INCOCLAD® 671/800HT®

Low grade coals form sodium and potassium sulfate complexes that eat away the protective oxide film on superheater and reheater tubing almost as fast as it forms. Low-grade oil fuels form vanadium compounds that do the same thing. This is “metal wastage corrosion” and it can cause tube failures in a matter of months, even days. Complexes formed by the sulfur/vanadium compounds create a molten flux which attacks and removes the protective oxide scale, exposing more base metal. This again oxidizes, is attacked by the flux, and so on, over and over again. Research by the U.S. Institute of Fuel has shown that higher chromium content alloys offer the best resistance to this type of corrosion, with a 50% chromium/50% nickel composition offering the optimum performance. See Figure 1.

In response to this need for a material for superheater and reheater tubing in power plant boilers, for high-temperature recuperators, and for coal gasification and liquefaction technologies, Special Metals Corporation has reintroduced INCOCLAD® 671/800HT® co-extruded, duplex tubing. In fact, the new product is an improvement over the earlier material in that the original alloy 800H substrate has been upgraded to alloy 800HT, with higher allowable design stresses.

The product combines the high-temperature strength and corrosion resistance of seamless INCOLOY® alloy 800HT tubing with the corrosion resistance of cladding in INCONEL® alloy 671, a nominal 50/50 Ni/Cr composition specially developed to resist metal wastage corrosion, with excellent resistance to oxidation and carburization, and particular resistance to fuel-ash corrosion in atmospheres containing sulfur and/or vanadium. This type of attack, variously known as coal-ash, fuel-ash or fly-ash corrosion, arises in coal-fired boilers at temperatures between 1100 and 1300°F (590 and 700°C) and can be so severe that tube service life can be severely curtailed.

INCONEL alloy 671 has an ideal resistance to fuel-ash corrosion and to oxidation and carburization even though its high-temperature strength is not appropriate for high-pressure applications. INCOLOY alloy 800HT, however, has exactly the right hot-strength qualities and has long been a standard material for a wide range of thermal processing applications. The combination of both materials in a co-extruded seamless tubular product (alloy 800HT clad with alloy 671) is the key to long service and cost-effective performance in this type of application. The compositions of both alloys contained in the duplex product are quoted in Table 1.

Table 1 - Chemical Compositions, %, of INCOCLAD 671/800HT Substrate and Cladding

	INCOLOY alloy 800HT Substrate* (Limiting)	INCONEL alloy 671 Cladding (Nominal)
Nickel	30.0-35.0	51.5
Chromium	19.0-23.0	48.0
Iron	39.5 min.	-
Carbon	0.06-0.10	0.05
Aluminum	0.25-0.60	-
Titanium	0.25-0.60	-
Al +Ti	0.85-1.20	-

*This composition can be specified to more restricted limits to meet specific order requirements.

Product Availability

INCOCLAD 671/800HT is produced by co-extrusion of a duplex billet. The process creates a metallurgical bond between the INCOLOY alloy 800HT substrate and the INCONEL alloy 671 cladding, providing good heat transfer properties and sufficient ductility for cold fabrication. The product is supplied in the solution-treated condition. INCOCLAD 671/800HT is available as extruded or cold-sized tubing in a range of diameters, wall thicknesses and lengths to accommodate most boiler designs. The nominal cladding thickness is, typically, 0.075 in (1.9 mm). Samples are available for testing and evaluation through the Special Metal Marketing group at info@smcwv.com.

ASME Codes

For installations constructed according to the ASME Boiler and Pressure Vessel Code, the design stresses specified by the code for INCOLOY alloy 800HT (UNS N08811) should be used for INCOCLAD 671/800HT. The thickness of the INCOLOY alloy 800HT substrate only should be used in determining design stresses.

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Corrosion Resistance

The high chromium of the INCONEL alloy 671 cladding provides excellent resistance to oxidation and corrosion in high-temperature environments containing sulfur or vanadium. Table 2 gives the results of laboratory crucible tests in which alloy 671 specimens were fully submerged in mixtures of vanadium pentoxide and sodium sulfate at 1650°F (900°C). The results of cyclic oxidation tests at 1800°F (980°C) on specimens coated with sodium sulfate are shown in Figure 2. Each cycle consisted of 15 minutes heating and 5 minutes air-cooling and the specimens were re-coated with sodium sulfate at 65-hour intervals.

