

On The Performance Of UNS S32100 vs N08825 Expansion Compensator Materials In Geothermal Applications

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ABSTRACT

Stressed bellows compensators heated by the transmission of two-phase geothermal fluid were exposed to atmospheric contaminants to simulate worst case external conditions. The tests aimed to determine time to failure under increasing severity of the external environment. Failure was not observed in the time period of the tests while the bellows were operated at temperatures above 150 °C regardless of the external contaminants. Cycling from high (105 °C achieved by steam heating internally) temperature to low (ambient) temperature gave accelerated damage mechanisms and failure from the external surfaces of both materials in a similar time period through pitting and Chloride SCC of the S32100 material and pitting of the N08825 material. Internal corrosion was also observed and attributed to the ambient standby conditions with no steam flow and the presence of weld spatter.

Key words: Bellows, compensators, stainless steel, Ni-base alloys, Chloride SCC, geothermal, corrosion.

INTRODUCTION

Geothermal fluid pipelines experience temperature changes on startup and shutdown that can be of the order 300 °C. Carbon steel pipeline design can include expansion loops and direction changes to allow for thermal expansion and contraction for the long lengths of pipeline commonly used from geothermal production wells to the geothermal power station and from the station to reinjection wells. In some instances, expansion compensators are used where there is insufficient area for such loops or where the pipe diameter is prohibitively large. Expansion compensators are used in the power plant, for example in steam pipelines next to the turbine and in geothermal heat exchanger shells to compensate

for the expansion of the tube materials. Stainless steels and Ni-base alloys are commonly used for the bellows materials in geothermal applications. The UNS S32100 alloy selected as a baseline alloy for this work was a common material used for example for older geothermal power stations in New Zealand and these compensators could last of the order of 20 years in steam pipelines. [1] Damage mechanisms that may be encountered for these bellows materials include:

- Pitting corrosion internally at shutdown and externally when wetted.
- Crevice corrosion at deposited scale edges under shutdown conditions.
- Sulfide Stress Cracking (SSC) for highly stressed or heavily cold worked material.
- Galvanic corrosion at the bellows to carbon steel contact.
- External Chloride SCC under leak conditions where brine or condensing steam contacts the outer surface.
- Internal pitting, crevice corrosion and Chloride Stress Corrosion Cracking (Cl SCC) at shutdown when hot, wet and in the presence of oxygen.
- Corrosion Under Insulation that may be seen as external Chloride SCC or simply as pitting corrosion.
- Fatigue (and corrosion fatigue) from pipeline vibration and flow induced vibration.
- Mechanical deformation on over bending.

This work aimed to simulate external and internal conditions leading to onset of corrosion with increasing severity of the test environments. This stepwise test approach was used to demonstrate the range of acceptable conditions for use of the two candidate materials considered, UNS S32100 (as a baseline material) and UNS N08825 (as a representative Ni-base alloy alternative material).

