IJSEAT
International Journal of
Science Engineering and Advance Technology

Manufacturing of Incoloy- 800 Tubes Nuclear Steam Generator Tubes

K. Siva Rama Krishna Rao, K.Praveena
Turbo machinery Institute of Science and Technology and Sciences

krishnarao.sivarama@gmail.com

ABSTRACT-- Incoloy-800 is a nickel-chromium alloy that is best known for its ability to maintain a stable structure during prolonged exposure to high temperatures. Incoloy-800 possesses more than the strength to withstand the basic stress caused by heat, though. It has high levels of resistance to oxidation and carbonization, making it one of the most effective materials for use in carbonizing equipment and heating element sheathing.

A Ni-Cr-Fe alloy that resists high temperature oxidation. This alloy is a first choice for an upgrade from the 300 series stainless steels when improved performance or strength at temperature is required.

It is an iron based super alloy for steam generators and its chemical composition is:

Ni=30-35% Cr=19-23% S=0.015%

Al=0.15-0.6% Ti=0.15-0.6% Cu=0.75%

C=0.1%max. Si=1% Mn=1.5%

Fe=balance

The chromium in the alloy imparts resistance to oxidation and corrosion. The high percentage of nickel maintains an austenitic structure so that the alloy is ductile. The nickel content also contributes resistance to scaling, general corrosion, and stress-corrosion cracking. The iron content provides resistance to internal oxidation.

Our present study aims to find out the manufacturing process of the Incoloy-800. The Incoloy-800 tubes are manufactured in the Nuclear Fuel Complex, by the extrusion process. Initially the powders of the alloy are mixed to proper composition and then compacted at high pressure. The compacted components are heated in the Electric Arc Furnace to prepare the Billets.

The Billets are extruded to form tubes and then it undergoes pillgaring to decrease the thickness of the tube wall and increase the length. The samples are taken from the billet, from the tube after extrusion and from the tube after final pillgaring. From the obtained samples the properties of the Incoloy-800 alloy is analyzed before extrusion, after extrusion and after final pillgaring. In the microstructure of the incoly-800 becomes finer as it undergoes pillgaring and mechanical properties of the Incoloy-800 alloy changes with microstructure.

1. INTRODUCTION:

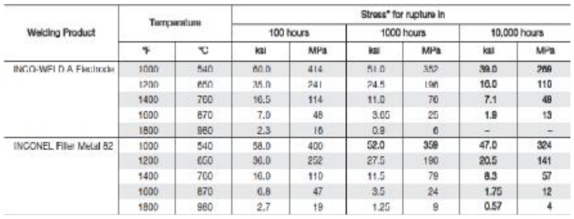
Incoloy-800 is a nickel-chromium alloy that is best known for its ability to maintain a stable structure during prolonged exposure to high temperatures. Incoloy-800 possesses more than the strength to withstand the basic stress caused by heat, though. It has high levels of resistance to oxidation and carbonization, making it one of the most effective materials for use in carbonizing equipment and heating element sheathing.

Incoloy-800 was introduced into the industries to replace the Inconel-600 alloy. Incoloy 800 is as effective in many aqueous environments as it is in high-temperature situations. It has the ability to withstand erosion and other decay that is often associated with aqueous settings. Its strength and resistance give Incoloy 800 a level of versatility that is not found in many alloys. It has been used in a variety of industries and has become a mainstay in high-temp, high-exposure applications.

The Incoloy-800 is iron based alloy it has high amount of chromium and nickel in it. The chromium in the alloy imparts resistance to oxidation and corrosion. The high percentage of nickel maintains an austenitic structure so that the alloy is ductile. The nickel content also contributes resistance to scaling, general corrosion, and stress-corrosion cracking. Incoloy 800 is as effective in many aqueous environments as it is in high-temperature situations. It has the ability to withstand erosion and other decay that is often associated with aqueous settings.

The Incoloy-800 tubes are manufactured in our project, the Incoloy-800 tubes are manufactured only by extrusion. The Incoloy-800 is initially formed as powders of the compounds and formed as components and formed as billet. The billet undergoes the extrusion process, for extruding the billet it is heated to 1160-1190°C. Then billet before extrusion have the initial size of 152cm diameter.

