

Tubes comprised of a ferritic boiler steel core with an austenitic, corrosion-resistant cladding of INCONEL® alloy 625 offer a unique combination of properties for service in aggressive elevated temperature conditions such as those encountered in many power and process boilers. Ferritic steels are favored for steam service because they are essentially immune to chloride stress corrosion cracking (SCC). Unfortunately, such steels have very marginal resistance to the aggressive corrodents in boiler environments. INCONEL alloy 625, however, offers excellent resistance to corrosive attack. Thus, ferritic steel tubes clad with INCONEL alloy 625 are ideal for steam service in boilers, especially those exhibiting very corrosive conditions.

Chemical Composition

The composition range of the alloy 625 cladding of the INCOCLAD® tubes is the same as that of conventional alloy 625 tubes and is specified by ASTM B 444 - UNS N06625. The limiting chemical composition of alloy 625 is given in Table 1.

The grade and composition of the steel substrate are dependent on the steel specified. Some of the common boiler steel grades used for the tube core are ASTM A 210 - grade A-1, ASTM A 213 - grade T-2, and DIN 17175 - grade 15Mo3.

Table 1 - Limiting Chemical Composition of INCONEL alloy 625 (UNS N06625), %

| | |
|------------------------------|------------|
| Nickel..... | 58.0 min. |
| Chromium..... | 20.0-23.0 |
| Molybdenum..... | 8.0-10.0 |
| Niobium (plus Tantalum)..... | 3.15-4.15 |
| Iron..... | 5.0 max. |
| Aluminum..... | 0.40 max. |
| Titanium..... | 0.40 max. |
| Manganese..... | 0.50 max. |
| Cobalt (if determined)..... | 1.0 max. |
| Carbon..... | 0.10 max. |
| Sulfur..... | 0.015 max. |
| Phosphorus..... | 0.015 max. |
| Silicon..... | 0.50 max. |

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Corrosion Resistance

The resistance to corrosion of the alloy 625 cladding is essentially the same as that of conventional alloy 625 products. To verify this, samples of INCOCLAD tubes (after removing the steel core) and wrought commercial alloy 625 were tested in a laboratory atmosphere designed to simulate the severe environment of a waste incinerator. The atmosphere was nitrogen with 10% oxygen, 10% carbon dioxide, 20% water (moisture), 1500 ppm hydrogen chloride, and 300 ppm sulfur dioxide. A synthetic ash of 41% lead chloride, 20% zinc chloride, 22% potassium chloride, and 17% sodium chloride was periodically applied to the cladding surface of the sample. The test samples were exposed at 550°C (1020°F) for 332 hours.

Duplicate samples of the INCOCLAD tube cladding corroded 0.002 and 0.008 in. (0.051 and 0.203 mm) while the conventional alloy 625 samples corroded 0.006 and 0.009 in. (0.152 and 0.229 mm).

INCOCLAD® 625 / Steel



Formability

INCOCLAD 625/Steel clad tubes are supplied in the annealed condition. Thus, both the steel core and the alloy 625 cladding exhibit excellent ductility. The metallurgical bond between the steel substrate and the alloy cladding is of very high strength such that tubes may be hot or cold formed by the conventional techniques commonly employed for solid monolithic alloy tubes. The formability limits of the clad tubes are demonstrated by a flattening test in Figure 1 and a flare test in Figure 2. It can be seen that the alloy/steel interface (delineated for the photographs by slightly oxidizing the steel surface prior to testing) is sound in both tests. No delamination is discernable. When clad tubes were deformed to failure, the fracture surface indicated that fracture was ductile.

Welding

INCOCLAD 625/Steel clad tubes may be joined by procedures essentially identical to those used for welding conventional INCONEL alloy 625 tubes. Recommended welding products are INCONEL Filler Metal 625 for GMAW and GTAW and INCONEL Welding Electrode 112 for SMAW. The included angle of the weld joint should be as steep as practical to minimize iron dilution of the weldment.

