# TABLE OF CONTENTS

**DISCLAIMER AND COPYRIGHT** ................................................................. 7

Disclaimer ........................................................................................................ 7
Copyright Protection ......................................................................................... 7

## 1 Introduction ................................................................................................. 8

### 1.1 Clad Plates .......................................................................................... 8

1.1.1 Rolled Clad Plates ............................................................................ 9
1.1.2 Explosion Clad Plates .................................................................... 16
1.1.3 Weld Overlay .................................................................................. 22
1.1.4 Size Range Comparisons ............................................................... 23

### 1.2 Clad Pipes ............................................................................................ 25

1.2.1 Metallurgically Bonded Clad Pipes ............................................ 26
1.2.2 Mechanically Bonded Clad Pipes .................................................. 28
1.2.3 Co-Extruded Seamless Clad Pipes ............................................. 29
1.2.4 Centrifugal Cast Pipe .................................................................... 30

### 1.3 Cost Comparison Clad vs. Solid Plate ............................................. 31

1.3.1 Grade 316 ...................................................................................... 31
1.3.2 Grade 825 ...................................................................................... 33
1.3.3 Grade 625 ...................................................................................... 35

## 2 Clad Plate Production ................................................................................ 37

### 2.1 Long Term Trend ............................................................................... 37

2.1.1 Correlation to Nickel and Oil Prices .......................................... 37
2.1.2 Long Term Trend China vs. ROW ............................................. 39
2.1.3 Long Term Trend Rolled vs. Explosion ..................................... 43

### 2.2 Production By Region ......................................................................... 44

2.2.1 Production by Region (2010 – 2015) .......................................... 44
2.2.2 Production by Region (2015) ...................................................... 47
2.2.3 Production by Country (2015) .................................................... 52

### 2.3 Production by Producer (2015) ......................................................... 55

2.3.1 Roll Bonded Clad Plate ............................................................... 55
2.3.2 Explosion Bonded Clad Plate ..................................................... 56
3 International Trade Flows ........................................................................................................ 57
4 Clad Plate Consumption ........................................................................................................ 59
  4.1 Consumption By region 2004 – 2015 ............................................................................... 59
  4.2 Consumption by Country 2014 - 2015 ............................................................................. 60
5 Market Structures 2015 ......................................................................................................... 61
  5.1 Market by Size .................................................................................................................. 61
      5.1.1 Total Clad Plate ........................................................................................................ 61
      5.1.2 Rolled Bonded Clad Plate ...................................................................................... 67
      5.1.3 Explosion Bonded Clad Plate ................................................................................ 69
  5.2 Market by Grade ............................................................................................................... 71
      5.2.1 Total Clad Plate ....................................................................................................... 71
      5.2.2 Roll Bonded Clad Plate .......................................................................................... 75
      5.2.3 Explosion Bonded Clad Plate ................................................................................ 76
  5.3 Market by Application and Industry ............................................................................... 77
      5.3.1 Clad Plate Consumption by Major Application .................................................... 77
      5.3.2 Clad Plate Consumption by Industry ................................................................... 79
6 Description of Applications .................................................................................................... 81
  6.1 Overview ........................................................................................................................... 81
  6.2 Oil & Gas ........................................................................................................................... 85
      6.2.1 Flowlines & Pipelines ............................................................................................ 85
      6.2.2 Steel Catenary Risers ............................................................................................ 92
      6.2.3 Subsea Jumpers ...................................................................................................... 95
      6.2.4 Subsea Manifold Piping Systems and Pigging Loops ........................................... 97
      6.2.5 Slug Catchers ......................................................................................................... 98
      6.2.6 Topside Pressure Vessels and Separators ........................................................... 101
      6.2.7 Topside Process Piping ......................................................................................... 104
      6.2.8 Splash Zone Sheathing .......................................................................................... 106
  6.3 Refineries, Petrochemical & Chemical Industry .............................................................. 107
      6.3.1 Towers & Columns ................................................................................................ 108
      6.3.2 Coke Drums .......................................................................................................... 114
      6.3.3 Reactors ................................................................................................................. 117
      6.3.4 High Pressure Vessels, Drums and Separators .................................................... 124
      6.3.5 Storage Tanks ........................................................................................................ 127

The World Market for Clad Plate
6.4 Heat Exchangers

6.4.1 Shell & Tube Heat Exchangers
6.4.2 Plate Heat Exchangers
6.4.3 Thin Film/Wiped Film Evaporators
6.4.4 Air/Gas Coolers

