C are common today to prevent brittle fracture, while CTOD requirements may be added to counteract crack propagation during service. Requirements may also be valid after stress relieve treatments applied to lower residual stresses in welds and heat affected zones.

Steel grades used depend on the type of structure and the expected service conditions. Topside facilities - such as modules for living quarters, processing equipment and drilling equipment - are constructed from normalized or TMCP (mild) construction steel with a yield strength of 350 to 400 MPa. Similar grades of shipbuilding steel are used for hulls of jack-up rigs, such as ABS AH36 to EH36.

Weight carrying jacket constructions for fixed platforms are today made from high strength steel with a yield strength ranging from 350 to 550 MPa in thicknesses up to 100mm. The principal application of very high strength steel in the range of 500 to 800 MPa yield strength is in the fabrication of legs, rack & cords and spud cans for jack-up rigs, and moorings and cranes. The very high strength grades S890 and S960 are not common so far.

Worldwide four major standards for construction steel for offshore fabrication are valid. The standards EN 10225 and the DNV-OS-B101 are primarily used in Europe (North Sea), while the American ABS and API standards are mainly applied in American and Asian areas. The table (see excel file) gives an overview of steel grades according these standards.

Platform components	Yield strength level MPa	EN 10225-2019	DNV	ABS	API offshore grades	API pipelines
Topsides Hulls Modules Decks Cantilevers Girders & cross beams	350 <Re<460	S355NLO, S355MLO S420MLO, S420QLO	NVA420, D420, E420, F420	DH36, EH36 EQ43, FQ43	2H/2W/2Y grade 50 (N), 2 MT-1 2Y/2W grade 60	5L X52, X56 (N,M,Q) 5L X65 (M,Q)
Fixed jackets Tubular frames/ TKY nodes	460 <Re < 550	S460MLO, S460QLO S500MLO, S500QLO	NV A460, D460, E460, F460 NV A500, D500, E500, F500	EQ47, FQ47 EQ51, FQ51		5L X70 (M,Q)
Jack-up rigs Legs/ cord & racks Bracing Spud cans Mud mats **Floating systems** Moorings Suction piles	≥ 550	S550QLO S620QLO S690QLO	NV A550, D550, E550, F550 NV A620, D620, E620, F620 NV A690, D690, E690, F690	EQ56, FQ56 EQ63, FQ63 EQ70, FQ70		5L X80 (M,Q) 5L X90 (M,Q) 5L X100 (M,Q)
		N= normalizing rolling M= thermo mechanical rolling Q= Quenched & tempered L= Specified impact properties @ -40°C	A= specified impact properties @ 0°C D= specified impact properties @ -20°C E= specified impact properties @ -40°C F= specified impact properties @ -60°C	Q= Quenched & tempered D= Specified impact properties @ -20°C E= Specified impact properties @ -40°C F= Specified impact properties @ -60°C	H= Normalized W= Thermo mechanical rolling	N= Normalized M=Thermo mechanical rolling Q= Quenched & tempered

Offshore platforms are highly complex structures exposed to severe forces and weather conditions and therefore subjected to stricter control required in terms of design, material selection, welding procedures, and inspection than in any other structural fabrication. They are constructed from high strength steel with often high wall thicknesses which poses a challenge in terms of the avoidance of hardening structures and hydrogen induced cracking in welds and their heat affected zone. Weld quality requirements are very stringent. Offshore constructions are subjected to national or international construction standards, such as the AWS D1.1 Structural Welding Code and ISO 19902 (Fixed steel offshore structures), with strict stipulations for welding and NDT, whereas classification authorities require approval of welder qualification and welding procedure qualifications. Steel and weld toughness demands are generally high, with guaranteed CVN toughness at -40 or -60°C; often with additional CTOD requirements at -10°C and or even down to -40 °C.

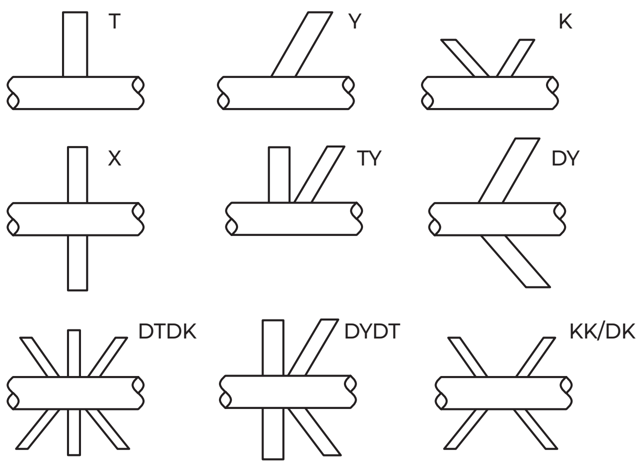
The table below gives the Hyundai Welding product range designed for offshore fabrication, along with the intended applications and mechanical properties of the weld metal.

Process	Product Name	AWS	EN/ISO	PLATFORM TYPES				PROPERTIES			
				MONO PILE	JACKET	JACK-UP RIG	TOP SIDE	MDMT Impact	PWHT	CTOD	NACE Ni<1%
SMAW	S-7016.LS	A5.5 E7016-G H4R	ISO 2560-A E46 6 1Ni B 1 2 H5		✓		✓	-60°C	✓	-10°C	✓
	S-76LTH	A5.5 E7016-G	ISO 2560-A E42 6 Z B 1 2 H5		✓			-60°C	✓	-40°C	✓
	S-78LTH	A5.5 E7018-G	ISO 2560-A E 46 6 1Ni B 3 2 H5		✓		✓	-60°C	✓		✓
	S-7018.1H	A5.5 E7018-1 H4R	ISO 2560-A E42 4 B 3 2 H5		✓			-45°C	✓	-10°C	✓
	S-86LTH	A5.5 E8016-G	-		✓	✓	✓	-60°C	✓		✓
	S-8018.C3	A5.5 E8018-C3 H4R	ISO 2560-A E46 4 1Ni B 3 2 H5				✓	-40°C			✓
	S-9018.M	A5.5 E9018-M	ISO 2560-A E50 4 B 4 2				✓	-50°C			
	S-10018.D2	A5.5 E10018-D2 H4R	-			✓		-50°C			
	S-11018.M	A5.5 E11018-M	ISO 2560-A E62 4 B 4 2			✓		-50°C			
FCAW	Supercored 71H	A5.20 E71T-1C,-9C-J	ISO 17632-A T 42 4 P C1 1 H5		✓			-40°C			✓
	SC-71MJ	A5.20 E71T-9M-J H4 / A5.29 E81T1-GM	ISO 17632-A T46 4 P M21 1 H5		✓			-40°C			
	SC-71LH	A5.20 E71T-1C,-9C	ISO 17632-A T 42 2 P C1 1 H5		✓			-20°C			✓
	SC-71SR	A5.20 E71T-1C,-9C-J,-12C-J H4	ISO 17632-A T 42 4 P C1 1 H5		✓			-46°C	✓	-10°C	✓
	SC-460	A5.29 E81T1-K2C	ISO 17632-A T 46 6 1.5Ni P C1 1 H5		✓			-60°C		-10°C	
	SC-81Ni1	A5.29 E81T1-Ni1C	ISO 17632-A T 46 4 1Ni P C1 1 H5				✓	-46°C	✓		✓
	Supercored 81MAG	A5.29 E81T1-Ni1M H4	ISO 17632-A T 50 6 1Ni P M21 2 H5		✓		✓	-46°C	✓	-10°C	✓
	Supercored 81-K2	A5.29 E81T1-K2C H4	ISO 17632-A T 46 6 1.5Ni P C 1 H5		✓			-60°C		-10°C	
	Supercored 81-K2MAG	A5.29 E81T1-K2M	ISO 17632-A T50 6 1.5Ni P M21 2 H5		✓			-60°C			
	Supercored 110	A5.29 E111T1-GC H4	ISO 18276-A T 69 4 ZMn2.5NiMo P C1 1 H5			✓		-40°C			
	SC-110MAG	A5.29 E111T1-GM	ISO 18276-A T 69 4 ZMn2NiMo P M21 1 H5			✓	✓	-40°C			
Self-Shielded FCW	Supershield 71-K6	A5.29 E71T8-K6-J H4	ISO 17632-A T 42 4 1Ni Y NO 1 H5		✓			-40°C			✓
SAW	Superflux787/H-12K	A5.17 F7A(P)8-EH12K	ISO 14171 S 42 6 FB S3Si	✓	✓		✓	-50°C	✓	-10°C	✓
	Superflux787/F-3	A5.23 F9A(P)8-EF3-F3	ISO 14171 S A FB 1 / S3NiMo				✓	-40°C			✓
	Superflux787/Ni-5	A5.23 F8A(P)8-ENi5-Ni1	ISO 14171 S 46 6 FB S3Ni1Mo0.2		✓		✓	-50°C	✓		✓
	Superflux787/A-3	A5.23 F8A6-EA3-A3	ISO 14171 S A FB 1 / S4Mo			✓		-20°C			✓

