A REVIEW OF EXPERIENCES WITH AL-6XN® AND ZERON® 100 IN AIR POLLUTION CONTROL EQUIPMENT

*Devin M. Wachowiak and Jason D. Wilson

Rolled Alloys
125 West Sterns Road
Temperance, MI 48182 USA
*(*Corresponding author: dwachowiak@rolledalloys.com)*

ABSTRACT

A variety of metallic alloys are currently used in pollution control systems. This paper reviews the use of AL-6XN (N08367) and ZERON 100 (S32760) alloys in various FGD and WESP applications. Experimental data will be reviewed that supports the use of the alloy in the high chloride, sulfuric acid containing environments encountered by many components of the pollution control system. Examples of the application of AL-6XN and ZERON 100 in actual service will be presented. AL-6XN and ZERON 100 alloys have proven to be cost effective materials of construction that fill the gap between the lower alloyed stainless steels, such as the 317L, 904L and 2205, and the high Mo nickel based alloys. As AL-6XN and ZERON 100 alloys are established materials of construction, they are readily available in product forms necessary to complete an FGD or WESP system.

INTRODUCTION

Industrial plants are now faced with increasingly strict air quality control laws and EPA rules. New multi-pollutant legislation is controlling a wider range of emissions, while existing legislation is being enforced at more plants. Coal fired power plants have had the most widespread requirements to control their emissions of sulfur compounds. A significant number of flue gas desulphurization (FGD) units worldwide employ wet scrubbing, to reduce sulfur dioxide emissions by more than 90%. Wet scrubbing has also been found to be effective at removing mercury in many cases.

Reduction of sub-micron particles, such as sulfuric acid aerosols particulates, may be efficiently removed through the use of a wet electrostatic precipitator (WESP). Due to the inherent contaminants generated by the combustion of coal, wet FGD and WESP's require the use of corrosion resistant materials in their construction. The use of these alloys in power plant FGD systems has led to their widespread use in other similar sulfur removal systems installed by the refining, cement, and mining industries.

AL-6XN and ZERON 100 have been used extensively in pollution control equipment such as FGD's and WESP's. Due to the high corrosivity of the environment in these systems, the use of corrosion resistant alloys is required. Historically, if a particular environment was too corrosive for the lower corrosion resistance stainless grades such as 316L, 317L, or 2205, the solution was to use a high nickel, high molybdenum alloy. AL-6XN and ZERON 100 create a bridge to the gap between stainless steels and the high nickel alloys in both corrosion resistance and in cost.

DISCUSSION OF ALLOYS

AL-6XN and ZERON 100 are both corrosion resistant alloys that have an extensive history in corrosive applications in industries including, but not limited to, the power industry, pulp and paper, mining, chemical process, seawater reverse osmosis desalination, and the oil and gas industry. Due to their high levels of chromium, molybdenum, and nitrogen, both the AL-6XN and ZERON 100 alloys have improved resistance to high chloride containing environments compared to previously used stainless steels and duplex alloys in many industrial process applications.

AL-6XN (UNS N08367)

AL-6XN is a super austenitic alloy that was designed to be a seawater resistant material and has since been demonstrated to be resistant to a broad range of very corrosive environments. AL-6XN is a six-percent molybdenum stainless steel that contains high amounts of nickel and chromium and has good resistance to various environments including high chloride environments and several acid environments. Below is a chemical content breakdown of the AL-6XN alloy including both nominal values and specified values per ASTM B 688 for plate products.

Table 1 – Chemical Composition of AL-6XN alloy

Element	Nominal Content (wt%)	Allowable Range (wt%)
Ni	24.0	23.5 – 25.5
Cr	20.5	20.0 – 22.0
Mo	6.3	6.00 – 7.00
N	0.22	0.18 – 0.25
C	0.02	0.030 Max
Cu	0.10	0.750 Max
Mn	0.30	2.00 Max
Si	0.40	1.00 Max
Fe	Balance	Balance

* Allowable Range per ASTM B688

Due to the interstitial strengthening effect of nitrogen, AL-6XN has great strength characteristics. The higher strength of AL-6XN allows for potential thickness reductions in tanks and other processing equipment. The wall thickness reduction of a vessel can sometimes be significantly reduced with the use of the AL-6XN alloy in comparison to other 300 series stainless steels.