6.5 Fertilizer Industry

6.6 Power Generation

6.6.1 Condensers
6.6.2 Geothermal
6.6.3 Coal Gasification/Liquefaction
6.6.4 Hydroelectricity

6.7 Flue Gas Desulfurization

6.8 Seawater Desalination

6.9 Pulp & Paper

6.9.1 Steaming Vessels
6.9.2 Digesters
6.9.3 Black Liquor Tanks
6.9.4 Paper Machine (Former, Press)
6.9.5 Bleaching
6.9.6 Evaporators/Boilers

6.10 Shipbuilding

6.10.1 Chemical Tankers
6.10.2 Icebreaker Hulls

6.11 Transition Joints

6.12 Hydrometallurgy

6.13 Polysilicon

6.14 Food and Beverage

7 Forecast

7.1 Project Activity by Region

7.1.1 Summary
7.1.2 Africa
7.1.3 Asia
7.1.4 Australia
7.1.5 CIS
7.1.6 Europe

The World Market for Clad Plate
7.1.7 Middle East ................................................................. 190
7.1.8 North America ............................................................ 192
7.1.9 South America ........................................................... 194

7.2 Clad Plate Demand Forecast by Region ................................ 195

8 Clad Plate Producers .......................................................... 197

8.1 Producers of Roll Bonded Clad Plate .................................. 197
8.1.1 voestalpine Grobbelch ................................................. 197
8.1.2 JSW ........................................................................... 200
8.1.3 JFE Steel Corporation ................................................. 202
8.1.4 Industeel ................................................................. 204
8.1.5 Nippon Steel & Sumitomo Metal Corp. ......................... 206
8.1.6 Shandong Baode Metal Clad ........................................... 207
8.1.7 Jiangsu Debei ............................................................ 211
8.1.8 AMETEK Specialty Metal Products ............................... 212

8.2 Producers of Explosion Bonded Clad Plate ......................... 214
8.2.1 NobelClad™/DMC Corporation ........................................ 214
8.2.2 BAACLAD™/Asahi Kasei Corporation ........................... 219
8.2.3 TISCO ................................................................. 221
8.2.4 Hanwha Corporation ................................................... 222
8.2.5 Shockwave Metalworking Technologies ................................ 223
8.2.6 Energometall .......................................................... 224
8.2.7 ICEM Engineering Company ......................................... 225
8.2.8 Sichuan Jinglei .......................................................... 226
8.2.9 Baoli Baotai ............................................................. 227
8.2.10 Dalian Shipbuilding ................................................... 228
8.2.11 Nanjing Baotai .......................................................... 229
8.2.12 Xian Tianli ............................................................. 230
8.2.13 Zhengzhou Yugunag ................................................... 231
8.2.14 Nanjing Runbang ...................................................... 232

9 Users of Clad Plate ................................................................ 233

9.1 Clad Pipe Producers and Providers of Weld Overlay ............ 233
9.1.1 List of Companies ....................................................... 233
9.1.2 Butting ................................................................. 234
9.1.3 Canadoil Group ........................................................ 237
9.1.4 Cladtek International ................................................... 240
9.1.5 EEW Erndtebrücker Eisenwerk ..................................... 241
9.1.6 Eisenbau Krämer (EBK) ............................................... 243
9.1.7 Gieminox Tectubi Racordi ............................................ 244

The World Market for Clad Plate
9.1.8 Inox Tech .............................................................................................................. 245
9.1.9 IODS Pipe Clad ........................................................................................................ 246
9.1.10 Jiuli Hi-Tech Metals ............................................................................................... 247
9.1.11 JSW ............................................................................................................................ 248
9.1.12 MesoCoat ................................................................................................................ 249
9.1.13 PCC Klad .................................................................................................................. 250
9.1.14 Proclad Group ......................................................................................................... 251
9.1.15 Protubo ...................................................................................................................... 252
9.1.16 Wellclad .................................................................................................................... 253

9.2 Other End Users .......................................................................................................... 254

10 Authors of this Report .................................................................................................. 255
    Wolfgang Lipp ................................................................................................................ 255
    Alina Racu ....................................................................................................................... 255
    Markus Moll ..................................................................................................................... 255

11 How to Order this report? ............................................................................................. 256
1 INTRODUCTION

1.1 CLAD PLATES

Extensively used in industrial applications, clad steel plates are composed of two or more different materials, called base metal and cladding metal (CRA incl. stainless steel, nickel alloy or Titanium). They combine the higher strength and better thermal conductivity of the base material with corrosion resistance of the cladding material. Due to lower material cost of the base material, clad plate are an economical option compared to solid CRA plates.

