Wrong Heat Treat Causes Expansion Joint Failure

Sometimes there is no complex, hard-to-understand, scientific explanation of the cause for equipment failure. Sometimes, as this case history shows, it is simply a human failure.

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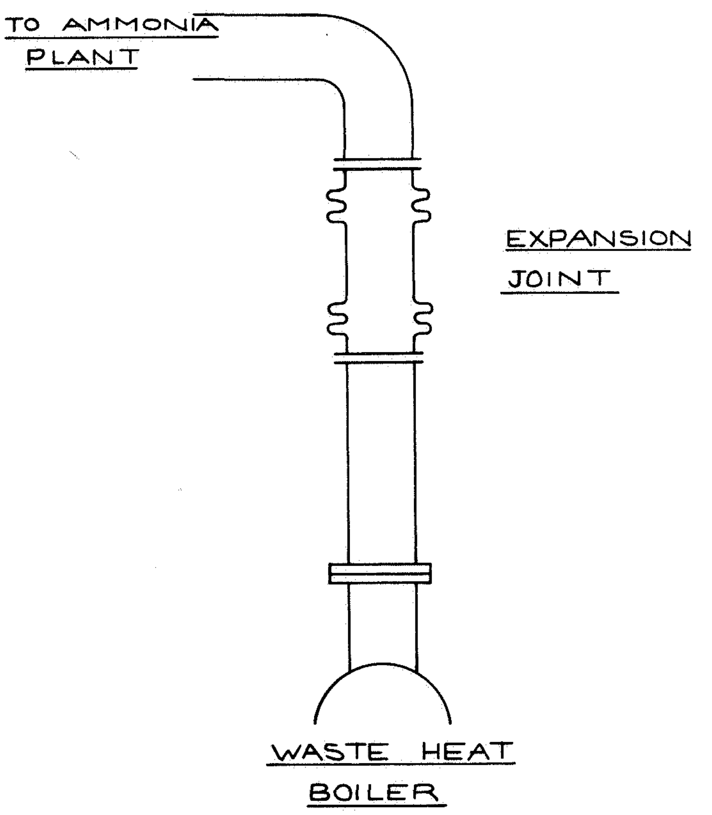

Figure 1. Location of bellows.

In an ammonia plant the hot gas line between the waste heat boiler and the next heat exchanger was subject to excessive stresses. First, the expansion joint of the heat exchanger failed. Then, the flange on the waste heat boiler started to crack. As a result of this, management installed an expansion joint in the line (Figure 1).

The joint consisted of two times two convolutions connected by a piece of pipe (Figure 2). The original expansion joint functioned well but twice developed pinhole leaks in one of the welds in the bellows. Alerted about this matter the expansion joint manufacturer supplied a spare joint, which was installed at the next shutdown. Within 45 days after start-up, the joint failed due to a long brittle fracture in one of the convolutions. This article covers the investigation of this fracture.