AL-6XN is approved under the ASME Boiler and Pressure Vessel Code as UNS N08367 in Section II Part D. AL-6XN is approved for use to 800°F for Section III and Section VIII Division 1 applications. The table below shows the ASME Maximum Allowable Design Stress Values in Tension for AL-6XN Alloy. Table 4 shows the typical mechanical properties for the AL-6XN alloy.

Table 2 – ASME Allowable Stress Values for AL-6XN

For Metal Temperature Not Exceeding (°F)	Allowable Stress, ksi (Plate, Sheet, Bar, Rod)	Allowable Stress, ksi (Welded Pipe & Tube, under 3/16” wall)
100	27.1	24.3
200	27.1	24.3
300	25.7	23.0
400	24.6	22.0
500	23.8	21.3
600	23.3	20.8
700	22.9	20.5
800	22.6	20.2

* Maximum Allowable Design Stresses per ASME Section VIII Div. 1

Table 3 – Representative Tensile and Impact Properties for AL-6XN Plate

Temperature, °F	Ultimate Tensile Strength, psi	0.2% Yield Strength, psi	% Elongation in 2”
-450	218,000	142,000	36
-320	196,000	107,000	49
70	108,000	53,000	47
200	99,900	49,400	47
400	90,300	40,400	46
600	86,000	36,300	47
800	87,000	36,000	48

ZERON 100 (UNS S32760)

ZERON 100 is a super duplex stainless steel containing 3.5 percent molybdenum that was developed specifically for corrosion resistance for applications in the oil and gas industry and the seawater desalination industry. ZERON 100 has since been used in several other industries including the power industry and mining industry in several different applications that involved the use of corrosion resistant alloys. Below is a chemical content breakdown of the ZERON 100 alloy including both nominal values and specified values per ASTM A240 for plate products.

Table 4 – Chemical Composition of ZERON 100 alloy

Element	Nominal Content (wt%)	Allowable Range (wt%)
Ni	7.0	23.5 – 25.5
Cr	25.0	20.0 – 22.0
Mo	3.5	6.00 – 7.00
N	0.22	0.18 – 0.25
C	0.02	0.030 Max
Cu	0.70	0.750 Max
Mn	0.50	2.00 Max
W	0.70	1.00 Max
Fe	Balance	Balance

* Allowable Range per ASTM A240

Due to its duplex structure and high nitrogen content, ZERON 100 also has great strength characteristics. The strength of ZERON 100 in many cases is twice the yield strength of many other 300 series stainless steels and other austenitic alloys. The higher strength of ZERON 100 allows for potential thickness reductions in tanks and other processing equipment. The wall thickness reduction of a vessel can sometimes be significantly reduced with the use of the ZERON 100 alloy.

ZERON 100 is approved under the ASME Boiler and Pressure Vessel Code as UNS S32760. ZERON 100 is approved for use to 600°F for Section VIII Division 1 applications under Code Case 2245.

The table below shows the ASME Maximum Allowable Design Stress Values in Tension for AL-6XN Alloy. Table 6 shows the typical mechanical properties for the ZERON 100 alloy.

Table 5 – ASME Allowable Stress Values for ZERON 100

For Metal Temperature Not Exceeding (°F)	Allowable Stress, ksi (Plate, Sheet, Bar, Pipe)
100	31.1
200	31.0
300	29.4
400	29.0
500	29.0
600	29.0

* Maximum Allowable Design Stresses per ASME Section VIII Div. 1, Code Case 2245

Table 6 – Representative Tensile Properties for ZERON 100 Plate

Temperature, °F	Ultimate Tensile Strength, psi	0.2% Yield Strength, psi
68	109,000	80,000
122	102,000	68,000
212	97,000	62,000
302	90,000	58,000
392	88,000	55,000
482	87,000	54,000
572	86,000	52,000

CORROSION DATA

Both AL-6XN and ZERON 100 have been subjected to countless corrosion tests in multiple corrosive environments. AL-6XN and ZERON 100 have shown to have great resistance to environments that contain high chloride environments, typical in seawater environments and many pollution control applications.

