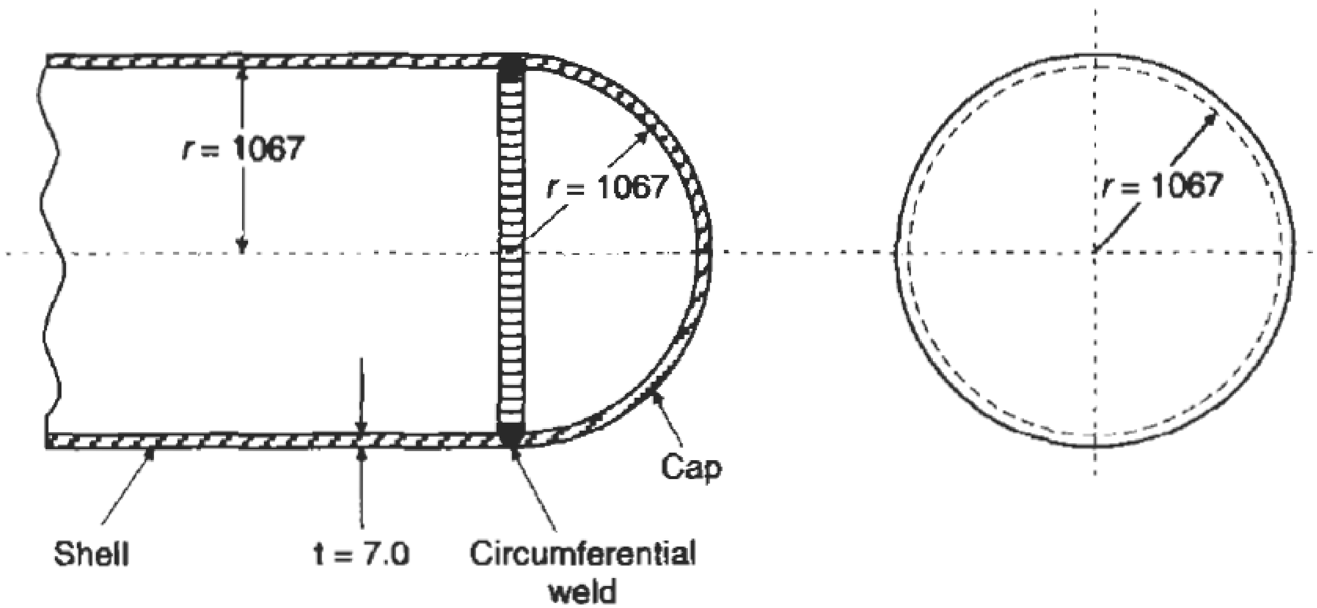
Figure 3. Left: Rail Car containing Anhydrous Ammonia. Right: Tanker Truck
(photo from http://home.comcast.net/~pchristou/2004June.html)

Liquid Ammonia tank

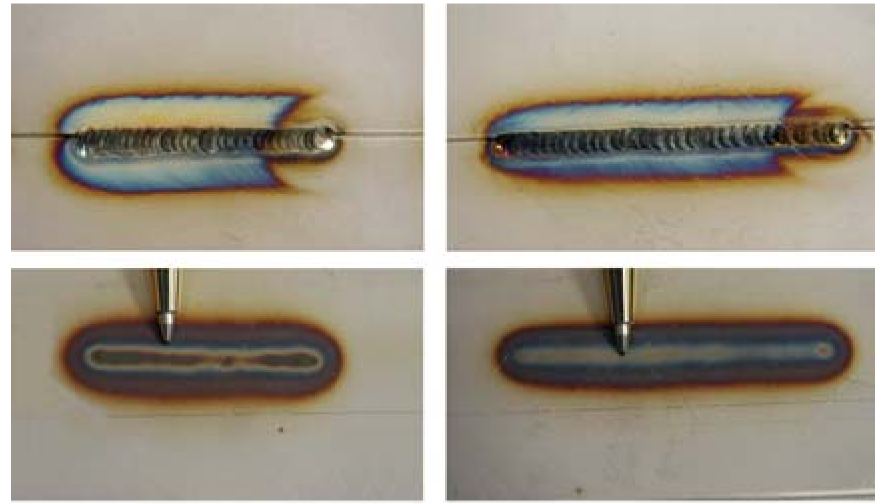


. The weld between the shell and the end cap of the pressure vessel. Dimensions in mm.