Welding of Jackets

A platform jacket is a tubular construction made from high strength steel with a yield strength ranging from 350 to 550MPa in thicknesses up to 100mm. These are mostly TMCP or Q&T types. It is submerged in water and supports the topside oil & gas platform with drilling facilities, modules and living quarters. A jacket is a lattice-like structure that consists of multiple legs and braces which are prefabricated in sections and then assembled at a yard located near a water way or harbour. There are basically two types of joints occurring during assembly of a jacket. The circular joints which connect two steel pipes are the least complicated of the two. Fit-up before welding is easier and productive pipe welding procedures can be applied, for instance by using FCAW with orbital welders for the filling passes.

TYK-nodes, named after their geometries in the construction (see figure), occur where pipes meet the surface of another pipe under an angle. These are about the most complicated welds to make. Weld preparations feature a bevel with an opening angle varying around the saddle-shaped circumference and welds are only accessible from one side. Precise fit-up with a constant root gap in particular is essential, as it involves manual welding, and with little room for electrode handling welding defects are easily made. They are mostly performed outdoors, in all welding positions, at height, and very often there is a need for preheating.



Fabricators traditionally use the shielded metal arc welding process (SMAW/MMA) for the entire TYK-joint, because the process is very suited for outdoor use, welding procedure qualifications are ample and qualified welders are widely available. Procedures that combine the use of stick electrodes for root deposition with gas shielded flux-cored arc welding for the filling passes (FCAW-G) are nowadays widely used to benefit from a substantially higher welding productivity and lower overall welding costs. The Hyundai Welding range of filler metals for offshore fabrication features a number of excellent products for these processes. They have earned a solid reputation in the industry for welder friendliness, productivity and mechanical properties.

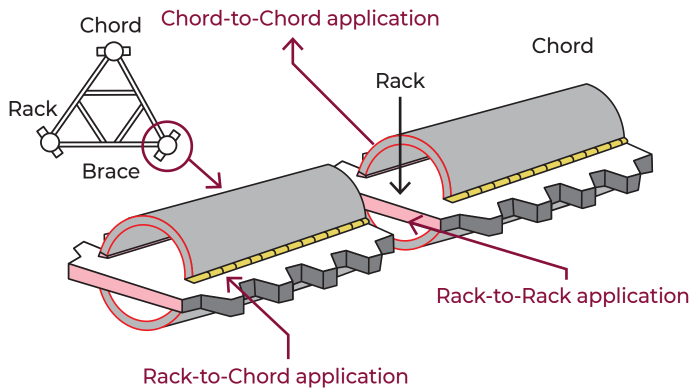

DTDK joint showing the complexity of welding offshore nodes with limited accessibility and a variety of welding positions.

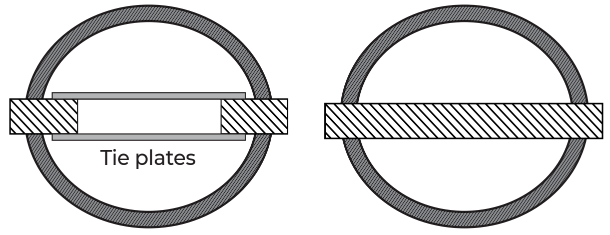
Welding of Jack-up Rigs

Jack-up rigs are offshore platforms that can float and travel between offshore wells. They rest on a number of retractable structural legs that can be truss types or columns made from tubes. When the rig arrives at the well, these legs are lowered onto the ocean floor to support the rig. The structural legs - the most important structural element of self-elevating platforms - are made from very high-strength steel; mostly Q&T grades with 500 to 800MPa yield strength. They feature a hydraulic jack system to lift the hull above sea level for which toothed racks are attached to the 3 or 4 chords forming the mainframe of truss type legs.

The truss design of legs offers excellent strength and stability, while minimising the load on the jack system. The toothed racks consist of a very heavy rack plate with teeth on both sides, sandwiched between two half pipes, the chords. This construction knows three principle welding applications in very high strength steel; chord to rack, rack to rack and chord to chord. Racks can be either solid or split. In the case of the split rack, two separate gear teeth are inter connected by tie-plates.


Hydraulic jack-up mounted on a truss type platform leg.





Split Rack-to-Chord
Solid Rack-to-Chord

As it involves time-consuming, heavy sections to be joined with through-thickness butt welds, fabricators strive to use the productive submerged arc welding (SAW) process, whenever possible. However, depending on the construction sequence fabricators follow and on the stage in prefabrication and erection, welding positions may not favor SAW and other welding processes may need to be used.

Applications	Welding positions	Welding processes
Cord to rack	1G/2G, PA/PB	SAW
	Other positions	SMAW, FCAW-G
	Tie-plates	SMAW, FCAW-G, FCAW-S
Rack to rack	1G/2G, PA/PB	SAW
	Other positions	SMAW, FCAW-G
Cord to cord	All positions	SMAW, FCAW-G