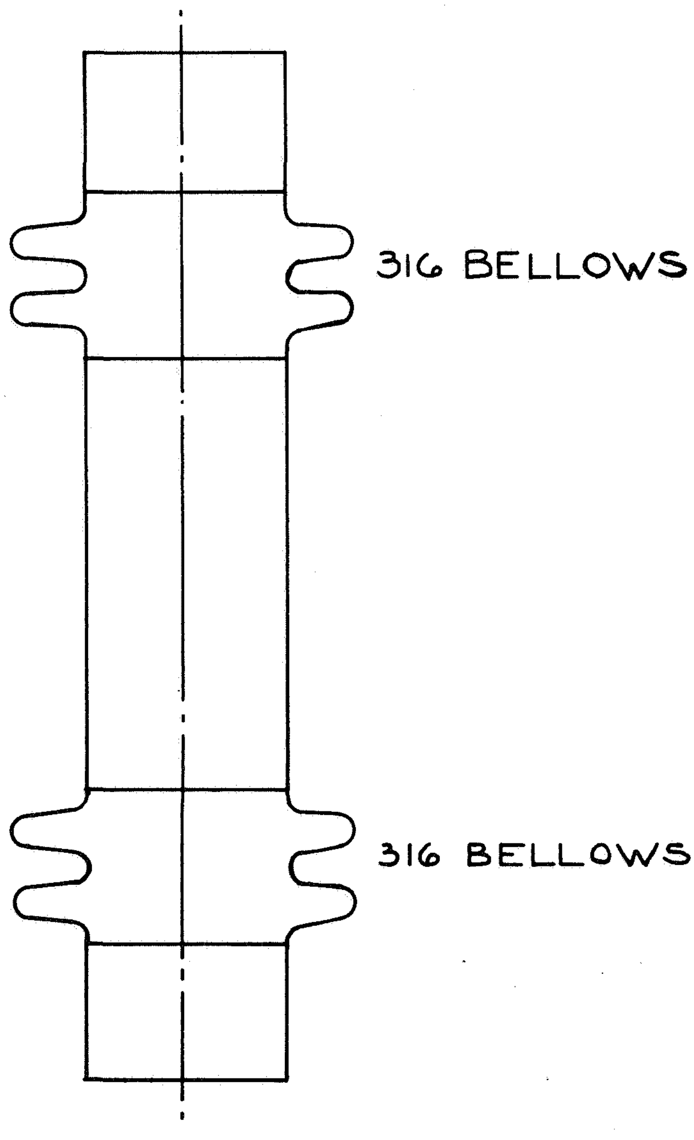

Figure 2. Expansion bellows.

Analysis of the material showed that it was within the type 316 steel specification. The edge of the fracture had a sawtooth-like appearance, indicating numerous cracks,

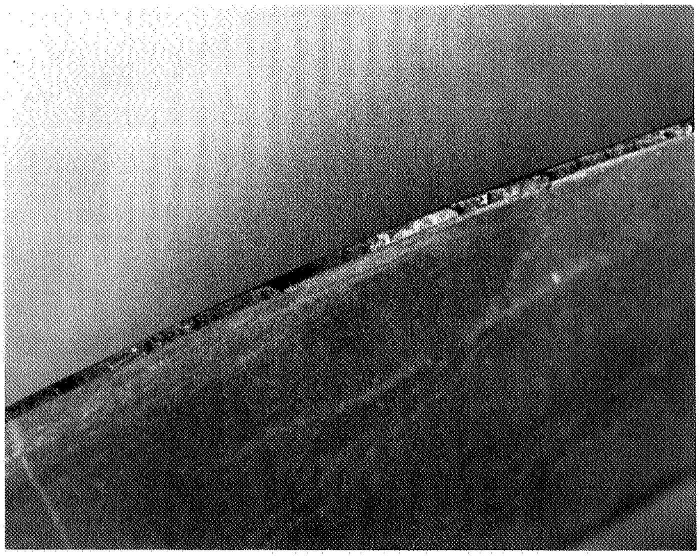

Figure 3. Portion of the fracture showing saw teeth.

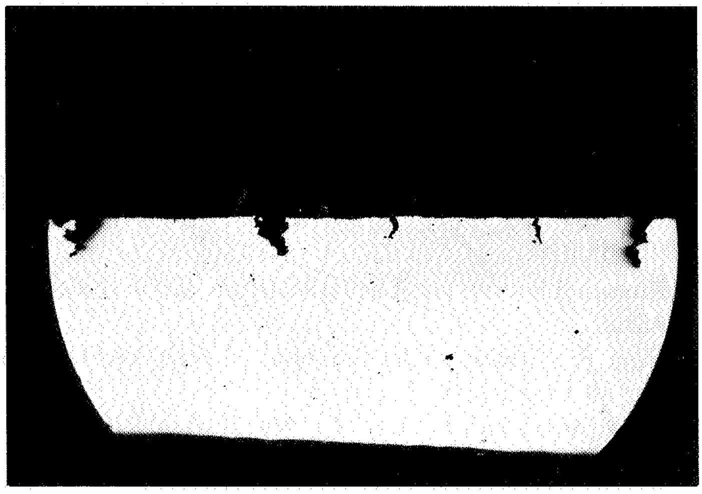

Figure 4. Multiple cracks in bellows surface (Mag. 50X).

