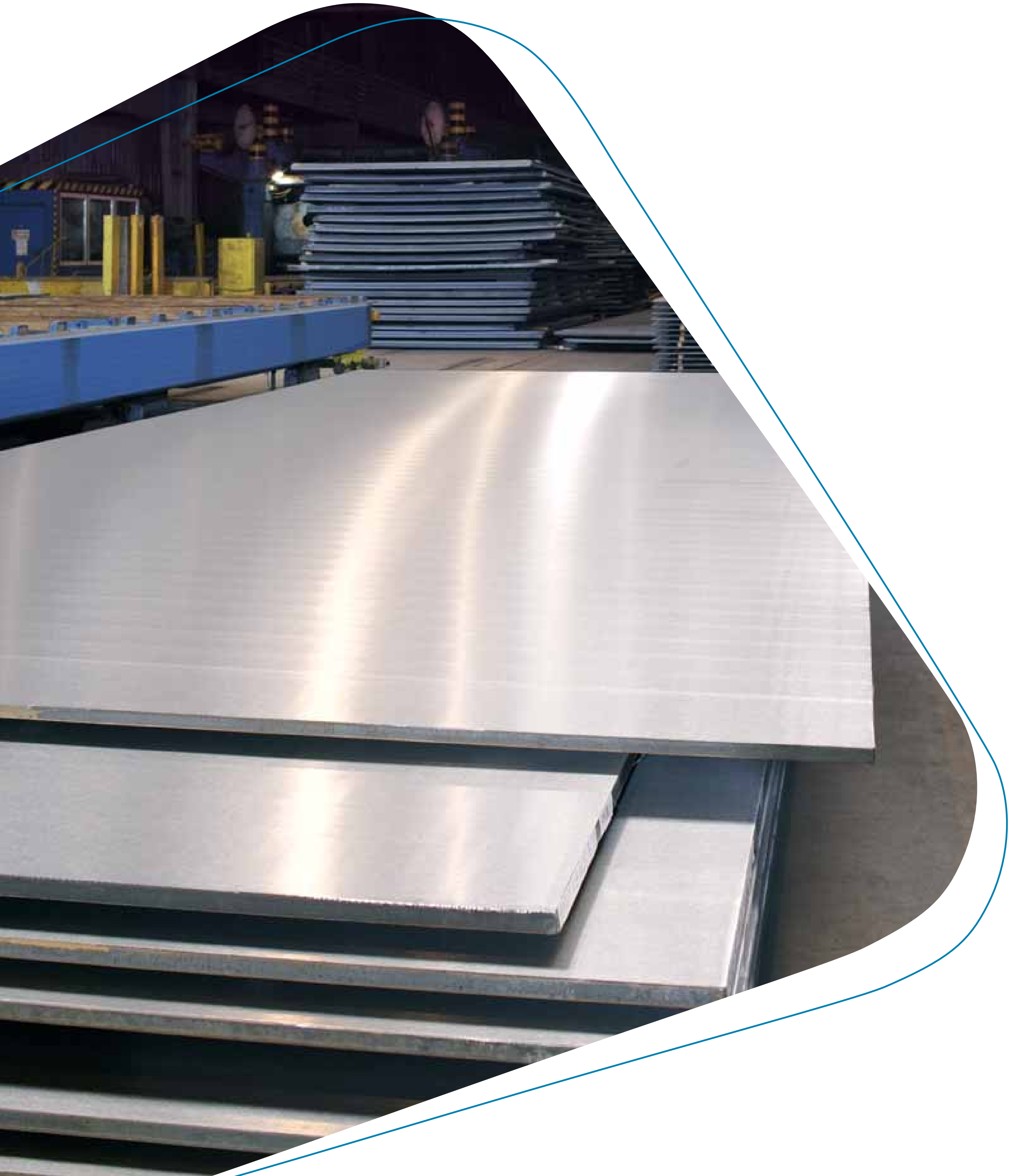
Roll-bonded clad plates

Our answer to corrosion

voestalpine Grobblech GmbH
www.voestalpine.com/grobblech

voestalpine
ONE STEP AHEAD.



Roll-bonded clad plates

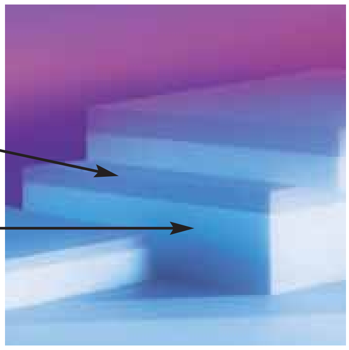
A thin layer of expensive corrosion-resistant alloy provides excellent corrosion protection while the thicker but less expensive base-material of high-strength carbon steel ensures adequate structural strength. A metallurgical bond between the two materials is achieved in a computer-controlled hot-rolling process. Roll-bonded clad plates are the economic solution for corrosion resistant applications in refineries, oil and gas production, chemical industry as well as in sea-water desalination plants and flue-gas desulphurisation units.

Definition

- Metallurgically bonded composite of two or more layers
- The bond is created by high temperature and high pressure
- Typical combination is a thin corrosion resistant alloy (CRA) as clad material and carbon steel or low-alloyed steel as base material

Clad material
for corrosion protection

Base material
for static demands



Advantages of roll-bonded clad plates

- Advantages compared with **solid CRA plates:**
  - Reduced material costs
  - Less weight due to reduction of wall thicknesses
  - Reduction of weld length due to larger dimensions
  - Lower cost of filler metal
  - Superior heat conductivity

- Advantages compared with **overlay welding:**
  - Improved surface conditions
  - No dilution from the base material
  - Homogenous chemical composition

- Advantages compared with **explosive cladding:**
  - Higher bonding quality
  - Reduction of weld length due to larger dimensions
  - Use of thinner clad material is possible

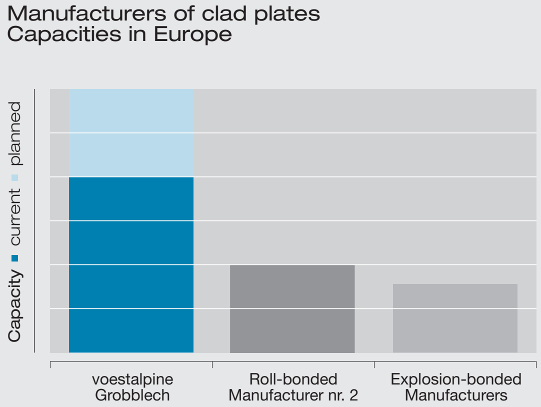
- Advantages compared with **rubber coatings and linings:**
  - Metallic bonding
  - Lower maintenance costs

Ready for future

We expand our cladding capacity

Already Europe`s leading producer of roll-bonded clad plates, heads and cones we invest substantially in expanding our capacity by 50 percent. By April 2009 we will be able to produce 30,000 tons of roll-bonded clad plates a year.

This reduces our delivery times and will consolidate our leading position in the market. Once the expansion is completed, we will be able to supply huge single projects up to 10,000 tons within a reasonable period of time according to market requirements.



Clad plates for clad pipes

We offer clad plates for clad pipes used in high-demanding projects in the offshore industry.

- Pipelines layed by reeling
- Catenary riser pipes
- Process pipes in refineries
- Bends and fittings

Together with our reliable pipe partners we are able to supply a production capacity of 10 kilometres of clad pipes a month.

Titanium clad plates

Advantages compared with explosive bonded material

- Wider range of dimensions
- Best shear strength
- Excellent flatness
- Superior surface finish
- No areas of non-bonds

Cost savings

- Lower costs due to reduced cladding thickness
- Lower costs due to larger plate dimensions

High-strength clad plates

The strength of a clad plate is mainly determined by the strength of the base material. By using a higher-strength base material the plate thickness of a given component can be reduced. This leads to reduction of steel weight and furthermore to cost saving of processing – in particular for welding – transport and assembly.
High-strength clad plates provide economic benefits in evaporator shells of thermal desalination plants.

The market

Our strength

voestalpine Grobblech GmbH is the leading manufacturer of roll-bonded clad plates in Europe – we offer clad plates, clad heads and clad cones from one source.

As a manufacturer with several decades of experience in roll bonding, we are your reliable partner in the pressure vessel and apparatus industry. We understand our customers, provide the quality they need, and produce the widest roll-bonded clad plates in Europe. These plates bring manufacturing and cost benefits during further processing.

Typical fields of application

Refineries
- fractionators
- vacuum towers
- coke drums
- process pipes

Oil and gas production
- clad pipelines
- catenary riser pipes

Chemical industry
- columns
- pressure vessels
- reactors
- washers
- heat exchangers

Sea-water desalination plants
- evaporator shells
- water boxes
- pump vessels

Flue gas desulphurisation plants
- flue gas channels
- chimneys
- flue gas scrubbers

Clad pipes

Made of clad plates

Clad pipes are used in oil and gas production under corrosive conditions: for pipelines, riser pipes in offshore applications and process pipes in refineries. We deliver clad plates for clad pipes.

Metallurgically bonded clad pipes are made of roll-bonded clad plates. These clad pipes provide the high strength and good toughness of the base material as well as the proper corrosion resistance of the clad material. A typical material combination is a pipe grade like X65 and a nickel-based alloy like Alloy 625.

