



# Failure of a pressure vessel for rail transport of fluid carbon dioxide



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## ARTICLE INFO

### Article history:

Received 19 August 2013

Received in revised form 27 November 2013

Accepted 2 December 2013

Available online 9 January 2014

### Keywords:

Transport failure

Pressure vessel

Notched-bar impact energy

Toughness

## ABSTRACT

In 1976, a pressure vessel of a tank wagon burst during gravity shunting. The pressure vessel was filled with cold fluid carbon dioxide and failed by cleavage fracture explosively. Big parts of the vessel were flung up to 300 m, a building was destroyed, and rails as well as the superstructure of the gravity shunting yard were damaged.

The initiation sites of the fracture and the orientations of crack propagation were determined by means of the patterns on the fracture surfaces of the broken parts. The initiation sites were located in the heat-affected zone (HAZ) of welds, close to transitions of cross-sections and the starting and end points, respectively, of the welds. The primary initiation of crack propagation was almost certainly on the left side, close to the weld of the fixed bearing connecting the vessel with the carriage.

The results of metallographic investigations indicated the development of cold weld cracks during welding. Mechanical behavior assessments on specimens extracted from the failed vessel indicated sufficient strength and ductility in tensile loading. The values of the notched-bar impact energy or toughness were within the limits according to industry rules and standards, except for one metal sheet of the vessel that was welded to the left fixed bearing.

During shunting, two tank wagons were inappropriately braked, and began to roll too quickly. One rail brake used for deceleration of the wagons caused impulsive noises and vibrations, resulting in high impulsive loading of the first wagon. The cold weld cracks in the heat-affected zones near the fixed bearing of the pressure vessel were initiation points for unstable crack growth. As the result of very low notched-bar impact toughness, crack propagation was not arrested and unstable cleavage fracture occurred.

Due to a second similar accident, happened one year before, a program was started to assess characteristic values of pressure vessel materials and the influence of weld parameters by the manufacturer, the inspecting authority, and BAM. The scientific findings led to modifications of industry rules and standards with regard to using ISO-V specimens and to higher required values for notched-bar impact energy for fine grain structural steels.

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## 1. Introduction

### 1.1. Background

Carbon dioxide is a by-product of chemical industrial processes and used in a variety of applications. Dry ice as solid carbon dioxide is used for cooling. Gaseous carbon dioxide as inert gas is applied in explosion prevention, during welding, and in the food industry.

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Carbon dioxide is primarily transported and stored in liquid form. The combination of high pressure and low temperature in the liquid state poses significant danger if transport and storage tanks are not designed correctly.

### 1.2. Description of the failure event

In 1976, a pressure vessel of a tank wagon burst during gravity shunting at the gravity shunting yard in Haltern, Northern Germany. Two coupled tank wagons, both containing pressure vessels filled with liquefied carbon dioxide, were not correctly braked and as a result rolled downhill too quickly onto two rail brakes that were positioned on the track by shunt operators. The first rail brake was ejected and the other one caused impulsive vibrations in the pressure vessels as it failed to arrest the wagons. The pressure vessel of the leading wagon failed explosively. The leading tank wagon was fully destroyed, and the second tank wagon of identical construction was damaged but the filled pressure vessel stayed intact (see Fig. 1).

Large pieces of the vessel were flung up to 300 m, resulting in damage to a building for railway staff (see Fig. 2), and the death of one shunt operator. Further wagons, tracks, and the superstructure of the gravity shunting yard were damaged.

The tank wagons collided with a group of five wagons on the same track. Two of them were loaded with barrels containing explosives (gelignite). Fortunately the barrels were not damaged.

### 1.3. Objectives

The objective of the investigation [1] was the determination of the causes of the cleavage failure of the pressure vessel. The investigation focused exclusively on recovered pieces of the pressure vessel, rather than including, for example, other pieces of the carriage. This article aims to show that the failure and subsequent findings were starting points for the development and improvement of material standards. Similar to the procedure Martens developed 118 years ago [2], a lot of work on “lessons learned” was performed following the failure analysis described here.



Fig. 1. Exploded tank wagon beside an identical tank wagon with damaged isolation cover.



Fig. 2. Vessel remnants, including a large piece that impacted a building used by railway staff.

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