

# Field Experience with Nickel-Base Alloys and Future Trends in Flue Gas Desulfurization Systems

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## **Abstract**

Since the mid seventies, more than 160 field tests have been conducted on several corrosion-resistant alloys in a multitude of Flue Gas Desulfurization (FGD) units. In addition, since 1980, over 57 utilities have installed HASTELLOY® alloys in the most corrosive conditions in wet scrubbing systems. This paper discusses a few results from field tests and the experience gained from several installations. The cost effectiveness of thin-sheet metallic lining is reviewed and the issues of quality control/reliability are discussed. Also, future trends related to corrosion- and wear-resistant alloys will be highlighted with potential answers to the erosion problems experienced in some FGD components.

## **Introduction**

The Clean Air Act of 1990 challenges designers and maintenance engineers to provide reliable and costeffective flue gas desulfurization (FGD) systems. This task, although enormous, can be achieved through the use of materials which have an established history of superior performance in severely corrosive FGD environments. Such history of successes (and occasionally some failures) serves as a practical and realistic guideline for materials selection for new FGD construction.

When faced with the selection of materials to protect costly new equipment from corrosion damage, it is important to have an idea about the anticipated life of the system and to select materials that have proven long-term reliable performance. A large percentage of the future FGD systems will utilize high efficiency wet limestone processing and high-performance corrosion-resistant materials already have established field experience in various wet limestone systems over the past ten years.

- Among these corrosion-resistant materials, the high performance nickel-base alloys play a dominant role.
- Experience with such high-performance alloys has been established through:
  - 1) Field test data
  - 2) Service performance

## **Field Test Data**

Two types of field testing have been performed in FGD. First, coupon rack configurations have been used to test a wide range of alloys, and secondly, alloy panels have been used to test a number of candidate alloys, but with larger areas of exposure to the environment in which each alloy is welded directly to the internal surface of the unit. Coupon test racks help in ranking a large number of alloys for potential service while test panels offer in-situ performance information for each candidate alloy under actual service conditions.

Test racks similar to that shown in Figure 1 have been used to test a variety of alloys in FGD systems. Each alloy coupon is isolated by ceramic spacers to protect against galvanic attack between dissimilar metals. The alloy specimens typically include a weld seam in order to test each material in the as-welded condition. This is important since FGD units are too large to receive post-fabrication annealing. In the as-welded condition, the weld zones have a cast microstructure which typically exhibits lower corrosion resistance (especially to pitting and crevice corrosion) than the wrought base-metal (Figure 2). Alloys which resist corrosion attack in both the weld and base metal can be selected for long-term reliable performance.

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Over the last 18 years Haynes International, Inc., has provided over 250 test racks for field tests. Of these racks, 164 racks have been returned for evaluation and tabulation of the data. Typical reporting of the results is shown in Tables 1 and 2. Sometimes, photographs of specific specimens (Figure 3) and/or of the whole group (Figure 4) are provided at the request of the utility engineer.

Carbon steels, stainless steels and high-performance, nickel-based alloys can be welded together to facilitate testing as panels. The ease of welding alloy panels to internal surfaces, coupled with the advantages of subjecting an alloy to realistic service conditions, has prompted many engineers to use this method' over the coupon test rack configuration.

Alloy panels (Figure 5) are inspected at every shutdown and, when required, observation of corrosion/degradation is documented. In some specific cases, small sections are cut out and returned for evaluation. Average thickness loss and pit/crevice depth are measured and recorded. If requested, metallographic cross-sections are examined and documented (Figure 6).

All the data gathered from field test evaluations are computerized into a proprietary data bank system which allows Haynes easy and rapid access to the information.

## Service Performance

The following case histories relates to the HASTELLOY® C-family alloys and HASTELLOY® H-9M alloy which have provided reliable performance in the power industry over the last ten years.

RD. Morrow Sr. Power Plant. This plant has two coal-fired units, each with a 200 MW capacity and a limestone FGD system. The plant burns 1.3 percent sulfur coal, and at full load, 62 percent of the flue gas is scrubbed, the balance being bypassed for reheat purposes. The corrosion problems and their solutions at this plant have been widely publicized.<sup>2</sup> It was found that the inlet duct floor wet/dry zone of the absorber section was a severely corrosive area.