Metallurgical bond

The metallurgical bond of the clad pipes is most efficient for highest mechanical demands and even can bear dynamic loads. Thus these clad pipes are highly useful in deepwater linepipes under corrosive conditions as well as for bends and fittings.

Reeling

Our roll-bonded clad plates offer the characteristics that allow the pipelines to be rolled and unrolled and they have the corrosion resistance needed in deep-sea environments. The reeling of pipelines is much faster – and thus cheaper – than welding pipes onboard

Steel catenary risers

Another application of metallurgically bonded clad pipes made of roll-bonded clad plates are so-called catenary risers in the offshore industry. These vertical pipelines connect the subsea gas or oil field with the production facilities above sea level. Due to the high pressure of deep water installations and dynamic loads by waves and drifts and due to the corrosive medium inside such riser pipes must provide excellent mechanical properties as high strength combined with good toughness and proper corrosion protection.
Double-side clad plates for inside and outside cladded pipes are possible as well.

Delivery condition:

The conventional delivery condition of clad plates used in clad pipes is quenched and tempered. We also can provide thermo-mechanically rolled and accelerated cooled (TMCP) clad plates. This online processing leads to high strength and excellent toughness combined with best weldability of the base material and keeps the proper corrosion properties of the clad material.

Clad heads and cones

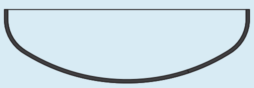
Plates and heads from one source

- We produce clad heads and clad cones from roll-bonded clad plates in-house
- In a package we supply shell plates, heads and cones for pressure vessel manufacture from one single source: of carbon steel, low-alloyed steel as well as cladded
- This aims in benefits for our customers:
  - Advantages in processing especially with welding when using same steel for shell plates and heads
  - Technical support and coordination from one research and quality department
  - Coordinated production and delivery of shell plates and heads from one hand
  - Smaller expenditure in purchasing for our customer

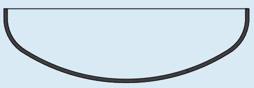
Claddings

We offer ferritic and austenitic stainless steels (Cr, CrNi, CrNiMo), nickel and nickel-based alloys, copper and copper-nickel-alloys as well as titanium as cladding materials for clad heads and cones.

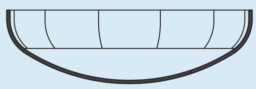
Products and dimensions



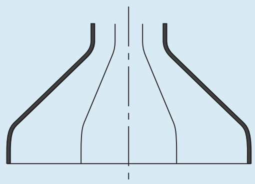
single-piece heads (pressed):
diameter: max. 3,700 mm*
thickness: max. 160 mm



single-piece heads (flanged):
diameter: max. 6,700 mm*
thickness: max. 65 mm



multi-piece heads (pressed):
diameter: max. 10,000 mm
thickness: max. 160 mm



multi-piece cones (pressed):
diameter: max. 10,000 mm
thickness: max. 160 mm

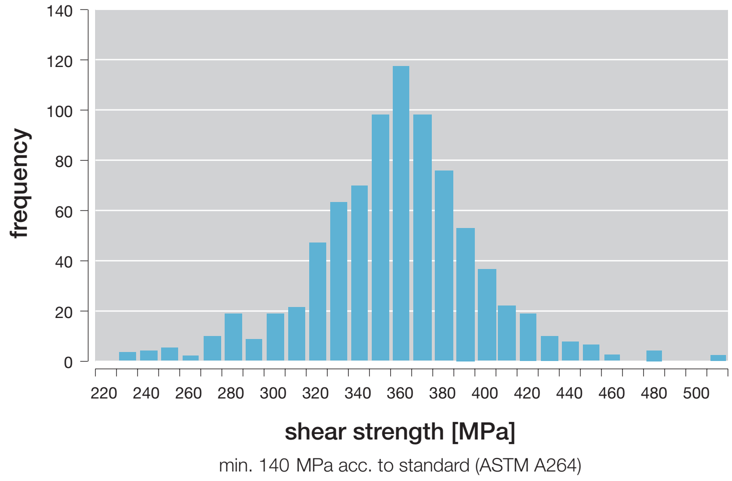
*from 3,400 – 6,700 mm with one weld seam

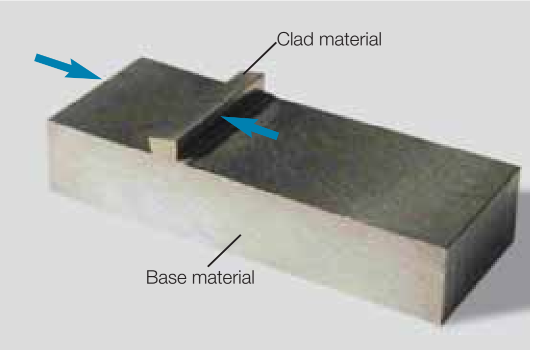
- Belt grinding or glass-bead blasting of clad surface
- Egde preparation for welding
- Heat treatment corresponding to material requirements; water quenching up to a diameter of 6,000 mm

More information about heads you will find in our special brochure „HEADS".

Quality

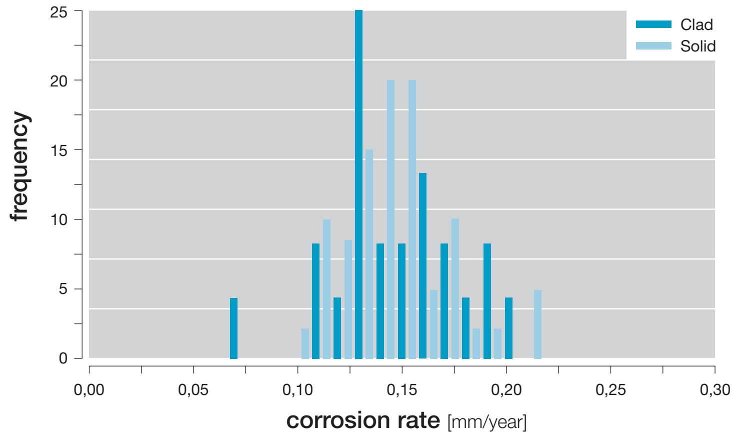
Bond quality





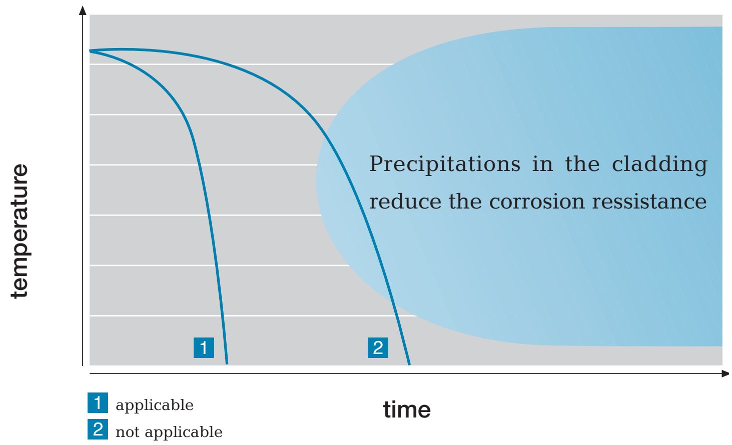
The bond between base and clad materials is unseparable.

Corrosion resistance



Concerning corrosion resistance clad plates perform as well as solid material.

Cooling curves of clad plates



Heat treatment

Based on the chemical composition the mechanical-technological properties of the base material as well as the corrosion properties of the clad material are adjusted by production route and proper heat treatment.

- As rolled with simulated testing
- Normalising rolled
- Normalised (furnace)
- Normalised and tempered
- Quenched and tempered
- Thermomechanically rolled and accelerated cooled (TMCP)

Quality assurance

Product integrity for pressure vessels is of great importance. Products, processes and business systems of voestalpine Grobblech are approved by Lloyds Register of Quality Assurance to ISO 9001. This approval covers all aspects of sales, service, design, manufacture and testing.
voestalpine Grobblech is certified for heavy plates as well as clad plates by the Verband der Technischen Überwachungsvereine (VdTÜV) (Union of Technical Inspection Groups) resp. by the Technischer Überwachungsverein Industrie Service GmbH (=TÜV-Süd) (former Technical Inspection Group Bavaria):

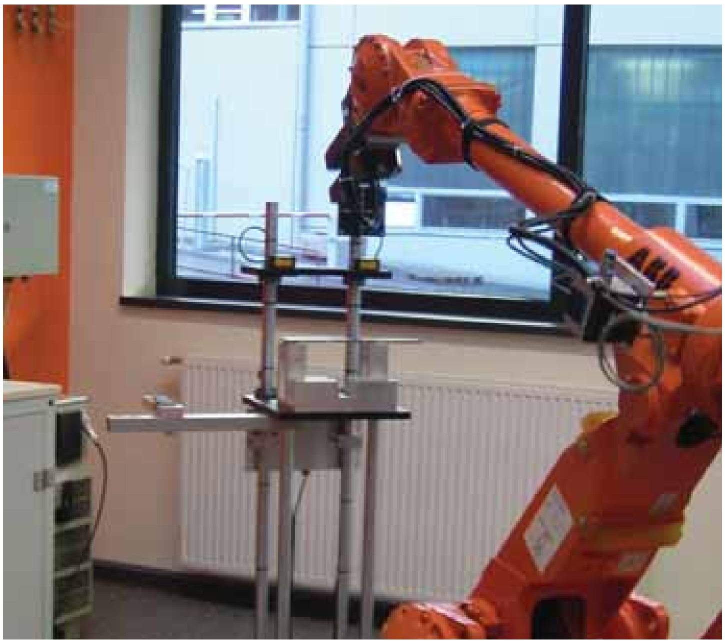
- AD-Merkblatt W0 / TRD 100
- EG-Druckgeräterichtlinie Nr. PED97/23/EG (PED = Pressure Equipment Directive)

Product support

- Our Research & Development department is a dedicated centre of expertise. We permanently invest in the education of our staff and into the latest research tools to assure first class technical investigation.