AL-6XN CORROSION DATA

AL-6XN has been known to have great resistance in flue gas desulphurization (FGD) applications. These applications involve environments that contain high chloride contents as well as lower pH’s and higher temperatures. Dependent on the concentration of chlorides along with the application temperatures, material selection for these applications are very crucial. AL-6XN has become the material of choice for many FGD applications.Typical environments may contain up to 50,000 mg/l chlorides with low pH’s and temperatures between 100°F and 160°F. Below is a chart showing the pitting resistance of AL-6XN in various environments that could be similar to those in FGD environments. As you can see, AL-

6XN has no problem handling 50,000 mg/l chlorides until temperatures reach above 160°F or when the pH gets too low.

Table 7 – Crevice Corrosion Test per ASTM G48 Procedure B. AL-6XN Alloy in 50,000 mg/l chloride water, pH and Temperature Varied

Temperature	pH 4	pH 2	pH 1	pH 0.5
130°F (54°C)	0.0000	0.0000	0.0000	0.0000
140°F (60°C)	0.0000	0.0000	0.0001	0.0252
150°F (66°C)	0.0000	0.0000	0.0001	0.0228
160°F (71°C)	0.0000	0.0003	0.0066	0.0460

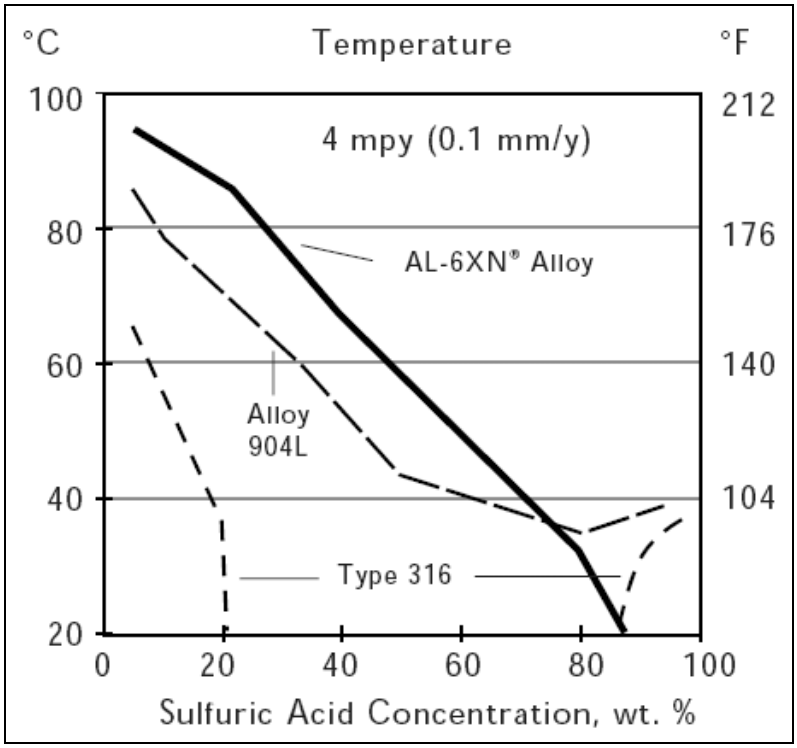

Figure 1 - Isocorrosion curve for various alloys in sulfuric acid. Corrosion curve represents a corrosion limit of 0.1 mm per year corrosion rate.

ZERON 100 CORROSION DATA

ZERON 100 is known to have superior performance in mining applications that involve sulfuric acid resistance. Due to the addition of copper to the chemical content of ZERON 100 super duplex, it has proven to have great resistance to sulfuric acid and sulfuric acid with chlorides present. ZERON 100 has also shown to have great resistance to other reducing acids. Below is a chart that compares ZERON 100 to other grades of stainless steel and nickel alloys. As you can see, in the more dilute concentrations of sulfuric acid, below 50 percent concentration, ZERON 100 has a higher temperature limitation to a

corrosion rate of 0.1mm per year. In very concentrated solutions, above 90 percent concentration, ZERON 100 also shows to be superior to the same group of alloys.