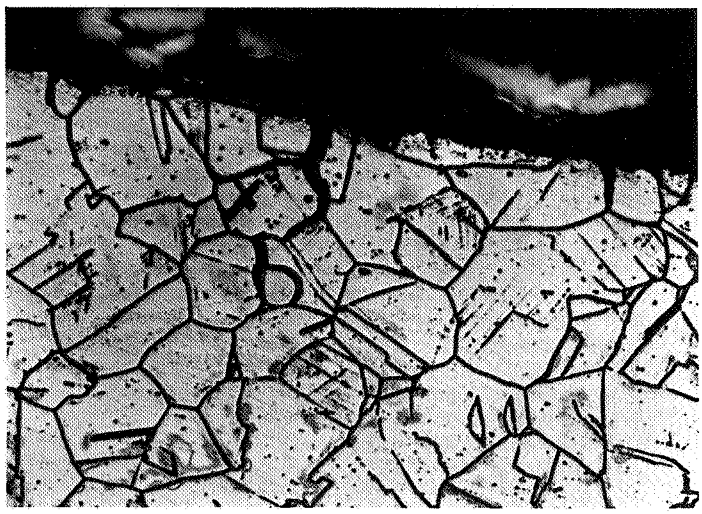

Figure 5. Surface of bellows with crack; 30-sec. oxalic acid electrolytic etch (Mag. 500X).

shown in Figure 3. This was confirmed by a cross section, shown in Figure 4. In fact, further investigation showed that the material was so full of cracks that it was surprising it stood up as long as 45 days (see Figure 5). It was clear that the material was completely embrittled.

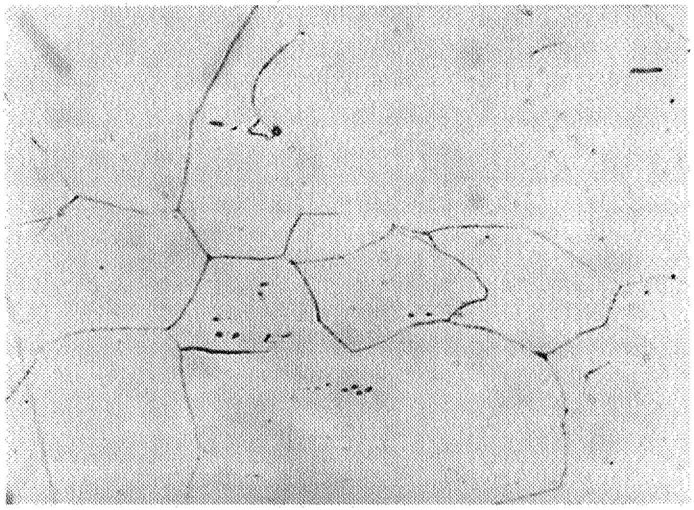

Figure 6. Bellows cross section; 1-min. NaCN electrolytic etch (Mag. 1000X).

