ArcelorMittal USA

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Plate

Roll-Bonded Clad Steels

Introduction

The former Lukens Steel Company, working with International Nickel Company, developed the process to produce roll-bonded clad plate and introduced the product to the industrial marketplace in 1930. Clad steels have provided a cost-effective solution to industry needs ever since.

Today, ArcelorMittal USA is a world leader in the production of roll-bonded clad and the leading producer of plate steels in North America.

The first clad steel plate application demonstrated the material's durability and corrosion resistance. The first nickel clad steel plate ever rolled was used in the construction of a railroad tank car designed to carry phenol and, later, caustic soda. Built in 1930, the tank car pictured on the right was in service for 45 years.

How Clad Plate Works

Clad plate is a composite, the thickness being comprised of two metals bonded across their interface by mill rolling. Because the two metals are metallurgically bonded, clad plates behave mechanically like single, homogeneous plates.

The base metal in the composite is carbon or alloy steel and is the thicker of the two metals. This economical "backing steel" provides the required strength and structural integrity to the composite.

The thinner layer of the composite, usually ranging between 10% and 20% of the total thickness, but available from 5% to 40%, may be stainless steel, nickel, nickel alloy, copper or copper alloy. This "cladding", is normally selected for corrosion resistance and allows the designer to gain the desired benefit of solid high-alloy plate.

In summary, roll-bonded clad steels provide several important benefits to the designer and fabricator.

- *They are economical,* providing the same level of performance as solid high-alloy plates, at a fraction of the cost.
- *They provide structural stability,* with a carbon or alloy steel providing the required strength.
- *They offer design freedom,* with integral bonding that allows for design and fabrication of shapes to meet a range of process and space needs.

Roll Bonding Process

Each order for clad is unique, representing the requirements of a custom-engineered end product. Cladding and backing materials, thicknesses, and plate dimensions, as well as other special requirements, must be considered in the manufacturing process.

While actual thickness or combinations of materials may necessitate the use of alternative plans, the manufacturing of most roll-bonded clad plates is accomplished by assembling a 4-ply clad "pack", comprised of two "backing steel" slabs and two "cladding" inserts, as shown in Figure 1. (Note the nickel plating is at the cladding-backing steel interface and parting compound is at the cladding-cladding interface). The thickness and size of these components are specially designed to produce finished plate with the customer's required parameters.

The assembled pack is hot-rolled at high temperature and pressure where the thickness is reduced and the backing steel is metallurgically bonded to the cladding, as shown in Figure 2.

The parting compound prevents bonding of one clad insert to the other. This allows the rolled assembly to be opened, yielding two clad plates, each having the required length, width, cladding and backing thickness as shown in Figure 3.

Figure 1
Schematic Assembly of 4-Ply Roll-Bonded Clad

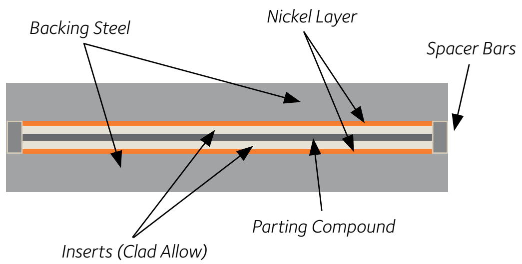


Figure 2
Hot Rolling Schematic 4-Ply Roll-Bonded Clad

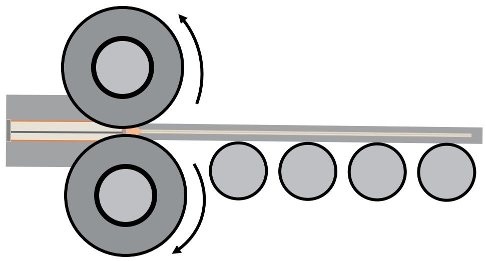
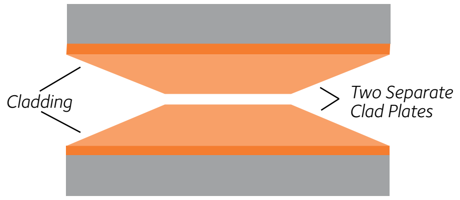


Figure 3



Clad Plate to Fit Your Needs

ArcelorMittal USA roll-bonded clad plates are normally available in widths up to 160 inches, lengths up to 500 inches and composite thicknesses to 6 inches. However, the roll-bonded process is most competitive in composite thickness under 3 inches. Refer to Table 2 for specific width, thickness and length combinations.