There are two different production process to produce clad plates: roll bonding and explosion bonding. Alternatively, weld overlay can be applied on finished equipment (e.g. vessel components, pipes) as a competing solution to clad plates.

The choice of the method depends primarily on the material and dimension requirements. While the roll bonded clad plates are considered to have superior quality over explosion bonding and are usually available in wider widths, the latter is preferred for larger thicknesses or for welding dissimilar metals. Weld overlay is used for large thicknesses but limited surfaces as the process is time consuming.

The tables below compare dimension and material ranges across the three types of metallurgical bonding processes.

<table>
<thead>
<tr>
<th>Clad Plate Type</th>
<th>Plate Thickness [in mm]</th>
<th>Cladding Thickness [in mm]</th>
<th>Width [in mm]</th>
<th>Length [in m]</th>
<th>Weight [in t]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roll Bonded Clad Plate</td>
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<tr>
<td>Explosion Bonded Clad Plate</td>
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<tr>
<td>Weld Overlay</td>
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</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Clad Plate Type</th>
<th>Thin Wall</th>
<th>Heavy Wall</th>
<th>Large Width</th>
<th>Refractory Metals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roll Bonded Clad Plate</td>
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<td></td>
<td></td>
<td>Only available for subscribers.</td>
</tr>
<tr>
<td>Explosion Bonded Clad Plate</td>
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<td></td>
<td>Only available for subscribers.</td>
</tr>
<tr>
<td>Weld Overlay</td>
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<td>Only available for subscribers.</td>
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</tbody>
</table>

This study will cover roll bonded and explosion bonded clad plates and also discuss metallurgical bonded clad pipes and mechanically lined pipes.
1.1.1 Rolled Clad Plates

The process of roll bonding involves a clad assembly made of two plates vacuum sealed together in the sandwich method (i.e. backing steel, cladding, parting compound, cladding and backing steel again) which is then rolled to achieve metal-to-metal bonding, then heat treated and cut. The metallurgical bond is created under high pressure and high temperature conditions.

Japan Steel Works (JSW), a major producer of clad plates and clad pipes describes the process as follows: “Two pairs of plates, each with the backing steel outside and cladding metal inside are matched together to form a composite assembly and then sealed along the edges by welding. The welding is performed to protect the corrosion resistant alloy from possible contamination by exposure to atmosphere during heating before rolling. The composite assembly is heated to the proper temperature in a heating furnace and rolled to the given sizes in order to bond the cladding and backing materials metallurgically. After rolling, the assembly is heat-treated as required considering the mechanical properties of the backing steel and corrosion resistance of the cladding metal. The assembly is then separated into two clad plates to be cut into given dimensions. In order to assure and guarantee the quality of the clad plates, ultrasonic examination and mechanical testing are conducted.”
The production process for producing roll bonded clad plates requires a lot of additional process steps compared to rolling solid steel plates resulting in higher processing and labour costs.

Source: voestalpine Grobblech GmbH, conference paper “Stainless steel clad plates - Production possibilities and typical applications” held at SMR Conference in Marbella, Spain in November 2009

A ‘sandwich’ clad assembly consists of the following layers:

- Base material (shot blasted, bottom side ground)
- CRA material (top side ground)
- Separating medium
- CRA material (bottom side ground=)
- Base material (shot boasted, top side ground)

Afterwards, the clad assembly is basically rolled in a plate mill like a solid plate (re-heating, hot rolling, levelling, and heat treatment). After hot rolling, the plates are separated from each other and processed like individual plates (incl. heat treatment, plasma torch cutting, ultrasonic testing, surface finishing, and packaging).
Materials
The following materials are most often used as base materials for roll bonding:

Carbon steel: ASTM A285 gr A, B, C
C-Mn steel: ASTM A516/ASME SA516 Gr. 60, 65, 70
ASTM A537/ASME SA537 Cl.1, 2
C-Mn-Mo steel: ASME SA204 Gr. A, B, C
Cr-Mo steel: ASTM A387/ASME SA387, Gr. 11, 12, 22, Cl. 1, 2
Cr-Mo-V steel: ASTM A542/ASME SA542, Gr. D

Cladding materials include stainless steel and nickel alloys most often, but also titanium and copper alloys.

