NTSB D036

National Board
CLASSIC
SERIES

EMAIL HOME
by Title by Date by Ca

Factors Affecting In-Service Cracking of Weld Zone in Corrosive Service

The following article is part of the National Board Classic Series. This installment was developed by the Illinois Office of State Fire Marshal Harold L. Schmeilski in conjunction with Packer Engineering. The article was reprinted in the January 1986 National Board *BULLETIN*. Permission to reprint was granted by the Illinois Division of Boiler and Pressure Vessel Safety, D. R. Gallup, Superintendent.

You can request your favorite "classic" *BULLETIN* article by sending the article title or subject information via email to getinfo@nationalboard.org.

Editor's note: The following article is reprinted from the January 1986 National Board *BULLETIN*. Some *ASME Boiler and Pressure Vessel Code* requirements may have changed because of advances in material technology and/or actual experience. The reader is cautioned to refer to the latest edition and addenda of the *ASME Boiler and Pressure Vessel Code* for current requirements.

Factors Affecting In-Service Cracking of Weld Zone in Corrosive Service

This article describes the cause of failure of a monoethandamine (MEA) absorber vessel that ruptured in the state of Illinois in 1984, resulting in 17 fatalities and property damage in excess of $100 million.

VESSEL DESCRIPTION

The ruptured vessel was designed in accordance with The American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section VIII rules. The vessel was constructed of 1 inch thick SA516 Gr 70 steel plates rolled and welded with full penetration submerged arc joints, without postweld heat treatment. The cylindrical vessel measures 81/2 feet in diameter with hemispherical ends comprising an overall height of 55 feet. Operating conditions were 200 psig internal pressure containing largely propane and hydrogen sulfide at 100¡F. An internal system distributed monoethanolamine (MEA) through the vessel for the purpose of removing hydrogen sulfide from the gas.

VESSEL OPERATING HISTORY

The vessel went into operation in 1969. Soon after start-up, hydrogen blisters were observed to be forming in the bottom two courses of the cylindrical vessel wall. Metallurgical analysis showed laminations to be present in the steel.

In 1974, due to the large blister area found in the second course, a full circumferential ring 8 feet high was replaced in field by inserting a preformed ring in three equal circumferential segments. The welding was accomplished by the shielded metal arc process ("stick welding") without preheating or postweld heat treating.

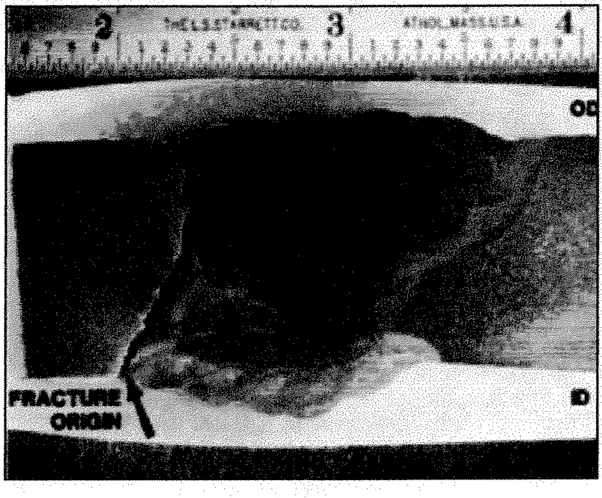
The ASME Code does not require preheating or postweld heat treatment for SA516 Gr 70 steel 1 inch thick or less. However, this steel is slightly air hardenable during welding, depending on the welding process, position and procedure employed. This material is classified as a P1, Group 2 material according to ASME Code Section IX.