- All roll-bonded clad plates are produced to conform to ASTM specifications for Chromium (A263), Chromium Nickel (A264), Nickel and Nickel-Base Alloy (A265) or Copper and Copper Alloy (B432) Clad Steel Plate.
- Backing materials can be produced to a variety of specifications, some of which are listed in Table 3. Any of these may include the ArcelorMittal USA Fineline® low sulfur melting practice.
- Complete heat treating, plasma and flame cutting, plate planing and polishing are available, all of which give the equipment designer and fabricator greater flexibility when using clad. Ultrasonic and other non-destructive tests are also available.
- ArcelorMittal USA clad products are packaged using wooden spacers, waterproof wrapping and steel banding to insure cleanliness and protection during shipment. Details are available on request.

Fabrication of Clad Plate

Although clad has been used for many years, some of the more frequently asked questions about clad deal with fabrication. How do I cut it? What about forming? Will the composite come apart?

In many cases, cutting, forming, welding, drilling or machining can be performed more easily on clad steels than on solid high alloy materials. However, like many high alloys, clad steels are premium products and should be handled as such. Care should be exercised to preserve the cladding surface properties by avoiding physical damage in handling or by contamination with free iron from contact with forming. For additional Fabrication information, refer to ArcelorMittal USA Customer Technical Service Department.

Shapecutter making multiple cuts on a clad plate.

Thermal Cutting

ArcelorMittal USA clad steels, with the exception of copper clad, can be thermal cut by following procedures similar to those used on carbon steel. For plates with cladding percentages up to 30%, greater if the composite is thicker than 1/2 inch, successful cutting is based on using lower oxygen cutting pressures and larger cutting tips than would be utilized for equivalent thickness of carbon steel. All types, thicknesses and percentages of cladding may be cut with plasma arc torches. Representative oxygen cutting conditions for various thicknesses of clad steel are given in Table 1.

Clad plate should be protected during any cutting, with the cladding side face down to facilitate cutting through the backing side. This is necessary to allow the resulting slag stream from the backing steel to act as the burning agent in cutting the cladding. For plasma-arc cutting, the cladding side may remain up. Cutting of copper or cupro-nickel clad requires specialized controls and settings. For help with these, or any other clad combination, please consult ArcelorMittal Customer Technical Service Metallurgists.

Shearing, Punching and Machining

Shearing and punching should be done with the cladding side up in order that the burr occurs on the backing steel side. Layout may be done on the cladding side. Shearing limits are essentially the same as for carbon steel.

If the sheared clad plates are to be welded, consideration should be given to shear droop. For machined edges, or when full alloy welding is employed, this effect is of no consequence. However, if the shear droop is to be removed, allowances up to 1/8 inch should be made.

Clad steels can be machined and drilled using sharp tools and firm feeds with tool speeds slightly slower than those used for carbon steel. Drilling should be done from the cladding side. With work hardenable stainless cladding, tools should continually traverse the stainless surface.

Table 1
Machine Flame Cutting Clad Steels

			Cutting Tips			
			Orifice Size		Approx. Equivalent Commercial Tip Size	
Plate Gauge, Inches	Cutting Speed Inches/ Minute	Oxygen Cutting Pressure Min.-Max. psi	Diameter Inch	Drill Number	Airco	Oxweld
3/16	22-25	5-7	.046	56	1	4
1/4	19-21	6-8	.055	54	2	4
3/8	16-18	7-10	.063	52	3	6
1/2	15-17	7-12	.073	49	4	6
5/8	14-16	8-13	.082	45	5	8
3/4	13-15	9-14	.096	41	6	8
1	12-14	10-16	.111	34	7	10
1-1/2	10-12	12-18	.128	30	8	12
2	9-11	12-18	.147	26	9	16
2-1/2	7-9	16-24	.169	18	10	16

Forming

Roll-bonded clad plates are readily formed, hot or cold, in much the same manner as solid carbon or alloy steel subject to any restrictions imposed to protect the cladding alloy from any ill effects of sensitization. Prior to forming, all working surfaces of the plate and machine must be free of loose scale, steel particles and shop dirt to prevent pitting and embedding of foreign material in the plate.