TYPICAL MECHANICAL PROPERTIES AND CHEMICAL COMPOSITION (%) OF ALL-WELD METAL

Process	Product Name	AWS	EN	Typical Chemical Composition of All-Weld Metal(%)											Typical Mechanical Properties of All-Weld Metal					
				C	Si	Mn	P	S	Ni	Cr	Mo	Ti	V	B	As Welded / PWHT	YS	TS	EL	Impact ISO-V	
																MPa (lbs/in²)	MPa (lbs/in²)	(%)	°C (°F)	J (ft-lbs)
SMAW	S-7016.LS	A5.5 E7016-G H4R	ISO 2560-A E46 6 1Ni B 1 2 H5	0.06	0.30	0.98	0.013	0.008	0.80	-	-	-	-	-	As Welded	538 (78,100)	589 (85,500)	30.0	-60 (-76)	73 (54)
	S-76LTH	A5.5 E7016-G	ISO 2560-A E42 6 Z B 1 2 H5	0.08	0.35	1.35	0.013	0.004	0.45	-	-	0.018	-	0.0015	As Welded	540 (78,400)	590 (85,600)	30.0	-60 (-76)	80 (59)
	S-78LTH	A5.5 E7018-G	ISO 2560-A E 46 6 1Ni B 3 2 H5	0.06	0.23	1.25	0.015	0.004	0.73	-	-	0.023	-	0.003	As Welded	525 (76,100)	600 (87,000)	32.0	-60 (-76)	85 (63)
	S-7018.1H	A5.5 E7018-1 H4R	ISO 2560-A E42 4 B 3 2 H5	0.06	0.25	1.35	0.014	0.005	-	-	-	-	-	-	As Welded	493 (71,500)	566 (82,100)	30.8	-45 (-49)	105 (77)
	S-86LTH	A5.5 E8016-G	-	0.05	0.29	1.49	0.01	0.002	0.91	-	-	0.022	-	0.003	As Welded	521 (75,600)	600 (87,000)	28.0	-60 (-76)	95 (70)
	S-8018.C3	A5.5 E8018-C3 H4R	ISO 2560-A E46 4 1Ni B 3 2 H5	0.07	0.59	1.00	0.02	0.009	0.94	-	-	-	-	-	As Welded	540 (78,400)	619 (89,900)	30.8	-40 (-40)	76 (56)
	S-9018.M	A5.5 E9018-M	ISO 2560-A E50 4 B 4 2	0.05	0.46	1.21	0.017	0.011	1.47	-	0.22	-	-	-	As Welded	585 (85,000)	646 (93,800)	27.6	-50 (-58)	89 (66)
	S-10018.D2	A5.5 E10018-D2 H4R	-	0.08	0.35	1.075	0.015	0.005	0.78	-	0.29	-	-	-	620°C (1148°F) X 1hr	625 (90,700)	705 (102,300)	26.0	-50 (-58)	45 (33)
	S-11018.M	A5.5 E11018-M	ISO 2560-A E62 4 B 4 2	0.07	0.48	1.62	0.023	0.012	2.04	-	0.35	-	-	-	As Welded	722 (104,900)	796 (115,600)	21.6	-50 (-58)	50 (37)
FCAW	Supercored 71H**	A5.20 E71T-1C,-9C-J	ISO 17632-A T 42 4 P C1 1 H5	0.03	0.46	1.36	0.008	0.011	0.40	-	-	-	-	-	As Welded	550 (79,900)	570 (82,800)	27.0	-40 (-40)	60 (44)
	SC-71MJ*	A5.20 E71T-9M-J H4 / A5.29 E81T1-GM	ISO 17632-A T46 4 P M21 1 H5	0.05	0.57	1.38	0.010	0.008	-	-	-	-	-	-	As Welded	580 (84,100)	640 (92,800)	27.8	-40 (-40)	81 (60)
	SC-71LH**	A5.20 E71T-1C,-9C	ISO 17632-A T 42 2 P C1 1 H5	0.06	0.47	1.35	0.014	0.012	-	-	-	-	-	-	As Welded	550 (79,900)	590 (85,600)	27.0	-30 (-22)	70 (52)
	SC-71SR**	A5.20 E71T-1C,-9C-J,-12C-J H4	ISO 17632-A T 42 4 P C1 1 H5	0.05	0.40	1.20	0.011	0.01	0.38	-	-	-	-	-	As Welded	560 (81,300)	580 (84,200)	28.0	-50 (-58)	65 (48)
	SC-460**	A5.29 E81T1-K2C	ISO 17632-A T 46 6 1.5Ni P C1 1 H5	0.06	0.35	1.20	0.008	0.011	1.50	-	-	-	-	-	As Welded	580 (84,200)	630 (91,400)	26.0	-60 (-76)	60 (44)
	SC-81Ni1**	A5.29 E81T1-Ni1C	ISO 17632-A T 46 4 1Ni P C1 1 H5	0.05	0.30	1.30	0.008	0.008	0.90						As Welded	560 (81,300)	620 (90,000)	28.0	-45 (-49)	70 (52)
	Supercored 81MAG*	A5.29 E81T1-Ni1M H4	ISO 17632-A T 50 6 1Ni P M21 2 H5	0.05	0.28	1.20	0.008	0.012	0.93	-	-	-	-	-	As Welded	550 (79,900)	590 (85,700)	26.0	-60 (-76)	60 (44)
	Supercored 81-K2**	A5.29 E81T1-K2C H4	ISO 17632-A T 46 6 1.5Ni P C 1 H5	0.04	0.35	1.35	0.012	0.011	1.50	-	-	-	-	-	As Welded	540 (78,400)	620 (90,000)	28.0	-60 (-76)	60 (44)
	Supercored 81-K2MAG*	A5.29 E81T1-K2M	ISO 17632-A T50 6 1.5Ni P M21 2 H5	0.03	0.35	1.25	0.012	0.01	1.55	-	0.003	0.045	-	0.004	As Welded	590 (86,000)	610 (88,000)	27.0	-60 (-76)	70 (52)
	Supercored 110**	A5.29 E111T1-GC H4	ISO 18276-A T 69 4 ZMn2.5NiMo P C1 1 H5	0.06	0.35	1.55	0.016	0.007	2.20	-	0.5	-	-	-	As Welded	780 (113,000)	830 (121,000)	19.9	-40 (-40)	60 (44)
	SC-110MAG*	A5.29 E111T1-GM	ISO 18276-A T 69 4 ZMn2NiMo P M21 1 H5	0.062	0.32	1.86	0.004	0.004	2.36	0.02	0.27	-	0.01		As Welded	748 (108,500)	792 (114,800)	22.2	-40 (-40)	76 (56)
Self-Shielded FCW	Supershield 71-K6	A5.29 E71T8-K6-J H4	ISO 17632-A T 42 4 1Ni Y NO 1 H5	0.05	0.14	1.25	0.009	0.001	0.80	0.15	-	-	-	-	As Welded	455 (66,000)	560 (81,200	28.0	-40 (-40)	125 (92)
SAW	Superflux787 / H-12K	A5.17 F7A(P)8-EH12K	ISO 14171 S 42 6 FB S3Si	0.07	0.36	1.57	0.015	0.004	-	-	-	-	-	-	As Welded	491 (71,000)	575 (83,000)	32.0	-62 (-80)	78 (58)
	Superflux787 / F-3	A5.23 F9A(P)8-EF3-F3	ISO 14171 S A FB 1 / S3NiMo	0.07	0.35	1.69	0.019	0.003	0.84	-	0.47	-	-	-	As Welded	675 (98,000)	729 (106,000)	26.0	-62 (-80)	98 (72)
	Superflux787 / Ni-5	A5.23 F8A(P)8-ENi5-Ni1	ISO 14171 S 46 6 FB S3Ni1Mo0.2	0.06	0.34	1.38	0.015	0.003	0.83	-	0.22	-			As Welded	592 (86,000)	614 (89,000)	31.0	-62 (-80)	83 (61)
	Superflux787 / A-3	A5.23 F8A6-EA3-A3	ISO 14171 S A FB 1 / S4Mo	0.07	0.20	1.70	0.024	0.002	-	-	0.49	-	-	-	As Welded	570(83,000)	641(93,000)	27.0	-50 (-58)	52 (38)