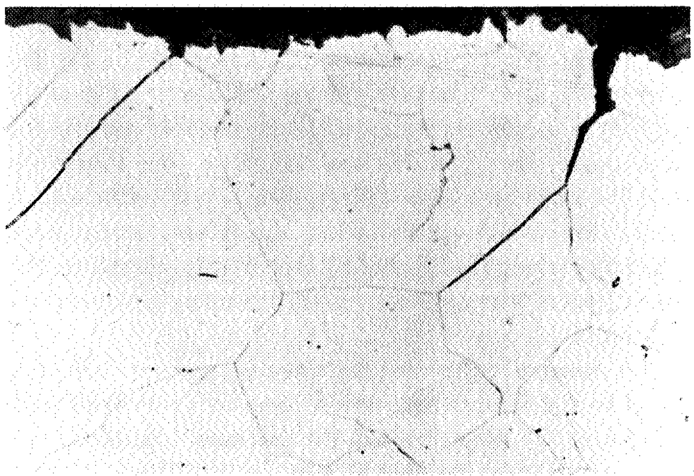

Figure 7. Surface cross section of bellows; 1-min. picral-HCl etch (Mag. 1000X).

Figure 8. Same as Figure 7; 30-sec. oxalic acid electrolytic etch (Mag. 1000X).

The first thought which occurred was that the embrittlement was due to sigma phase. Due to the presence of molybdenum, 316 often contains some ferrite from which sigma phase is easily formed when exposed to the wrong temperature range.

This assumption, however, appeared to have no founda-

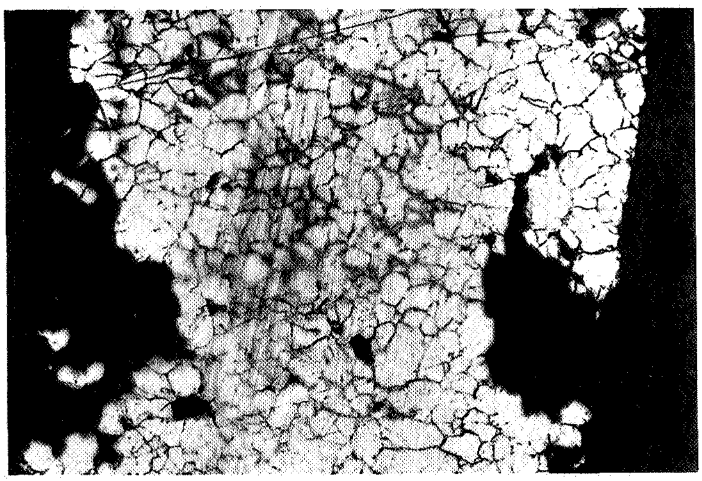

Figure 9. Disintegrating bellows material after Strauss test (Mag. 100X).

tion whatsoever. Sigma phase shows up as bluish gray islands after 10 seconds electrolytic etching in NaCn. However, in the present material the structure has hardly become visible after 1 minute etching in NaCn (see Figure 6). Similarly a 1-minute, picral-HCl etch, another specific for sigma phase, hardly shows any structure (see Figure 7); while the same area etched electrolytically in oxalic acid, a specific for carbide precipitation, shows very severe grain boundary etching (See Figure 8). Apparently, therefore, the embrittlement was caused by grain boundary precipitation of carbides.

This became quite obvious when a specimen was submitted to the Strauss test, which dissolves Cr-depleted gain boundaries. *(1)* After this test the specimen crumbled practically completely, so that it was quite difficult to save a piece large enough to make a cross section, shown in Figure 9.

The time-temperature curves for formation of sigma phase (in pure austenitic material) for formation of chi phase and for precipitation of carbides at the grain boundaries (see Figure 10) show that the danger of carbide precipitation is indeed much greater than that of sigma phase. *(2) (3)*

As a matter of fact, initial carbide precipitation begins at 1350°F within minutes, while after 30 minutes at that temperature carbide precipitation has progressed to a point where the corrosion rate of the metal is 400 mpy when exposed to a corrosive environment.