straight polarity (electrode negative) is recommended. Keep as short an arc length as possible and use care to keep the hot end of filler metal always within the protective atmosphere. Shielded Metal-Arc Welding: Electrodes should be kept in dry storage and if moisture has been picked up the electrodes should be baked at 600 F for one hour to insure dryness. Current settings vary from 60 amps for thin material (0.062" thick) up to 140 amps for material of 1/2" and thicker. It is best to weave the electrode slightly as this alloy weld metal does not tend to spread. Cleaning of slag is done with a wire brush (hand or powered). Complete removal of all slag is very important before successive weld passes and also after final welding. Gas Metal-Arc Welding: Reverse-polarity DC should be used and best results are obtained with the welding gun at 90 degrees to the joint. For Short-Circuiting-Transfer GMAW a typical voltage is 20- 23 with a current of 110-130 amps and a wire feed of 250-275 inches per minute. For Spray-Transfer GMAW voltage of 26 to 33 and current in the range of 175-300 amps with wire feed rate of 200-350 inches per minute are typical. Submerged-Arc Welding: Matching filler metal, the same as for GMAW, should be used. DC current with either reverse or straight polarity may be used. Convex weld beads are preferred.



Welding Product	Temperature		Stress* for rupture in					
			100 hours		1000 hours		10,000 hours	
	°F	°C	ksi	MPa	ksi	MPa	ksi	MPa
INCO-WELD A Electrode	1000	540	60.0	414	51.0	352	39.0	269
	1200	650	35.0	241	24.5	196	16.0	110
	1400	700	16.5	114	11.0	76	7.1	49
	1600	870	7.0	48	3.65	25	1.9	13
	1800	980	2.3	16	0.9	6	–	–
INCONEL Filler Metal 82	1000	540	58.0	400	52.0	359	47.0	324
	1200	650	36.0	252	27.5	190	20.5	141
	1400	700	16.0	110	11.5	79	8.3	57
	1600	870	6.8	47	3.5	24	1.75	12
	1800	980	2.7	19	1.25	9	0.57	4

Fig-12, Rupture Strengths of Welding Products (All-Weld-Metal Specimens) for INCOLOY alloys 800.

2.4.5. Joining

Alloys 800H and 800HT have the same good weld ability as alloy 800. Both are normally used for applications requiring high creep-rupture strength and should be joined with welding products that have suitable strength characteristics for the intended service temperatures.

For temperatures up to 1450°F (790°C), INCO-WELD A Electrode is used for shielded-metal-arc welding, and INCONEL Filler Metal 82 is used for gas-shielded welding.

Filler Metal 82 is also used with INCOFLUX 4 Submerged Arc Flux for submerged-arc welding of Incoloy alloys 800. For service temperatures over 1450°F (790°C) the optimum welding product choice depends on the specific service temperatures involved and the properties needed in the welded joint. For applications that require the highest strength and corrosion resistance, INCONEL Welding Electrode 117 and INCONEL Filler Metal 617 are recommended. Figure 14 compares the stress-rupture strengths of Electrode 117 and Incoloy alloys 800.

2.5. 300 Series Steels

In metallurgy stainless steel, also known as inox steel or inox from French "inoxydable", is defined as a steel alloy with a minimum of 10.5 or 11% chromium content by mass. Stainless steel does not stain, corrode, or rust as easily as ordinary steel, but it is not stain-proof. It is also called corrosion-resistant steel or CRES when the alloy type and grade are not detailed, particularly in the aviation industry. There are different grades and surface finishes of stainless steel to suit the environment the alloy must endure. Stainless steel is used where both the properties of steel and resistance to corrosion are required.

Stainless steel differs from carbon steel by the amount of chromium present. Unprotected carbon steel rusts readily when exposed to air and moisture. This iron oxide film (the rust) is active and accelerates corrosion by forming more iron oxide. Stainless steels contain sufficient chromium to form a passive film of chromium oxide, which prevents further surface corrosion and blocks corrosion from spreading into the metal's internal structure. Passivation only occurs if the mixture of chromium is high enough.

A few corrosion-resistant iron artifacts survive from antiquity. A famous example is the Iron Pillar of Delhi, erected by order of Kumara Gupta I around AD 400. Unlike stainless steel, however, these artifacts owe their durability not to chromium but to their high phosphorus content, which, together with favorable local weather conditions, promotes the formation of a solid protective passivation layer of iron oxides and phosphates, rather than the non-protective cracked rust layer that develops on most ironwork.

The corrosion resistance of iron-chromium alloys was first recognized in 1821 by French metallurgist Pierre Berthier, who noted their resistance against attack by some acids and suggested their use in cutlery. Metallurgists of the 19th century were unable to produce the combination of low carbon and high chromium found in most modern stainless steels, and the high-chromium alloys they could produce were too brittle to be practical.