* With M21 Shielding Gas   ** With C1 Shielding Gas

APPROVALS

Process	Product Name	AWS	EN	CWB	TÜV	DB	CE	NAKS	KR	ABS	LR	BV	DNV	NK	RS	RINA	CCS	CRS
SMAW	S-7016.LS	A5.5 E7016-G H4R	ISO 2560-A E46 6 1Ni B 1 2 H5	-	-	-	-	-	3H10,3YH10 (-60°C≥34 J)	3H10,3Y (-60°C≥34 J)	5Y40H15	3,3YHH (-60°C≥34 J)	5YH10	-	-	-	-	-
	S-76LTH	A5.5 E7016-G	ISO 2560-A E42 6 Z B 1 2 H5	-	-	-	✓	-	-	5Y, 5Y400 H5	5Y40 H5	-	5Y40 H5 NV 4-4L	-	-	-	-	-
	S-78LTH	A5.5 E7018-G	ISO 2560-A E 46 6 1Ni B 3 2 H5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	S-7018.1H	A5.5 E7018-1 H4R	ISO 2560-A E42 4 B 3 2 H5	✓	-	-	✓	-	-	4Y H5	4YH5	4Y HHH	4YH5	-	-	-	-	-
	S-86LTH	A5.5 E8016-G	-	-	-	-	-	-	-	AWS A5.5 E8016-G (-60 ≥47 J)	-	-	-	-	-	-	-	-
	S-8018.C3	A5.5 E8018-C3 H4R	ISO 2560-A E46 4 1Ni B 3 2 H5	-	-	-	-	-	-	AWS A5.5 E8018-C3	-	-	-	-	-	-	-	-
	S-9018.M	A5.5 E9018-M	ISO 2560-A E50 4 B 4 2	-	-	-	-	-	-	AWS A5.5 E9018-M	-	-	-	-	-	-	-	-
	S-10018.D2	A5.5 E10018-D2 H4R	-	-	-	-	-	-	-	AWS A5.5 E10018-D2 H4R	-	-	-	-	-	-	-	-
	S-11018.M	A5.5 E11018-M	ISO 2560-A E62 4 B 4 2	-	-	-	-	-	-	AWS A5.5 E11018-M	-	-	-	-	-	-	-	-
FCAW	Supercored 71H	A5.20 E71T-1C,-9C-J	ISO 17632-A T 42 4 P C1 1 H5	✓	✓	✓	✓	✓	4YSMG(C) H10, 3SMG(C) H10 / 3YSMG(C) H10	4YSAH10 3YSA H10	4YSH10	4YSA H10, 3YSA H10	IVMSH5	KSW54G(C) H10 KSW53G(C) H10 KAW53MG(C) H10	4Y40SM H5, 3Y40SM H5	3YSH10	3YSM H10, 4YSM H10	-
	SC-71MJ	A5.20 E71T-9M-J H4 / A5.29 E81T1-GM	ISO 17632-A T46 4 P M21 1 H5	-	-	-	-	-	-	4YSA, 4Y400SA H5	4Y40S H5	SA4Y, SA4Y40 HHH	IVY40MS (H5)	-	-	-	-	-
	SC-71LH	A5.20 E71T-1C,-9C	ISO 17632-A T 42 2 P C1 1 H5	-	✓	-	✓	-	3YSG(C) H5	3YSA H5	3YS H5	SA3Y HHH	IIIYMS H5	KSW53Y40G(C) H5	3YS H5, 3Y40S H5	3YS H5	-	3YS H5
	SC-71SR	A5.20 E71T-1C,-9C-J, -12C-J H4	ISO 17632-A T 42 4 P C1 1 H5	✓	-	-	✓	-	4Y40SG(C)H5	4Y400SA H5	4Y40S H5	SA4Y40 HHH	IV Y40MS (H5)	KSW54Y40G(C)H5	-	-	4Y40SH5	-
	SC-460	A5.29 E81T1-K2C	ISO 17632-A T 46 6 1.5Ni P C1 1 H5	-	-	-	-	-	5Y46SG(C1) H5	5YQ460SA H5	5Y46S H5	SA5Y46 HHH	VY46MS (H5)	KSW5Y46G(C)H5 KSW63Y47G(C)H5 (-20°C≥53J)	-	-	-	-
	SC-81Ni1	A5.29 E81T1-Ni1C	ISO 17632-A T 46 4 1Ni P C1 1 H5	-	-	-	-	-	-	AWS A5.29 E81T1-Nilc	-	-	-	-	-	-	-	-
	Supercored 81MAG	A5.29 E81T1-Ni1M H4	ISO 17632-A T 50 6 1Ni P M21 2 H5	✓	✓	✓	✓	-	-	5Y400SA H5	5Y40S H5	SA5Y40M HHH	VY40MS H5	-	5Y40SM H5	5Y40S H5	-	-
	Supercored 81-K2	A5.29 E81T1-K2C H4	ISO 17632-A T 46 6 1.5Ni P C 1 H5	✓	-	-	✓	-	5Y40SG(C) H5, L3SG(C) H5	5Y400SA H5	5Y40S H5	SA5Y40 HHH	VY40MS H5, NV2-4L, 4-4L	KSWL3SG(C) H5 KSW54Y40G(C)H5	5Y40SM H5	5YS H10	5Y40S H5	-
	Supercored 81-K2MAG	A5.29 E81T1-K2M	ISO 17632-A T50 6 1.5Ni P M21 2 H5	-	✓	✓	✓	-	-	5Y400SA H5	5Y40S	SA5Y40M HHH	VY40MS H5	-	5Y40SM H5	-	-	-
	Supercored 110	A5.29 E111T1-GC H4	ISO 18276-A T 69 4 ZMn2.5NiMo P C1 1 H5	-	-	-	-	-	3Y69S(C) H5	AWS A5.29 E111T1-GC-H4 (IV-40°C ≥41J)	-	-	IIIY69 MSH5	-	-	-	-	-
	SC-110MAG	A5.29 E111T1-GM	ISO 18276-A T 69 4 ZMn2NiMo P M21 1 H5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Self-Shielded FCW	Supershield 71-K6	A5.29 E71T8-K6-J H4	ISO 17632-A T 42 4 1Ni Y NO 1 H5	-	-	-	-	-	-	4YSA H5	-	-	IV YMS, H5	-	-	-	-	-
SAW	Superflux787 / H-12K	A5.17 F7A(P)8-EH12K	ISO 14171 S 42 6 FB S3Si	-	-	-	✓	-	-	4YM H5	-	-	VY42M H5	-	-	-	-	-
	Superflux787 / F-3	A5.23 F9A(P)8-EF3-F3	ISO 14171 S A FB 1 / S3NiMo	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Superflux787 / Ni-5	A5.23 F8A(P)8-ENi5-Ni1	ISO 14171 S 46 6 FB S3Ni1Mo0.2	✓	✓	-	✓	-	-	AWS A5.23 F8A8-ENi5-Ni1	-	-	-	-	-	-	-	-
	Superflux787 / A-3	A5.23 F8A6-EA3-A3	ISO 14171 S A FB 1 / S4Mo	-	-	-	-	-	-	AWS A5.23 F8A6-EA3-A3, F8P4-EA3-A3	-	-	-	-	-	-	-	-

SUPERCORED 81MAG

All positional rutile cored wire for offshore steel grades with a minimum yield strength of 460 or 500 MPa. Alloyed with less than 1.0% Ni and with TiB micro-alloying, it meets CVN toughness requirements down to -60°C in the as welded condition and down to -46°C after post weld heat treatment. It is CTOD tested at -10°C (AW) and fulfills the NACE chemical requirements for applications in environments where sulphide-induced stress corrosion cracking may be a risk. Very low-hydrogen weld metal according to AWS class H4 gives optimal protection against hydrogen induced cold cracking. The wire is developed for use with Ar/CO_2 mixed shielding gas (M21).

Supercored 81MAG is specifically suited for demanding manual welding applications in offshore fabrication, such as T-Y-K joints in jacket construction. With a soft, spatter-free spray arc at all currents and in any position, it is extremely "welder friendly", and facilitates the deposition of high quality and defect-free joints. The slag releases easily, leaving welds with a smooth tie-in and a nice appearance and thereby resistance to crack initiation.

It is a very productive consumable. The fast freezing slag effectively supports the weld pool until solidification and allows deposition rates in positional welding that are several times higher than from stick electrodes. Root passes can be deposited very economically on ceramic backing material, although in many offshore applications it is used for filling over root welds produced with SMAW/MMA.