In Figure 2, it is shown that ZERON 100 has great resistance to sulfuric acid in the presence of chlorides as well. Once again, in concentrations below 50 percent, ZERON 100 shows to have great corrosion resistance in comparison to other alloys.

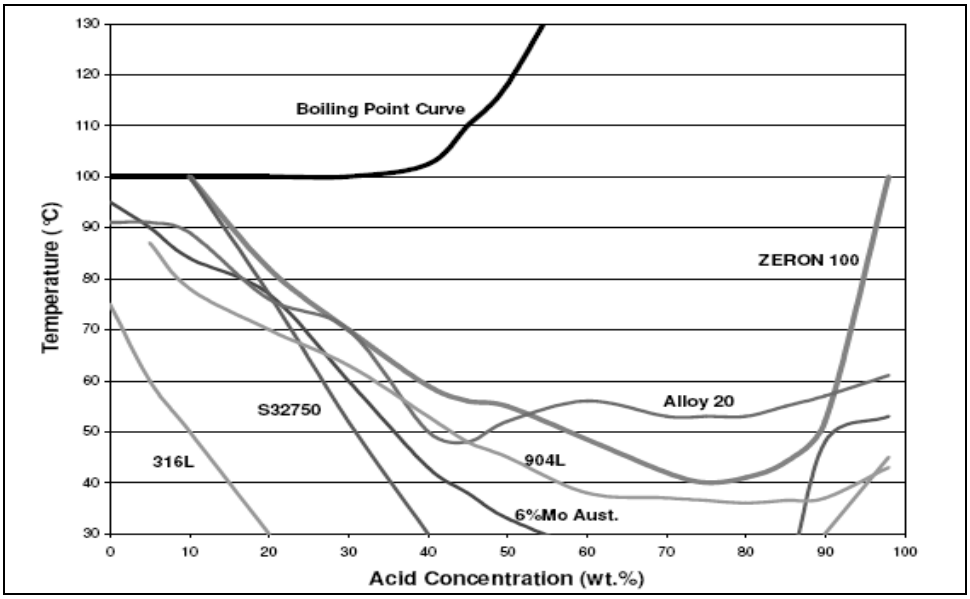

Figure 2 – Isocorrosion curve for various alloys in sulfuric acid. Corrosion curve represents a corrosion limit of 0.1 mm per year corrosion rate.