Stainless steel: Ferritic/martensitic: 405, 410S, 430
Austenitic: 304/L, 316/L/LMo/Ti/Cb, 317L/LN/LMN, 309, 310S, 321, 347
Super-austenitic: 6Mo, 254SMO, AL-6XN, 25-6Mo, Alloy 28, 926, 904L
Duplex & Super Duplex: 2304, 2205, 2507, 329, 44LN, 255

Ni alloys: Inconel 600, 625, Incoloy 800, 825, Hastelloy C276, C22, C4, Monel 400, Ni 200, 201

Titanium: Gr. 1, 2, 3, 4, 7, 11

Cu alloys: C10200 (B152), C12200, C61400 (B169), C63000 (B171), C46400 (B171), C70600 (B122, B171), C71500
Roll bonded clad plate, source: Voestalpine, www.voestalpine.com

**Dimensions**

Plate thickness:

Cladding thickness:

---

Only available for subscribers.

Plate width:

Plate length:

Plate weight:

Usually the clad plate is supplied with the base material as rolled or shot blasted and the cladding material ground with a grain size of 80.
1.1.2 Explosion Clad Plates

Explosion bonded plates are produced by means of explosion welding, which involves the bonding of two or more dissimilar metals with the aid of explosives. The metal surfaces are compressed together under high pressure from the explosion, which causes the valence electrons of the metals to cross into each other’s sphere of influence. The entire process is carried out at ambient temperature, thus there is no heating of the metals.

During the explosion, a shockwave is created which is transmitted through the two metal layers which can produce a slight wave effect in the material which can be seen with the naked eye in the area where the metals join. This wavy structure constitutes according to roll bonding plate producers a disadvantage in regards with precision, while explosion bonding plate producers argue that this is a sign of better bonding.

Explosion bonding is used to weld compatible metals such as stainless steel and nickel alloys to carbon steel, but especially metals that cannot be welded by conventional processes, such as titanium to steel, aluminium to steel and aluminium to copper or refractory metals to steel.


The World Market for Clad Plate
Dimensions

Plate thickness:

Cladding thickness:

Only available for subscribers.

Plate width:

Plate length:

Weight:

In theory there is no limit to the thickness of the base metal, but rather the limitation comes from the weight capacity of the producers.

Explosion bonded clad plate producers tend to be more competitive compared to roll bonded plate producers in thicknesses above 50 mm. For thicknesses above 100 – 150 mm, end users (pressure vessel manufacturers) often prefer forgings for vessel shells which are then cladded with weld overlay.

Testing

- Shear strength test
- Tensile strength test
- Bending test (face bend test, reverse face bend test)
- Hammer bend test
- Hardness test (for explosion cladding, annealing is necessary for stress relief)
- Ultrasonic testing
1.1.4 Size Range Comparisons

The following chats summarize the size ranges for roll bonded and explosion clad plate. Typically, roll bonded plates have lower thicknesses (most common 25 – 75 mm) compared to explosion bonded plates (most common 75 – 150 mm). As the sizes of explosion bonded plate are limited by the maximum weight per plate (up to 35 t), plates with heavier thicknesses are only available in narrower widths and/or shorter lengths.

![Clad Plate Production – Size Range](image)

*(assumed plate length 12 m, weight limitation explosion 35 t, rolled 17 t)*
1.2 CLAD PIPES

Clad pipes constitute a major end use segment (volumes heavily fluctuating depending on number of pipe projects) application for clad plates as they are used across most of the industries, especially in the oil & gas industry. The adoption of clad pipes as a solution began in the 1990s and the demand in oil & gas is expected to continue to increase.

One reason for choosing clad pipe over solid CRA pipe is the higher strength of the carbon steel host material allowing thinner walls and less weight. The second reason is lower costs with the same corrosion resistance compared to solid CRA material.

There are several production processes for clad pipes. Considering the entire pipe laid since the early 1970s, approximately 50% by length is metallurgically clad (longitudinally welded and seamless) and 50% is lined. However, an emergency replacement project in Kazakhstan brought unexpected demand for metallurgical clad pipe in 2015.