Transportation of ammonia

- The tank was used to transport liquid ammonia.
- In order to contain the liquid ammonia the pressure had to be equal to the saturation pressure (the pressure at which a mixture of liquid and vapour is in equilibrium).
- The saturation pressure increases rapidly with temperature: at 20°C the absolute pressure is 8.57 bar; at 50°C it is **20.33** bar. The ***gauge*** pressure at 50°C is 19.33 bar, or 1.9 MN m^{-2}. Because of this the tank had to function as a pressure vessel.
- The maximum operating pressure was 2.07 MN m^{-2} gauge. This allowed the tank to be used safely to 50^{o}C**,** above the maximum temperature expected in even a hot climate.

Failure in HAZ



Slower Travel Speed　　*Faster Travel Speed*

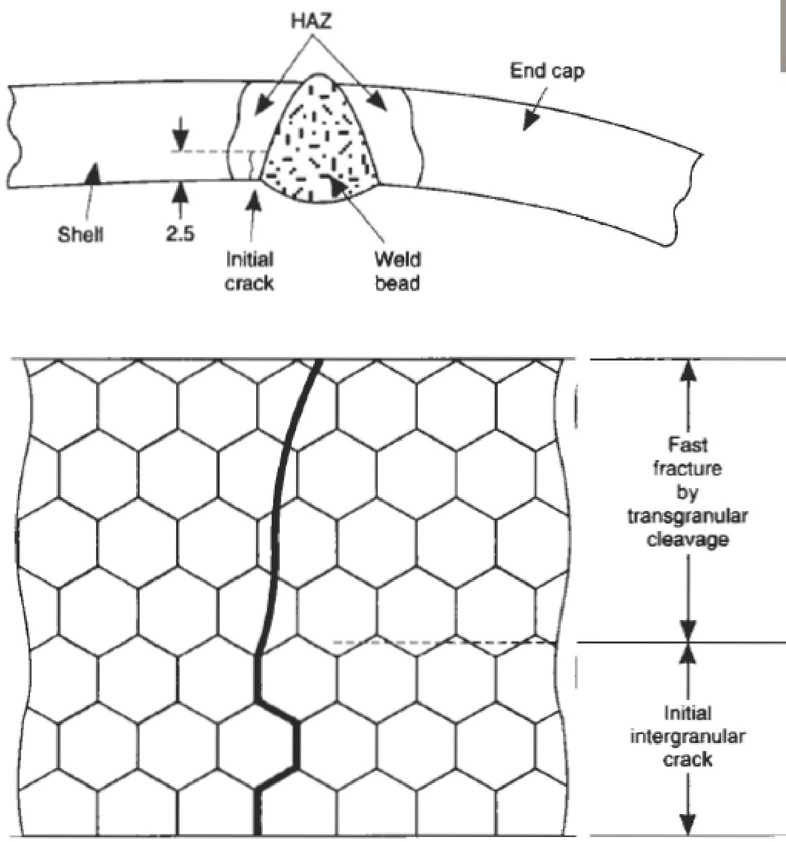
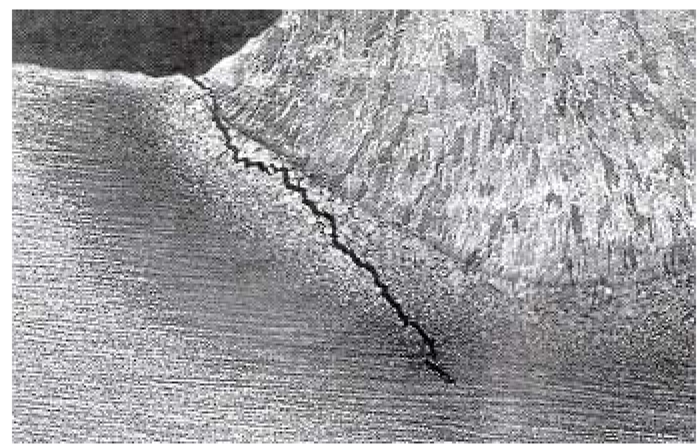


Fig. 16.2. The geometry of the failure. Dimensions in mm.