The sludge was monitored for a period of time in the inlet zone area in order to assess the corrosivity of the environment. Samples taken at two different times showed wide fluctuation in fluoride and chloride concentrations. One sludge sample showed 80,000 ppm chlorides while the other was found to contain 6,300 ppm chlorides and 87,000 ppm fluorides. Alloy G panels welded with HAYNES® C-276 alloy wire was installed to help resist the environment. After 6 months service, alloy G failed; however, the C-276 alloy welds performed reliably. As a result, C-276 alloy was selected to sheet line the corrosive areas.

During a shutdown in 1987, seven years after its installation, a small section of alloy C-276 began to exhibit excessive crevice attack. The material was removed (about one square foot) and replaced during a normal shutdown. Meanwhile HASTELLOY® C-22® alloy was tested in this difficult area to compare both alloys in the same environment. Figure 7 identifies the top view of the inlet floor area and location of the C-22 alloy (1/16 inch thick x 12 inches x 24 inches) test panel. The C-22 alloy in the adjacent area showed minor etching in a 1 inch diameter area and no attack was found under 10 X magnification inspection on the balance of the test panel after six and one-half years of exposure.

Texas Utilities. The Sandow Power Plant inlet duct section was suffering corrosion problems. Temperature ranges from 180° to 350° F (82° to 177°C) in this section tend to cause a wet/dry interface. The Technical Specialists for Texas Utilities made several trips to various power plants to view the performance of high alloy sheet linings. Based on their findings, a metallic lining of C-22 sheet was chosen as the most reliable and costeffective answer to the inlet duct corrosion problem. Presently, about 1,200 square feet of C-22 alloy has performed satisfactorily since the 1988 installation.

In 1989 T.U. Electric again selected C-22 sheet to line a problem area in the scrubber outlet duct and floor (2,700 square feet). Maintenance inspection, in the spring of 1990, of this duct revealed corrosion rates beyond what was expected. The majority of the corrosion was observed in a stagnant area where an accumulation/concentration of acid products occurred. Repairs were undertaken during this routine maintenance and a permanent solution is underway to eliminate the stagnant areas and improve the bypass reheat mixing, performed satisfactorily since the 1988 installation.

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**Lower Colorado River Authority.** The Fayette Power Project is a new 400 MW power plant. The start-up date was planned for March 1, 1988. Gunitite was originally specified for the outlet duct area, however, in an effort to reduce future maintenance costs and potential unscheduled downtime, the entire outlet duct area (31 ,000 square feet) was lined with C-22 alloy. To date no significant corrosion-related problems have occurred in the C-22 alloy lined sections of this FGD unit.

**San Miguel Electric Cooperative, Inc.,** Jourdentown, Texas, has one of the most advanced maintenance programs in the industry. The Engineering Supervisor went to great lengths to utilize metallic linings as an answer to their corrosion problems. Based on the performance of H-9MTM alloy in the Unit #1 reheat mixing zone area, coupled with a 15 percent materials cost advantage, the decision to use the H-9M alloy in the scrubber outlet area was made in January, 1987. To date this alloy is performing well in both areas.

**National Power, United Kingdom.** The Drax station is one of the largest wet FGD systems in the world. The outlet duct system combines six 660 MW power units to a common stack. The decision to use C-22 alloy (more than 1 million pounds in weight) to protect the outlet duct, dampers and internals from corrosion damage was made based on a test rig which subjected test panels to the expected corrosive environment. The highest level of reliability of the materials of construction is a necessity for this facility since the Drax station will be supplying power without a scheduled shutdown for 39 months at a time. More examples of field-installed metallic linings are listed in Table 3 for HASTELLOY C-276 and C-22 alloys, and in Table 4 for H-9M alloy.

## **Cost Effectiveness of Thin-Sheet Metallic Lining**

One reason for the rapid acceptance of the high-performance HASTELLOY alloys is the use of a fabrication technique, welded-in liners, long used in the chemical processing industries. This metallic lining technique (also referred to as the "wallpaper concept") has been well received by the utilities due to economics. More details of this technique are described in Haynes International, Inc. Brochure H-2037.

