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.

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

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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.

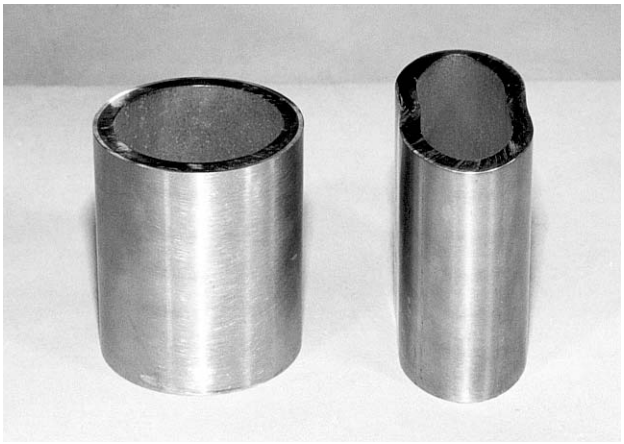

Figure 1.

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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