EXPERIMENTAL PROCEDURE

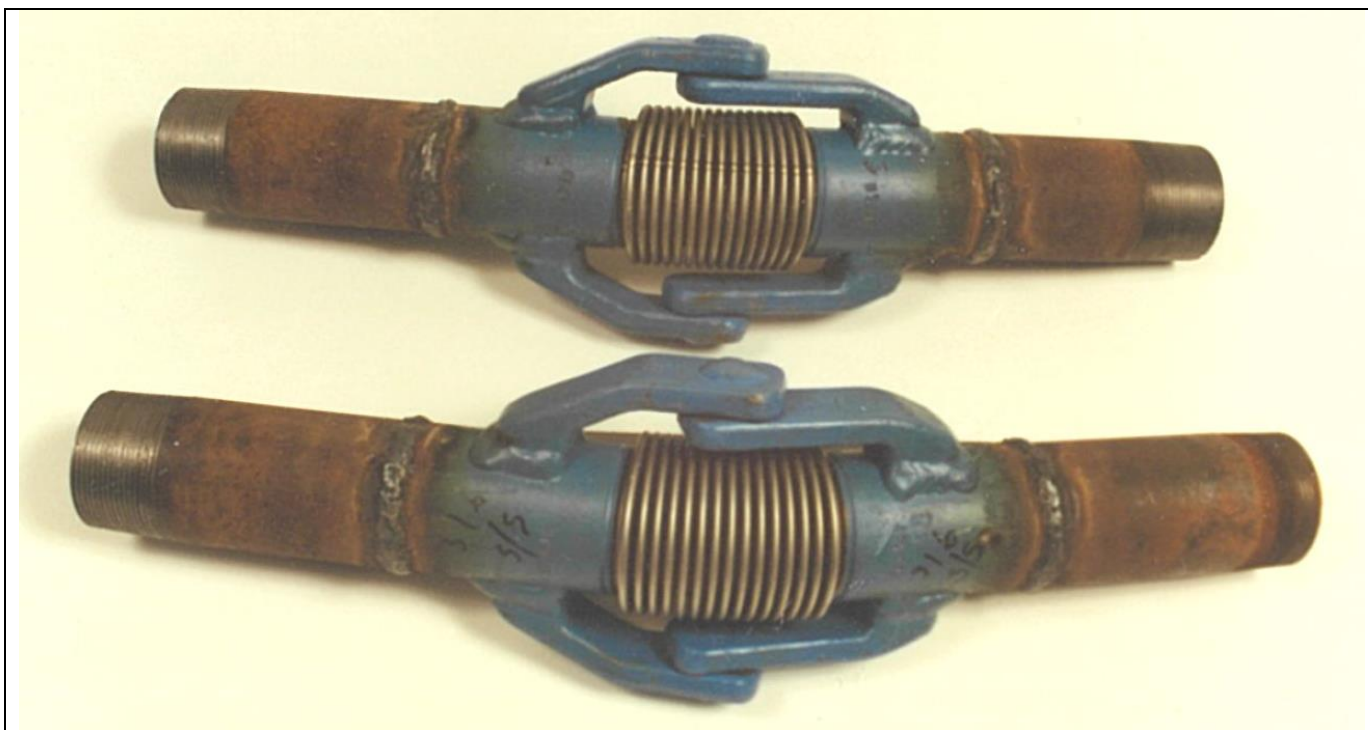
Prestressed, internally heated, 50 mm diameter expansion compensator bellows, one of S32100 and one of N08825, were exposed to external contaminants as might be encountered under leak conditions or under wet insulation in a geothermal two-phase fluid, steam or brine pipeline. The test bellows were individually attached to 50 mm ID carbon steel steam pipe and stressed to approximately 22 degrees in an angled position. Figure 1 shows as-received samples and the bellows under test at the start of the 1st test. The as-analysed materials of construction were as given in Table 1. The Pitting Resistance Equivalent Number (PREN) calculated using Equation 1 is also given in the table for the S32100 and N08825 materials. The bellows materials were of the order of 0.46 mm thick and the convolution heights were of the order of 10 mm.

$$\text{PREN} = \text{wt\% Cr} + 3.3 * (\text{wt\% Mo} + 0.5 * \text{wt\% W}) + 16 * \text{wt\% N} \quad (1)$$

Exposure Conditions

Internal heating was initially achieved using two-phase fluid followed by low pressure steam. The external contaminant sequence used for exposure included brine and 1 % brine in steam condensate. The test conditions and exposure times are summarized in Table 2.

The initial drip of brine at 160 °C was near the bellows inlet end as shown in Figure 1 with heavy silica scales as shown in Figure 2 and was on opposite sides of the stressing bars for the two bellows units tested. The deposited silica was easily cleared from readily exposed surfaces, but some scale was left between the bellows convolutions at the start of the 2nd test. The 2nd test with condensate + 1% brine at 150 °C was also done with the solution dripped in the same location. Figure 3a shows the bellows at the end of the 2nd test. The 3rd and 4th tests at 105 °C were done with the drip solution near the bellows exit and on the opposite sides of the stressing bars than for the first two tests, but at the same locations for both the 3rd and 4th tests. Figure 3b shows the appearance of the bellows after the 3rd test.