2.5.1. Properties

High oxidation-resistance in air at ambient temperature is normally achieved with additions of a minimum of 13% (by weight) chromium, and up to 26% is used for harsh environments. The chromium forms a passivation layer of chromium (III) oxide (Cr_2O_3) when exposed to oxygen. The layer is too thin to be visible, and the metal remains lustrous. The layer is impervious to water and air, protecting the metal beneath. Also, this layer quickly reforms when the surface is scratched. This phenomenon is called passivation and is seen in other metals, such as aluminum and titanium. Corrosion-resistance can be adversely affected if the component is used in a non-oxygenated environment, a typical example being underwater keel bolts buried in timber.

When stainless steel parts such as nuts and bolts are forced together, the oxide layer can be scraped off, causing the parts to weld together. When disassembled, the welded material may be torn and pitted, an effect known as galling. This destructive galling can be best avoided by the use of dissimilar materials for the parts forced together, for example bronze and stainless steel, or even different types of stainless steels (martensitic against austenitic), when metal-to-metal wear is a concern. Nitronic alloys reduce the tendency to gall through selective alloying with manganese and nitrogen. In addition, threaded joints may be lubricated to prevent galling.

2.5.2. Applications

Fig-13, The pinnacle of New York's Chrysler Building is clad with type 302 stainless steel..

Stainless steel's resistance to corrosion and staining, low maintenance, relatively low cost, and familiar luster make it an ideal material for many applications. There are over 150 grades of stainless steel, of which fifteen are most commonly used. The alloy is milled into coils, sheets, plates, bars, wire, and tubing to be used in cookware, cutlery, hardware, instruments, major, industrial equipment (for example, in sugar refineries) and as an automotive and aerospace structural alloy and construction material in large buildings. Storage tanks and tankers used to transport orange juice and other food are often made of stainless steel, due to its corrosion resistance and antibacterial properties. This also influences its use in commercial kitchens and food processing plants, as it can be steam-cleaned and sterilized and does not need paint or other surface finishes. Stainless steel is used for jewelry and watches with 316L being the type commonly used for such applications. It can be re-finished by any jeweler and will not oxidize or turn black.

Some firearms incorporate stainless steel components as an alternative to blued or parkerized steel. Some handgun models, such as the Smith & Wesson Model 60 and the Colt M1911 pistol, can be made entirely from stainless steel. This gives a high-luster finish similar in appearance to nickel plating. Unlike plating, the finish is not subject to flaking, peeling, wear-off due to rubbing (as when repeatedly removed from a holster), or rust when scratched. Some automotive manufacturers use stainless steel as decorative highlights in their vehicles.

2.5.3. Architectural

Stainless steel is used for buildings for both practical and aesthetic reasons. Stainless steel was in vogue during the art deco period. The most famous example of this is the upper portion of the Chrysler (pictured). Some diners and fast-food restaurants use large ornamental panels and stainless fixtures and furniture. Owing to the durability of the material, many of these buildings retain their original appearance.

The forging of stainless steel has given rise to a fresh approach to architectural blacksmithing in recent years. Type 316 stainless is used on the exterior of both the PETRONAS Twin Towers and the Jin Mao Building, two of the world's tallest skyscrapers.

The Parliament House of Australia in Canberra has a stainless steel flagpole weighing over 220 tons. The aeration building in the Edmonton Composting Facility, the size of 14 hockey rinks, is the largest stainless steel building in North America.

Types of Stainless steel

There are different types of stainless steels: when nickel is added, for instance, the austenite structure of iron is stabilized. This crystal structure makes such steels virtually non-magnetic and less brittle at low temperatures. For greater hardness and strength, more carbon is added. With proper heat treatment, these steels are used for such things as razor blades, cutlery, and tools.

Significant quantities of manganese have been used in many stainless steel compositions. Manganese preserves an austenitic structure in the steel as dose nickel, but at a lower cost.

Stainless steels are also classified by their crystalline structure. Austenitic, or 300 series, stainless steels make up over 70% of total stainless steel production. They contain a maximum of 0.15% carbon, a minimum of 16% chromium and sufficient nickel and/or manganese to retain an austenitic structure at all temperatures from the cryogenic region to the melting point of the alloy. A typical composition of 18% chromium and 10% nickel, commonly known as 18/10 stainless, is often used in flatware. 18/0 and 18/8 are also available. Super austenitic stainless steels, such as alloy AL-6XN and 254SMO, exhibit great resistance to chloride pitting and crevice corrosion due to high molybdenum content (>6%) and nitrogen additions, and the higher nickel content ensures better resistance to stress-corrosion cracking versus the 300 series. The higher alloy content of super austenitic steels makes them more expensive. Other steels can offer similar performance at lower cost and are preferred in certain applications.[citation needed] Low-carbon versions, for example 316L or 304L, are used to avoid corrosion problems caused by welding. Grade 316LVM is preferred where biocompatibility is required (such as body implants and piercings). The "L" means that the carbon content of the alloy is below 0.03%, which reduces the sensitization effect (precipitation of chromium carbides at grain boundaries) caused by the high temperatures involved in welding.