FGD life-cycle economics dictate the need for reliable materials. Installation of an FGD system may run between 10 to 20 percent of the total power plant cost. With any increased system reliability, there is usually an associated higher initial cost. These two seemingly contradictory features, i.e., reliability and cost effectiveness, have been reconciled by the use of the metallic lining technique with HASTELLOY® alloys in FGD systems. <sup>4,5</sup>

Many techniques exist to estimate the economic benefits of alternative corrosion control methods. NACE standard RP-Q2-72 gives a method of calculating the equivalent uniform "Annual Cost", which is well recognized and has been widely used in the FGD industry. Figure 8 shows annual cost calculations, using this NACE Standard, which includes certain assumptions on the life for both metals and non-metals; interest rate (cost of capital), tax rate and depreciation. Various calculations indicate that for non-metals the annual cost could be greater than \$200K for a two-year life. If one takes into account the lost revenues due to the unscheduled shutdowns and reliability aspects, the use of alloyed liners looks even more attractive and desirable. The excellent performance at the various power plants over the last ten years gives credibility to the cost effectiveness of the metallic lining method using high performance Ni-base alloys. In aggressive conditions, where lower grade materials do not work, costly replacements were incurred before the final installation of HASTELLOY® alloy (Table 5). The illusion of lower initial cost often turns into a much larger expense through trial and error of material selection.

## **Reliability and Quality Control**

Based on the experience of some nickel-base alloys (e.g. HAYNES® 625 alloy and G-type alloys) and of the improved HASTELLOY C-family of alloys' in the past ten years, a considerable amount of confidence has been achieved with these alloys for offering reliable, low maintenance FGD equipment. In order to assure this level of superior performance, quality control measures are becoming important issues to design and procurement engineers. These engineers would like to be assured that the alloy they are purchasing is of the same quality as that of the alloy selected based on history test and proven service performance.

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The specification of ASTM G-28 Methods A and B corrosion testing has been widely used to help insure the quality of material supplied by the various vendors (Table 6). These tests help determine whether the high performance alloys are supplied in the proper metallurgical condition for optimum resistance to corrosion in aggressive FGD environments. Other procurement managers opt for tighter chemical control limits than the broad range of UNS designation chemistry limits (Table 7).

The subject of performance of welded structure is a complex issue. Evaluation through testing in ASTM G-28 Methods A and B solutions show limited differences between different welding techniques (Table 8). Similar testing in other environments,7 did not indicate a major distinction between "good" and "bad" welds, based on differences in critical pitting temperature as function of heat input (Table 9). To date there is no practical corrosion test that can be used to adequately address the issue of weld quality. It is presumed that differentiation through corrosion testing will be possible in the future when the effect of welding technique on the microsegregation in the weld and the heat-affected zone can be quantified.

## Erosion Corrosion

The problem of erosion-corrosion in FGD systems has not been successfully addressed by the gamut of nickel-base alloys offered to-date. However, ULTIMET® alloy, a newly developed cobalt-base alloy, has shown excellent performance when subjected to both erosive and corrosive test conditions. ULTIMET alloy has exhibited cavitation erosion resistance equivalent to STELLITE® alloy 6B (Figure 9). In addition, this alloy offers comparable pitting corrosion resistance to the HASTELLOY C-type alloys and better than that of alloy 625 (Table 10). ULTIMET alloy is available commercially and is currently being evaluated in FGD systems (field tests as welded coupons and as panels). Due to its excellent corrosion and wear properties, the alloy lends itself to a variety of equipment found in FGD systems including damper seals, 1.0. fan components, spray nozzles (Figure 10) and slurry agitators/pumps (Figure 11).

## Summary

- Decisions on materials selection for new FGD wet scrubbing systems are favoring corrosion-resistant Ni-base alloys, based on many years of established, reliable performance.
  - The successful use of C-22 and H-9M thin-sheet liners in these systems offers a cost effective approach to protect large areas exposed to corrosive environments.
  - Procurement of these high performance alloys to standardized quality control specifications helps ensure that reliable corrosion protection is achieved in the field.
  - Finally, new generation alloys, such as ULTIMET alloy, offer superior corrosion- and wear-resistance required for specific FGD components.
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## References

- 1) D. C Agarwal and W. L. Silence, "Evolution of Reliable FGD Components and Technology-A Chronological Review", Paper No.452, Corrosion/88, NACE, March, 1988.
- 2) D. Froelich and M. Ware, "Corrosion Problems with a Closed Loop Limestone FGD System", Paper No. 203, Corrosion/82. NACE, Houston, Texas 1982.
- 3) P. Radcliffe, "FGD Economics", EPRI Journal, Pg. 33, December 1990.
- 4) D. C. Agarwal, "Cost Effectiveness and Maintenance Free Reliability in Performance: The Two Seemingly Contradictory Features of An FGD System". Paper No. 46. Corrosion /85, NACE, Houston, Texas 1985.
- 5) R. L. Richard, "Economics of a C-276 Outlet Duct Wallpaper Retrofit at Public Service Indiana Gibson NO.5" paper presented at the 5th International Symposium on Corrosion/Pollution Control, Buffalo. New York, October 1987.
- 6) A. I. Asphahani, A. F. Nicholas, W. L. Silence and T. H. Meyer, "High Performance Alloys for Solving Severe Corrosion Problems in Flue Gas Desulfurization Systems", Werkstoffe Und Korrosion, Vol. 40, p. 409, 1989.
- 7) L. H. Flasche and I. J. Storey, "Factors Affecting the Corrosion Resistance of Ni-Cr-MO alloy weldments in FGD Systems", paper presented at WECDTECH-88, London-UK, 1988.