- We have an independent and fully accredited test house at our site.

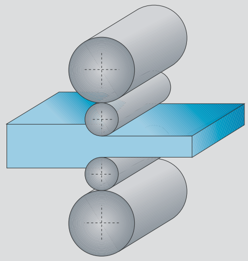
- Our R & D continually developes the basis for new materials for more complex applications and contributes to the optimisation of our production processes. Additional work includes simulations of material performance such as weldability, deformation and edging behaviour, fatigue tests and fracture mechanics. These tests provide a complete performance profile of our steels under practical conditions.



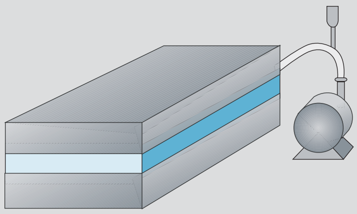
CTOD (Crack Tip Opening Displacement)
Qualification for excellent fracture toughness

Cladding process

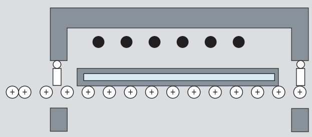
1. Rolling of base and clad material



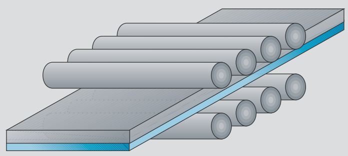
4. Evacuation



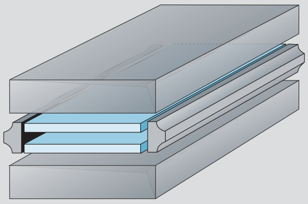
7. Heat treatment



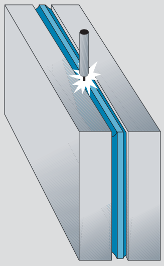
10. Levelling



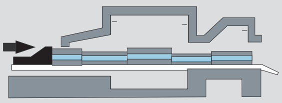
2. Package assembly



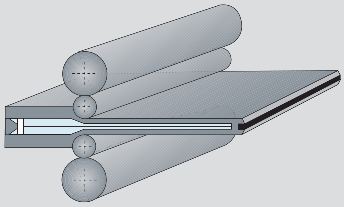
3. Package welding



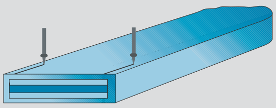
5. Reheating



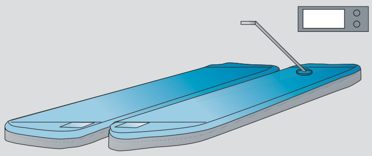
6. Rolling



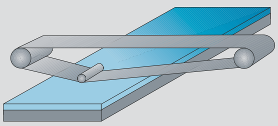
8. Plasma torch cut



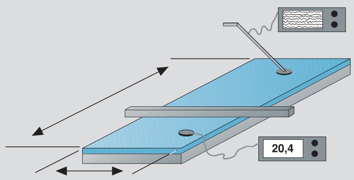
9. Ultrasonic testing



11. Grinding



12. Final check



Dimensions

■ Clad material: ferritic and austenitic stainless steel

Total thickness		6 - 120 mm
Clad thickness		1,5 - 10 mm
Width		max. 3,800 mm
Length		max. 15,000 mm (water quenched: max. 12,000 mm)
Weight per plate	min. 2 tons	max. 17 tons
Area		min. 6 m²

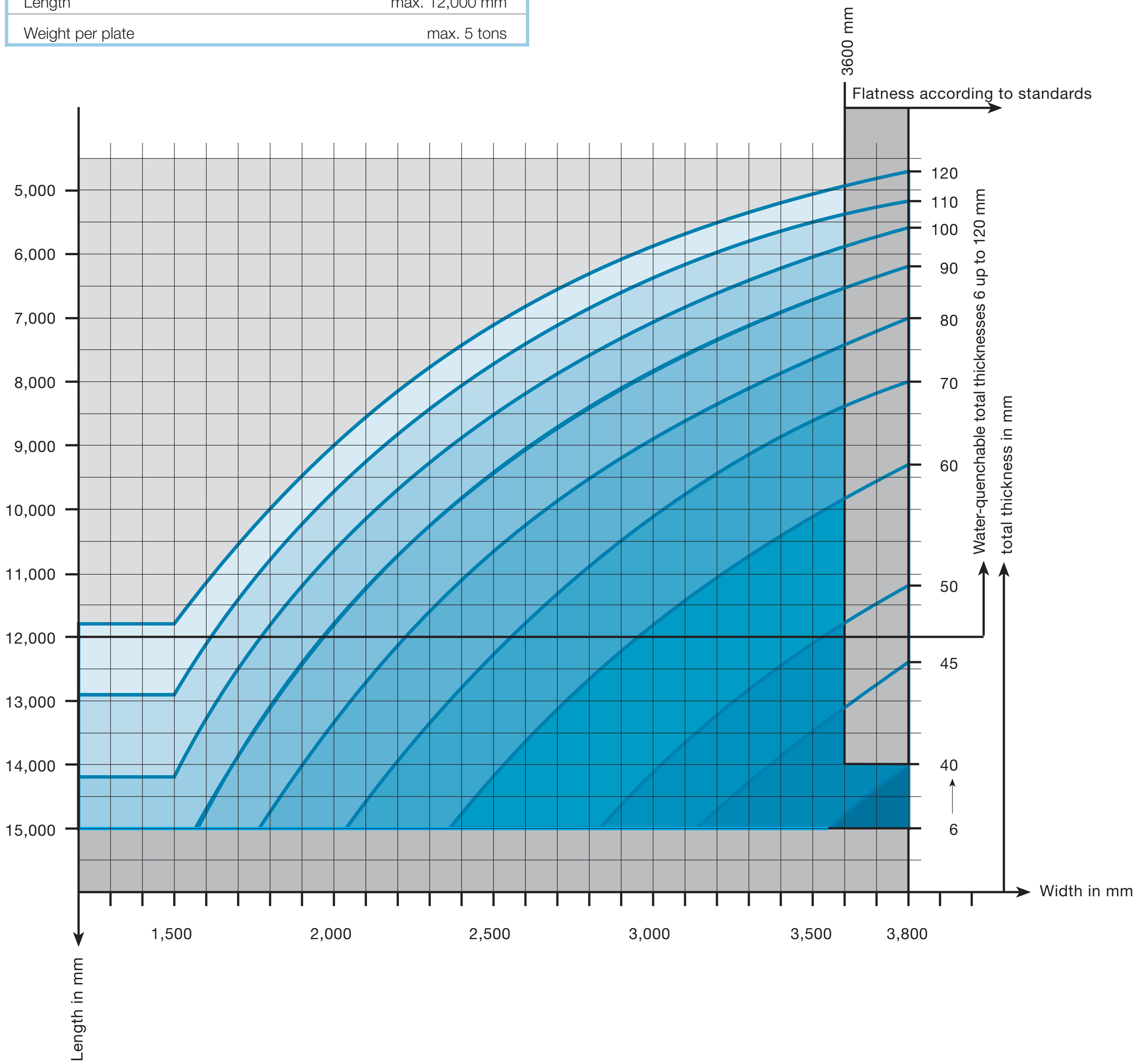
■ Clad material: nickel and copper alloys

Total thickness		6 - 65 mm
Clad thickness		1,5 - 10 mm
Width		max. 3,800 mm
Length		max. 15,000 mm (water quenched: max. 12,000 mm)
Weight per plate	min. 2 tons	max. 9 tons
Area		min. 6 m²