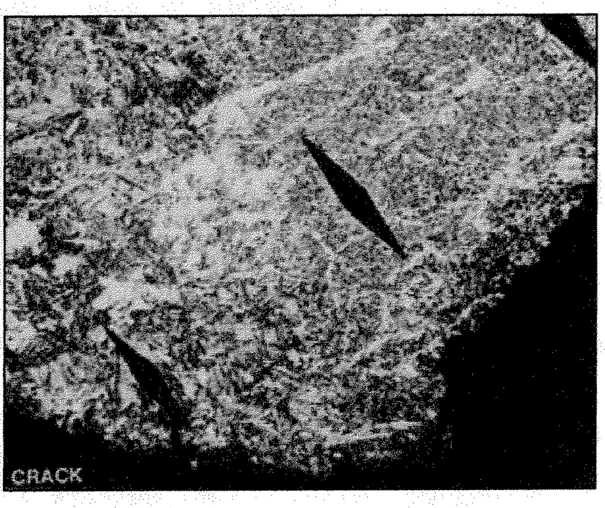
The vessel was operated under the owner/user option of the Illinois Boiler and Pressure Vessel Safety Act and received a certification inspection approximately every two years. Continuing corrosion problems in the lower end of the vessel resulted in the installation of an internal Monel liner in 1976 covering the bottom head and most of the first ring, stopping short of the replaced ring. Periodic internal inspections were mainly visual with wall thickness determinations made by an ultrasonic thickness gauge.

Just prior to the rupture, an operator noted a horizontal crack about 6 inches long spewing a plume of gas. While attempting to close off the main inlet valve, the operator noted the crack had increased in length to about 2 feet. As the operator was evacuating the area and as the firemen were arriving, the vessel ruptured releasing a large quantity of flammable gas which ignited shortly thereafter creating a large fireball and the ensuing of deaths and damage. The separation occurred along the lower girth weld joint made during the 1974 repair. The upper portion of the vessel was propelled 3500 feet by the thrust of the escaping gas.

METALLURGICAL EXAMINATION

The fracture surfaces exhibited the presence of four major prerupture cracks in the heat affected zone (HAZ) of the lower girth field repair weld. The cracks originated on the inside surface and had progressed nearly through the wall over a period of time. The largest precrack was located in the same area as the prerupture leak reported by the operator. In total, the four cracks encompassed a circumferential length of about 9 feet (33.7% of circumference). The remainder of the fracture exhibited a fast running brittle separation.





Microscopic examination of various cross sections through the failed weld joint area showed the cracking originated in a hard microstructure in the HAZ and progressed in a manner characteristic of hydrogen related damage in hard steels (see figures above). The HAZ exhibited hardness of up to 45 HRC (Hardness Rockwell "C") (450 Brinell), equivalent to a tensile strength of over 200,000 psi in the region of weld cracking. By comparison, the base metal had a hardness value of less than 20 HRC (229 BHN [Brinell Hardness Number], 110,000 psi tensile strength). The following sections discuss technical factors contributing to in-service cracking of weld joints under such conditions.

WELDING FACTORS

Welding procedures adopted must take into account not only the minimum requirements of ASME Code Section IX and the appropriate design section, but must also be suitable for the specific service conditions likely to be encountered. Stress corrosion cracking, hydrogen embrittlement and corrosion fatigue are typical of material/environment interactions that are not fully accounted for in the ASME Code design rules. Appreciation of such potential problems is left to the process designer, vessel designer, owner, contractor or inspector. Reliance on only the ASME Code rules is not enough to assure safety of vessels operating in many corrosive environments.

The weld HAZ contains potentially crack susceptible metallurgical structure, hardness variations and residual stresses that can promote various types of unexpected service induced cracking depending on the chemical environment and operating temperature. Industry experience has shown that steel having a hardness of 22 HRC maximum is resistant to cracking even under severe exposure conditions where hydrogen can be absorbed by the steel. At hardness levels above 22 HRC, steel becomes less resistant to hydrogen induced cracking and other environmental effects. At high hardness (above about 40 HRC), steel becomes quite susceptible to cracking in the presence of hydrogen.

In potentially critical environments, the weld joint properties must be carefully controlled. Weld HAZ hardness is a function of the cooling rate after welding. Preheating to at least several hundred degrees and maintaining an interpass temperature during welding can warm the joint area sufficiently to prevent rapid cooling after welding. Carbon content and alloy composition will dictate the appropriate temperature. Rapid cooling of even mild steel can result in unacceptably high HAZ hardness for service in aggressive chemical environments.

