

Stress Relaxation Cracking of Thin Alloy 800/800H Electric Heater Tubular Heating Elements

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ABSTRACT

Stress relaxation cracking (SRC) is known to occur in austenitic stainless steels and nickel alloys operating between 550°C (1020°F) and 750°C (1380°F). Commonly, failures occur in heavy wall welded components. This paper, however, will discuss two SRC failures that occurred in thin non-welded components. Both of these failures occurred in electric heaters and, specifically, in tubular heating elements made of alloy 800 and 800H. Failure analysis of the components indicated intergranular cracking due to SRC as the cause of these failures. Both failures initiated in areas of relatively high hardness due to cold work. This paper provides details related to manufacturing, environmental conditions, metallurgical analysis and provides recommendations to avoid such failures in the future.

Keywords: Stress relaxation Cracking, SRC, Alloy UNS N08800, Alloy 800, electric heater, tubular heating elements, high hardness.

INTRODUCTION

Stress relaxation cracking (SRC) is a failure mechanism known to occur in austenitic stainless steels and nickel alloys operating at moderate to high temperatures.

Typically, SRC failures tend to occur under the following conditions: ¹⁻⁶

1. Susceptible material: 800H, 347H, 617, etc. (typically materials with low creep ductility)
2. High residual stresses: Hardness > 200 HV (welded thick section)
3. Specific temperature range: usually between 500 °C (932 °F) and 750 °C (1382 °F).

Under these conditions, component stresses are relieved by time dependent inelastic deformation.³ In susceptible materials, this process occurs by intergranular cracking and is essentially a creep mechanism.²⁻⁶ In this respect, materials with low creep ductility tend to be prone to this type of damage mechanism. On the other hand, materials that have good creep ductility can tolerate the inelastic strains due to relaxation without cracking.³

SRC is known by several other names such as stress-relief-cracking, reheat cracking, strain-age cracking (SAC), Stress oxidation cracking, stress assisted grain boundary oxidation as well as others.^{3-4,6}

Commonly, failures occur in heavy wall welded components. however, this paper will discuss two SRC failures that occurred in thin unwelded components.

BACKGROUND

The first failure (Case 1) occurred in a regeneration gas electric heater at a natural gas liquid (NGL) recovery plant. The operator reported noticing gas leaking from the process side of the electric heater. Both the terminal box and the heater were then opened for internal inspection (Figure 1). Upon inspection, it was also observed that the heating elements experienced failure of the sheaths (tubes) at several of the hairpin (U-shape) bends. These failures had occurred several times prior to this investigation at the same locations and were replaced in-kind by the manufacturer.



Figure 1: Electric heater bundle (Case #1)

The second failure (Case 2) occurred in a condensate stabilizer reboiler electric heater at an upstream gas processing plant. The condensate stabilizer re-boiler had suffered from frequent tripping due to electrical grounding fault. The heater was opened for internal inspection and heavy deposits were observed (Figure 2). It was also reported that the heating elements experienced failure at the bottom section.

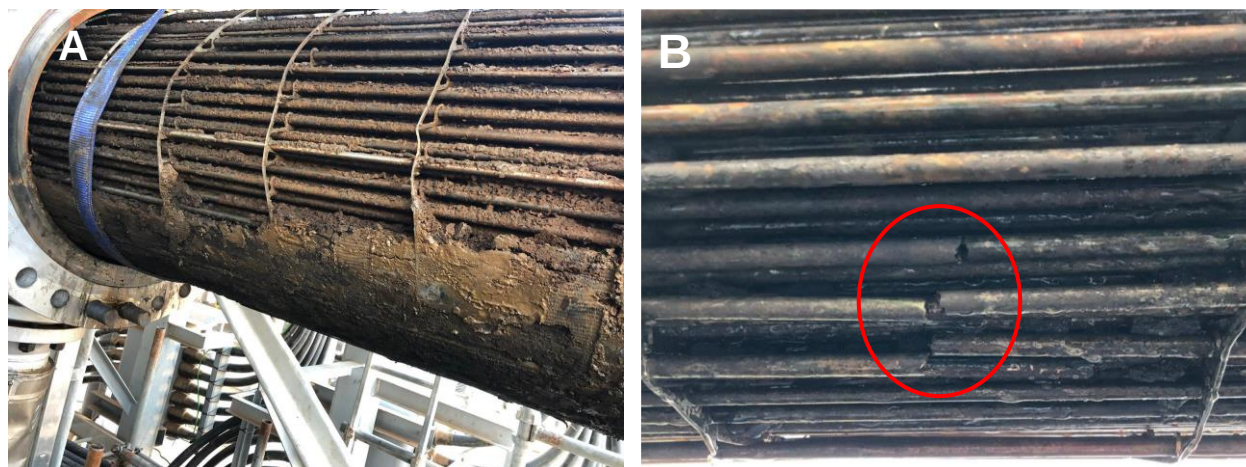


Figure 2: (A) Sludge accumulation at the bottom of the bundle. (B) Cracked tubes (Case #2)