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# Corrosion-Resistant Alloys

**TABLE 1**

Results from Rack No. 516 Reheat Bypass Duct  
450 MW; 1.8% Sulfur Coal; 12-Month Exposure Wet-Limestone Scrubbing System (1983)

Alloy	Corrosion Rate (mpy)	Pitting* Attack		Crevice* Attack	Maximum Pit Depth (mils)
		Base Metal	Weld Metal		
C-steel	31	(Partially Dissolved)		-	-
316L	6	Very Severe	Very Severe	Very Severe	35
317L	4	Very Severe	Very Severe	Very Severe	35
317L+	3	Severe	Very Severe	Moderate	28
20CB-3* alloy	6	Very Severe	Severe	Severe	38
825	5	Very Severe	Very Severe	Severe	47
904L	3	Very Severe	Severe	Severe	35
700	2	Severe	Very Severe	Severe	27
777	3	Very Severe	Very Severe	Severe	38
FERRALIUM* alloy	4	Severe	Very Severe	Severe	24
625	0.5	Severe	Moderate	Slight	28
G-3	0.7	Severe	Severe	Moderate	19
C-276	0.1	Slight	Slight	Very Slight	1

mpy: mils per year (mm/year: divide by 39.4)

**\*Pitting or Crevice (depth of attack)**

Very Severe	:	more than 30 mils
Severe	:	15 to 30 mil
Moderate	:	5 to 15 mil
Slight	:	2 to 5 mil
Very Slight	:	less than 2 mils

**TABLE 2**

Results from Rack No. 593 Bypass Duct  
620 MW; 2.7% Sulfur Coal; 12-Month Exposure Limestone Scrubbing System (1984)

Alloy	Corrosion Rate (mpy)	Pitting* Attack		Crevice* Attack	Maximum Pit Depth (mils)
		Base Metal	Weld Metal		
C-steel	20	(Partially Dissolved)		-	-
316L	2	Very Severe	Very Severe	Very Severe	57
317L	2	Very Severe	Very Severe	Very Severe	37
317L+	1	Severe	Severe	Severe	17
20CB-3* alloy	2	Very Severe	Very Severe	Very Severe	77
825	2	Very Severe	Very Severe	Very Severe	66
904L	0.7	Very Severe	Very Severe	Very Severe	125
254 SMO* alloy	1	Moderate	Very Severe	Moderate	8
700	1	Moderate	Moderate	Moderate	11
777	0.9	Severe	Severe	Very Severe	16
FERRALIUM* alloy	2	Moderate	Severe	Moderate	15
625	0.1	Moderate	Severe	Severe	9
G-3	0.1	Moderate	Severe	Very Severe	7
G-30* alloy	0.1	Moderate	Moderate	Severe	8
C-276	0.1	No Attack	No Attack	No Attack	0
C-22° alloy	0.1	No Attack	No Attack	No Attack	0
Titanium	0.1	No Attack	No Attack	No Attack	0

mpy: mils per year (mm/year: divide by 39.4)

**\*Pitting or Crevice (depth of attack)**

Very Severe	:	more than 30 mils
Severe	:	15 to 30 mil
Moderate	:	5 to 15 mil
Slight	:	2 to 5 mil
Very Slight	:	less than 2 mils