Consumables	Tensile Test			CVN Impact Test J (ft.lbs)		Remark
	YS MPa (ibs/in²)	TS MPa (ibs/in²)	EL(%)	-30˚C (-20˚F)	-60˚C (-80˚F)	
Supercored 81MAG	550 (80,000)	590 (86,000)	26.0	100(74)	60(44)	As welded
	510 (74,000)	570 (83,000)	28.0	90(66) at -46˚C (-50˚F)		PWHT (620˚C×2hr)
AWS A5.29 E81T1-Ni1M H4	≥470 (68,000)	550~69 (80,000~100,000)	≥19	≥27(20) at -30˚C (-20˚F)		As welded

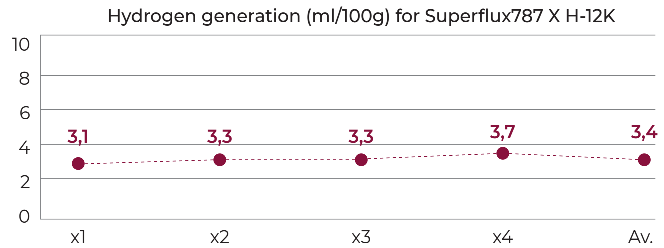
SUPERFLUX 787

Superflux 787 is a versatile submerged arc welding flux. With the same flux and various wires, it covers different yield strength levels and CVN toughness requirements in offshore fabrication. Offshore grade steel with Re >460 or >500 MPa is covered with the combination Superflux 787/EH12K. The weld metal meets CVN impact toughness requirements down to -60°C*, both in the as welded and stress relieved conditions. This combination is also CTOD tested at -10°C(AW) and fulfills the NACE chemical weld metal requirements for applications in environments where sulphide-induced stress corrosion cracking may be a risk.

Superflux 787 is a high basic agglomerated flux with a neutral character, promoting a homogeneous chemistry and consistent mechanical properties throughout thick multi-layer welds. It is highly insensitivity to rust, scale or primer on the surface to be welded and gives excellent X-ray characteristics. It is an AC/DC+ flux and can be used in single and multi-wire operation. Slag removal is excellent.

Hydrogen Generation Using Gas Chromatograph Method

Diameter	4.0mm(5/32in)
Welding Speed	42cm/min(16.53in/min)
Polarity	DC+
Stick-out	38mm(1.5in)
Parameters	575A/27V



Superflux 787 is a very low-hydrogen flux. It produces weld metal with a diffusible hydrogen content according to AWS class H4 for optimal protection against hydrogen induced cold cracking. It is recommended to re-dry the flux prior to use. Flux from moisture proof cans can be used directly without re-drying.

Flux Properties

Chemical Composition, wt%		
MgO+MnO	CaF2+CaO	Al2O3+SiO2
35	35	30

Particle size(mesh)	Type of Flux	Basicity index	H2O(1000°C) / CO_2(%)
10 x 48	Agglomerated	2.7	0.05/0.50

Mechanical Properties of All weld metal

Consumables	Consumables	Tensile Test			Remark
		YS MPa (ibs/in²)	TS MPa (ibs/in²)	EL (%)	-62˚C (-80˚F)
Superflux787 X H-12K	As welded	491 (71,000)	575 (83,000)	32	78 (58)
	620˚C×1hr	447 (65,000)	553 (80,000)	33	89 (66)
	620˚C×12hr	438 (64,000)	540 (78,000)	34	102 (75)
	620˚C×24hr	427 (62,000)	532 (77,000)	35	101 (75)
AWS A5.17 F7A(P)8-EH12K		≥400	490~660	≥22	≥27J at -62˚C

ALLOYED PRODUCT RANGE

Topside Modules

A topside module of an offshore platform refers to the upper part of the structure that sits above the waterline. This section includes all the facilities and equipment necessary for drilling, production, processing, and support operations. Typically, 355MPa yield grades are applied for the outer structure or framework, but the topside also contains 300 series and duplex stainless steels for machinery for water & gas treatment units, oil and gas separators as well nickel or copper base materials for sea water cooling.

Semi-Submersible Drilling Rigs

A type of floating mobile offshore drilling platform designed to operate in deep waters. Its great stability is achieved through a combination of submerged pontoons and vertical columns supporting a deck structure. Stainless steel is used for flowlines, risers, and piping systems that transport oil, gas, and drilling fluids. Duplex and super duplex steels are applied where high strength and corrosion resistance are required, such as subsea manifolds and control systems.

FPSO Vessels

FPSO (Floating Production, Storage, and Offloading) vessel is a type of ship used in to process and store primarily crude oil, and to offload it to tankers or pipelines for transportation. Stainless and nickel-base materials are widely used for piping systems, heat exchangers, reactors, separators and other processing equipment, due to their excellent corrosion resistance, high-temperature strength, and durability.

Base Material	Base metal	Process	Product name	AWS	EN
Stainless Steel	304(L)	SMAW	S-308L.16N S-308LT.16 S-308L.15 S-308L.17	A5.4 E308L-16 A5.4 E308L-16 A5.4 E308L-15 A5.4 E308L-17	ISO 3581-A E 19 9 L R ISO 3581-A E 19 9 L R ISO 3581-A E 19 9 L B ISO 3581-A E 19 9 L R
		GMAW	SM-308L SM-308	A5.9 ER308L A5.9 ER308	ISO 14343-A G 19 9L ISO 14343-A G 19 9
		GTAW	ST-308L ST-308	A5.9 ER308L A5.9 ER308	ISO 14343-A W 19 9L ISO 14343-A W 19 9
		FCAW	SW-308L Cored	A5.22 E308LT1-1/-4	ISO 17633-A-T 19 9 L P M21/C1 2
		SAW	Superflux300S x YS-308L S-300B x YS-308L	- -	ISO 14174-S A AB 2 ISO 14174-S A AF 2
	316(L)	SMAW	S-316L.16N S-316LT.16 S-316L.15 S-316L.17	A5.4 E316L-16 A5.4 E316L-16 A5.4 E316L-15 A5.4 E316L-17	ISO 3581-A E 19 12 3 L R ISO 3581-A E 19 12 3 L R ISO 3581-A E 19 12 3 L B ISO 3581-A E 19 12 3 L R
		GMAW	SM-316L SM-316	A5.9 ER316L A5.9 ER316	ISO 14343-A G 19 12 3L ISO 14343-A G 19 12 3
		GTAW	ST-316L ST-316	A5.9 ER316L A5.9 ER316	ISO 14343-A W 19 12 3L ISO 14343-A W 19 12 3
		FCAW	SW-316L Cored SW-316LT	A5.22 E316LT1-1/-4 A5.22 E316LT1-1/-4	ISO 17633-A-T 19 12 3 L P M21/C1 2 -
		SAW	Superflux300S x YS-316L S-300B x YS-316L	- -	ISO 14174-S A AB 2 ISO 14174-S A AF 2
	309	SMAW	S-309L.16 S-309L.15 S-309L.17	A5.4 E309L-16 A5.4 E309L-15 A5.4 E309L-17	ISO 3581-A E 23 12 L R ISO 3581-A E 23 12 L B ISO 3581-A E 23 12 L R
		FCAW	SW-309L Cored	A5.22 E309LT1-1/-4	ISO 17633-A-T 23 12 L P M21/C1 2
		GMAW	SM-309L SM-309	A5.9 ER309L A5.9 ER309	ISO 14343-A G 23 12L ISO 14343-A G 23 12
		GTAW	ST-309L ST-309	A5.9 ER309L A5.9 ER309	ISO 14343-A W 23 12L ISO 14343-A W 23 12
	309MoL	SMAW	S–309Mo.16 S–309MoL.16	A5.4 E309Mo-16 A5.4 E309LMo-16	ISO 3581-A E 23 12 2 R ISO 3851-A E 23 12 2 L R
		FCAW	SW-309MoL Cored Supercored 309MoL	A5.22 E309LMoT1-1/-4 A5.22 E309LMoT0-1/-4	ISO 17633-A-T 23 12 2 L P M21/C1 2 ISO 17633-A-T 23 12 2 L R M21/C1 3
	310	SMAW GMAW	S-310.15 SM-310	A5.4 E310-15 A5.9 ER310	ISO 3581-A E 25 20 B ISO 14343-A G 25 20
	317	SMAW FCAW	S-317L.16 SW-317L Cored	A5.4 E317L-16 A5.22 E317LT1-1/-4	- -
	347 (321)	SMAW GMAW GTAW FCAW SAW	S-347.16 SM-347 ST-347 SW-347 Cored S-300B x YS-347	A5.4 E347-16 A5.9 ER347 A5.9 ER347 A5.22 E347T1-1/-4 -	ISO 3581-A-E 19 9 Nb R ISO 14343-A G 19 9 Nb ISO 14343-A W 19 9 Nb ISO 17633-A-T 19 9 Nb P M21/C1 2 ISO 14174-S A AF 2
Duplex & Super Duplex	2209	SMAW GTAW FCAW SAW	S-2209.16 ST-2209 SW-2209 Cored Superflux209 x YS-2209	A5.4 E2209-16 A5.9 ER2209 A5.22 E2209T1-1/-4 -	ISO 3581-A-E 22 9 3 N L ISO 14343-A W 22 9 3N L ISO 17633-A-T 22 9 3 N L M21/C1 2 ISO 14174-S A AF 2
	2594	SMAW GTAW FCAW	S-2594.16 SMT-2594 SW-2594 Cored	A5.4 E2594-16 A5.9 ER2594 A5.22 E2594T1-1/-4	ISO 3581-A-E 25 9 4 N L ISO 14343-A G 25 9 4 NL -
Nickel Base	Inconel 600 (Incoloy 800)	SMAW SMAW GMAW GTAW	SR-182 SR-133 SM-82 ST-82	A5.11 ENiCrFe-3 A5.11 ENiCrFe-2 A5.14 ERNiCr-3 A5.14 ERNiCr-3	ISO 14172 Ni 6182 ISO 14172 Ni 6092 ISO 18274 S Ni 6082 ISO 18274 S Ni 6082
	Inconel 625 (825, 20)	SMAW GMAW GTAW FCAW	SR-625 SMT-625 SMT-625 SW-625 Cored	A5.11 ENiCrMo-3 A5.14 ERNiCrMo-3 A5.14 ERNiCrMo-3 A5.34 ENiCrMo3T1-1/-4	ISO 14172 Ni 6625 (NiCr22Mo9Nb) ISO 18274 Ni 6625 (NiCr22Mo9Nb) ISO 18274 Ni 6625 (NiCr22Mo9Nb) ISO 12153 T Ni 6625 P M/C 2
	9%Ni	SMAW SMAW GMAW GTAW FCAW SAW	SR-134 SR-08 SMT-08 SMT-08 SW-82H S-Ni2 x SA-08	A5.11 ENiCrFe-4 A5.11 ENiMo-8 A5.14 ERNiMo-8 A5.14 ERNiMo-8 A5.34 ENiGT1-1/-4 A5.14 ERNiMO-8	- - - - - -
Non-Ferrous (Cupro Nickel)	Cu-Ni	GTAW	SMT-7030	A5.7 ERCuNi	-