The probable cause of this mishap is that the manufacturer stress-relieved the expansion bellows after forming, but at the wrong temperature. Normally, austenitic stainless is given a full anneal between 1850° and 2050°F to relieve stresses caused by cold working. In the present case either

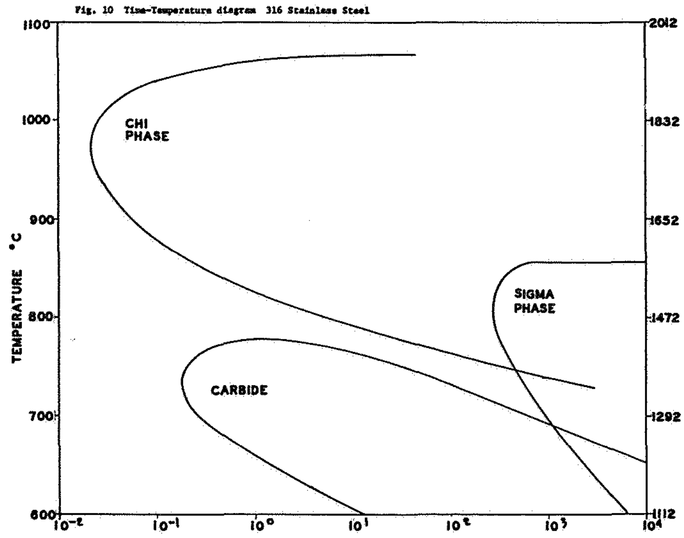

Figure 10. Time-temperature diagram for sigma formation in purely austenitic Type 316 stainless steel.

the stress-relieving temperature was too low, or cooling from full annealing temperature was so slow as to permit extensive carbide precipitation in the dangerous temperature range.

If there is a conclusion to be drawn from this, it is that no matter what you do, somebody will goof. #

Literature cited

1. American Society for Testing Materials ASTM Standard A262E.
2. Cihal, V., "Intergranular Corrosion of Stainless Steels," Fig. 70. Prague (1967).
3. White, W.E., and Le May, I., "Metallographic Observations on the Formation and Occurrence of Ferrite, Sigma Phase, and Carbides in Austenitic Stainless Steels, Part II: Studies of AISI Type 316 Stainless Steel," *Metallography*, 3, 51-60 (1970).

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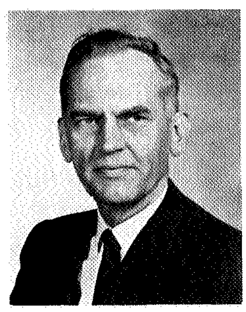

VAN DER HORST, J. M. A.

DISCUSSION

E.H. PHELPS, U.S. Steel Corp.: In your talk you indicated the failure which occurred was mechanical as a result of the heavy carbide precipitation. In my opinion the failure looks more like intergranular corrosion or intergranular stress corrosion resulting from heavy grain boundary carbide precipitation.
VAN DER HORST: Well, it might look that way but the temperature of the assembly is so high (about 900°F) that corrosion, at least aqueous corrosion, is excluded. The gas stream contains H_2, N_2, CO_2 and CO.
PHELPS: Did the cracking initiate from the inside or the outside?
VAN DER HORST: The cracking was from the inside.

In my opinion the cracking was caused by flexing of the expansion bellows, which was deformed to its limit. The material was completely embrittled; it could be broken in any direction.

PHELPS: Normally carbide precipitation does not cause brittleness in austenitic stainless steel.
VAN DER HORST: The amount of precipitation was enormous. The grain boundaries were completely filled with precipitates. Metallographically we checked also for chi-phase and Laves phase and found indications for both. The precipitates were thus probably a mixture of carbides, chi-phase and Laves phase.
W.D. CLARK, ICI, England: In our experience trouble with austenitic steel bellows in steam systems is all too common. We have had very many failures with 321, 347 or 316 bellows, but in no case can I recall that the condition of the steel was unsatisfactory. We are quite certain that under shut-down/start-up conditions the bellows can be wet and then dried out, and conditions are such as to cause trans-granular stress corrosion cracking of the steel. We therefore prefer to use alloy 800, or even alloy 825.