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**Table 3**

**Metallic Lining Installations with Alloy C-276 and C-22® Thin-Sheet**

<u>Utility</u>	<u>Alloy</u>	<u>Approximate Year of First Installation</u>
South Mississippi Electric Power R.D Morrow Station	C-276	1980
Central Illinois Light Co. Duck Creek Station	C-276	1983
Central Illinois Public Service Newton Station	C-276	1984
East Kentucky Spurlock Station	C-276	1984
Louisville Gas & Electric Mill Creek Station	C-276	1984
Texas Utilities, Tatum, Texas	C-276/C-22®	1984
Arizona Public Service, Cholla Station	C-22®	1985
City Utilities, Springfield, Missouri	C-276	1985
Public Service of Indiana, Gibson Station	C-276	1985
Northern Indiana Public Service, Schahfer Station	C-276/C-22®	1985
Southern Illinois Power Co-Op, Marion, Illinois	C-276	1985
Tampa Eelectric, Big Bend 4 Station	C-276	1985
Northern Indiana Public Service, Schahfer Station	C-22®	1985
Utah Power and Light, Hunter Station	C-276/C-22®	1986
Southwestern Electric Power, Marshall, Texas	C-22®	1986
San Miguel Electric Co-Op, Jourdontown, Texas	C-276/C-22®	1986-87
Alabama Electric, Tombigbee Station	C-22®	1986-87
Lower Colorado River Authority LaGrange, Texas	C-22®	1987
Utah Power and Light, Huntington, Utah	C-22®	1987
Associated Electric, Clifton Hill, Missouri	C-22®	1987
Minnkota Power Cooperation, Milton R. Young Station	C-22®	1987
Indianapolis Power and Light, Petersburg, IN	C-22®	1987
Southern Indiana Gas & Electric, AB Brown Station	C-22®	1987
Desert G & T, Bonaza, Utah	C-22®	1988
New York State Electric & Gas Sommerset, New York	C-22®	1988
Texas Utilities, Rockdale, Texas	C-22®	1988
Deserret Coop, Vernal, Utah	C-22®	1988
Santee Cooper Cross, South Carolina	C-22®	1988
Cities Utilities, Springfield, Missouri	C-22®	1988
Nevada Power, Reid Gardner Station	C-22®	1988
Arizona Public Service, Four Corners #5 Station	C-22®	1988
Southern Indiana Gas and Electric, W. Franklin, Indiana	C-22®	1988
Santee Cooper, Cross, South Carolina	C-22®	1989
Texas Utilities, Monticello, Texas	C-22®	1989
Minnkota Power Cooperation, Milton R. Young Station	C-22®	1989
Rummelsburg, Eastern Germany	C-22®	1989

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# Corrosion-Resistant Alloys

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**Table 3**

**Metallic Lining Installations with Alloy C-276 and C-22® Thin-Sheet**

<u>Utility</u>	<u>Alloy</u>	<u>Approximate Year of First Installation</u>
National Power, Drax Station, United Kingdom	C-22®	1989
Houston Light & Power, Thompson, Texas	C-22®	1990
Arizona Public Service, Four Corners #4 Station	C-22®	1990
New York State Electric & Gas, Sommerset, New York	C-22®	1990
Texas Utilities, Mt. Pleasant, Texas	C-22®	1990
Lower Colorado River Authority, LaGrange, Texas	C-22®	1990
Northern Indiana Public Service, Chesterton, Indiana	C-22®	1990
Central Louisiana Electric Co., Mansfield, Louisiana	C-22®	1990
San Miguel Electric Co-Op, Jourdantown, Texas	C-22®	1991
Georgia Power, Yates Station	C-22®	1991
Houston Light and Power, Paris, Texas	C-22®	1991
Lower Colorado River, LaGrange, Texas	C-22®	1991
Nevada Power, Reid Gardner Station	C-22®	1991
Northern Indiana Public Service, Bailly Station	C-22®	1991
Colorado UTE, Craig Station	C-22®	1991
Jacksonville Electric, St. Johns River Station	C-22®	1991
Indianapolis Power and Light, Petersburg, Indiana	C-22®	1991
National Power, DRAX Station, United Kingdom	C-22®	1991
Northern Indiana Public Service, Schahfer Station	C-276	1991
ENEL, Brindisi South and Fiume Santo, Italy	C-22®	1991

**Table 4**

**Field Tests and Service Trials with H-9M Alloy**

- Northern Indiana Public Service
  - Big Rivers Electric (1,600 lbs.)
  - San Miguel Electric (2,600 lbs.)
  - Associated Electric (16,500 lbs)
  - New England Power (17,000 lbs.)
  - Tempco Electric (250 ft. Welded Tubing)
  - Jacksonville Electric (7,600 lbs)
  - Electrofilters/Municipal Incinerators (10,000 lbs.; France, Japan)
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# Corrosion-Resistant Alloys