Expansion compensator bellows units in stressed condition viewed from extension side.
Bottom S32100 and Top N08825.



N08825 (left) and S32100 (right) with brine drip.



1st test of N08825 with brine drip.

Figure 1: Prestressed expansion compensator bellows units shown as received and in the 1st test arrangement with brine dripping onto the external surfaces.

Table 1: Analysis of bellows materials used in this work (Element wt%)

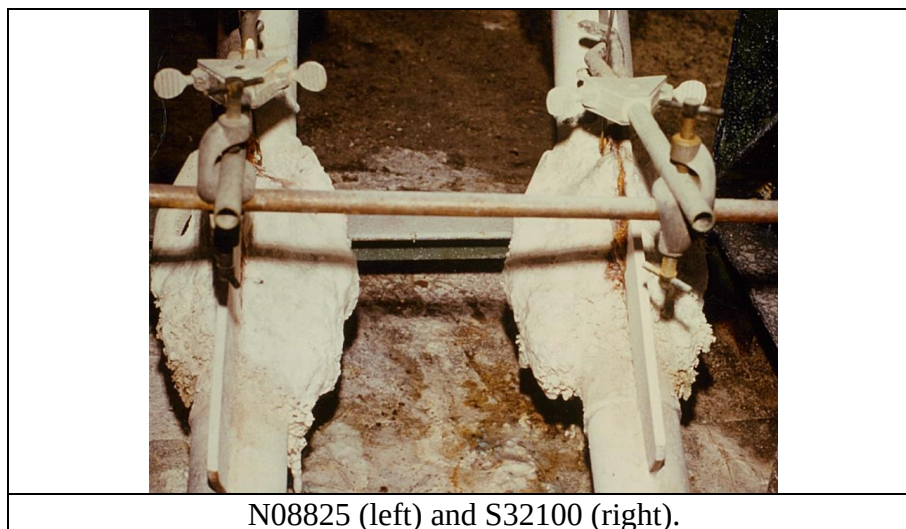
Material	C	Si	Mn	Ni	Cr	Mo	V	Cu	Co	Ti	Al	Fe	PREN
S32100	0.02	0.62	1.1	9.7	18.4	0.37	0.2	0.2	0.23	0.24	0.03	REM	22.8
N08825	≤0.01	0.29	0.7	REM*	23	2.0	0.05	2.7	0.1	1.0	0.18	28	43.6
Pipe	0.09	0.27	0.46	0.09	0.06	<0.03	<0.01	0.1	0.02	<0.01	<0.01	REM	---

REM = Remainder

*Ni of the order of 42.4 wt%

Table 2: Test bellows exposure conditions used.

Temperature of Heating Fluid	Heating Fluid Internal Flow	Contaminant Drip Solution	Exposure Time	External Surface Observations While Testing
1 st Test 160 °C	Two-Phase Fluid	Cooled Brine	5 months No failures	Silica Scaling
2 nd Test 150 °C	Two-Phase Fluid	Condensate + 1 % Brine	8 months No failures	Rust coloured staining and surface corrosion
3 rd Test 105 °C	Wet Steam	Condensate + 1 % Brine	3 months No failures	Rust staining and pitting
4 th Test 105 °C Cycling 5 days Hot 2 days Ambient	Wet Steam and No Flow	Condensate + 1 % Brine	2 months to failure of both compensators	Pitting and SCC of S32100 Pitting of N08825

**Figure 2: Appearance of expansion compensator bellows of N08825 (left) and S32100 (right) after 1st test with silica scale deposited by evaporative concentration, seen after 5 months.**