In uniform single phase alloys or pure metals, contrast is obtained and the grain boundaries are made visible because of the differences in the rate at which various grains are attacked by the reagent. This difference in the rate of attack is mainly associated with the angle of different grain sections to the plane of polished surface. Because of the chemical attack by the etching reagent, the grain boundaries will appear as valleys in the polished surface.

Light from the microscope hitting the side of these valleys will be reflected out of the microscope, making the grain boundaries appear as dark lines.

The etching reagent used for Incoloy-800 is of the following composition.

Nitric acid	(HNO_3)	-40%
Water	(H_2O)	-30%
Hydrochloric acid	(Hcl)	-30%

3.5. Microstructure Analysis

The microstructure of the specimens was analyzed using an Olympus optical microscope under the magnification of 100X.

The micrographs of these samples were taken and their grain sizes were measured using ‘Arbitary Line Method’, with the help of the software,’OLYSIA’.Arbitary Line Method: In this, a particular area of the specimen was focused.

The vertical and horizontal dimensions of all the grains present in the focused area were measured individually and their average was taken. The same procedure was repeated for three different areas of the same specimen and their average was considered as the average grain size of the specimen.

Fig-15, Olympus optical microscope.

4. RESULTS AND DISCUSSIONS

4.1. Chemical Analysis

Element	Wt.% of the element
Nickel	30-35 %
Chromium	19-23 %
Aluminum	0.15-0.6 %
Carbon	0.1 % max
Copper	0.75 % max
Manganese	1.5 % max
Silicon	1 % max
Sulphur	0.015 % max
Titanium	0.15-0.6 %
Iron	balance