Hot forming may be performed using conventional equipment, however, care must be exercised to maintain backing steel properties and corrosion resistance of the cladding. Furnace atmosphere is important. Reducing conditions should be avoided on stainless clad to prevent carburizing conditions that might impair corrosion resistance.

In contrast, materials clad with nickel, INCONEL® and MONEL®, should be heated in reducing atmosphere furnaces. More conventional practices for heating clad products, such as low sulfur fuels, removing grease, paint and other marking materials and, whenever possible, heating with the cladding side up, are also recommended. Heating temperatures normally augment the heat treatment given clad steels at the mill, with the same schedules used as would be for carbon or alloy steel. Successful forming has been performed in the normalizing range of 1550ºF – 1750ºF, or from the solution annealing temperature, if applicable, which will vary with the cladding alloy. Care should be exercised to avoid excessive heating in the sensitizing range for cladding alloys subject to that condition. When mill heat treatments are affected, restoration by following the conditions reported on the mill certifications can be accomplished. Consult ArcelorMittal USA Customer Technical Service Department for specific technical assistance.

For cold forming applications, special attention should be paid to the condition of the plate edges. Flame cut surfaces should be machined or softened, and notches or rough cuts conditioned prior to fabrication. Formability of the composite plate will depend on the ductility of the backing and the cladding. It will not be affected by the bond characteristics under normal forming conditions. In the presence of excessive stress or strain, as in the cold forming of heads where repeated blows or spinning operations are encountered, extra precautions are recommended because of clad's high value. Clad heads are successfully produced using conventional or proprietary methods. Consult ArcelorMittal USA Customer Technical Service Department for technical assistance if your applications involve severe cold forming.

The integrity of the roll-bonded clad demonstrated by twist and bend samples.

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Welding

Welds in clad materials are made with the same fit-for-service requirements as solid material welds, with one notable exception. Due to the presence of a backing steel substrate, care must be taken to avoid welding procedures that produce chemically diluted welds on the cladding side. The normal procedure for butt-welding clad plates is to weld the backing steel side with the appropriate carbon or alloy steel consumable first, then weld the cladding side with the high alloy consumable as shown in Figure 4. This process avoids depositing carbon steel on high alloy, a situation that can result in sufficient dilution of nickel, chromium and molybdenum to produce an air hardenable intermetallic which may be susceptible to weld cracking. In the case of more highly alloyed cladding, the use of overmatching consumables may be considered.

Design considerations may render welding from both sides impossible. In this case, welding can be accomplished from the cladding side only as shown in Figure 5. While more demanding and requiring more control of dilution, usually with higher alloy consumables (overmatching), functional, corrosion resistant welds can be produced. It is important to note that during this process, care should be exercised to avoid contaminating the initial passes into the backing with the cladding, particularly with the high alloys, so as to avoid producing brittle intermetallics. This is easily accomplished by proper joint design or sufficiently stripping back the cladding.

Thin clad plates are usually most economically welded using full alloy welds. This has been particularly true with the high performance clads used in flue gas desulfurization applications where synergic feedback Gas Metal Arc Welding (GMAW) equipment has proven to be a major advancement in the production of low heat input welds necessary to reduce dilution and produce sound, corrosion resistant welds. Gas Tungsten Arc Welding (GTAW) has also been used for these purposes, though it is usually less efficient. In these cases, the sequence of welding may involve the cladding side first.

Welding of straight chromium (400-series stainless) clad, nickel clad, copper and copper-nickel clad steels involves slightly special considerations, but are readily weldable like the 300-series stainless clads. Consult ArcelorMittal USA plate offices to discuss your special needs.

Welding solid alloy internals of a clad reactor.

Figure 4
Typical welding procedure. Note the backing steel side is welded first.