**Table 5**

**256 MW; 3.4% S Coal; FMC Dual Alkali**

- FGD Start-up: April 1979
  - Original Duct: Carbon Steel
  - Absorber Outlet: Lined Carbon Steel (Flake Glass) and 317L
  - 1983: Repaired Carbon Steel with same and with 316L
    - : Repaired "by-pass" duct with clad 317L
    - : Repaired "outlet" duct with clad 316L
  - 1985: Repaired both ducts with 317LM
  - 1988: Repaired fan housing with HASTELLOY® C-22® alloy
  - 1989: Replaced "by-pass" duct with HASTELLOY® C-22® alloy
- 52 tons (115 Klbs) of 1/4" plate; 6 tons (13Klbs) of 1/16" sheet HASTELLOY® C-22® alloy

**Table 6**

**ASTM Quality Control Tests Average Corrosion Rates in Mils Per Year**

	<u>625 Alloy</u>	<u>C-276 Alloy</u>	<u>C-22® Alloy</u>
ASTM G-28A 50% H <sub>2</sub> SO <sub>4</sub> + 42 g/l Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> Boiling	23	250	40
ASTM G-28B 23% H <sub>2</sub> SO <sub>4</sub> + 1% CuCL <sub>2</sub> + 1.2% HCl Boiling	2721 (pit)	55	8

\*divided by 39.4 for mm/year

**Table 7**

**Chemical Composition Ranges**

<u>C-22® Alloy</u>	<u>Ni</u>	<u>Cr</u>	<u>Mo</u>	<u>W</u>	<u>Fe</u>	<u>C</u>
UNS N06022	Balance	20.0-24.0	12.0-17.0	2.0-4.0	2.0-8.0	0.02-max
HASTELLOY® C-22® alloy	Balance	21.3-22.1	13.0-13.8	2.7-3.3	3.6-4.5	<0.007

**Table 8**

**Corrosion Rates of Various Welding Techniques**

ASTM G-28A (50% H<sub>2</sub>SO<sub>4</sub> + 42 g/l Fe<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>) Boiling -24 Hours

Corrosion Rates (mpy)

	<u>Base Metal</u>	<u>SMAW</u> (5.4 KJ/cm) (12.7 mm)	<u>GMAW Sp.A.M.</u> (12.6 KJ/cm) (19 mm)	<u>GMAW Sh.A.M.</u> (7.8 KJ/cm) (9.5 mm)	<u>GTAW</u> (7.9 KJ/cm) (3.2 mm)
C-276 Alloy	250	235	246	344	207
C-22® Alloy	40	69	56	53	44

# Corrosion-Resistant Alloys

**Table 8 (Continued)**

ASTM G-28A (23% H<sub>2</sub>SO<sub>4</sub> + 1.2 HCl + 1% FeCl<sub>3</sub> + 1% CuCl<sub>2</sub>) 85°C - 24 Hours

Corrosion Rates (mpy)

	Base Metal	SMAW (5.4 KJ/cm) (12.7 mm)	GMAW Sp.A.M. (12.6 KJ/cm) (19 mm)	GMAW Sh.A.M. (7.8 KJ/cm) (9.5 mm)	GTAW (7.9 KJ/cm) (3.2 mm)
C-276 Alloy	250	235	246	344	207
C-22® Alloy	40	69	56	53	44

**Table 9**

**Effect of Welding Technique/Heat Input on Resistance to Corrosion 24-Hour Exposure;  
11.5% H<sub>2</sub>SO<sub>4</sub> + 1.2% HCl + 1% FeCl<sub>3</sub> + 1% CuCl<sub>2</sub>**

Critical\* Pitting Temperature (°C)

Welding Process	Thickness (mm)	Heat Input (KJ/cm)	C-22® alloy	C-276 alloy	625 alloy
GTAW automatic Cu clamps	3.2	7.9	100	100	55
GMAW manual short arc mode	9.5	7.8	102	95	50
SMAW manual 3.2 mm dia.	12.7	5.4	100	100	50
GMAW manual spray arc mode	19.0	12.6	102	95	50
	Average		101	97.5	51.3
Typical unwelded base material			120	110	75