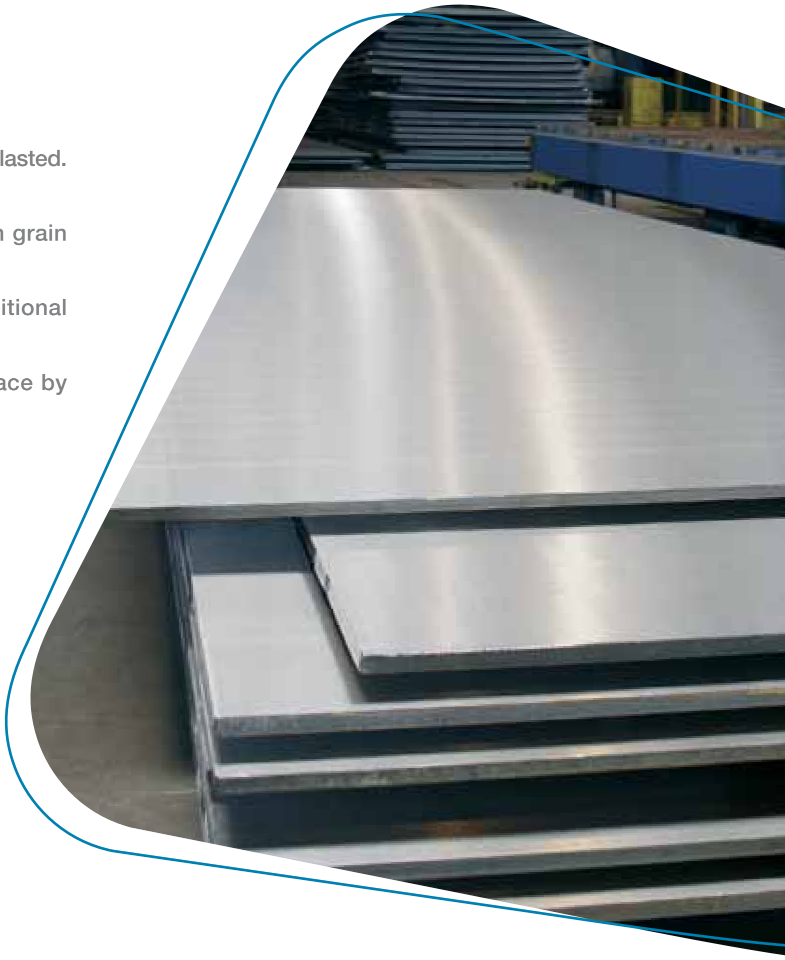
■ Clad material: titanium or zirconium

Total thickness	10 - 40 mm
Clad thickness	2 - 5 mm
Width	max. 3,200 mm
Length	max. 12,000 mm
Weight per plate	max. 5 tons

Different dimensions on request.



Surface finish



The surface of the base material is normally „as rolled“ or shot blasted.

The surface of the cladded material is normally ground with grain size 80. Other grain sizes are available on request. Any additional future surface treatment (e.g. fine grinding) of the clad surface by the costumer must be indicated at ordering.

Reference values for roughness

- Clad material: ferritic and austenitic stainless steel, nickel-based alloys

Grain size	80	120	180	240
Depth of rouhgness Rt in µm	18	14	9	4
Mean roughness Ra in µm	2,6	2,0	1,4	0,9

- Clad material: copper and copper alloys, nickel

Grain size	120
Depth of rouhgness Rt in µm	14
Mean roughness Ra in µm	2,0

Base materials

The base materials for roll-bonded clad plates are made of slabs cast at voestalpine steel mill onsite in Linz.

Mainly used are
- structural steels
- pressure vessel steels
- linepipe steels

Dependent on the requirements of the respective standards and customer specifications as well as on the demands of the cladding materials due to corrosion resistance we provide the following delivery conditions:
- as rolled with simulated testing
- normalising rolled
- normalised (furnace)
- normalised and tempered
- quenched and tempered
- thermomechanically rolled and accelerated cooled (TMCP)

At the side you will find a summary of the most applicable base materials for roll-bonded clad plates. Other base materials on request. The indicated chemical and mechanical data refer to the smallest thickness group.

Standard	Steel grade	C[1) max.	Si max.	Mn max.
EN 10025-2	S235JR	0.17	–	1.40
	S355JR	0.24	0.55	1.60
EN 10028-2	P235GH	0.16	0.35	0.60 - 1.20
	P265GH	0.20	0.40	0.80 - 1.40
	P295GH	0.08 - 0.20	0.40	0.90 - 1.50
	P355GH	0.10 - 0.22	0.60	1.10 - 1.70
	16Mo3	0.12 - 0.20	0.35	0.40 - 0.90
	20MnMoNi4-5	0.15 - 0.23	0.40	1.00 - 1.50
	13CrMo4-5	0.08 - 0.18	0.35	0.40 - 1.00
	10CrMo9-10	0.08 - 0.14	0.50	0.40 - 0.80
	12CrMo9-10	0.10 - 0.15	0.30	0.30 - 0.80
EN 10028-3	P275 NH P275 NL1	0.16	0.40	0.80 - 1.50
	P275 NL2			
	P355 NH P355 NL1	0.18	0.50	1.10 - 1.70
	P355 NL2			
	P460 NH P460 NL1	0.20	0.60	1.10 - 1.70
	P460 NL2			

Structural steels and pressure vessel steels

according to EN 10025-2, EN 10028-2 and EN 10028-3

Chemical composition (heat analysis) %					Mechanical properties		
P max.	S max.	Cr max.	Ni max.	Mo max.	Yield strength[1)] min. [MPa]	Tensile strength[1)] [MPa]	Comparable ASTM-steel grade
0.035	0.035	–	–	–	235	360 - 510	–
0.035	0.035	–	–	–	355	510 - 680	–
0.025	0.015	0.30	0.30	0.08	235	360 - 480	A285 GradeC
0.025	0.015	0.30	0.30	0.08	265	410 - 530	A516 Grade60
0.025	0.015	0.30	0.30	0.08	295	460 - 580	A516 Grade65
0.025	0.015	0.30	0.30	0.08	355	510 - 650	A516 Grade70
0.025	0.010	0.30	0.30	0.25 - 0.35	275	440 - 590	–
0.020	0.010	0.20	0.40 - 0.80	0.45 - 0.60	470	590 - 750	A533 Type B Class2
0.025	0.010	0.70 - 1.15	–	0.40 - 0.60	300	450 - 600	A387 Grade12 Class2
0.020	0.010	2.00 - 2.50	–	0.90 - 1.10	310	480 - 630	–
0.015	0.010	2.00 - 2.50	0.30	0.90 - 1.10	355	540 - 690	A387 Grade22 Class2
0.025	0.015	0.30	0.50	0.08	275	390 - 510	A516 Gade60
0.020	0.010						
0.025	0.015	0.30	0.50	0.08	355	490 - 630	A516 Grade70
0.020	0.010						
0.025	0.015	0.30	0.80	0.10	460	570 - 720	A572 Grade65
0.020	0.010						

1) dependent on thickness

Structural steels and pressure vessel steels

according to ASTM

Standard	Steel grade			
		C[1)2)] max.	Si max.	Mn[2)] max.
ASTM	A285 GradeC	0.28	–	0.90
	A516 Grade60	0.21	0.15 - 0.40	0.60 - 1.20
	A516 Grade65	0.24	0.15 - 0.40	0.85 - 1.20
	A516 Grade70	0.27	0.15 - 0.40	0.85 - 1.20
	A572 Grade65 Type1	0.23	0.40	1.65
	A533 Type B Class2	0.25	0.15 - 0.40	1.15 - 1.50
	A387 Grade11 Class2	0.05 - 0.17	0.50 - 0.80	0.40 - 0.65
	A387 Grade12 Class2	0.05 - 0.17	0.15 - 0.40	0.40 - 0.65
	A387 Grade22 Class2	0.05 - 0.15	0.50	0.30 - 0.60

Fitting steels and linepipe steels

according to ASTM, API 5L and DNV OS-F101

Standard	Steel grade				
		C[1)2)] max.	Si max.	Mn[2)] max.	P max.
ASTM	A106 GradeB	0.30	0.10	0.29 - 1.06	0.035
	A672 GradeC60	0.27	0.40	0.85 - 1.20	0.035
	A672 GradeC70	0.27	0.40	0.85 - 1.20	0.035
ASTM A860	WPHY 42 WPHY 52 WPHY 60 WPHY 65	0.20	0.40	1.00 - 1.45	0.030
API 5L	GradeB – PSL2	0.22	–	1.20	0.025
	X52 – PSL2	0.22	–	1.40	0.025
	X60 – PSL2	0.22	–	1.40	0.025
	X65 – PSL2	0.22	–	1.65	0.025
DNV OS-F101	SAWL 245	0.14	0.40	1.35	0.020
	SAWL 360	0.12	0.45	1.65	0.020
	SAWL 415	0.12	0.45	1.65	0.020
	SAWL 450	0.12	0.45	1.65	0.020

Chemical composition (heat analysis) %					Mechanical properties		
P max.	S max.	Cr max.	Ni max.	Mo max.	Yield strength[1)] min. [MPa]	Tensile strength[1)] [MPa]	Comparable steel grade of EN 10028
0.035	0.035	–	–	–	205	380 - 515	P235GH
0.035	0.035	–	–	–	220	415 - 550	P275
0.035	0.035	–	–	–	240	450 - 585	–
0.035	0.035	–	–	–	260	485 - 620	P355
0.040	0.050	–	–	–	450	≥ 550	P460
0.035	0.035	–	0.40 - 0.70	0.45 - 0.60	485	620 - 795	20MnMoNi4-5
0.035	0.035	1.00 - 1.50	–	0.45 - 0.65	310	515 - 690	–
0.035	0.035	0.80 - 1.15	–	0.45 - 0.60	275	450 - 585	13CrMo4-5
0.035	0.035	2.00 - 2.50	–	0.90 - 1.10	310	515 - 690	12CrMo9-10