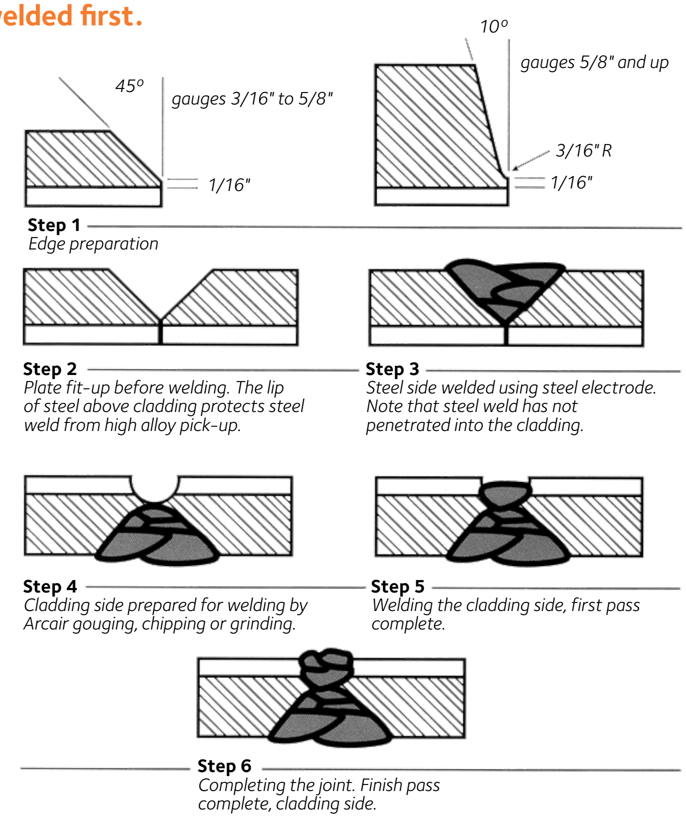

Figure 5
Typical welding procedure from cladding side only.

