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ETS-1 STEAM GENERATOR INJECTOR FACE WELD CORROSION

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REON TECHNICAL MEMORANDUM

RN-TM-0370

ETS-1 STEAM GENERATOR INJECTOR FACE WELD CORROSION

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ETS-1 STEAM GENERATOR INJECTOR FACE WELD CORROSION

I. INTRODUCTION

The three ETS-1 steam generator injectors S/N's 016, 017 and 018 experienced extensive preferential corrosion and pitting attack in the LOX nozzle to injector face weld joint areas during test series operations. The corrosion was detected during disassembly after the EP VI-J16 test series. The injectors had been subjected to intermittent "full steam" and "idle" operating conditions during EP IV, V and VI test series. "Full steam" condition utilizes propane rich fuel and LOX combustion (mixture ratio 2.2 to 2.4) with injection of water in the combustion chamber for generation of steam. "Idle" operation is the injector on standby (1st and 2nd stage ignition operating) with the other one or two parallel injectors under "full steam" operation. Operating times of each injector during the test series are shown in Table I.

TABLE I

OPERATING TIME AS OF THE END OF THE EP VI-J16 TEST SERIES

<u>Injector, S/N</u>	<u>Idle Time</u>	<u>Full Steam Time</u>
016	32.4 min.	25.8 min.
017	25.8 min.	22.1 min.
018	36.9 min.	9.6 min.

Weld cracks detected during initial testing required that injector S/N 016 and 018 be refurbished while injector S/N 017 did not require refurbishing. Injector face weld electrode and base materials specified by Thiokol were N-61 and 200-Nickel respectively.

Investigation was conducted to determine cause of failure and recommend design changes necessary for correction.

II. CONCLUSIONS

A. The corrosion took place as a result of galvanic couple set up between the 200 nickel metal and N-61 weld joint in the presence of steam or water electrolyte. The N-61 weld material is anodic to 200 nickel under these conditions.

B. The weld electrode material used for the weld joint on injectors S/N's 016, 017 and 018 was N-61 composition, as evidenced by greater than 90% nickel and 2-4% titanium and residue amounts of chromium, silicon and aluminum found in the weld joint material.

C. The weld joint areas on injectors S/N 017 and 018 are intergranularly attacked and pitted to a depth of .008-.010 inch depth. Injector S/N 016 weld joints are intergranularly pitted to a depth of .004 inch.

D. The galvanic corrosion attack is enhanced by an unfavorable large cathode to anodic "area ratio" and probable presence of sulfur and carbonic compounds in the steam from the combustion products that increased electrolyte ion strength and caused elevated temperature attack.

E. If the sulfur content of the propane is above 100 ppm, it could cause corrosive attack of the injector face at temperatures above 700°F.

III. RECOMMENDATIONS

A. Hastelloy "W" or Inconel 82 weld filler material should replace the N-61 weld material used.

B. Determine the sulfur content of the propane in the storage tank. The sulfur content of the supplied propane should be determined periodically.

C. The steam and combustion products should be sampled during a run, and tested for ion concentration to determine its effect as an electrolyte for enhancing the galvanic corrosion.

IV. RESULTS

A. Visual Observations

The preferential corrosion and pitting of the injector face welds was apparent on all three injectors. However, the corrosion on injector S/N 018 was much more severe than on either injector S/N 017 and S/N 016, and is as presented in Figure 1. The corrosive attack on injector S/N 016 was not of the same general appearance as the other injectors and was characterized by localized pitting, as shown in Figure 2. In all cases, the corrosive attack was limited to the welds and seemed to be somewhat concentrated in areas that were in alignment with the LOX orifices in an area where higher localized combustion temperatures could possibly be present.

B. Investigation

Material samples were taken from each injector face weld and tested spectrographically and metallographically to determine the chemical analysis and the nature of corrosion present. The results of the spectrographic analysis are tabulated in Table II and show that the chemical analysis is the same as the N-61 weld electrode composition. Differences in Al, Si and Mn are due to weld oxidation and dilution during the TIG weld process.

Metallographic examination disclosed that the weld corrosion in injectors S/N 017 and 018 was intergranular pitting and attack to a depth of from .006 to .010 inch as shown in Figure 3. Examination of the samples from injector S/N 016 disclosed that only intergranular pitting corrosion was present to a depth of .004 inch as shown in Figure 4. Injector S/N 016 did not have the severe intergranular attack that was present on the injector welds of injectors S/N 017 and 018.