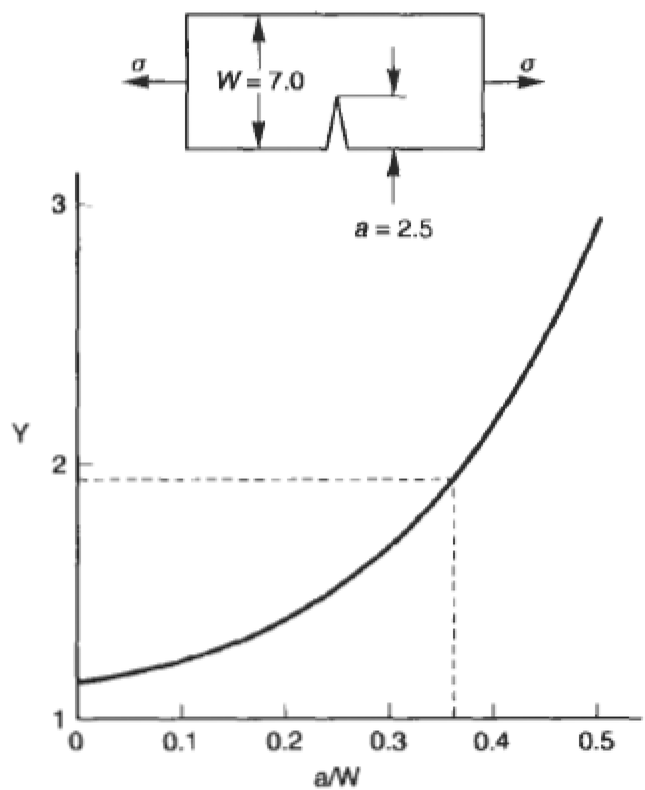
Observations

- The normal operating pressure of the compressor was 1.83 MN m^{-2}; the maximum pressure (set by a safety valve) was 2.07 MN m^{-2}.
- The initial crack, 2.5mm deep, had formed in the heat-affected zone between the shell and the circumferential weld.
- The defect went some way around the circumference of the vessel.
- The cracking was intergranular, and had occurred by a process called stress corrosion cracking.
- The final fast fracture occurred by transgranular cleavage.
- This indicates that the heat-affected zone must have had a very low fracture toughness.

Material

- The tank was made from high-strength low-alloy steel with a yield strength of 712MPa and a fracture toughness of 80MPa $m^{-1/2}$.
- The heat from the welding process had altered the structure of the steel in the heat-affected zone to give a much greater yield strength (940 MPa) but **a** much lower fracture toughness
- (39MPa $m^{-1/2}$).

Additional info



Y value for the crack. Dimensions in mm.

Additional info

Calculation of critical stress for fast fracture

The longitudinal stress σ in the wall of a cylindrical pressure vessel containing gas at pressure p is given by

$$\sigma = \frac{pr}{2t},$$

provided that the wall is thin ($t \ll r$). $p = 1.83\,\mathrm{MN\,m^{-2}}$, $r = 1067\,\mathrm{mm}$ and $t = 7\,\mathrm{mm}$, so $\sigma = 140\,\mathrm{MN\,m^{-2}}$. The fast fracture equation is

$$Y\sigma\sqrt{\pi a} = K_c.$$

Because the crack penetrates a long way into the wall of the vessel, it is necessary to take into account the correction factor Y (see Chapter 13). Figure 16.3 shows that Y = 1.92 for our crack. The critical stress for fast fracture is given by

$$\sigma = \frac{K_c}{Y\sqrt{\pi a}} = \frac{39}{1.92\sqrt{\pi .0.0025}} = 229\,\mathrm{MN\,m^{-2}}.$$