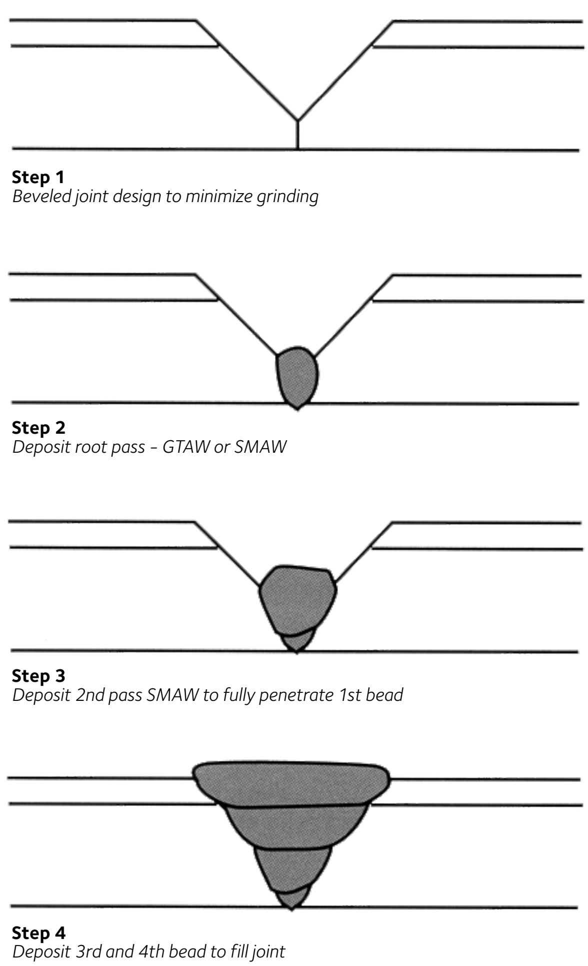

Table 2
Standard Size Card: 300-Series and 400-Series Stainless Clad

		Length										
Total Thickness	Cladding Thickness	70″ 1778 mm	80″ 2032 mm	90″ 2286 mm	100″ 2540 mm	110″ 2794 mm	120″ 3048 mm	126″ 3200 mm	130″ 3302 mm	140″ 3556 mm	150″ 3810 mm	160″ 4064 mm
.25″ 6.35 mm	40%	540 13716	540 13716	540 13716	540 13716	540 13716	540 13716	540 13716	—	—	—	—
.375″ 9.53 mm	40%	560 14224	600 15240	600 15240	600 15240	600 15240	600 15240	600 15240	—	—	—	—
.50″ 12.7 mm	.125″ 3.175 mm	560 14224	600 15240	600 15240	600 15240	600 15240	600 15240	600 15240	600 15240	600 15240	600 15240	—
.75″ 19.05 mm	.125″ 3.175 mm	560 14224	600 15240	600 15240	600 15240	600 15240	600 15240	600 15240	600 15240	600 15240	600 15240	600 15240
1.00″ 25.4 mm	.125″ 3.175 mm	560 14224	600 15240	600 15240	600 15240	600 15240	600 15240	600 15240	600 15240	600 15240	600 15240	600 15240
1.25″ 31.75 mm	.125″ 3.175 mm	560 14224	600 15240	600 15240	600 15240	600 15240	600 15240	600 15240	600 15240	580 14732	520 13208	490 12446
1.50″ 38.1 mm	.125″ 3.175 mm	560 14224	600 15240	600 15240	600 15240	600 15240	540 13716	520 13208	500 12700	460 11684	430 10922	400 10160
1.75″ * 44.45 mm	.125″ 3.175 mm	560 14224	600 15240	600 15240	560 14224	510 12954	460 11684	440 11176	430 10922	400 10160	370 9398	340 8636
2.00″ * 50.8 mm	.125″ 3.175 mm	560 14224	600 15240	540 13716	490 12446	460 11684	420 10668	400 10160	390 9906	360 9144	340 8636	320 8128
2.50″ * 63.5 mm	.125″ 3.175 mm	480 12192	480 12192	480 12192	440 11176	400 10160	360 9144	350 8890	320 8128	300 7620	270 6858	250 6350
3.00″ 76.2 mm	.125″ 3.175 mm	480 12192	480 12192	480 12192	440 11176	400 10160	360 9144	350 8890	320 8128	300 7620	270 6858	250 6350
3.50″ 88.9 mm	.125″ 3.175 mm	480 12192	480 12192	480 12192	440 11176	400 10160	360 9144	350 8890	320 8128	300 7620	270 6858	250 6350
4.00″ 101.6 mm	.125″ 3.175 mm	480 12192	440 11176	390 9906	350 8890	320 8128	300 7620	290 7366	270 6858	250 6350	240 6096	220 5588
4.50″ 114.3 mm	.125″ 3.175 mm	450 11430	390 9906	350 8890	310 7874	280 7112	260 6604	250 6350	240 6096	220 5588	210 5334	200 5080
5.00″ 127 mm	.125″ 3.175 mm	400 10160	350 8890	310 7874	280 7112	260 6604	230 5842	225 5715	220 5588	200 5080	190 4826	180 4572
5.50″ 139.7 mm	.125″ 3.175 mm	370 9398	320 8128	280 7112	260 6604	230 5842	210 5334	210 5334	200 5080	180 4572	170 4318	160 4064
6.00″ 152.4 mm	.125″ 3.175 mm	340 8636	300 7620	260 6604	240 6096	210 5334	200 5080	200 5080	180 4572	170 4318	160 4064	160 4064

Note:

Refer the following to ArcelorMittal USA for availability:

1. Widths greater than 120″ – indicated by shading in the table above
2. Cladding materials other than the 300-series and 400-series stainless
3. Cladding thickness over .125 inches (3.175 mm)
4. Widths under 70 inches (1778 mm) and over 160 inches (4064 mm)
5. Total thickness indicated by an asterisk (*) when longer lengths are required

Table 3

International Cross Reference of Commonly-Specified Cladding and Backing Materials

(Other grades of Carbon, Alloy and Stainless Steel, Nickel and Nickel Alloys and Copper Alloys are available. Please refer others to ArcelorMittal USA)