Samples of the water from the ETS-1 water tank and line were tested for sulfur compounds and chloride content. An insignificant amount of both (less than 5-6 ppm) was found in both samples.

The investigation disclosed that the sulfur content of the propane used during the tests was not available. If the sulfur content is above a 100 ppm concentration, it could cause corrosive attack at elevated temperatures (700°F or above) and be a contributing factor of the corrosion attack that occurred.

In order to determine if there was a higher temperature at the weld joint location adjacent to and aligned with the LOX nozzle orifices, an injector face plate that experienced steam generator test conditions was examined. The material in alignment with the LOX orifices was compared to material in between the orifices and at the same radial distance from the nozzle center. The section with orifice alignment showed complete grain recrystallization as shown in Figure 5 as compared with the material away from the orifice which was not recrystallized and shown in Figure 6. This indicates that the temperatures in the vicinity of the LOX orifices was in excess of 1200°F (the recrystallization temperature of 200-nickel material) during the steam generator operation.

V. DISCUSSION

Consultation with the International Nickel Company revealed that preferential corrosion of the weld joint of a N-61 weld and 200 nickel base metal combination has occurred in an aqueous atmosphere and was as a result of galvanic corrosion. The aqueous atmosphere would be the steam atmosphere in combination with the products of combustion and would cause corrosive attack during periods of "idle" operation. Under these conditions, the N-61 weld material is strongly anodic to the base 200 nickel parent material. Further evidence is furnished by the operational times for each injector. The injector that had the greatest exposure time to the steam atmosphere (greatest idle operation time) was S/N 018 and was also the most severely corroded.

A factor that encourages the galvanic corrosion is a high area ratio of the exposed cathodic area to the exposed anodic area. For the injectors, the cathodic 200 nickel metal has a much greater exposed area than the anodic weld joint areas. This would result in an exposed cathode to anode area ratio of approximately 120 to 1.

The 1200°F or above temperature in the weld joint adjacent to the LOX orifice would adversely affect the corrosion resistance of the material and make it susceptible to intergranular attack by sulfur. At concentrations of 100 ppm or above, the sulfur reacts with the nickel at these temperatures to form NiS_2 and Ni_3S_2 compounds that attack the material intergranularly and embrittle the material.

The strength of the electrolyte present would also encourage the galvanic corrosion. The electrolyte strength is increased by greater ion concentration which would be caused by formation of

steam or water soluble compounds from contamination elements introduced by combustion products. These would include soluble carbon, sulfur, or chloride compounds that may be present.

Hastelloy "W" or Inconel 82 weld filler materials are recommended as materials to be used to replace the N-61 weld filler material. These materials possess superior corrosion resistance to sulfur attack up to temperatures of 1500°F as well as having higher stable oxide films that would protect the metal from galvanic corrosion attack. In addition, these materials are not anodic to the 200 nickel base metal and would be less susceptible to galvanic corrosive attack.

Table II

Chemical Analysis of Weld Material

<u>Semi-Quantitative-Emission Spectrographic Results</u>	<u>N-61 Weld Electrode Composition</u>	
Ni - greater than 90%	93%	Ni + Co
Ti - 2 to 4%	2 - 3.5%	Ti
Fe - 1%	1.5%	Al
Mn, Cu, Cr, Si and Al - 0.5% or less	0.75%	Si
	1%	Mn
	1%	Fe
	.025% Max.	Cu
	.15% Max.	S
	.15% Max.	C

FIGURE 1 - Preferential and Pitting Corrosive Attack in the Weld Joint Area from Injector S/N 18 as Revealed by Dye Penetrant Inspection --- MAG - 2X

FIGURE 2 - Pitting Corrosive Attack at Weld Interface from Injector S/N 16 as Revealed by Dye Penetrant Inspection.

MAG 10X

FIGURE 3 - Intergranular Pitting and Attack in
N-61 Weld Joint Area of Injector S/N 18 to Depth of .010"
Etchant 5% H_2SO_4 MAG - 250X

FIGURE 4 - Intergranular Pitting Present in N-61 Weld
Joint Area of Injector S/N 16 to Depth of .004"
Etchant 5% H_2SO_4 MAG - 250X

FIGURE 5 - Representative Recrystallized
200 Nickel Base Metal in Location Aligned
with LOX Orifices and Adjacent to Weld
Joint Area - Etchant 5% H_2SO_4 - MAG 250X

FIGURE 6 - Representative Unaffected 200 Nickel
Base Metal in Location away from LOX orifices
and adjacent to Weld Joint Area.
Etchant: 5% H_2SO_4 MAG: 250X