

FOR BETTER CORROSION-RESISTANT WELDED TUBING:

A DISTINCTION BETWEEN "BEAD WORKED" AND "COLD REDUCED" TUBULAR PRODUCTS

PREFACE

Many fluid process designs require tubular products for use as piping and in various heat exchanger systems. When aggressive process streams are involved, corrosion-resistant alloys (e.g. nickel-base alloys) are selected.Since weldments are usually the most vulnerable to corrosive attack (Figure 1), seamless tubing is often considered. However, cost considerations steer the designers to the selection of welded tubing that has been cold worked and annealed. The cold working plus annealing steps are performed to provide complete recrystallization and substantial homogenization of the seam weld and thus approach performance similar to that of a wrought seamless microstructure.



Most welded high-molybdenum nickel-base alloy tubing is procured to specification ASTM B 626 class III. The class III designation covers cold-worked and solution annealed product.* Within this class designation, however, the method of cold working the seam weld prior to annealing is left up to the buyer.

Different tube mills use different techniques to accomplish the cold working step. "Bead working" or "bead rolling" (i.e., rolling only the seam weld to introduce some degree of cold work) is a common method practiced by stainless steel mills to supply tubing to ASTM B 626 specifications. In contrast, "cold drawing" or "cold pilgering" (i.e., cold reduction of the seam weld and the tube wall) is the preferred technique used by specialty mills for the production of nickel-base alloy tubing.

* See Appendix I for further descriptions of ASTM B 626 classes I, II and III.

The "bead worked" type and the "cold reduced" type tubing are both covered by the same classes (IIA, IIB and III) of ASTM B 626 specification. To some procuring personnel, the only difference between both types appears to be a few thousand dollars of cost saving. While such a saving might be applicable to stainless steel tubing, it has been proven devastating for plant operation when HASTELLOY® alloy tubing is required to handle aggressive chemicals. Many "bead worked" generic alloy C-276 tubes have failed prematurely at the seam welds in various corrosive services. Some were scrapped (Figure 2) and were replaced by "cold drawn" HASTELLOY tubing, within the same ASTM specification.

Thus, while the original purchasing decision may have been made on the basis of cost saving, such experience confirmed to the plant personnel that the saving was a delusion for far greater cost was incurred from the unanticipated shut down and the replacement of the unit.



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EFFECTS ON CORROSION RESISTANCE OF HASTELLOY ALLOYS

Even though HASTELLOY tubular products are highly alloyed with chromium, molybdenum and tungsten to withstand aggressive chemicals, they need to be in an "optimum" metallurgical condition in order to provide the anticipated resistance to corrosion (comparison between two different metallurgical conditions is illustrated in Appendix II). When the HASTELLOY alloys are supplied in "non optimum" conditions, such as the case of "partially" recrystallized and "non-fully" homogenized seam weld, corrosive attack is very likely to initiate and propagate along the weld (Figure 3).



Failure analyses conducted on several "bead worked" tubes and pipes, confirm that preferential corrosion often initiates at the seam weld (whether ID or OD, Figure 4). The corrosive attack propagates along "segregated"/"depleted" zones within the "partially" recrystallized structure of the "bead worked" seam weld. Perforation and leaks can ensue.



Figure 4: Examples of Selective Corrosive Attack on the ID and/or OD Surfaces of "Bead Worked" Seam Welds.

METALLURGICAL CONSIDERATIONS

For material ordered to ASTM specification B 626, the classes II A, II B and III are usually relied upon to procure welded tubing with an optimum recrystallized and homogenized seam weld microstructure for enhanced resistance to corrosion. In theory, "bead working" or "bead rolling" the seam weld should provide an adequate amount of cold work of the weld cast structure.Complete recrystallization and substantial homogenization of the seam weld into a wrought structure should take place in the solution annealing step.

For many stainless steel welded tubing, "bead working" often yields the desired microstructure and corrosion resistance within the applicable ASTM specifications. However, it is common knowledge that high-molybdenum nickel-base alloys are much more difficult to cold work than stainless steels, and that minor irregularities are usually encountered in the seam weld. Such weld irregularities and deformation characteristics stand in the way of achieving a completely recrystallized microstructure, via "bead working" of welded HASTELLOY alloy tubing. In addition, the issue of interdendritic segregation of highmolybdenum nickel-base alloy welds is an important one and a carefully selected heat treatment cycle (time and temperature) is a must in order to achieve the desired homogenization of the seam weld.