		Similar Types		
	ASTM (ASME) ALLOY TYPE (USA)	DIN (GERMAN)	BS (BRITISH)	JIS (JAPANESE)
Popular Backing Steels *				
Structural – Carbon	A36	17100 - St44-2	4360-43B	G3106-SM400
Pressure Vessel – Carbon	A285**	17155 - HI, HII	1501 – 151, 360,400	G3103-SB410
	A515**	17155 - HII, HIII, HIV	1501 – 161, 360,400, 430	G3013 – SB410, 450, 480
	A516**	17135 - ASt41, 45, 52	1501 – 224, 360, 400	G3118 – SGV410, 450, 480
Pressure Vessel – Alloy	A204**	17155 - 15Mo3, 16Mo5	1501 –240	G3103 – SB46M
	A387**	17155 - 13CrMo44	1501 – 620 Gr27, 31	G4109 – SCMV (1-6)
		17175 - 10CrMo9.10	1501 – 621, - 622 Gr. 31, 42	__
Popular Cladding Metals *				
Stainless Steels	A240 Type410S	17440 - 1.4000	403S167	G3601 – 410-S
	A240 Type 304	17440 - 1.4301	304S15	G3601 – 304
	A240 Type 304L	17440 - 1.4306	304S12	G3601 – 304L
	A240 Type 321	17440 - 1.4541	321S12	G3601 – 321
	A240 Type 347	17440 - 1.4550	347S17	G3601 – 347
	A240 Type 316	17440 - 1.4401	316S16	G3601 – 316
	A240 Type 316L	17440 - 1.4404	316S12	G3601 – 316L
	A240 Type 317L	17440 - 1.4438		G3601 – 371L
Nickel & Nickel Alloys				
	B 162/Alloy 200	17743 - 2.4066	3072 NA11	G3602, G4902
	B 127/Alloy 400	17743 - 2.4360	3072 NA13	G3602, G4902
	B 168/Alloy 600	17743 - 2.4816	3072 NA14	G3602, G4902
	B 443/Alloy 625	17774 - 2.4856	3072 NA21	G3602, G4902
	B 409/Alloy 800	17774 - 1.4876	3072 NA15	G3602, G4902
	B 424/Alloy 825	17774 - 2.4858	3072 NA16	G3602, G4902
	B 575/Alloy C276	17774 - 2.4819		G3602, G4902
Copper & Copper Alloys				
	B171 No.706/Alloy Cu-Ni-90-10	17663 - 2.0872	__	G3604
	B171 No. 715/Alloy Cu-Ni 70-30	17663 - 2.0882	__	G3604

* This cross reference is provided as a guide to similar grades only. Exact substitution may not be possible.

** Various grades and/or classes available

Stress relieving may be required by the design specifications or as a result of the ASME Pressure Vessel Code and would be based on the thickness of the backing steel. The 400-series stainless clad should be stress relieved in the range of 1100ºF – 1350ºF with consideration given to the backing properties. The 300-series stainless steels can be subject to carbide precipitation during stress relief, but this can be minimized by the use of extra low carbon or stabilized grades.

Preheating before welding is a requirement determined by the nature of the backing steel. A302, A204 and A387 are some of the common alloy steels requiring preheating. Preheating may also be considered or heavy thickness clad plate or for highly restrained joints. Refer to the ArcelorMittal USA Fabrication Guide for preheating guidelines.

Meeting the Challenge

Since its successful application in 1930, clad plate has found its way into a wide range of applications across a number of industries.

Process Vessels

Used extensively in the construction of vessels for processing petroleum, chemicals, paper, food and other products, clad plate has proven its ability to withstand elevated temperatures and thermal and pressure cycling.

- ArcelorMittal USA roll-bonded clad can be found in catalytic cracking units, hydrocrackers, reactors, coke drums and other equipment used in petroleum refining and natural gas processing.
- The chemical industry uses roll-bonded clad for a number of applications, such as reactor vessels, rotating disk columns and vapor bodies.
- In the pulp and paper industry, roll-bonded clad has been used in batch and continuous pulp digesters, evaporators and other equipment.

Pressure vessels used in the hydrocarbon processing industry represent the single largest application of roll-bonded clad plate.

Inspecting the interior of a formed clad column.

Pollution Control

ArcelorMittal USA clad is helping many electrical utilities solve material performance problems in flue gas desulfurization (FGD) systems. Clad offers an economical, effective solution in the highly corrosive environments found in areas of wet limestone scrubbing systems such as absorber towers, outlet and breeching ducts and in chimney liners. See #9 in Technical Literature below.

Other

Used in hoppers, chutes, bins and other material handling applications, roll-bonded clad helps assure long, virtually maintenance-free service life.

The holds of ships carrying corrosive bulk cargo benefit from roll-bonded clad plate.

The new 1000-foot concrete chimney (left, foreground) at Allegheny Power System's Harrison Station, W. VA, contains three roll-bonded clad flues fabricated and erected by Graver Tank & Manufacturing of Houston, TX. This tower represents the largest application for roll bonded clad in the power generation market at the time..

Technical Literature:

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3. Morse, S. L. and Stevens, C.E.: *"Alloy C-276 Clad Steel Plate for Handling Scrubbed Flue Gases,"* Paper No. 29, AIRPOL/90, Nashville, TN October 1990.
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9. NACE RP0199 – "Installation of Stainless Chromium-Nickel Steel and Nickel-Alloy Roll-Bonded and Explosion-Bonded Clad Plate in Air Pollution Control Equipment", Houston, TX 2001.

Additional Information

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