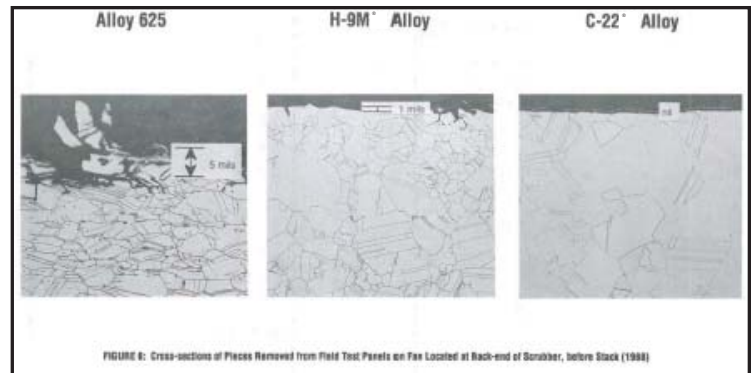
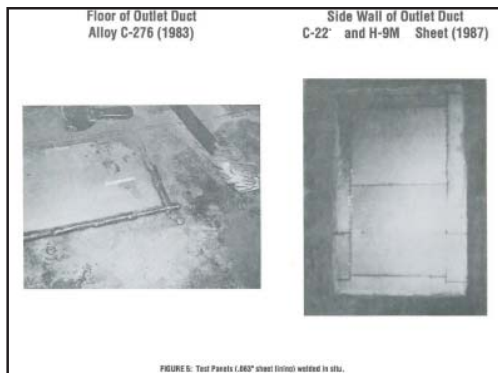
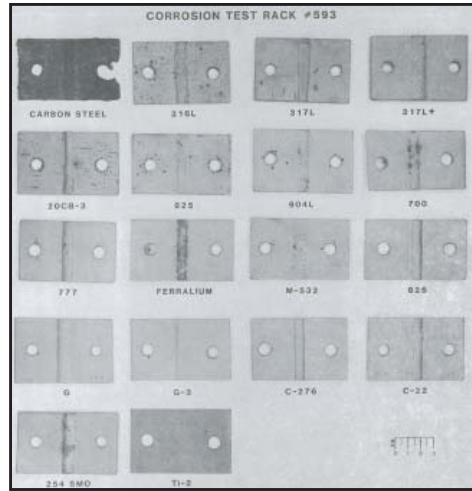
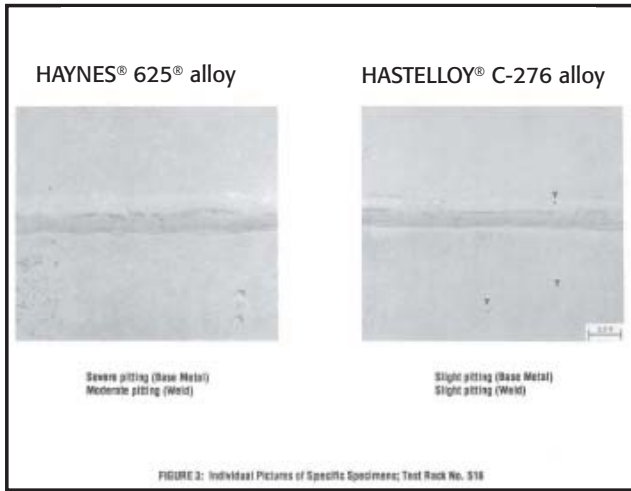
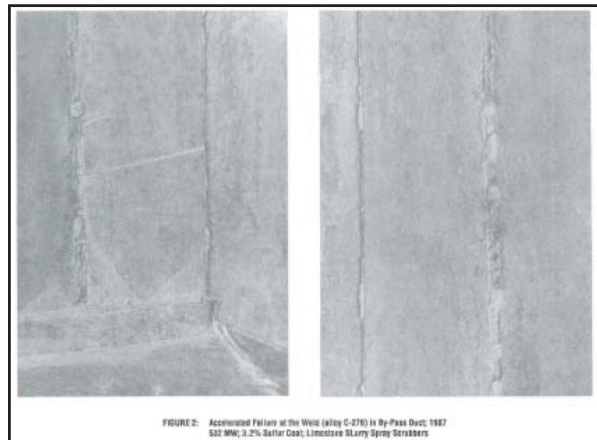
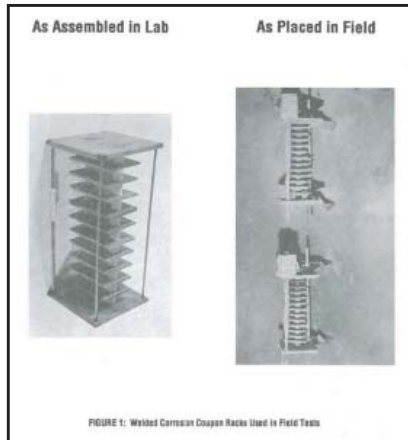
**Table 10**