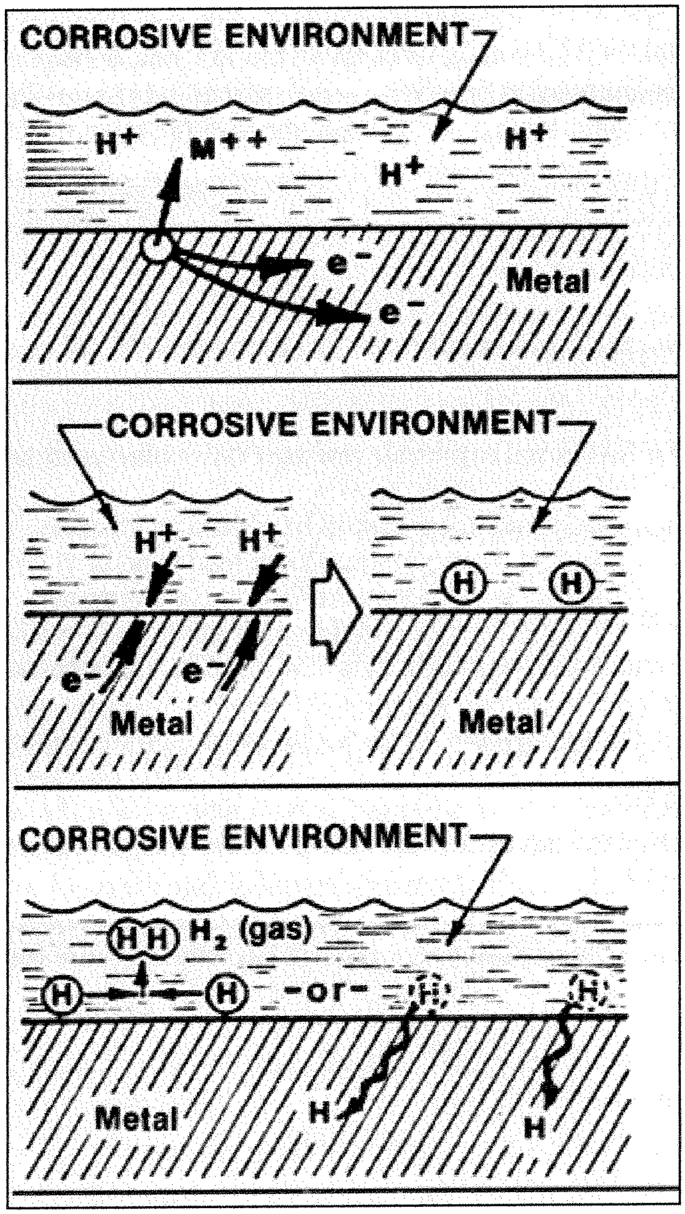
Postweld heat treating (PWHT) is often necessary in critical weld joints to temper (soften) or stress relieve weld joints in rugged duty or aggressive chemical environments. Higher carbon steels and more alloyed steels are nearly always given PWHT. Even when not specifically called for in ASME Code Section IX, preheating or PWHT may be necessary. In hydrogen environments, avoiding formation of a hard HAZ is crucial. Other corrosive environments present similar concerns.

The specific weld procedure employed must be developed by individuals with pertinent knowledge of the ASME Code (which should be viewed as the minimum guideline) as well as material behavior expertise in aggressive environments.

CORROSION FACTORS

There are many specific ways that corrosion may contribute to unexpected failures. Often, corrosion problems are handled simply by making the component thicker (a corrosion allowance). This is appropriate so long as the corrosive conditions are known, the vessel is periodically inspected and if the corrosion is not highly localized. Corrosion fatigue, pitting, stress corrosion and hydrogen attack are examples of metal/environment problems that cannot be adequately handled by a corrosion allowance and superficial inspection methods alone.

Hydrogen-assisted cracking and stress corrosion cracking will not always be readily apparent. Carefully preparing the surface for visual examination, along with other techniques such as dye penetrant, magnetic particle, or shear wave ultrasonic inspection methods, may be required to detect such defects. Corrosion-enhanced damage is often associated with welds, nozzles, or areas of unstable environmental conditions; places where either the environment, stress, or metallurgical condition may abruptly change.



High pressure hydrogen or acidic environments can introduce damaging levels of hydrogen into steel, particularly hard steels or hard HAZs. The mechanism of hydrogen evolution and penetration is illustrated above. The absorbed hydrogen atoms are attracted to high stress regions in the structure, such as crack-like defects. The combination of hard steel and absorbed hydrogen leads to the development of cracks. Once inside the steel, these hydrogen atoms also migrate to inclusions or laminations and create