Table 2 - Laboratory Corrosion Tests in Mixtures of Vanadium Pentoxide and Sodium Sulfate at 1650°F (900°C)

Material	Test Environment	Time h	Weight Loss g/cm²
INCONEL alloy 671	80% V_2O_5/20% Na_2SO_4	16	0.0972
		150	0.6136
		300	0.7678
	20% V_2O_5/80% Na_2SO_4	16	0.00090
		150	0.00663
		300	0.01821
20% Cr-12% Ni-3% W steel	80% V_2O_5/20% Na_2SO_4	16	0.421
		300	1.823
	20% V_2O_5/80% Na_2SO_4	16	0.009
		300	0.031
AISI 310 stainless steel	80%V_2O_5/20% Na_2SO_4	16	0.314

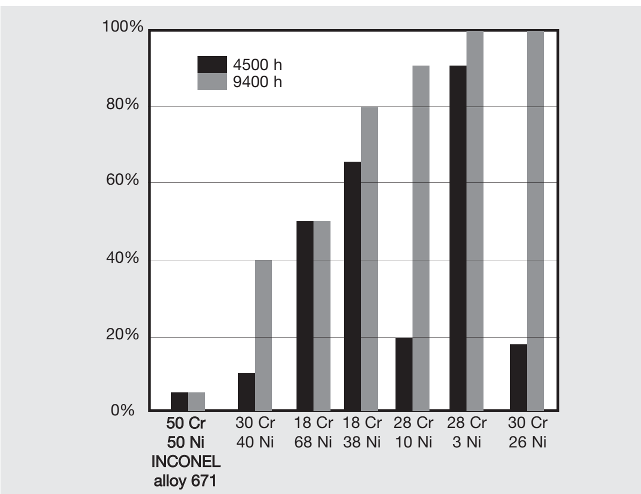

Figure 1. Percentage of metal wastage at gas temperatures of 1400-1700°F (760-920°C) in fuel oil with a vanadium content of up to 300 ppm. (Journal of the U.S. Institute of Fuel).

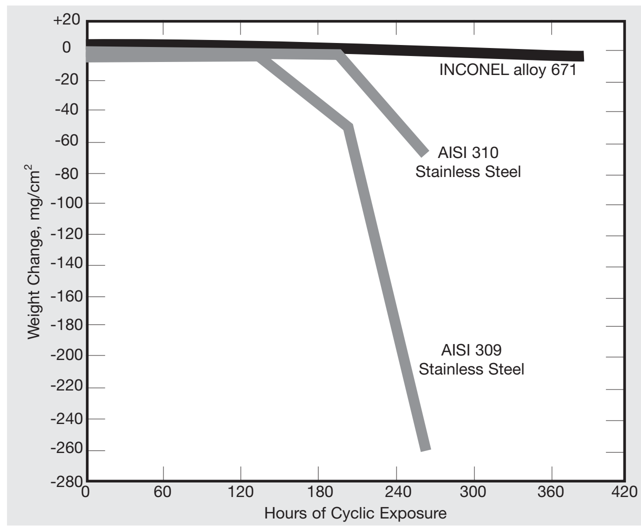

Figure 2. Cyclic oxidation tests at 1800°F (980°C) on specimens coated with Na_2SO_4. Each cycle was 15 minutes heating/5 minutes air cooling. Specimens re-coated at 65-hour intervals.

Fabrication

The duplex product can be formed and machined by conventional techniques. The tubing is readily weldable and welding products are available with strength and corrosion-resistance properties comparable with those of the tubing.

Information on fabricating is available in the Special Metals publication "Fabricating" on the website, www.specialmetals.com.

Cold Forming. Cold-formed bends such as those required for superheater pendants have been produced in INCOCLAD 671/800HT. Press bending has yielded good results with sand-filled tubing.

Machining. Techniques for Group D-1 alloys should be used for the INCONEL alloy 671 cladding, and those for Group C alloys for the INCOLOY alloy 800HT substrate.

Information on machining is available in the Special Metals publication "Machining" on the website, www.specialmetals.com.

Joining. INCOCLAD 671/800HT is normally welded by the gas-tungsten-arc process, using INCONEL filler metal 82 with the alloy 800HT base material. INCONEL Filler Metal 72 with a composition similar to alloy 671 is used to weld the cladding.

Information on joining is available in the Special Metals publication "Joining" on the company website, www.specialmetals.com.