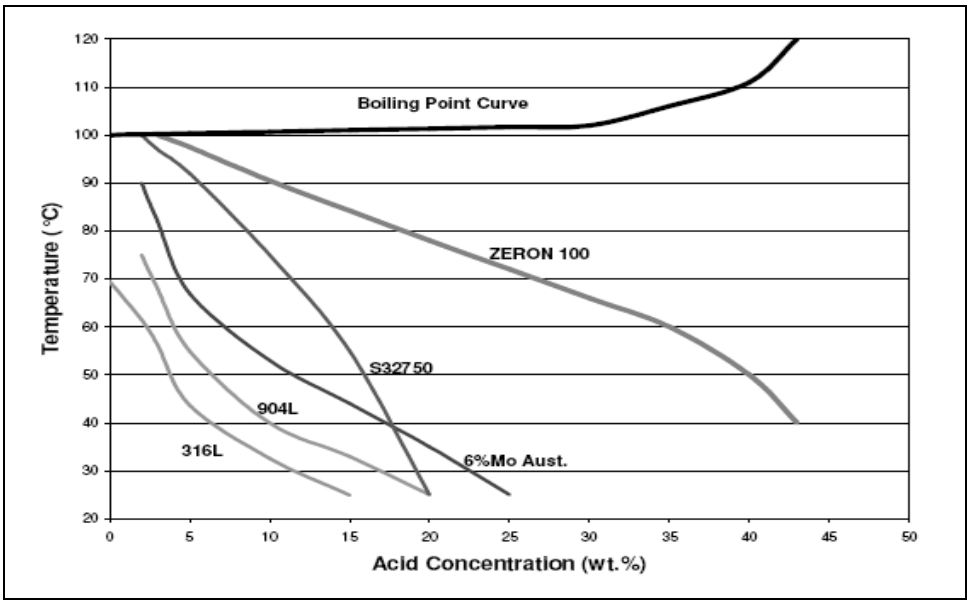

Figure 3 – Isocorrosion curve for various alloys in sulfuric acid plus 2,000 mg/l chlorides. Corrosion curve represents a corrosion limit of 0.1 mm per year corrosion rate.

APPLICATIONS

AL-6XN FLUE GAS SULPHURIZATION APPLICATIONS

Figure 4 – AL-6XN replaced 317LMN stainless for the lining in two FGD duct systems. 317LMN failed after three years in service. AL-6XN has been in operation after 10 years in service to date. Louisville Gas & Electric was the utility and Cane Run #6 was the unit.

Figure 5 – AL-6XN piping was used for the construction of slurry recirculation piping and rotary sparger unit submerged in limestone scrubber tank. This NIPSCO Bailly Generating Station Units #7 & 8 has used AL-6XN for over 10 years. Environment estimates in the absorber are a pH of 6, 11,000 mg/l chlorides and 130°F.

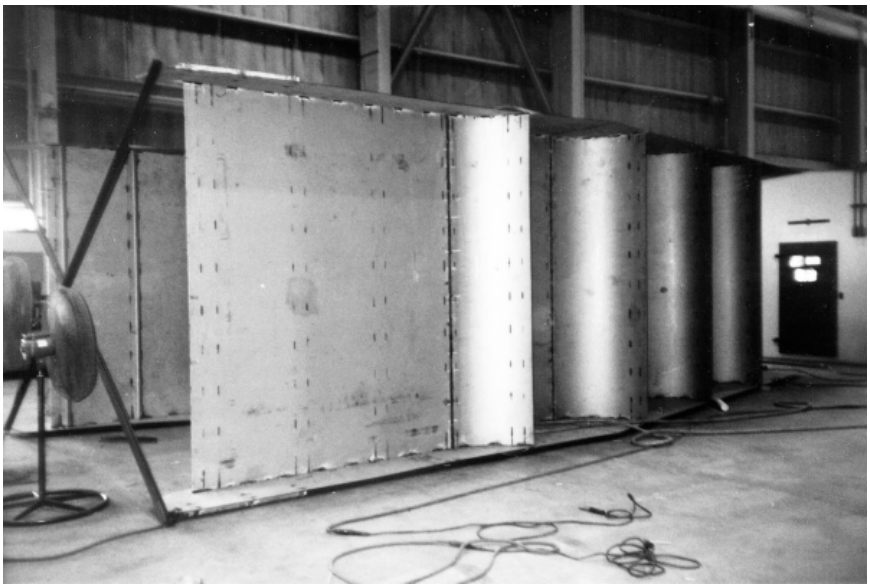

Figure 6 – AL-6XN was used for turning vanes installed in the flue stack at this Central Illinois Public Service Company Newton Power Station. This plant burns high sulfur coal hence condensation of a combination of acids and chlorides on the turning vane was a concern. AL-6XN was selected after testing.

Figure 7 – AL-6XN was used for the wallpapering of a carbon steel duct connecting the electrostatic precipitator to the flue stack. Lower than expected temperatures led to condensation in the bottom of the 12-foot wide duct. Duct was approximately 150 feet long. After 5 years in service, the duct was removed from service with no reported problems. Removal was due to installation of a new wet FGD scrubber system.

ZERON 100 MINING APPLICATIONS

Figure 8 – ZERON 100 pump in a copper mine in the USA. ZERON 100 was used as it was subjected to sulfuric acid.