HIGH STRENGTH STEEL WELDING

Offshore constructions feature the application of medium to very high strength steel; often in high wall thickness. With increasing strength level, use of steel production routes shifts from normalized rolling to thermo-mechanically rolled & accelerated cooled to quenched & tempered grades. TMCP enables the production of steel with a similar strength level as normalized grades, but with a lower carbon equivalent and thereby a better weldability. The TMCP route is less suited for the production of very high strength steels, because of limitations in wall thickness to be obtained. For this purpose, the Q&T method is commonly applied. Q&T steels use higher alloying resulting in higher carbon equivalents* and thereby a more difficult weldability in terms of necessary precautions.

Fabrication of offshore constructions, in general, is characterised by the use of heavy plate or pipe sections which poses the following challenges for welding:

- Potentially 3-dimensional (fast) cooling of welds and heat affected zones (HAZ) with a risk of formation of brittle hardening structures
- Fully restrained joints with high residual stresses
- Potential risk of hydrogen induced cracking starting at crack initiation points such as welding defects
- Potential risk of fatigue cracking starting at crack initiation points such as welding defects

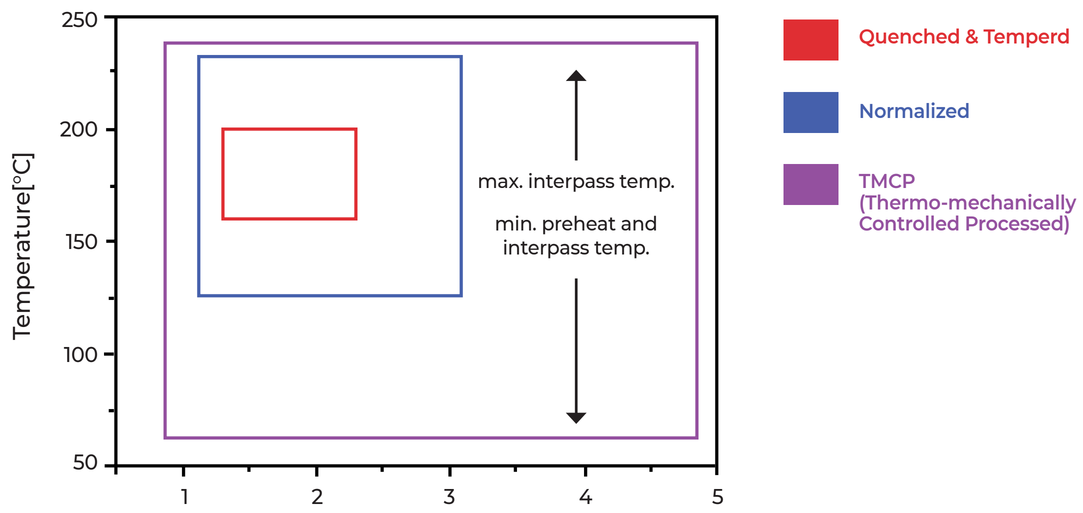
The above explains why welding in the offshore industry is subjected to strict welding procedure specifications and qualifications (WPS & PQR) per steel grade and per joint, why NDT is often 100% and why welders need to pass qualification for all welding processes and welding positions applied.

Preheating is one of the measures prescribed in welding procedures to avoid fast cooling of weld and HAZ through the critical temperature zone for most steels between 800 and 500°C (t8/5) and prevent the formation of brittle hardening structures. At the same time, interpass temperatures are prescribed to avoid weld cooling rates that are to low and may lead to loss of strength and toughness properties in weld and heat affected zone.

Preheating is time-consuming and costly and fabricators prefer to avoid it whenever possible. This explains the popularity of TMCP steel, offering better opportunities to lower preheating temperatures or avoid preheating all together, due to lower carbon equivalents.

*CEq (%) = %C + %Si/25 + (%Mn+%Cu)/16 + %Ni/40 + %Mo/15 +%V/10 : the Ito-Bessyo formula for steel with less than 0.18% carbon. The carbon equivalent value allows statements to be made about the susceptibility to cold-cracking.

The figure below gives a general idea of heat input, minimum preheat and maximum interpass temperature for TMCP, normalized and Q&T steel grades.

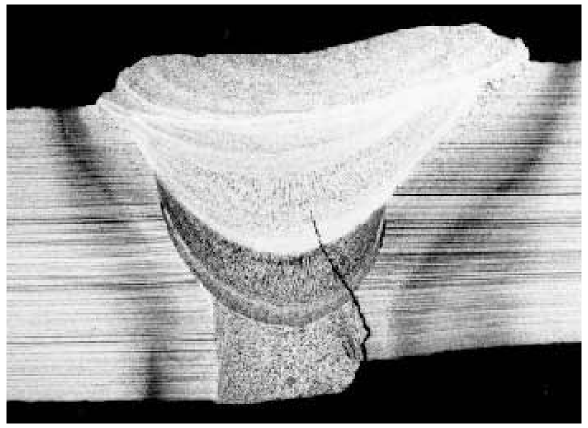


It shows that safe operating windows are smallest for Q&T grades and widest for TMCP grades, which in practice, translates in more flexible, less time-consuming and less costly welding for TMCP types.