Case Histories

Philadelphia Electric Company. PEC's Eddystone Station, Unit 2, is a 350,000 kW unit with double reheat. After 37,000 hours of operation, up to 35% wall loss had occurred in the 9% Cr-1% Mo steel reheater tubes, forcing a downrating of the unit, with steam temperature lowered by 50° F (28°C) from the start-up throttle of 1050°F (565°C).

Searching for a material that would resist the environment, PEC installed experimental INCOCLAD 671/800H duplex alloy tubing. The substrate alloy tube had an outside diameter of 2.28 in (58 mm) and a wall thickness of 0.23 in (5.8 mm). The cladding was 0.064 in (1.6 mm) thick. The material under test was installed in an area where the risk of corrosion was highest, suffering direct impingement of the flue gas. A wide range of coal was burned during the exposure period, with an average 2.44% sulfur content; an average 10.76% ash content; and high metallics, e.g. 3100 ppm iron, 330 ppm sodium and 1190 ppm potassium.

Laboratory evaluation after nine years of service showed that the tubing had performed well. The INCONEL alloy 671 cladding was essentially unaffected by coal-ash corrosion. No deterioration of the metallurgical bond between the cladding and the substrate was observed. The alloy 800H had shown excellent resistance to steam-side corrosion and had retained good tensile properties, stress-rupture strength and ductility. It was not sensitized to intergranular corrosion after the long exposure at 1100°F (595°C).

The Outlet Leg of a Secondary Superheater. At another power plant in North America, the tubing, 2 in (51 mm) O.D. x 0.252 in (6.4 mm) wall with 0.075 in (1.9 mm) cladding, was installed as the outlet leg of a secondary superheater. The 225 MW unit was cyclone fired with coal containing 4.5 to 5% sulfur and 20% ash. Steam temperature was 1000°F (540°C). After approximately 5½ years' operation, a visual examination of the tubes showed no evidence of corrosion or pitting.

The United Kingdom. The U.K. Central Electricity Generating Board ran a trial reheater assembly using INCOCLAD co-extruded tubing at a 550 MW power station between 1974 and 1980 and achieved trouble-free service. This compared with the stainless steel tubes previously in service which had corroded at 0.14 in/year (3.5 mm/a) due to the particularly aggressive fuel being burned. The INCOCLAD alloy tubing was found to have suffered at only one fortieth of this rate. This assessment led to a full replacement of 32 x 24 chevron bends on the reheater, using the INCOCLAD alloy tubing.

Fuel-Ash Corrosion-Resistance in Power Plant Steam Superheaters. INCOCLAD 617/800H tubing, 2.25 in (57 mm) O.D. x 0.375 in (9.5 mm) wall, with a cladding thickness of 0.075 in (1.9 mm), was installed in a superheater unit operating at 1055°F (570°C) and 2150 psig (14.8 MPa). The boiler, rated at 1,200,000 lb/h (540,000 kg/h) was fired by high-sulfur pulverized coal. After 32 months, the INCOCLAD alloy sample was removed and evaluated.

Cladding thickness remained uniform, circumferentially and longitudinally. Cladding exposed on the fire side showed only minimal corrosion; the most severe attack being pitting to a depth of 0.002 in (0.05 mm). The back side of the tube was essentially free of coal-ash corrosion and pitting. The INCOLOY alloy tube interior showed only a uniform, adherent oxide about 0.002 in (0.05 mm) thick.

A sample of tubing from the same installation was examined after 66 months' service. Cladding thickness remained relatively uniform, with some superficial gas impingement erosion on the fire side. The worst attack showed fissures in the cladding to a maximum depth of about 0.012 in (0.30 mm). However, about 0.060 in (1.5 mm) of cladding still remained unattacked beneath the fissures. The inside of the tubing was unchanged from the earlier review and evaluation.

U.S.A., 1997. Twenty years ago, American Electric Power (AEP) specified INCOCLAD 671/800H for superheater tubing in coal-fired boilers. The product met the twenty-year design life expectations. AEP reordered the alloy product, upgraded to alloy 800HT, for two of its power utilities, at Muskingum River in Ohio, and Kammer in the north of West Virginia. The 115,000 ft (35,000 m), 785,000 lb (350 tonne) order was engineered by the company selected for the original installation, Babcock & Wilcox, of Barberton, Ohio.

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