4.2. Microstructure Analysis

4.2.1. Microstructure of Billet.

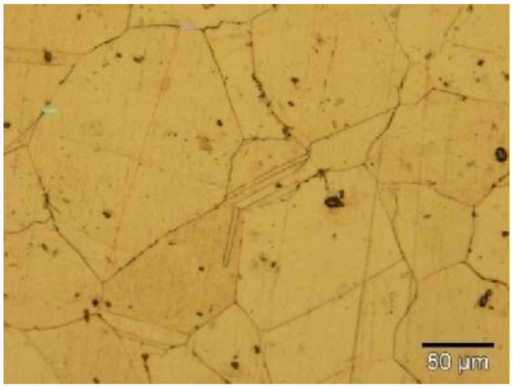


Fig-16 , Microstructures of the centre of the billet

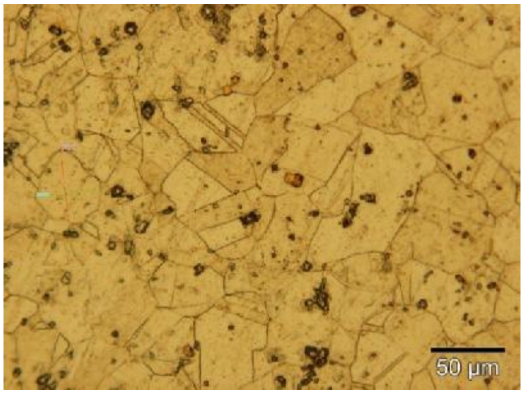


Fig-17 , Microstructures of the periphery of the billet

4.2.2. Microstructure of the extruded tube of size 142mm dia x 50mm WT

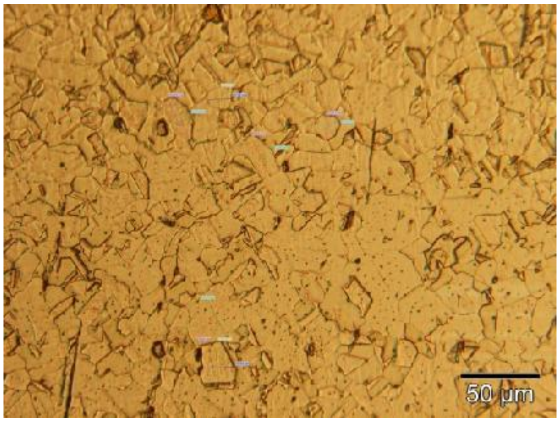


Fig-18 , Microstructure after extruded Longitudinal of the tube

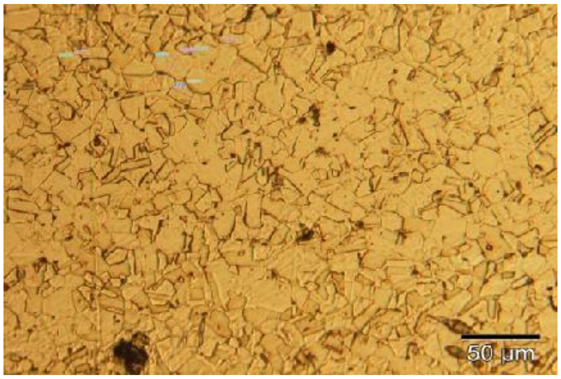


Fig-19 , Microstructure after extruded Transverse of the tube

4.2.3. Microstructure of the pillgared tube of size OD 19.1 x 1.1 WT

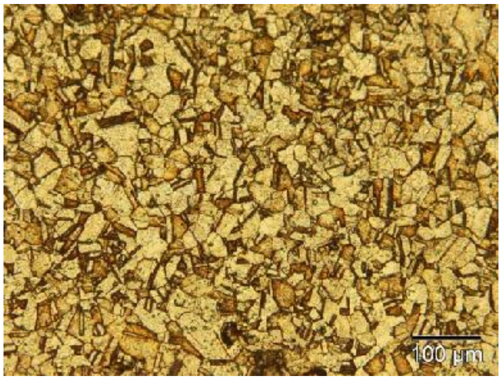


Fig-20 , Microstructure after final pillgaring inside tube

Fig-21 , Microstructure after final pillgaring outside tube

4.2.4. Grain size

- The average grain size of the billet at the centre in fig-16 has 2 microns grain size and periphery in the fig-17 has 4 microns grain size.
- The average grain size of the extruded tube at longitudinal in fig-18 has 4 microns grain size and transverse in fig-19 has 5 microns grain size.
- The average grain size of the final pillgared tube in fig-20 and 21 is 8 microns at longitudinal and transverse.

4.3. Hardness values

The hardness value of the Incoloy-800 is determined by Vickers hardness method. The Vickers hardness test method consists of indenting the test material with a diamond indenter, in the form of a right pyramid with a square base and an angle of 136 degrees between opposite faces subjected to a load of 30 kgf.

Product	**Hardness value (HV)**
Billet	140 HV
After extrusion of billet into tube	160 HV
Final tube product	290 HV

The hardness value increases with decrease in the grain size. The hardness value of the billet is less then that of the tube after extrusion. The hardness value of the final tube product is high then that of other tubes.

4.4. Strain Rate

Calculating the strain rate of a billet having dimensions 1 mm OD x 45mm IDx 500mm length is extruded to 63mm OD and 9mm WT (main ram speed 100mm/sec)

We know

$$€ = \frac{6 \times V \ln(R) \times d^2 \times \tan\alpha}{[D^3-(\text{Billet OD}^3)]}$$

Where

V=Main ram speed

Ln(R) =extrusion ratio (A/Af)

Tanα=semi cone diangle

D=outer dia of the extrusion product

D=outer dia of the billet

A=πt (OD-t) [A=initial thickness of the billet]

=3.14(105/2) (150-150/2)

=3.14 x 52.5 x 150-52.5

A=16080

Af =πt (OD-t)

=3.14 x 9 x 63-9

=3.14 x 9 x 54

=1526

A/Af=16080/1526=10.54 [A/Af=extrusion ratio]

Substituting extrusion ratio (Er) in strain rate

$$€ = \frac{1685 \times 600 \times 2035}{3124953} = 0.73/\text{sec}$$

5. CONCLUSION

- The billet temperature should be maintained in between 1160°-1190°C.
- For 150mm OD x 45mm ID billet after extrusion tube size 63mm x 9mm WT the strain rate is 0.73m/s.
- The hardness value of the final tube product is high then that of the other tubes. The hardness value increases with decrease in grain size.

6. References

1. Joseph R. Davis, Nickel, cobalt, and their alloys, ASM International Handbook Committee. **Page-38, 39.**

2. Ruth Jane Salomon, The ductility behavior of Incoloy alloy MA956, University of Birmingham in Birmingham, 1994.

3. Harry Chandler Heat treater's guide: practices and procedures for nonferrous alloys. Page:-112-115.

4. Dumitra Lucan, Degradations of Incoloy 800 Steam Generator Tubing.

5. The 14th International Conference on Wear of Materials took place in Washington, DC, USA,2003.

6. Bruce D. Craig, David S. Anderson, Handbook of corrosion data, ASM International Handbook Committee**.**

7. www.steelforge.com/metaltidbits/incoloy.html.

8. www.specialmetals.com/Incoloy.pdf.