Welding of Q&T grades is therefore more challenging and may, additionally, be accompanied by a post weld heat treatment (PWHT), typically for 1h/25mm thickness at around 600°C, to reduce residual stresses to enhance crack resistance. In this case, also the weld metal needs to withstand such a treatment without loss of mechanical properties and, therefore needs to pass welding procedure qualification. Always refer to the recommendations given by the steel manufacturer for the correct welding of a specific steel grade.

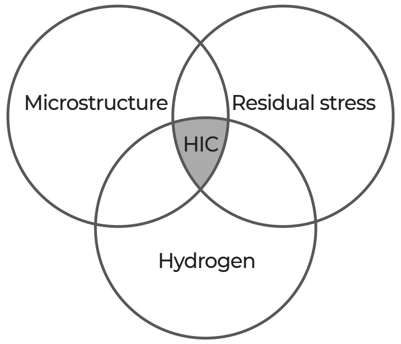
HIC (Hydrogen induced cracking)

Hydrogen induced cracking, or cold cracking, is a phenomenon that can occur when welding high strength steel in thick dimensions in fully restrained constructions, as in offshore fabrication. Under the presence of high residual stresses, a susceptible micro structure (hardening structure) and crack initiation points in the form of welding defects (stress raisers), atomic hydrogen can act as a crack propagator. Hydrogen induced cracking can be immediate, but is often delayed hours or days after welding, because diffusion hydrogen of the critical zones in the weld and HAZ is time-dependant.



Typical example of root HAZ hydrogen crack extending into the weld metal. (Source: TWI Global)

Avoidance of hydrogen induced cold cracking (HIC) is an important aspect in the welding of high strength steel, as these grades may be susceptible to the formation of brittle structures in the weld and heat affected zone. HIC requires three factors to occur.



- The presence of brittle structires
- High levels of restraint in the weld zone
- The presence of hydrogen in weld or heat affected zone

Brittle structures in weld and heat affected zone can be avoided by applying strict thermal control of welding. The steel manufacturer provides valuable recommendations for a correct welding procedure in terms of preheating, interpass temperature, cooling rate and post weld heat treatment. It is recommended to follow these at all times. Also, there are different measures that can be taken to avoid formation of hydrogen in the weld metal:

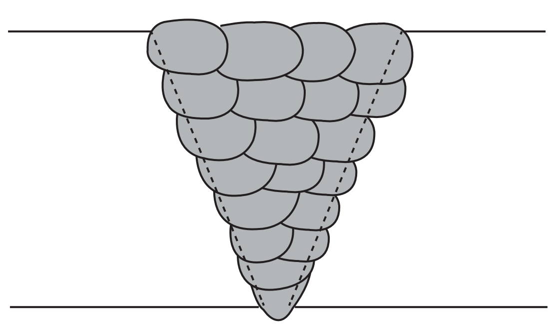
- Removal of dirt, grease, oil and mill scale from the welding zone
- Removal of moisture (rain, dew) by warming up the welding zone
- Use of dry, low-hydrogen welding consumables

Also the welding consumable itself can be a notorious source of hydrogen when they contain moisture in some form. It is still common practice to re-dry stick electrodes and submerged arc fluxes and store them in dry cabinets before welding. Modern welding consumables for offshore fabrication should be low-hydrogen; EN class H5 or AWS class H4. Re-drying prior to welding according to the prescriptions of consumables suppliers is advised, but can be avoided when ordered in special moisture proof packaging. Safe welding times after opening the moisture proof packaging, given by the suppliers, must be observed at all times.

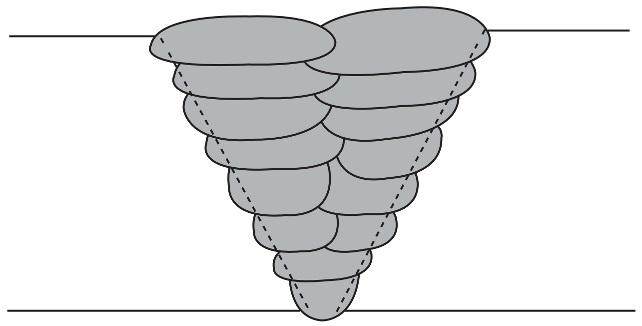
Hydrogen can be effectively removed from weld and HAZ, by holding the welding zone for 2-4 hours at a temperature of 200-300°C directly after welding. This is costly and time-consuming and fabricators prefer to avoid such a treatment.

Split weave, stringer and temper beads

There are certain welding techniques commonly used in offshore fabrication to promote optimal sub -zero toughness of welds. Large areas with unfavorable weld solidification structures are avoided, using the heat of the next weld bead to heat treat the underlying bead and improve the toughness by grain refinement.

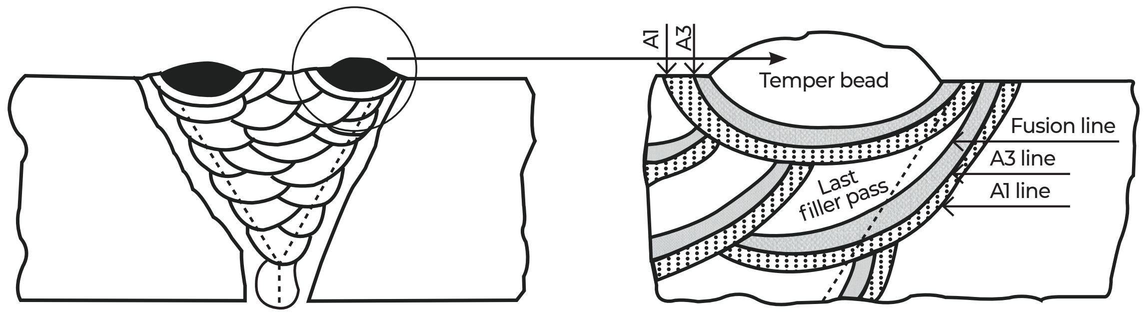


Stringer beads: low heat input



Split weave: medium heat input

Temper bead welding is a practice often applied in offshore fabrication. A final weld bead is placed at a specific location in or at the surface of a weld for the purpose of affecting the metallurgical properties of the heat-affected zone or previously deposited weld metal.



Important Elements for Procedure Approval

The goal of welding specification procedures is to confirm that welds produced under the procedure will consistently meet the necessary quality standards and performance criteria. To achieve good mechanical results that meet requirements of high strength steel, stringent procedural control is essential during both qualification and fabrication with below mentioned elements:

· Customer requirements
· Base material specifications and properties
· Steel type and production route (normalized, TMCP etc.)
· Welding process selection
· Joint design
· Welder qualification
· Welding consumable selection
· Welding parameters
· Preheating and interpass temperature
· Post-weld heat treatment requirements (heating & cooling rate, holding time & temp)
· Post-weld heat treatment methods (external heating, internal heating etc.)
· Weld sample preparation

PACKAGING SPECIFICATIONS

SMAW Electrodes

Type	Packet	Carton
STANDARD	5kg  5kg 	20kg 
ALUMINUM VACUUM PACK	1.5kg 	15kg 

Standard carton:

Carton Size mm (in)	
d	82 (3.2)
e	180-275 (7.1-10.8)
f	312-562 (12.3-22.1)

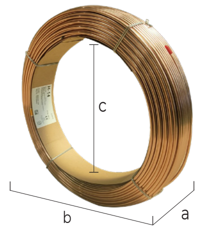
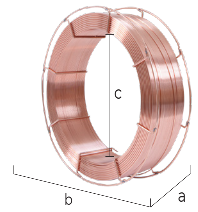
Aluminum vacuum pack carton:

Carton Size mm (in)	
d	96 (3.8)
e	260 (10.2)
f	470-570 (18.5-22.4)

Type	Packet	Carton
PVC BOX (HEXAGONAL)	2.5kg (5.5lbs) 	10-20kg (22-44lbs) 
TIN CAN	4.5kg (9.9lbs) 	
PVC BOX (SQUARE)	5kg (11lbs) 	

Carton Size mm (in)			
Packet	PVC 2.5kg (5.5lbs)	Can 4.5kg (9.9lbs)	PVC 5kg (11lbs)
Carton	10kg (22lbs)	18kg (39.7lbs)	20kg (44.1lbs)
d	80 (3.1)	85 (3.3)	80-85 (3.1-3.3)
e	310-330 (12.2-13)	317 (12.5)	310-345 (12.2-13.6)
f	360-405 (14.2-16)	383-433 (15.1-17)	325-375 (12.8-14.8)

Subarc Wire

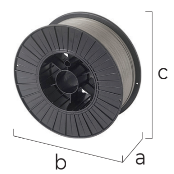
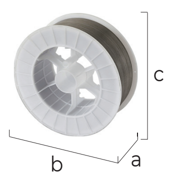
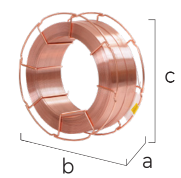
Type	Wire	Size mm (in)			
		Wire	a	b	c
Coil Type		25kg (55lbs)	75/100 (3.0/3.9)	410/420 (16.1/16.5)	305/315 (12.0/12.4)
		30kg (66lbs)	95 (3.7)	400 (15.7)	305 (12.0)
		100kg (220lbs)	90/100 (3.5/3.9)	760 (29.9)	630 (24.8)
Basket Spool		150kg (330lbs)	90 (3.5)	790 (31.1)	630 (24.8)
		25kg (55lbs)	103 (4.1)	413-419 (16.3-16.5)	297-303 (11.7-11.9)

* Other coil sizes available upon request

Subarc Flux

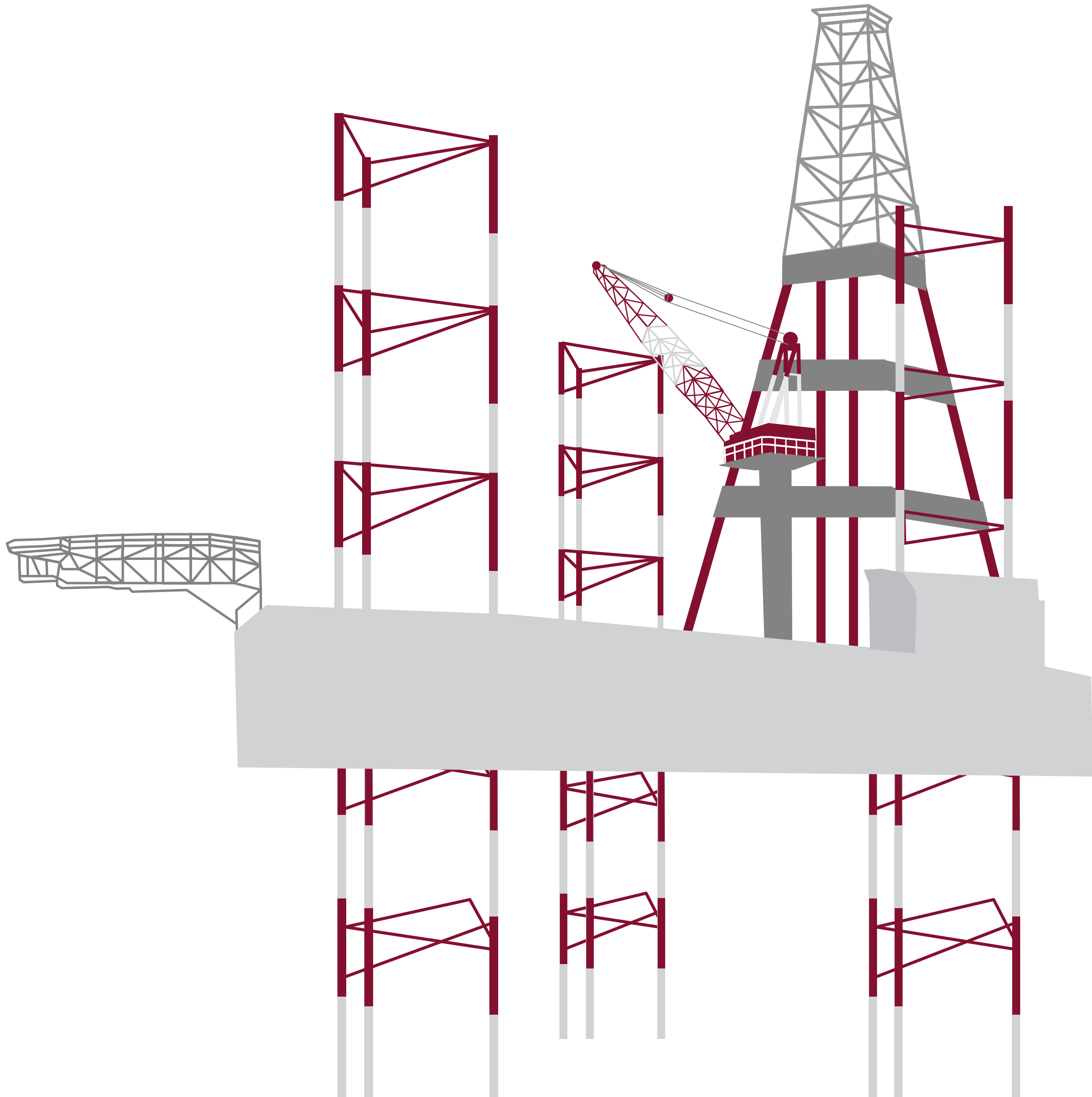
Packaging		
TIN CAN	PE BAG	PAPER BAG
		
15kg, 20kg (33lbs, 44lbs)	20kg, 25kg (44lbs, 55lbs)	20kg, 25kg (44lbs, 55lbs)

GMAW / MIG and Flux Cored Wires

Type	Spool			
Spool Type	Plastic Spool (GMAW / MIG wires Flux Cored wires)	12.5kg (27.6lbs) / 15kg (33lbs)	Basket Spool (GMAW MIG wires)	15kg (33lbs)
				

Spool Size mm (in)		
	Plastic Spool (GMAW / MIG wires Flux Cored wires)	Basket Spool (GMAW MIG wires)
a	110 (4.3)	98 (3.9)
b	270-280 (10.6-11.0)	298 (11.7)
c	270-280 (10.6-11.0)	298 (11.7)

REFERENCES



HYUNDAI WELDING is a global manufacturer of welding consumables and equipment. As the top leading manufacturer of welding consumables in Korea, and with a global network of sales, distribution and manufacturing plants, HYUNDAI WELDING has developed into a key player in the international welding industry.

Our company is fully committed to the ever-changing needs of our customers and has evolved in just under 50 years to provide welding expertise and breakthroughs in welding technology. HYUNDAI WELDING understands customer needs and offers customers world-class products and world-class solutions.

HYUNDAI WELDING's offshore welding solutions meet customer requirements for offshore platform construction backed with a superior customer service and support. By using high quality consumables and equipment portfolio of HYUNDAI WELDING, our customers experience improved productivity and competitiveness in the market.

HYUNDAI WELDING is a world-class manufacturer that specializes in providing optimum welding solutions to its customers, by supplying top-notch welding consumables and equipment. HYUNDAI WELDING has contributed to the development and success of the global welding industry for more than 40 years since its foundation in 1975.

For more information on HYUNDAI WELDING, please visit www.hyundaiwelding.com

E-book

HYUNDAI WELDING

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