SECTION 4.0

GENERAL DAMAGE MECHANISMS – ALL INDUSTRIES

4.2.5 885°F (475°C) Embrittlement

4.2.5.1 *Description of Damage*

885°F (475°C) embrittlement is a loss in toughness due to a metallurgical change that can occur in alloys containing a ferrite phase, as a result of exposure in the temperature range 600°F to1000°F (316°C to 540°C).

4.2.5.2 Affected Materials

a) 400 Series SS (e.g., 405, 409, 410, 410S, 430 and 446).

b) Duplex stainless steels such as Alloys 2205, 2304 and 2507.

4.2.5.3 *Critical Factors*

a) The alloy composition, particularly chromium content, amount of ferrite phase, and operating temperature are critical factors.

b) Increasing amounts of ferrite phase increase susceptibility to damage when operating in the high temperature range of concern. A dramatic increase in the ductile-to-brittle transition temperature will occur.

c) A primary consideration is operating time at temperature within the critical temperature range. Damage is cumulative and results from the precipitation of an embrittling intermetallic phase that occurs most readily at approximately 885°F (475°C). Additional time is required to reach maximum embrittlement at temperatures above or below 885°F (475°C). For example, many thousands of hours may be required to cause embrittlement at 600°F (316°C).

d) Since 885°F embrittlement can occur in a relatively short period of time, it is often assumed that susceptible materials that have been exposed to temperatures in the 700°F to 1000°F (371°C to 538°C) range are affected.

e) The effect on toughness is not pronounced at the operating temperature, but is significant at lower temperatures experienced during plant shutdowns, startups or upsets.

f) Embrittlement can result from tempering at higher temperatures or by holding within or cooling through the transformation range.

4.2.5.4 *Affected Units or Equipment*

a) 885°F embrittlement can be found in any unit where susceptible alloys are exposed to the embrittling temperature range.

b) Most refining companies limit the use of ferritic stainless steels to non-pressure boundary applications because of this damage mechanism.

c) Common examples include fractionator trays and internals in high temperature vessels used in FCC, crude, vacuum and coker units. Typical failures include cracking when attempting to weld or to straighten bent, upset tower trays of Type 409 and 410 material (occurs often with vacuum tower trays of this material).

d) Other examples include duplex stainless steel heat exchanger tubes and other components exposed to temperatures above 600°F (316°C) for extended time periods.

4.2.5.5 *Appearance or Morphology of Damage*

a) 885°F embrittlement is a metallurgical change that is not readily apparent with metallography but can be confirmed through bend or impact testing (Fig 4-6).

b) The existence of 885°F embrittlement can be identified by an increase in hardness in affected areas. Failure during bend testing or impact testing of samples removed from service is the most positive indicator of 885°F embrittlement.

4.2.5.6 *Prevention / Mitigation*

a) The best way to prevent 885°F embrittlement is to use low ferrite or non-ferritic alloys, or to avoid exposing the susceptible material to the embrittling range.

b) It is possible to minimize the effects of embrittlement through modifications in the chemical composition of the alloy, however, resistant material may not always be readily available in most commercial forms.

c) 885°F embrittlement is reversible by heat treatment to dissolve precipitates, followed by rapid cooling. The de-embrittling heat treatment temperature is typically 1100°F (593°C) or higher and may not be practical for many equipment items. If the de-embrittled component is exposed to the same service conditions it will re-embrittle faster than it did initially.

4.2.5.7 *Inspection and Monitoring*

a) Impact or bend testing of samples removed from service is the most positive indicator of a problem.

b) Most cases of embrittlement are found in the form of cracking during turnarounds, or during startup or shutdown when the material is below about 200°F (93°C) and the effects of embrittlement are most detrimental.

c) An increase in hardness is another method of evaluating 885°F embrittlement.

4.2.5.8 Related Mechanisms

Not applicable.

4.2.5.9 *References*

1. “High Temperature Characteristics of Stainless Steels,” A Designers Handbook Series, American Iron and Steel Institute, Washington, DC, 1979.
2. G. E. Moller, “Experiences With 885°F (475°C) Embrittlement in Ferritic Stainless Steels,” Materials Protection, NACE International, May, 1966.