Even with near-perfect seam welds, the "bead working" might lead to slight undercut at the weld fusion line. These undercut regions could act as crevice corrosion sites in aggressive media. While many HASTELLOY alloys provide enough resistance to corrosion at such potential crevice sites, it is the partial recrystallization and the lack of full homogenization of the seam weld that represent the major concern for optimum corrosion resistance.

In practice, perfect seam welds and good bead working are not always achieved consistently in high-molybdenum nickel-base alloys. In fact, "off symmetry" seam weld have been encountered in tubular products. In such cases, only some zones of the weld get the proper amount of cold deformation via bead working while other zones may not get cold worked at all. As such, the annealing step would lead to partial recrystallization of the seam weld (Figures 5, 6 and 7). Additional schematics of cross-sections of beadworked tubing are illustrated in Appendix III.





IMPACT ON END USERS

Consistent quality levels with optimum metallurgical conditions are sought by plant personnel when using welded tubular products. In theory, procurement to ASTM specifications should lead to assurance of <u>consistent</u>, well-defined metallurgical conditions. However, the ASTM specifications leave the option to the buyer to select between the cold working of the weld metal only (bead working) or of cold working both the weld and the base metal (cold reduction via drawing or pilgering). As such, additional detailed specifications are required to insure optimum metallurgical conditions for best resistance to corrosion.

To some "equipment specifiers", inconsistent metallurgical conditions in seam welds might be avoided by relying on traditional appraisal techniques, such as inspection. However, inspection does not always prevent tubing with undesirable metallurgical characteristics from being delivered to end users. Such cases have occurred with devastating consequences to plant operations (the following passages illustrate a case in point).

Alloy C-276 (3/4 x .065 in.) to ASTM B 626 Class III ASME SB 626 - N10276
"THE TUBE SECTION IS FROM THE BUNCH OF ALLOY C-276 TUBES MADE BY THAT GAVE US ALL THE TROUBLES WITH LEAKS"
"THE LEAKS WERE DUE TO WELD DEFECTS* THAT WERE PASSED BY POOR INSPECTION. THE TUBE WAS ONLY BEAD WORKED PRIOR TO ANNEALING"
"END USER" DECEMBER, 1988

*Tubing with weld defects may not necessarily be rejected at an inspection test for quality control (Eddy current test, ultrasonic test). This is inherent to the inspection procedures, especially when the defect produces a signal that is smaller than the "acceptance percentage" of the model defect signal set at calibration.

HAYNES INTERNATIONAL TUBULAR PRODUCTS (ARCADIA PLANT)

Keeping in mind that quality is not to be inspected into a product, rather it is built into the product from its earliest stages of production, major end users prefer the consistent quality of "cold reduced" and annealed tubing. Many share the concern that seam welding might vary from batch to batch and that bead rolling will not consistently produce the appropriate cold worked condition for complete recrystallization and that proper annealing step is required for homogenization of the seam weld.

Haynes International, Inc., has recognized the problems associated with welded highmolybdenum nickel-base alloy tubing/piping, since the early 70's. In response to the plea of many end users for improved quality, a tubing Mill was built in Arcadia, LA, in 1976 with full dedication to quality HASTELLOY alloy welded tubes and pipes.

The Arcadia Specialty Mill relies on the "cold drawing" or the "cold pilgering" process to produce consistent quality HASTELLOY alloy tubing supplied to ASTM B 626 class III (cold worked, annealed and non-destructively tested). Unless the end user insists, Arcadia avoids quotations and shipments of welded tubing to ASTM B 626 classes I A and I B (sized and annealed). This is due to the fact that all standard tubing processes at Arcadia are set to achieve optimum metallurgical conditions, using cold reduction of both the seam weld and the tube wall.



Figure 8: Sections of Arcadia's Specialty Mill Facilities.