Table 1
Design Specifications and Operating Conditions

	Case #1	Case #2
Equipment	Electric heater 2000 kW Seamless tube sheath	Electric heater 1,722 x 1.10 kW.480V 3 phase
Material of fabrication	Alloy 800	Alloy 800
Diameter	12.5 mm	12.8 mm
Thickness	1.2 mm	1.25 mm
Service environment	Wet methane gas (+7% N ₂)	Hydrocarbon condensate
Length of service	12 Years	3 Years
Gas operating temperature	400 °F (204.44 °C) – Inlet 550 °F (287.78 °C) - Outlet	368 °F (186.67 °C) – Inlet 407 °F (208.33 °C) - Outlet
Gas operating pressure	650 psig (4481.59 KPa)	135.7 psig (935.62 KPa)
Heating element wattage	16.7 kW Rating, 7.38 W/cm ² Wattage density	1,722 x 1.10 kW 3.1 W/cm ² Wattage density
Location of failure	3 rd stage	1 st stage

FAILURE ANALYSIS – EXAMINATION

Failure analysis was performed on the failed tubes (sheaths) including visual and metallurgical examination, mechanical testing, and chemical analyses.

Case 1: Regeneration Gas Electric Heater at NGL Recovery Plant

Visual Examination

Three tubes (heating elements) were submitted for analysis. All the failed tubes analyzed showed similar findings. For the purpose of this paper only one bend was examined in details. Figure 3 shows the tube sample of an electric heater that was sent for failure analysis. The sample was visually examined thoroughly. The heating elements consisted of a heating resistance wire embedded within compressed powder (acting as insulator and heat conductor) inside a sheath (tube). Two portions could be noticed for each heating element; namely the straight portion and the hairpin bend portion.



Figure 3: photograph of failed sample (Case 1)

Examination of the straight portion

Visual examination of the heating elements by stereomicroscope revealed no cracks on the straight portion. In this portion, the tubes were full of compacted white powder with the heating resistance wire embedded within. The white powder was reported to be magnesium oxide (MgO).

Examination of the hairpin bend portion:

The tube failed at the hairpin bend portion on both the extrados and intrados as shown in Figure 4. The tube failure manifested itself as a crack extending only along the weld-like protrusion. On the extrados, the crack was relatively wide open as the heating resistance wire could be clearly seen. Figure 5 shows the extrados crack extension along the hairpin bend, focusing on crack ends. However, the crack on the intrados was narrower and the heating resistance wire could not be seen through the crack. It was observed that a small amount of MgO fell out of the tube as the crack opened.



Figure 4: A cross-section view of tube #1 showing both extrados (right) and intrados cracks (left) of the hairpin bend portion.

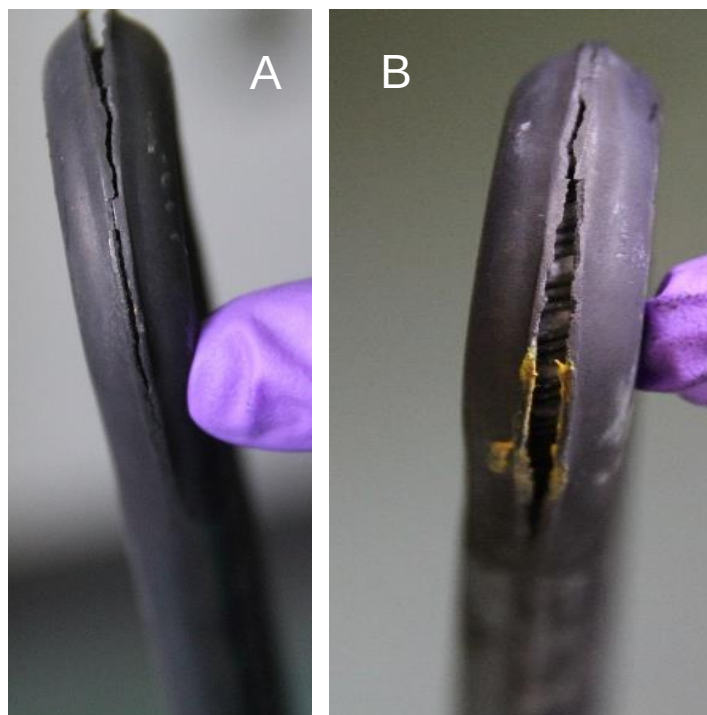


Figure 5: Views on extrados crack extension of tube #1, close-up on section-1 (A) and section-2 (B) crack end.