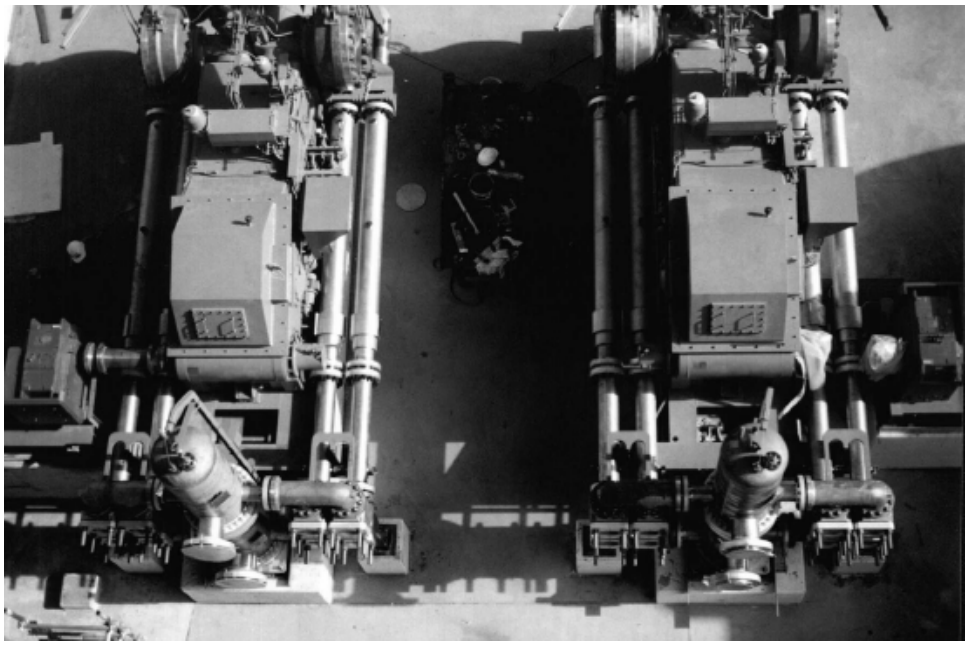

Figure 9 – ZERON 100 used for a nickel laterite-mining project in Australia. Pictured above are Geho positive displacement pumps made from ZERON 100.

Figure 10 – ZERON 100 oxygen sparge pipes used for main autoclave at Lihir gold mine, PNG.

The excellent corrosion resistance of ZERON 100 combined with its high strength makes it suitable for a wide range of applications in FGD plants. With absorber towers, the high strength of super duplex stainless steel means it is more economic to make absorber vessels from solid alloy rather than clad steel. One power station in the USA has changed from clad to solid super duplex stainless steel for the absorber vessels because of the economics.

ZERON 100 has been used successfully for the slurry pumps, agitator stools, and gas distribution plates at the Drax FGD Plant in the UK since 1994. The pumps are lasting 30,000 to 40,000 hours between major overhauls. ZERON 100 also had the advantage that minor damage can be weld repaired, while cast irons, as used for FGD pumps, cannot.

The slurry centrifuges at Ratcliffe FGD Plant were supplied in ZERON 100 in 1996. After 12 years in operation, they are in excellent condition. After a short time of operation the GRP slurry return lines at Ratcliffe FGD Plant were suffering severe erosion. These have now been replaced with spools in ZERON 100 and have given no further problems.

CONCLUSION

The combination of high strength and good corrosion resistance of both AL-6XN and ZERON 100 make these alloys eminently suitable for a wide range of applications in FGD and Mining industries. The excellent case histories of both the AL-6XN and ZERON 100 in FGD plants around the world have led to these two alloys being two of the main materials of construction for several applications within an FGD plant.

With the ever increasing demand for more stringent pollution control systems in not only the power industry, but also the refining and chemical process industry, corrosion resistant materials will need to be used to help clean the various gases, chemicals and acids involved in the pollution control equipment. With the experience of both AL-6XN and ZERON 100 in this industry, they show to be the alloys of choice for new pollution control systems.

AL-6XN and ZERON 100 are available in all product forms including plate, sheet, round bar, pipe, fittings, flanges and welding consumables.