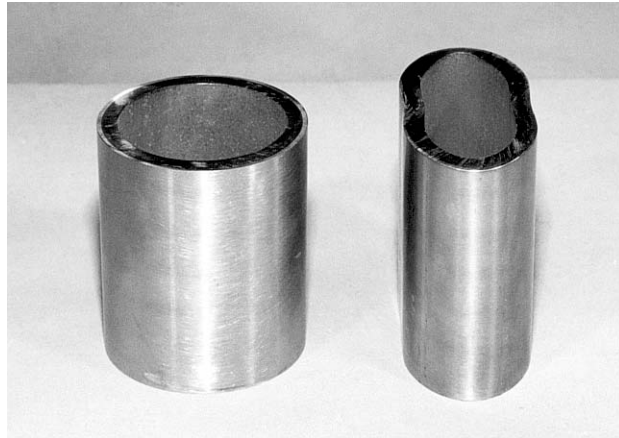


Figure 1.



Figure 2.

Product Availability

INCOCLAD 625/Steel tubes are manufactured to customer specifications. Potential customers should contact Special Metals with their dimensional needs and the grade of steel required. The INCONEL alloy 625 cladding is typically 0.050 to 0.100 in. (1.27 to 2.54 mm) in thickness.

Applications

INCOCLAD® alloy 625/Steel bimetallic clad tubes are designed for service as boiler tubes for steam generation and heating in municipal solid waste (MSW) fired boilers in waste-to-energy (WTE) incineration systems. Boiler tubes in these environments are exposed to corrosion by halogens such as chlorine and fluorine generated during the incineration of plastics. Steels and iron-base alloys are rapidly attacked by these elements because iron forms stable compounds with the halogens at elevated temperatures. Alloy 625, however, by virtue of its high nickel content and low iron content offers excellent resistance to attack by halogens as nickel does not form stable compounds with these elements at elevated temperatures. Alloy 625 also offers excellent resistance to oxidation, sulfidation, and carburization due to its content of chromium. INCONEL Filler Metal 625 has been successfully used for many years for weld overlay of boiler components for increased resistance to corrosion in WTE boilers in MSW incineration systems. Production of alloy 625 clad tubes is an extension of that proven technology and provides an even better product due to the fine-grained wrought structure of the alloy 625 cladding.

The black liquor recovery boilers used in pulp processing for paper production should also benefit from the use of INCOCLAD alloy 625/Steel boiler tubes. These boilers burn the concentrate left from de-watering the spent liquor from the pulp digestion process. Consequently, the boiler tubes are exposed to a very corrosive environment that contains significant concentrations of halides and sulfur. As in WTE boilers, INCONEL Filler Metal 625 weld overlays have been widely used for protection of the boiler components against corrosion. Thus, alloy 625 clad tubes offer proven corrosion resistance to the exterior environment and SCC resistance to the steam in the interior in a fully wrought tube.

Production and Testing of Clad Tubes

INCOCLAD tubes are produced by means of co-extrusion. The inner component (structural steels such as ASTM A213 T-2 or 15Mo3) and outer component (INCONEL alloy 625) are assembled together as a billet which is hot extruded. The metallurgical bond between the two alloys is achieved by the high temperature and pressure required in this process. The tube shell is then cold worked to the required diameter and wall thickness by standard tube reducing/pilgering techniques. Tubing is ultrasonically tested to ensure a good metallurgical bond between the two alloy layers. This is essential in service for effective heat transfer. The inner tube material is mechanically tested to ensure conformance to the normal pressure vessel standards.