1) dependent on thickness
2) if C-content is reduced, Mn-content may be increased

Chemical composition (heat analysis) %						Mechanical properties		
S max.	Cr max.	Ni max.	Cu max.	Mo max.	V max.	Yield strength[1)] min. [MPa]	Tensile strength[1)] [MPa]	Comparable steel grade of ASTM / DNV / API
0.035	0.40	0.40	0.40	0.15	0.08	240	≥ 415	ASTM A516 Grade65
0.035	–	–	–	–	–	220	415 - 550	ASTM A516 Grade60
0.035	–	–	–	–	–	260	485 - 620	ASTM A516 Grade70
0.010	0.30	0.50	0.35	0.25	0.10	290 360 415 450	415 - 585 455 - 625 515 - 690 530 - 705	–
0.015	–	–	–	–	–	241 - 448	414 - 758	DNV SAWL 245
0.015	–	–	–	–	–	359 - 531	455 - 758	DNV SAWL 360
0.015	–	–	–	–	–	414 - 565	517 - 758	DNV SAWL 415
0.015	–	–	–	–	–	448 - 600	531 - 758	DNV SAWL 450
0.010	0.30	0.30	0.35	0.10	–	245	370	API 5L GradeB
0.010	0.50	0.50	0.50	0.10	0.05	360	460	API 5L X52
0.010	0.50	0.50	0.50	0.50	0.08	415	520	APL 5L X60
0.010	0.50	0.50	0.50	0.50	0.10	450	535	API 5L X65

1) dependent on thickness
2) if C-content is reduced, Mn-content may be increased

Claddings

The clad materials for the roll-bonded clad plates are supplied by leading manufacturers in form of slabs or plates.

Mainly used are
- ferritic and austenitic stainless steels and heat-resistant steels
- nickel and nickel-base alloys
- copper and copper-alloys
- titanium

Below you will find a summary of the most frequently used clad materials for roll-bonded clad plates. Other clad materials on request.

Standard	EN material number	Grade	C max.	Si max.	Mn max.
EN 10088	1.4000	X6Cr13	0.08	1.0	1.0
	1.4301	X5CrNi18-10	0.07	1.0	2.0
	1.4306	X2CrNi19-11	0.03	1.0	2.0
	1.4541	X6CrNiTi18-10	0.08	1.0	2.0
	1.4550	X6CrNiNb18-10	0.08	1.0	2.0
	1.4401	X5CrNiMo17-12- 2	0.07	1.0	2.0
	1.4404	X2CrNiMo17-12-2	0.03	1.0	2.0
	1.4571	X6CrNiMoTi17-12-2	0.08	1.0	2.0
	1.4432	X2CrNiMo18-14-3	0.03	1.0	2.0
	1.4435	X3CrNiMo17-13-3	0.03	1.0	2.0
	1.4429	X2CrNiMoN17-13-3	0.03	1.0	2.0
	1.4438	X2CrNiMo18-15-4	0.03	1.0	2.0
	1.4439	X2CrNiMoN17-13-5	0.03	1.0	2.0
SEW 470	1.4828	X 15 CrNiSi 20 12	0.20	1.5–2.5	2.0

Standard	UNS number	Type	C max.	Si max.	Mn max.
ASTM A240 and ASME SA240	S41008	410S	0.08	1.00	1.0
	S30400	304	0.08	0.75	2.0
	S30403	304L	0.03	0.75	2.0
	S32100	321	0.08	0.75	2.0
	S34700	347	0.08	0.75	2.0
	S31600	316	0.08	0.75	2.0
	S31603	316L	0.03	0.75	2.0
		316L Mod Mo≥2.5	0.03	0.75	2.0
	S31635	316Ti	0.08	0.75	2.0
	S31653	316LN	0.03	0.75	2.0
	–	316LN Mod Mo≥2.5	0.03	0.75	2.0
	S31703	317L	0.03	0.75	2.0
	S31726	317LMN	0.03	0.75	2.0

Chemical composition (heat analysis) % (extract)							
P max.	S max.	Cr	Ni	Mo	Others	Mean effective sum Cr+3.3Mo+16N [%]	Comparable ASTM A240 / ASME SA240 type
0.040	0.015	12.0 - 14.0	–	–	–	–	410S
0.045	0.015	17.0 - 19.5	8.0 - 10.5	–	N ≤ 0.11	–	304
0.045	0.015	18.0 - 20.0	10.0 - 12.0	–	N ≤ 0.11	–	304L
0.045	0.015	17.0 - 19.0	9.0 - 12.0	–	5xC < Ti ≤ 0.70	–	321
0.045	0.015	17.0 - 19.0	9.0 - 12.0	–	10xC < Nb ≤ 1.00	–	347
0.045	0.015	16.5 - 18.5	10.0 - 13.0	2.0 - 2.5	N ≤ 0.11	25	316
0.045	0.015	16.5 - 18.5	10.0 - 13.0	2.0 - 2.5	N ≤ 0.11	25	316L
0.045	0.015	16.5 - 18.5	10.5 - 13.5	2.0 - 2.5	5xC < Ti ≤ 0.70	25	316Ti
0.045	0.015	16.5 - 18.5	10.5 - 13.5	2.5 - 3.0	N ≤ 0.11	27	316L Mod Mo≥2.5
0.045	0.015	17.0 - 19.0	12.5 - 15.0	2.5 - 3.0	N ≤ 0.11	28	316L Mod Mo≥2.5
0.045	0.015	16.5 - 18.5	11.0 - 14.0	2.5 - 3.0	N = 0.12–0.22	29	316LN Mod Mo≥2.5
0.045	0.015	17.5 - 19.5	13.0 - 16.0	3.0 - 4.0	N ≤ 0.11	31	317L
0.045	0.015	16.5 - 18.5	12.5 - 14.5	4.0 - 5.0	N 0.12 - 0.22	35	317LMN
0.045	0.030	19.0 - 21.0	11.0 - 13.0	–	–	–	–

Chemical composition (heat analysis) % (extract)							
P max.	S max.	Cr	Ni	Mo	Others	Mean effective sum Cr+3.3Mo+16N [%]	Comparable grade of EN 10088
0.040	0.030	11.5 - 13.5	max. 0.60	–	–	–	1.4000
0.045	0.030	18.0 - 20.0	8.0 - 10.5	–	N ≤ 0.10	–	1.4301
0.045	0.030	18.0 - 20.0	8.0 - 12.0	–	N ≤ 0.10	–	1.4306
0.045	0.030	17.0 - 19.0	9.0 - 12.0	–	N ≤ 0.10 5x(C+N) < Ti ≤ 0.70	–	1.4541
0.045	0.030	17.0 - 19.0	9.0 - 13.0	–	10xC < Nb ≤ 1.00	–	1.4550
0.045	0.030	16.0 - 18.0	10.0 - 14.0	2.0 - 3.0	N ≤ 0.10	25	1.4401
0.045	0.030	16.0 - 18.0	10.0 - 14.0	2.0 - 3.0	N ≤ 0.10	25	1.4404
0.045	0.030	16.0 - 18.0	10.0 - 14.0	2.5 - 3.0	N ≤ 0.10	27	1.4432/1.4435
0.045	0.030	16.0 - 18.0	10.0 - 14.0	2.0 - 3.0	N ≤ 0.10 5x(C+N) < Ti ≤ 0.70	25	1.4571
0.045	0.030	16.0 - 18.0	10.0 - 14.0	2.0 - 3.0	N = 0.10-0.16	27	–
0.045	0.030	16.0 - 18.0	10.0 - 14.0	2.5 - 3.0	N = 0.10-0.16	29	1.4429
0.045	0.030	18.0 - 20.0	11.0 - 15.0	3.0 - 4.0	N ≤ 0.10	31	1.4438
0.045	0.030	17.0 - 20.0	13.5 - 17.5	4.0 - 5.0	N = 0.10-0.20	35	1.4439

Special steels,
non-ferrous metals and alloys

ASTM	Type	C max.	Si max.	Mn max.	P max.
B 409 UNS N08800	Alloy 800	0.10	1.00	1.5	–
B 625 UNS N08904	Alloy 904 L	0.02	1.00	2.0	0.045
B 709 UNS N08028	Alloy 28	0.03	1.00	2.5	0.030
B 625 UNS N08926	Alloy 926	0.02	0.50	2.0	0.030
B 463 UNS N08020	Alloy 20	0.07	1.00	2.0	0.045
B 424 UNS N08825	Alloy 825	0.05	0.50	1.0	–
B 443 UNS N06625	Alloy 625	0.10	0.50	0.5	0.015
B 575 UNS N06022	Alloy C 22	0.015	0.08	0.5	0.020
B 575 UNS N06455	Alloy C 4	0.015	0.08	1.0	0.040
B 575 UNS N10276	Alloy C 276	0.01	0.08	1.0	0.040
B 575 UNS N06059	Alloy 59	0.01	0.10	0.5	0.015
B 333 UNS N10665	Alloy B 2	0.02	0.10	1.0	0.040
B 168 UNS N06600	Alloy 600	0.15	0.50	1.0	–
B 127 UNS N04400	Alloy 400	0.30	0.50	2.0	–
B 162 UNS N02200	Alloy 200	0.15	0.35	0.35	–
B 162 UNS N02201	Alloy 201	0.02	0.35	0.35	–
–	–	–	–	–	0.001 - 0.005
B 152 UNS C12200	–	–	–	–	0.015 - 0.040
B 171 UNS C70600	Alloy CuNi 90/10	–	–	1.0	–
B 171 UNS C71500	Alloy CuNi 70/30	0.05	–	1.0	–
B 265 Grade 1	Titanium Grade 1	0.08	–	–	–
B 265 Grade 2	Titanium Grade 2	0.08	–	–	–