Another technique to manufacture clad pipes is weld overlay where the clad metal layer is deposited on the base metal using arc welding type processes. Weld overlay offers a long life and high reliability corrosion resistance. However, due to the fact that it is very labour intensive and time consuming, weld overlay is used only for small surfaces and niche applications. The main suppliers of weld overlay pipes are ProClad and IODS.

The following table summarizes the main sizes available for each clad pipe process.

<table>
<thead>
<tr>
<th>Clad Pipe Type</th>
<th>NB [in inch]</th>
<th>WT [in mm]</th>
<th>Length [in m]</th>
<th>Suppliers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metallurgically Bonded</td>
<td>4” - 100”</td>
<td>6 - 80</td>
<td>12.8</td>
<td>Butting, Canadoil, EEW, EBK, Gieminox, JSW, Inox Tech, Mechanically Bonded</td>
</tr>
<tr>
<td>Mechanically Bonded</td>
<td>4” - 40”</td>
<td>5 - 65</td>
<td>12.0</td>
<td>Butting, Cladtek, Kuroki, PCC Klad, Proclad</td>
</tr>
<tr>
<td>Co-Extruded Seamless</td>
<td>2” - 14”</td>
<td>6 - 35</td>
<td>12.8</td>
<td>Schulz USA</td>
</tr>
</tbody>
</table>

Only available for subscribers.
2 CLAD PLATE PRODUCTION

2.1 LONG TERM TREND

2.1.1 Correlation to Nickel and Oil Prices


The volumes of clad plate tends to correlate with nickel prices, as high nickel prices make cladding more economical compared to solid plates. However, major projects like Kashagan in 2015 can distort this picture.
European and Japanese suppliers are still leading the market for roll bonded clad plate but Chinese producers are steadily entering the market, building up capacities that could potentially exceed the volumes of today’s top producers.
2.3 PRODUCTION BY PRODUCER (2015)

2.3.1 Roll Bonded Clad Plate

*Top Roll Bonded Clad Plate Producers (2015)*

Only available for subscribers.
2.3.2 Explosion Bonded Clad Plate

*Top Explosion Bonded Clad Plate Producers (2015)*

Only available for subscribers.
Explosion Bonded Clad Plate Consumption by Thickness and Width (2015)

Only available for subscribers.
### 5.2 MARKET BY GRADE

#### 5.2.1 Total Clad Plate

**Clad Plate Consumption by Cladding Grade (2015)**

<table>
<thead>
<tr>
<th>Cladding Grade</th>
<th>Roll Bonded Clad Plate</th>
<th>Explosion Bonded Clad Plate</th>
<th>Total Roll Bonded Clad Plate</th>
<th>Total Explosion Bonded Clad Plate</th>
<th>Total Clad Plate</th>
</tr>
</thead>
<tbody>
<tr>
<td>304/L</td>
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<tr>
<td>316/L</td>
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<tr>
<td>Other 300</td>
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<tr>
<td>Super Austenitic</td>
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<tr>
<td>400 Series</td>
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<tr>
<td>Duplex/Super Duplex</td>
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<td>Other Stainless Steel</td>
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<td>Other Nickel Alloys</td>
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<td>Titanium</td>
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<td>Aluminium &amp; Aluminium Alloys</td>
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<td>Copper &amp; Copper Alloys</td>
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<td>Other</td>
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<tr>
<td>Total Clad Plate</td>
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Only available for subscribers.
5.3.2 Clad Plate Consumption by Industry

*Including: Building & Construction, Yellow Goods, Hydrometallurgy, Defence

<table>
<thead>
<tr>
<th>Industry</th>
<th>Roll Bonded Clad Plate</th>
<th>Explosion Bonded Clad Plate</th>
<th>Total</th>
<th>Roll Bonded Clad Plate</th>
<th>Explosion Bonded Clad Plate</th>
<th>Total</th>
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<tbody>
<tr>
<td>Oil &amp; Gas Upstream</td>
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<tr>
<td>Refineries, Petrochemical, Chemical</td>
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<tr>
<td>Power Generation</td>
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<td>Environmental Control, FGD</td>
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<td>Desalination</td>
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<td>Pulp &amp; Paper</td>
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<td>Food &amp; Beverage</td>
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<td>Shipbuilding</td>
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<tr>
<td>Yellow Goods, Mining</td>
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<tr>
<td>Building &amp; Construction</td>
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<tr>
<td>Transition Joints</td>
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<tr>
<td>Others (Metallurgy, Defence, etc.)</td>
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<td><strong>Total</strong></td>
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<td><strong>Total</strong></td>
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</table>