APPENDIX I

ASTM B 626 Specification

Description of Scope, Manufacture and Non-Destructive Testing Requirements

Paragraphs* referenced from ASTM B 626:

- 1.3 Five classes are covered as follows:
- 1.3.1 Class IA Welded, sized solution annealed, and non-destructively (NDT) tested in accordance with 10.5.1
- 1.3.2 Class IB Welded, sized and solution annealed. (No NDT required.)
- 1.3.3 Class IIA Welded, cold worked, solution annealed and non-destructively tested in accordance with 10.5.1.
- 1.3.4 Class IIB Welded, cold worked, and solution annealed. (No NDT required.)
- 1.3.5 Class III Welded, cold worked, solution annealed and non-destructively tested in accordance with 10.5.2.
- 4.2 Subsequent to welding and prior to final heat treatment, Class II and Class III tubes shall be cold worked either in both weld and base metal or in weld metal only. The method and amount of cold working may be specified by the purchaser. When cold drawn, the purchaser may specify the minimum amount of reduction in cross-sectional area or wall thickness, or both.
- 10.5.1 Class IA and Class IIA Tubes Each finished tube shall be subjected to the hydrostatic test, the pneumatic test, or the eddy current test at the manufacturer's option.
- 10.5.2 Class III Tubes Each finished tube shall be subjected to the pneumatic test and the eddy current test. Tubes larger than 1-1/2 in. (3.1mm) in outside diameter may be subjected to the hydrostatic test in lieu of the pneumatic test at the manufacturer's option.

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APPENDIX II





APPENDIX III

Schematics illustrating examples of cross-section appearances of some "bead worked" high molybdenum nickel-base alloys tubular products.



HAYNES® and HASTELLOY® High Performance Alloys

High-Temperature Alloys

HASTELLOY alloy S (N06635)	Ni-16Cr-15Mo-La alloy with excellent thermal stability, good thermal fatigue resistance, good oxidation-resistance & relatively low expansion characteristics. Used in low-stress gas turbine parts. Excellent dissimilar filler metal.
HASTELLOY alloy W (N10004)	Ni-24Mo-5Cr-6Fe alloy that is excellent for welding dissimilar high-temperature alloys. Major use is in aircraft engine repair and maintenance.
HASTELLOY alloy X (N06002)	Ni-22Cr-19Fe-9Mo alloy with very good balance of strength, oxidation-resistance & fabricability. Most widely used material for aircraft, marine and industrial gas turbine engine combustors and fabricated parts.
HAYNES alloy 25 (R30605)	Co-10Ni-20Cr-15W alloy with excellent strength, good oxidation-resistance to 1800°F (980°), excellent sulfidation- resistance, and good wear and galling-resistance. Used in gas turbine parts, bearings, and various industrial applica- tions.
HAYNES alloy 31 (R30031)	Co-11Ni-26Cr-8W alloy used primarily in wire form for weld-repairing cobalt-base cast gas turbine parts such as blades and vanes.
HAYNES alloy R-41 (N07041)	Ni-11Co-19Cr-10Mo-3Ti-1.5Al age-hardenable alloy with excellent strength in the 1000°F-1800°F (540°C-980°C) temperature range. Used for critical gas turbine engine components.
HAYNES alloy HR-160	Ni-27Co-28Cr-4Fe-2.7Si alloy with superior sulfidation resistance. Useful in aggressive environments associated with applications such as waste incinerators, boilers and high-temperature reaction vessels.
HAYNES alloy 188 (R30188)	Co-22Ni-22Cr-14W-La alloy with excellent strength and superior oxidation-resistance and thermal stability compared to HAYNES alloy 25. Good sulfidation-resistance. Used extensively in demanding military & civil aircraft gas turbine engine combustors & other key components.
HAYNES alloy 214	Ni-16Cr-4.5Al-3Fe-Y alloy with outstanding oxidation-resistance to 2300°F (1260°C), excellent carburization-resistance, and excellent resistance to chlorine-bearing environments. Used in demanding industrial heating applications and specialized gas turbine parts, such as honeycomb seals, T/C tubes, and others.
HAYNES alloy 230 (N06230)	Ni-22Cr-14W-2Mo-La alloy with the best balance of strength, thermal stability, oxidation-resistance, thermal cycling- resistance and fabricability of any major high-temperature alloy. Used in gas turbine combustors & other key stationary components. Also used in many industrial heating and chemical process industry applications.
HAYNES alloy 263 (N07263)	Ni-20Co-20Cr-6Mo-2Ti-0.5Al age-hardenable alloy with excellent strength in the 1000°F-1600°F (540°C-870°C) temper- ature range and excellent forming and welding characteristics.
HAYNES alloy 242	Ni-25Mo-8Cr age-hardenable alloy with excellent strength to 1300°F, low thermal expansion characteristics, good oxidation-resistance to 1500°F (815°C) and excellent fabricability. Used for gas turbine seal and containment parts and other specialized components. Excellent resistance to fluorine, HF & fluorides.
HAYNES alloy 556 (R30556)	Fe-20Ni-18Co-22Cr-3Mo-2.5W-0.6Ta-La alloy with broadest spectrum of resistance to high-temperature corrosive environments of any high-strength alloy. Used in waste incineration, heat-treating, calcining, chemical processing, galvanizing, refinery, boiler and gas turbine components of various types.
HAYNES alloy 625 (N06625)	Ni-22Cr-9Mo-3.5Cb alloy widely used in various aerospace, chemical process and industrial heating components.
HAYNES alloy 718 (N07718)	Ni-19Fe-18Cr-5Cb-1Ti-0.5Al age-hardenable alloy with excellent strength to 1200°F (650°C). Used extensively in gas turbine components.
HAYNES alloy X-750	Ni-16Cr-7Fe-2.5Ti-0.7Al-1Cb age-hardenable alloy with good strength to 1500°F (815°C).
MULTIMET® alloy	Fe-20Ni-20Co-21Cr-3Mo-3W-1Cb alloy predecessor of HAYNES alloy 556 used extensively in older aircraft gas turbines
WASPALOY™ alloy (N07001)	Ni-14Co-19Cr-4Mo-3Ti-1.5Al age-hardenable alloy with excellent strength in the 1000°F-1800°F (540°C-980°C) temperature range. Used for critical gas turbine engine components.