Chemical composition (heat analysis) % (extract)						Comparable grades		
S max.	Cr	Ni	Mo	Others	Mean effective sum Cr+3.3Mo+16N [%]	EN material number	EN / DIN / SEW	VdTÜV material sheet
0.015	19.0 - 23.0	30.0 - 35.0	–	Al = 0.15 - 0.60 Ti = 0.15 - 0.60 Cu ≤ 1.5, Fe ≥ 39.5	–	1.4876	SEW 470	412
0.035	19.0 - 23.0	23.0 - 28.0	4.0 - 5.0	Cu = 1.0 - 2.0	36	1.4539	EN 10088	421
0.030	26.0 - 28.0	29.5 - 32.5	3.0 - 4.0	Cu = 0.60 - 1.40	39	1.4563		–
0.010	19.0 - 21.0	24.0 - 26.0	6.0 - 7.0	Cu = 0.50 - 1.50 N = 0.15 - 0.25	44	1.4529		502
0.035	19.0 - 21.0	32.0 - 38.0	2.0 - 3.0	Cu = 3.0 - 4.0 8xC < (Nb+Ta) ≤ 1.0	28	2.4660	DIN 17744	–
0.030	19.5 - 23.5	38.0 - 46.0	2.5 - 3.5	Cu = 1.5–3.0 Ti = 0.60–1.20 Fe ≥ 22.0, Al ≤ 0.2	31	2.4858	DIN 17744	432
0.015	20.0 - 23.0	≥ 58.0	8.0 - 10.0	Fe ≤ 5.0, (Co ≤ 1.0) Nb = 3.15 - 4.15 Al ≤ 0.40, Ti ≤ 0.40	51	2.4856	DIN 17744	499
0.020	20.0 - 22.5	Rest	12.5 - 14.5	Fe = 2.0 - 6.0 W = 2.5 - 3.5 V ≤ 0.35, Co ≤ 2.50	66	2.4602	DIN 17744	479
0.030	14.0 - 18.0	Rest	14.0 - 17.0	Fe ≤ 3.0 Ti ≤ 0.70 Co ≤ 2.0	67	2.4610	DIN 17744	424
0.030	14.5 - 16.5	Rest	15.0 - 17.0	W = 3.0 - 4.5 Fe = 4.0 - 7.0 Co ≤ 2.5, V ≤ 0.35	68	2.4819	DIN 17744	400
0.010	22.0 - 24.0	Rest	15.0 - 16.5	Al = 0.1 - 0.4 Fe ≤ 1.5, Co ≤ 0.3 Cu ≤ 0.5	75	2.4605	DIN 17744	505
0.030	1.0	Rest	26.0 - 30.0	Fe ≤ 2.0 Co ≤ 1.00	–	2.4617	DIN 17744	436
0.015	14.0 - 17.0	≥ 72.0	–	Fe = 6.0 - 10.0 Cu ≤ 0.50	–	2.4816	DIN 17742	305
0.024	–	≥ 63.0	–	Cu = 28.0 - 34.0 Fe ≤ 2.5	–	2.4360	DIN 17743	263
0.010	–	≥ 99.00	–	Fe ≤ 0.4 Cu ≤ 0.25	–	2.4066	DIN 17740	–
0.010	–	≥ 99.00	–	Fe ≤ 0.4 Cu ≤ 0.25	–	2.4068		345
–	–	–	–	Cu ≥ 99.95	–	2.0070	DIN 1787	–
–	–	–	–	Cu ≥ 99.90	–	CW 024 A	EN 1652	–
–	–	9.0 - 11.0	–	Fe = 1.0 - 1.8, Cu Rest, Zn ≤ 1.0, Pb ≤ 0.05	–	CW 352 H		420
–	–	29.0 - 33.0	–	Fe = 0.40 - 1.0, Cu Rest Zn ≤ 1.0, Pb ≤ 0.05	–	CW 354 H		–
–	–	–	–	Fe ≤ 0.20 O ≤ 0.18, N ≤ 0.03 Ti Rest	–	3.7025	DIN 17850	230
–	–	–	–	Fe ≤ 0.30 O ≤ 0.25, N ≤ 0.03 Ti Rest	–	3.7035		230

Processing

voestalpine Grobblech is pleased to provide customers with the know-how and technical experience gained in decades of research and development work.

Cutting

Roll-bonded clad plates are best cut using plasma torches. This cutting process provides clean cut edges which are prepared for subsequent welding by simply removing the oxide skin.
Note: The plasma cut is always performed from the clad side.

It is also possible to use oxy-gas cutting (starting from the base material side) or oxy-gas cutting with flux addition (starting from the clad side). However, this is rarely done because it produces irregular cut edges.
Thin clad plates can be shear cut (cladding material on top) without problems. The following general rules are applicable: sharp blades, exact setting of the cutting clearence and optimum blankholder force.

Cold forming

Cold forming of roll-bonded clad plates is possible by applying the following techniques:

- bending
- pressing
- dishing
- rolling

Clean surfaces of the cladding and tools are of great importance in all forming processes. Roll-bonded clad plates provide excellent forming behaviour.
The material-specific properties must be taken into account, particularly in the case of stainless ferritic claddings.

Hot forming

Roll-bonded clad plates are formed in accordance with accepted technologies and by taking into consideration the cladding material. The surfaces of the cladding materials must be free of contaminations like grease, oil, marking colours etc. in order to prevent carburisation. It is very important to obtain an atmosphere with low sulphur content.

In some cases heat treatment is required after hot forming. High-alloy claddings can only achieve their optimum corrosion resistance by means of special temperature controls.
Therefore, voestalpine Grobblech should be contacted as early as in the beginning stages of component design. To avoid corrosion, the surface of the cladding material must be cleaned after the last processing step. Oxide skins, annealing colours, welding spatters, any scratches resulting from ferrous materials, marks, rust from external sources etc. must be removed.

Welding

The instructions in this brochure are of a general nature. For detailed information, experienced welding engineers are at your disposal.

Welding processes

As a rule the base materials are welded by applying shielded metal arc welding (SMAW), gas tungsten arc welding (GTAW), gas metal arc welding (GMAW), submerged arc welding (SAW), submerged arc strip cladding (SASC) and electro slag strip cladding (ESSC).

The following welding processes for cladding materials are used, where base metal are less diluted, such as

- SMAW
- GTAW, pulse GTAW
- pulse GMAW
- electro slag strip cladding (ESSC)
- submerged arc strip cladding (SASC)

Filler metals

The same filler metals are used for welding the base materials as for plates without cladding.
The recommended filler metals for the claddings of the tables on pages 20/21 and 22/23 are indicated in the tables on pages 27 and 28/29. Selections are done after considering the following aspects:

- If possible, the first layer should be welded with over-alloyed fillers, in order to approximate to the composition of the cladding during mixing with the base material.

- For 13% Cr steel claddings, not only the buffer is welded with an over-alloyed austenitic electrode, type 23 12 L, but frequently also the cover pass. If standard fillers of 19/9-types are used, there is a risk of martensite formation at high dilution of 13% Cr steel. A buffer with electrode type 23 12 L is also recommended for cover passes with 13% Cr weld metals. When applying ESSC several solutions exist to clad with single layer (without buffer layer).

- In contrast to weld metal that is similar in composition to the base material, low-carbon 18-8 CrNi and CrNiMo steels do not become susceptible to intergranular corrosion by stress-relief annealing. Thus we recommend Nb-stabilised low-carbon weld metal for subsequent stress-relief annealing.

- For austenitic steels and nickel alloys with more than 3.0% Mo, the recommended filler materials for the filler and cover passes should be over-alloyed by a factor of 1.3 with respect to Mo. This is done to reduce the risk of pitting corrosion, where the pren is decisive. In every cast material and especially in the not solution annealed weld metal Mo is more segregated than in the cladding. Therefore Mo-depleted zones occur which have only 70-80% of the average Mo-content.

- Soldering brittleness may occur when welding Cu, CuNi 90/10 and CuNi 70/30 onto steel. Therefore we recommend a buffer with alloy 400 (table on page 28/29).