*Only available for subscribers.*
6 DESCRIPTION OF APPLICATIONS

6.1 OVERVIEW
Clad plates are used for the following industries and applications:

- **Oil & Gas**: separators, absorbers, slug catchers, flowlines, pipelines, catenary risers (SCR), fittings

- **Refineries/Petrochemical Industry**: columns, reactors, fractionators, vacuum towers, distillation towers, hydrocrackers, hydrosulphurisers, coke drums

- **Fertilizer Industry (Urea, Ammonia)**: strippers, reactors, heat exchangers

- **Chemical Industry**: columns, pressure vessels, reactors, polymerisers, pipes, heat exchangers, evaporators, washers

- **Power Generation**: condenser tube sheets, geothermal plants, coal gasification, hydroelectricity (dam gates, shield plates), nuclear plant components, biofuels

- **Environmental Technology**: flue gas desulphurization (flue gas channels, chimney, scrubbers, ducts), garbage incineration plants

- **Seawater Desalination**: pipes, heat exchangers, evaporator shells, water boxes, pump vessels, flash chambers

- **Pulp & Paper**: pulp boilers, bleaching plants, steaming vessels, digesters, evaporators, evaporator pipe plates

- **Food Industry**: boiling pans for breweries, equipment for industrial kitchens, fermenters, premium induction cookware

- **Shipbuilding**: chemical tankers, ice breakers, propeller systems

- **Others**: e.g. transition joints, hydrometallurgy (reactors), metallurgy (electro galvanizing rolls, nitriding salt baths), defence, electrical equipment
6.2.5 Slug Catchers

A slug catcher, which is a part of the gas pipeline system, is essential equipment at the receiving terminal of a multiphase-flow processing plant. Slug catchers can be broadly classified into three following categories:

- Vessel type
- Stored-loop type
- Finger (multiple-pipe) type

A vessel-type slug catcher is a simple two-phase separation vessel.

In a stored-loop-type slug catcher the gas/liquid separation occurs in the vessel, while the liquid is stored in the stored-loop-shaped fingers.

A finger-type slug catcher uses pieces of large-diameter pipe instead of a conventional vessel to provide a buffer volume. Since pipe can be more easily designed to withstand high pressures compared to a vessel, this design is better suited for large-diameter pipes.

![Stored-loop-type slug catcher and finger-type (multiple-pipe) slug catcher](image)


In 2010 NobleClad supplied clad plate (carbon steel API 5L X65M cladded with Inconel 625) for slug catchers in the Gorgon gas project, Australia’s largest resource project:

- 17 plates, thickness 37 mm, width 3.2 m, length 12.6 m
- 136 plates, thickness 37 mm, width 3.2 m, length 12.3 m
In 2016, Belleli Energy/Exterran is set to supply several slug catchers to the Al Dabb'ya onshore pipeline project (for natural gas) in UAE:

- Slug catcher: ID 6.4 m, thickness 48 mm carbon steel SA516 Gr.70N cladded with 3 mm nickel alloy 825, total weight 270 t
- 1st stage separator: ID 6.9 m, thickness 44 mm carbon steel SA516 Gr.70N cladded with 3 mm nickel alloy 825, total weight 270 t
- 2nd stage separator: ID 6.4 m, thickness 26 mm carbon steel SA516 Gr.70N cladded with 3 mm nickel alloy 825, total weight 168 t

Separator equipment, source: NobleClad, www.nobleclad.com

Italian equipment maker Bremaba & Rolle e.g. produced the following slug catcher vessels. Weld overlay was used as competing technology to clad plate. The left one was supplied for a refinery project in Qatar and had a weight of 140 t.; A516 Gr. 70 + 316L (76 + 5 mm) were used. The vessel on the right was delivered for a gas plant in the UAE. The weight was 400 t; thickness of 135 mm (SA5126 Gr. 65 + 625).

Source: Brembana&Rolle, www.brembanarolle.com

The World Market for Clad Plate
Dimensions:

Thickness:  26 – 150 mm plus cladding; e.g. 26 + 3, 37 + 3, 40 + 4, 44 + 3, 48 + 3, 76 + 5, 135 + 3, 150 + 3 mm

Length:  around 12 m

Materials

Base:  Carbon steel (e.g. SA516 G70)

Cladding:  316L, 825, 625
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