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U.S.A. Special Metals Corporation

Billet, rod & bar, flat & tubular products

3200 Riverside Drive
Huntington, WV 25705-1771
Phone +1 (304) 526-5100
+1 (800) 334-4626
Fax +1 (304) 526-5643

Billet & bar products

4317 Middle Settlement Road
New Hartford, NY 13413-5392
Phone +1 (315) 798-2900
+1 (800) 334-8351
Fax +1 (315) 798-2016

Atomized powder products

100 Industry Lane
Princeton, KY 42445
Phone +1 (270) 365-9551
Fax +1 (270) 365-5910

Shape Memory Alloys

4317 Middle Settlement Road
New Hartford, NY 13413-5392
Phone +1 (315) 798-2939
Fax +1 (315) 798-6860

United Kingdom

Special Metals Wiggin Ltd.

Holmer Road
Hereford HR4 9SL
Phone +44 (0) 1432 382200
Fax +44 (0) 1432 264030

Special Metals Wire Products

Holmer Road
Hereford HR4 9SL
Phone +44 (0) 1432 382556
Fax +44 (0) 1432 352984

China

Special Metals Pacific Pte. Ltd.

Room 1802, Plaza 66
1266 West Nanjing Road
Shanghai 200040
Phone +86 21 3229 0011
Fax +86 21 6288 1811

Special Metals Pacific Pte. Ltd.

Room 910, Ke Lun Mansion
12A Guanghua Road
Chaoyang District
Beijing 100020
Phone +86 10 6581 8396
Fax +86 10 6581 8381

France

Special Metals Services SA

17 Rue des Frères Lumière
69680 Chassieu (Lyon)
Phone +33 (0) 4 72 47 46 46
Fax +33 (0) 4 72 47 46 59

Germany

Special Metals Deutschland Ltd.

Postfach 20 04 09
40102 Düsseldorf
Phone +49 (0) 211 38 63 40
Fax +49 (0) 211 37 98 64

Hong Kong

Special Metals Pacific Pte. Ltd.

Unit A, 17th Floor, On Hing Bldg
1 On Hing Terrace
Central, Hong Kong
Phone +852 2439 9336
Fax +852 2530 4511

India

Special Metals Services Ltd.

No. 60, First Main Road, First Block
Vasantha Vallabha Nagar
Subramanyapura Post
Bangalore 560 061
Phone +91 (0) 80 2666 9159
Fax +91 (0) 80 2666 8918

Italy

Special Metals Services SpA

Via Assunta 59
20054 Nova Milanese (MI)
Phone +390 362 4941
Fax +390 362 494224

The Netherlands

Special Metals Service BV

Postbus 8681
3009 AR Rotterdam
Phone +31 (0) 10 451 44 55
Fax +31 (0) 10 450 05 39

Singapore

Special Metals Pacific Pte. Ltd.

24 Raffles Place
#27-04 Clifford Centre
Singapore 048621
Phone +65 6532 3823
Fax +65 6532 3621

Affiliated Companies

Special Metals Welding Products

1401 Burriss Road
Newton, NC 28658, U.S.A.
Phone +1 (828) 465-0352
+1 (800) 624-3411
Fax +1 (828) 464-8993

Canada House

Bidavon Industrial Estate
Waterloo Road
Bidford-On-Avon
Warwickshire B50 4JN, U.K.
Phone +44 (0) 1789 491780
Fax +44 (0) 1789 491781

Controlled Products Group

590 Seaman Street, Stoney Creek
Ontario L8E 4H1, Canada
Phone +1 (905) 643-6555
Fax +1 (905) 643-6614

A-1 Wire Tech, Inc.

A Special Metals Company

4550 Kishwaukee Street
Rockford, IL 61109, U.S.A.
Phone +1 (815) 226-0477
+1 (800) 426-6380
Fax +1 (815) 226-0537

Rescal SA

A Special Metals Company

200 Rue de la Couronne des Prés
78681 Epône Cédex, France
Phone +33 (0) 1 30 90 04 00
Fax +33 (0) 1 30 90 02 11

DAIDO-SPECIAL METALS Ltd.

A Joint Venture Company

Daido Shinagawa Building
6-35, Kohnan 1-chome
Minato-ku, Tokyo 108-0057, Japan
Phone +81 (0) 3 5495 7237
Fax +81 (0) 3 5495 1853

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