**Ranking for Resistance to Pitting Corrosion  
11.5% H<sub>2</sub>SO<sub>4</sub> + 1.2% HCl + 1% FeCl<sub>3</sub> + 1% CuCl<sub>2</sub>**

<u>Material</u>	<u>Critical Pitting Temperature (°C)</u>
C-22® alloy	120
ULTIMET® alloy	115
C-276	110
625	75
6B	45
20CB-3® alloy	30
316L	25

\*Temperature at and above which pitting has been observed within 24-hours exposure

# Corrosion-Resistant Alloys



# Corrosion-Resistant Alloys

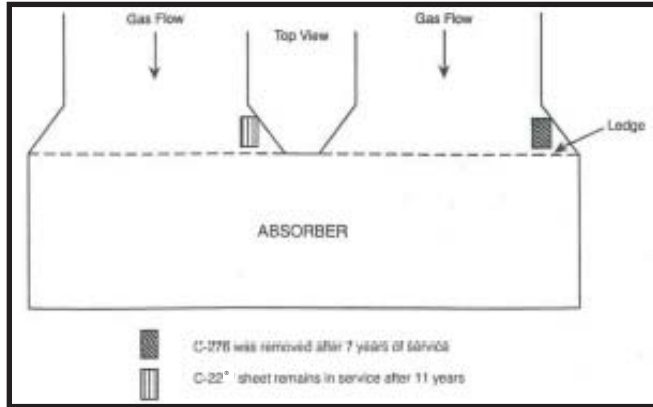


FIGURE 7: Schematic of R. D. Morrow Inlet Dust and Panels Locations

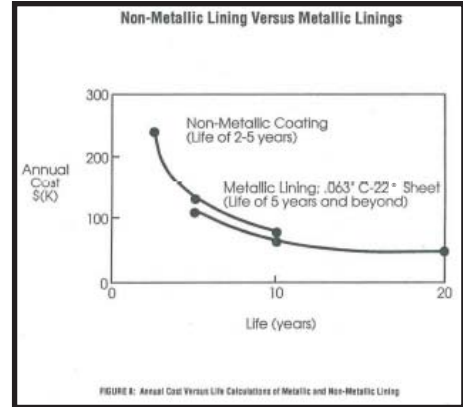


FIGURE 8: Annual Cost Versus Life Calculations of Metallic and Non-Metallic Lining

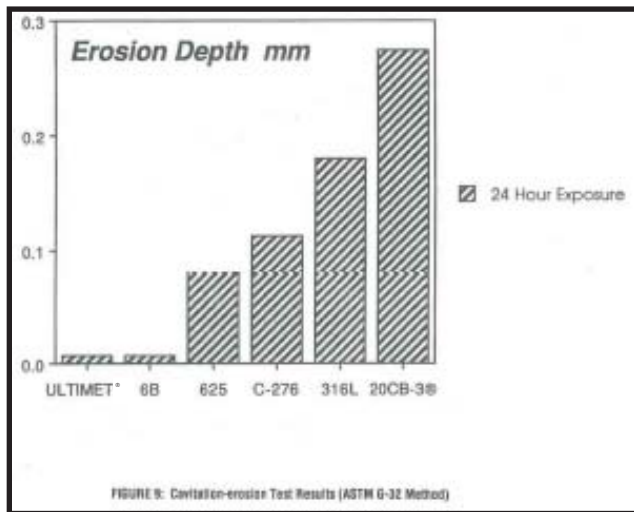


FIGURE 9: Cavitation-erosion Test Results (ASTM G-32 Method)



FIGURE 10: ULTIMET Cast Nozzle (Waste Scrubbing)

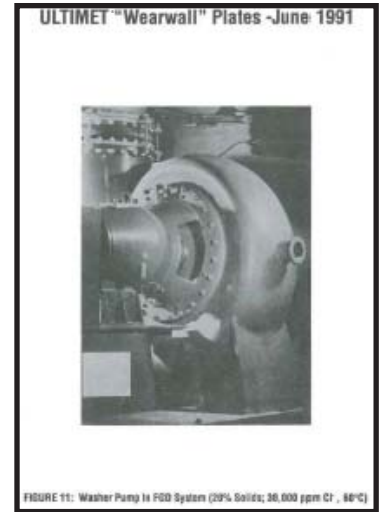


FIGURE 11: Washer Pump in PDS System (20% Solids; 30,000 ppm Cr, 60°C)

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