Corrosion-Resistant Alloys

HASTELLOY alloy B-2 (N10665)	Ni-28Mo alloy with superior resistance to hydrochloric acid, aluminum chloride catalysts and other strongly reducing chemicals. Excellent high-temperature strength in inert atmospheres or vacuum.
HASTELLOY alloy N (N10003)	Ni-17Mo-7Cr-5Fe alloy with good resistance to aging and embrittlement and good fabricability. It has excellent resistance to hot fluoride salts in the temperature range of 1300°F to 1600°F.
HASTELLOY alloy C-276 (N10276)	Ni-16Cr-16Mo-4W alloy, a versatile corrosion-resistant alloy. Excellent resistance to oxidizing and reducing corrosives, mixed acids, and chlorine-contaiminated hydrocarbons.
HASTELLOY alloy C-4 (N06455)	Ni-16Cr-16Mo alloy with high-temperature stability in the 1200-1900°F (650-1040°C) range as evidenced by good ductility and corrosion resistance. Virtually the same excellent corrosion resistance as alloy C-276.
HASTELLOY alloy C-22 (N06022)	Ni-22Cr-13Mo-3W-3Fe alloy with better overall corrosion resistance and versatility than alloys C-4, C-276 and 625. Outstanding resistance to localized corrosion, stress corrosion cracking and oxidizing and reducing chemicals. Best alloy to use as universal weld filler metal to resist corrosion of weldments.
HASTELLOY alloy G-30 (N06030)	Ni-30Cr-6Mo-2.5W-15Fe alloy which has many advantages over other metallic and non-metallic materials in handling phosphoric acid, sulfuric acid, nitric acid, fluoride environments and oxidizing acid mixtures.
HASTELLOY alloy H-9M	Ni-22Cr-9Mo-2W-18Fe alloy has equivalent or better localized corrosion resistance compared to alloy 625 but is in a price range close to those of superstainless steels. The alloy also has good resistance to hot acids and excellent resistance to stress corrosion cracking.

Super Stainless Steel

FERRALIUM® alloy 255 (S32550)	Ferritic-austenitic (duplex) stainless steel with exceptional strength and outstanding resistance to localized corrosion. (Fe-26Cr-6Ni-3Mo-2Cu15N).

Used

Titanium Alloy

HAYNES alloy Ti-3AI-2.5V	Alloy used where strength/weight ratio is of prime importance (43 percent lighter than 21-6-9 stainless steel).
(R56320)	mostly in the form of seamless tubing for aircraft hydraulic systems.

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