Examples of filler metals for welding of stainless or heat-resistant claddings

according to EN 1600 and EN 12072 as well as AWS A 5.4, A 5.9 and A 5.14

Cladding		Filler metal type[1]					
		multi-pass (SMAW)[2]				single-pass ESSC (SASC) strip[3]	
EN material number	ASTM A 240 type	buffer		subsequent passes			
		EN	AWS	EN	AWS	EN	AWS
1.4000	410S	23 12 L	E309L	22 12 13 L	E309 E410L	X2 CrNi 24 12 X5 Cr 17	ER309L ER430L
1.4301	304	23 12 L	E309L	19 9 L	E308L	X2 CrNi 23 11 X2 CrNi 24 12 X2 CrNiNb 21 10[4] X2 CrNiNb 24 12[4]	ER309L ER309CbL[4]
1.4306	304L			19 9 L 19 9 Nb L	E308L E347L[4]		
1.4541	321			19 9 Nb	E347	X2 CrNiNb 21 10 X2 CrNiNb 24 12	ER309CbL[4]
1.4550	347			19 9 Nb L	E347L[4]		
1.4401	316	23 12 2 L	E309 MoL	19 12 3 L[5] 19 12 3 Nb[5]	E316L[5] E318[5]	X2 CrNiMo 21 13[5] X2 CrNiMnMoN 20 16[5]	ER309MoL[5]
1.4404	316L						
1.4571	316Ti						
1.4432	316L Mo ≧ 2.5			18 16 5 L	E317L	X2 CrNiMoCu 20 25	ER385
1.4435	316 Mo ≧ 2.5						
1.4429	316LN Mo ≧ 2.5						
1.4438	317L	18 16 5 L	–	18 16 5 L	–	UP-NiCr21Mo9Nb (Alloy 625)	ERNiCrMo-3 (Alloy 625)
1.4439	–	20 25 6 Cu L		20 25 6 Cu L	–		
1.4828	305	23 12 L	E309L	23 12 L	E410L	X2 CrNi 24 12	ER309L

[1] Some of the filler metals are not included in the standards, but available on the market.
[2] For GTAW or GMAW welding, types of similar composition are used.
[3] The selection of the strip depends on the welding process (ESSC, SASC), the flux, the base material, the required bead thickness etc. We would be glad to provide you with a comprehensive consultation.
[4] To be applied for stress-relief annealing.
[5] If stress-relief annealing is applied, please contact us.

Examples of filler metals for welding of cladding

according to EN ISO 18274, EN 14640 and/or EN 1600, EN 12072 as

Cladding		
Alloy type	EN material number	buffer
		EN
Alloy 800	1.4876	SG-NiCr21Mo9Nb
Alloy 904L	1.4539	20 25 5 Cu L
Alloy 28	1.4563	27 31 4 Cu L
Alloy 926	1.4529	SG-NiCr21Mo9Nb
Alloy 20	2.4660	SG-NiCr21Mo9Nb
Alloy 825	2.4858	
Alloy 625	2.4856	SG-NiCr21Mo9Nb
Alloy C22	2.4602	SG-NiCr21Mo14W
Alloy C4	2.4610	SG-NiMo16Cr16Ti
Alloy C-276	2.4819	SG-NiMo16Cr16W
Alloy 59	2.4605	SG-NiCr23Mo16
Alloy B2	2.4617	SG-NiMo27
Alloy 600	2.4816	SG-NiCr20Nb
Alloy 400	2.4360	SG-NiCu30MnTi
Alloy 200	2.4066	SG-NiTi4
Alloy 201	2.4068	
SE-Cu	2.0070	SG-NiCu30MnTi
SF-Cu	CW024A	
Alloy CuNi 90/10	CW352H	
Alloy CuNi 70/30	CW354H	
Titanium Grade1	3.7025	Titanium must not therefore only
Titanium Grade2	3.7035	

[1] Over-alloyed – for maximum corrosion resistance – e.g. ERNiCrMo-13

[2] Matching – at least two passes are required

[3] for higher electrical conductivity

materials made of special steels, non-ferrous metals and alloys

well as AWS A 5.7, A 5.14 and A 5.16

Filler metal type				
multi-pass (GTAW, GMAW)			single-pass ESSC (SASC) strip	
buffer	subsequent passes			
AWS	EN	AWS	EN	AWS
ERNiCrMo-3	SG-NiCr21Mo9Nb	ERNiCrMo-3	UP-NiCr21Mo9Nb	ERNiCrMo-3
ER385	20 25 5 Cu L	ER385	UP-NiCr21Mo9Nb	ERNiCrMo-3
ER383	27 31 4 Cu L	ER383	UP-NiCr21Mo9Nb	ERNiCrMo-3
ERNiCrMo-3	SG-NiCr21Mo9Nb	ERNiCrMo-3	UP-NiCr21Mo9Nb	ERNiCrMo-3
ERNiCrMo-3	SG-NiCr21Mo9Nb	ERNiCrMo-3	UP-NiCr21Mo9Nb	ERNiCrMo-3
	SG-NiCr21Mo9Nb	ERNiCrMo-3	UP-NiCr21Mo9Nb	ERNiCrMo-3
ERNiCrMo-3	SG-NiCr21Mo9Nb	ERNiCrMo-3	UP-NiCr23Mo16	ERNiCrMo-13
ERNiCrMo-10	SG-NiCr21Mo14W[1)]	ERNiCrMo-10[1)]	UP-NiCr21Mo14W[1,2)]	ERNiCr21Mo-14W[1,2)]
ERNiCrMo-7	SG-NiMo16Cr16Ti[1)]	ERNiCrMo-7[1)]	UP-NiMo16Cr16Ti[1,2)]	ERNiCrMo-7[1,2)]
ERNiCrMo-4	SG-NiMo16Cr16W[1)]	ERNiCrMo-4[1)]	UP-NiMo16Cr16W[1,2)]	ERNiCrMo-4[1,2)]
ERNiCrMo-13	SG-NiCr23Mo16	ERNiCrMo-13	UP-NiCr23Mo16[2)]	ERNiCrMo-13[2)]
ERNiMo-7	SG-NiMo27	ERNiMo-7	UP-NiMo27[2)]	ERNiMo-7[2)]
ERNiCr-3	SG-NiCr20Nb	ERNiCr-3	UP-NiCr20Nb	ERNiCr-3
ERNiCu-7	SG-NiCu30MnTi	ERNiCu-7	UP-NiCu30MnTi[2)]	ERNiCu-7[2)]
ERNi-1	SG-NiTi4	ERNi-1	UP-NiTi4[2)]	ERNi-1[2)]
ERNiCu-7	SG-CuAg[3)]	–	Welding of Cu and Cu-Alloys onto carbon steel without buffer layer is not recommended.	
	SG-CuSn	ERCu		
	SG-CuNi30Fe	ERCuNi		
	SG-CuNi30Fe	ERCuNi		
be diluted with steel, batten straps.	3.7025	ERTi-2	–	–
	3.7035	ERTi-3	–	–

Weld shapes

Preparation and execution of welding must be performed in such a way that the weld metal for the base material does not fuse the cladding. This prevents the formation of brittle or hot-crack sensitive weld metal. During pre-processing of the weld edges the actual thickness of the cladding needs to be taken into consideration. Any filling of the base material weld should be executed from the base material side, if possible, in order to avoid contamination of the cladding material.

Butt welds

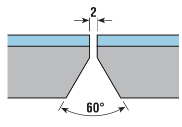
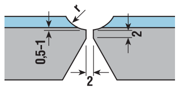
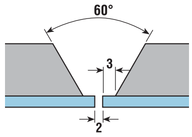
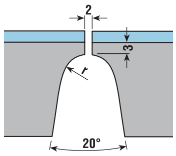
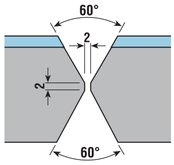
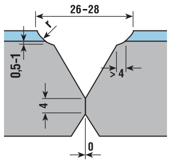
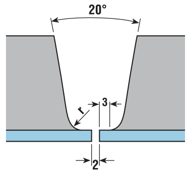
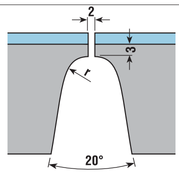
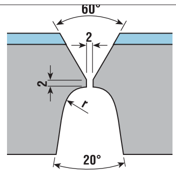
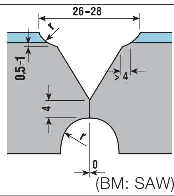
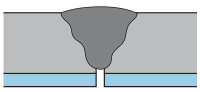
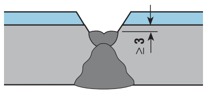
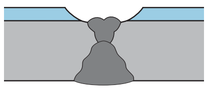
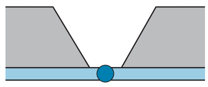
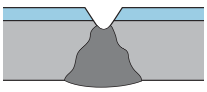
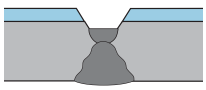
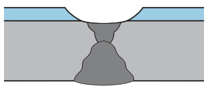
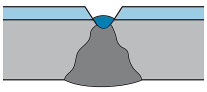
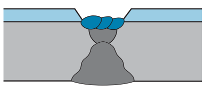
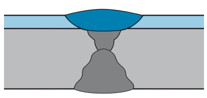
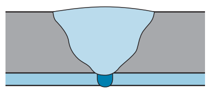
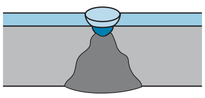
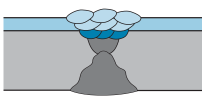
The weld shapes shown on page 31 apply to nearly all clad plates. Titanium and steel cannot be directly fusion welded to each other due to brittle intermetallic phases. Therefore, batten straps are chosen to join titanium clad plates.

Fillet welds

The bonding of the cladding in our roll-bonded clad plates is that strong that even considerably overdimensioned fillet welds do not cause any detachment of the cladding material. However, the standards for the ultrasonic testing of clad plates allow certain bonding defects. When welding fillet welds onto the cladding material, the plate must be carefully checked for proper bonding by ultrasonic testing in the area of the weld before and after the welding operation. Removal of the cladding with subsequent weld cladding to prepare vertical connection is only required in areas where bonding defects have been found in the ultrasonic test. Any melting through the cladding has to be compensated by a corresponding over-alloyed filler metal.

Butt seam welding

Examples of weld shapes and welding sequences (not applicable to titanium clad plates).

Thickness [mm]	WELD PREPARATION [1]: access from both sides 2)	access from both sides 3)	access from both sides 4)	access from one side
5 - 19	 (BM: GMAW)		 (BM: GTAW root)	
20 - 30	 (BM: GMAW)	 (BM: SMAW)	 (BM: SAW)	
> 30	 (BM: GMAW)	 (BM: SMAW)	 (BM: SAW)	radius r depending on the process[1] BM... base material
WELDING (EXAMPLES)				
Welding process for cladding	SMAW, GTAW	SMAW, GMAW	ESW (SAW) strip single-pass	GTAW root
Base material welding				
Grinding				1. GTAW welding of the cladding
Buffer layer welding				
Welding of the filler and cover layers				2. Welding of the base material with filler metal for mixed composition

[1] The root gap, the thickness of the root face, the radii and the weld preparation angle depend on the welding processes used. The drawings show examples of dimensions and appropriate processes for welding of the base material. Favourable radii are: r = 8 mm for the base material; r = 4 mm for the clad material and welding with wire electrodes, r = 8 mm with strip electrodes.

[2] Preferable weld shapes for all welding positions and high-alloy claddings.

[3] Weld shape for thicker plates; SAW for base material.

[4] Weld shape if the total base material thickness is included in the calculation of the strength. The welded cladding should melt down the base material as little as possible. Mainly applied for manual MAW or ESW (SAW) strip.

Welding execution

Cleaning

During welding of the cladding layer the cleanliness demands are met as for solid material of similar composition. Consequently, chippers, brushes etc., of stainless steel are to be used. In the case of Ni and Ni-alloys, prevention of all sulphur-containing contaminations is of utmost importance. Therefore only grinding materials with sulphur-free bonding agents (synthetic resin adhesion) should be used.

Weld design

The full alloy content (or a limitation to a maximum of 5% Fe for Ni or Alloy 400) is often only achieved in the third pass. Consequently, in most cases a weld reinforcement of 2 up to 3 mm is allowed on the side of the cladding material in order to obtain sufficient room for three passes. If a limit is set for the weld reinforcement, the first and the second pass must be heavily ground before welding is continued.

Preheating and heat control

Welding of the base material:
We recommend to use EN 1011-2 for calculating the minimum preheating temperature, which depends on the chemical analysis, the thickness and the welding process employed.

Welding of the buffer:
Most of the buffers are welded using austenitic filler materials which give off very little hydrogen to the base material. According to experience, the preheating temperature may therefore be lower than calculated:

- approx. 50°C lower for SMAW
- up to 100°C lower for GMAW, GTAW and ESW (SAW) strip welding.

Welding of the cladding material:
An overview of the heat control during welding of the cladding material is given in the table below.

Stress-relief annealing

Generally, stress-relief annealing of roll-bonded clad plates is only necessary as a requirement of the base material. By stress-relief annealing the properties of the cladding and the corresponding weld metal may deteriorate due to precipitation of carbides, intermetallic phases etc. Therefore stress-relief annealing is to be avoided if possible or adjusted to the base and cladding materials.

Post-treatment of the welds

Smoothening of the weld to prevent deposits (crevice corrosion), pickling to remove annealing colours or similar measures may be required, depending on the type of the cladding material and the attacking medium.

Welding of the cladding

Cladding	Filler	Preheating min. °C	Interpass temp. max. °C
13% Cr-steels	austenitic	–	200
	matching	150	250
CrNi-steels	matching	none	150
Ni and Ni-alloys	matching	none	150
Cu	matching	> 400	600
CuNi and NiCu-alloys	matching	none	150
Ti	matching	none	100

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References

Clad plates for refinery vessels including heads

Year	Project	Destination	Base material	Clad material
2007	Valero (Port Arthur and Saint Charles)	USA	A 387 Grade12 Class2	410S
2007	Motiva Enterprises (Port Arthur)	USA	A 387 Grade12 Class2	410S
2007	Marathon Petroleum (Garyville)	USA	A 387 Grade12 Class2	410S
2007	Al Jubail	Saudi Arabia	A 516 Grade70	304L
2006	Conoco Philips - Woodriver	USA	A 387 Grade12 Class2	410S
2005	Sharq	Saudi Arabia	A 516 Grade70	304L
2004	Kazakhstan Offshore Oilfield	Kazakhstan	A 516 Grade70	304L
2004	Al Jubail	Saudi Arabia	A 516 Grade70	316L

Clad plates for pipes
(line pipes, process pipes, steel caternary riser pipes, bends, fittings, splash zone)

Year	Project	Destination	Base material	Clad material
2007	Darquain	Iran	API 5L X60	Alloy 625
2007	Morvin	Norway	SAWL 415	Alloy 825
2006	ONGC	India	API 5L X60	Alloy 825
2006	Angel	Australia	SAWL 415	Alloy 400, 316L, 316L 2,5Mo
2006	Asgard	Norway	API 5L X65	Alloy 825
2006	Flint Hill	USA	A 516 Grade70	317L
2006	RasGas 6	Qatar	A 516 Grade65 / API 5L X65	316L
2006	Jerneh B	Malaysia	DNV Grade450	Alloy 825, Alloy 400
2006	OSO	Nigeria	API 5L X65	Alloy 825, Alloy 400
2005	Greater Plutonio	Angola	API 5L X65	Alloy 625
2005	Horizon	USA	A 516 Grade60	CuNi 70/30
2005	Qatargaz	Qatar	A 516 Grade65 / API 5L X65	316L
2005	Tyrihans	Norway	SAWL 450	316L
2004	BuHasa	United Arabic Emirats	API 5L X65	Alloy 825
2004	Buzzard	Great Britain	API 5L X65	Alloy 625
2004	Perseus over Goodwyn	Australia	DNV Grade450	316L 2,5 Mo
2003	Kristin Field	Norway	SAWL 450	Alloy 825
2002	Bonga	Nigeria	API 5L X65	Alloy 825
2002	Citgo	Canada	API 5L X70	Alloy 625
2001	Bintang Field Development	Malaysia	API 5L X65	Alloy 825, Alloy 400
2000, 2004	Sarawak	Malaysia	API 5L X60	Alloy 400
2000, 2003, 2004	South Pars	Iran	API 5L X65	Alloy 625

Clad plates for desalination projects

Year	Project	Destination	Base material	Clad material
2001, 2004, 2005, 2007	Jebel Ali Phase Station K, L and M	Dubai	A 516 Grade70, P355GH	316L, CuNi 90/10
2004, 2005, 2006	Shoaiba	Saudi Arabia	A 516 Grade70, P355GH	316L, 317L, CuNi 90/10
1995, 2005	Al Taweelah	Abu Dhabi	P355GH	316L, CuNi 90/10
2002, 2005	Ras Laffan	Qatar	A 515 Grade70	316L, 317L, CuNi 90/10
2004, 2005	Sabiya	Kuwait	A 516 Grade70	316L, 317L, CuNi 90/10
2003	Arzew	Algeria	P355NH	CuNi 90/10
2002	Mellitah	Libya	P355GH	CuNi 90/10
1999	Ruwais Refinery	United Arabic Emirats	A 515 Grade70	316L, CuNi 90/10
1990, 1991, 1994, 1995	Ras Abu Fontas	Qatar	A 515 Grade70	316L, CuNi 90/10
1993	Ras Lanuf	Libya	A 285 GradeC	316L, CuNi 90/10
1992	Yanbu Medina	Saudi Arabia	Fe 355-2	316L, 317L, CuNi 90/10

Clad plates for flue-gas desulphurisation plants

Year	Project	Destination	Base material	Clad material
2007	Compostilla	Spain	A36	Alloy C276
2007	Pego	Portugal	A36	Alloy 59
2006	Sines	Portugal	A36	Alloy C276
2002	Syncrude	Canada	A 516 Grade70, 38 WT	Alloy 59
2000	Centralia	USA	A36	Alloy C276
2000	Niederaussem	Germany	S235JRG2	Alloy 59
1998	Rutenberg	Israel	A36	Alloy C276
1997	Lippendorf	Germany	S235JRG2	Alloy 59
1994	Jänschwalde	Germany	RSt 37-2	Alloy C276
1993	Boxberg III	Germany	RSt 37-2	Alloy 59

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