

AB 250 587

F.
23
.U68
A34
no.
FRA-
ORD&D-
75-52

REPORT NO. FRA-OR&D 75-52

METALLURGICAL INVESTIGATION OF A FULL-SCALE INSULATED RAIL TANK CAR FILLED WITH LPG SUBJECTED TO A FIRE ENVIRONMENT

J. G. Early
C. G. Interrante

Dept. of Transportation
JUN 7 1976
Library



**JANUARY 1975
FINAL REPORT**

DOCUMENT IS AVAILABLE TO THE PUBLIC
THROUGH THE NATIONAL TECHNICAL
INFORMATION SERVICE, SPRINGFIELD,
VIRGINIA 22161

**Prepared For
DEPARTMENT OF TRANSPORTATION
FEDERAL RAILROAD ADMINISTRATION
Office of Research and Development
Washington, D.C. 20590**

23
U32 A34
FPA-
ORDY2
75-52

1. Report No. FRA-OR&D 75-52		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle A METALLURGICAL INVESTIGATION OF A FULL-SCALE INSULATED RAIL TANK CAR FILLED WITH LPG SUBJECTED TO A FIRE ENVIRONMENT			5. Report Date January 1975		6. Performing Organization Code
			8. Performing Organization Report No. NBSIR 75-657		10. Work Unit No. (TRAIS)
7. Author(s) J.G. Early, C.G. Interrante			11. Contract or Grant No. DOT-AR-40008		13. Type of Report and Period Covered FINAL REPORT
9. Performing Organization Name and Address National Bureau of Standards Washington, D.C. 20234			14. Sponsoring Agency Code		15. Supplementary Notes
			12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Railroad Administration, Office of Research and Development Washington, D.C. 20590		16. Abstract
<p>An analysis of the failure of an insulated rail tank car, RAX 202, which had been tested to failure in a fire environment at White Sands Missile Range, New Mexico, was requested by the Federal Railroad Administration, Department of Transportation.</p> <p>The tank car, filled with approximately 33,000 gallons of liquified petroleum gas (LPG), failed after approximately 94 minutes of exposure to a JP-4 jet fuel fire. The car fractured into four fragments which were examined in the field. Five plate samples from the four fragments were selected for laboratory study at the National Bureau of Standards.</p> <div data-bbox="868 1249 1234 1501" data-label="Text"><p>Dept. of Transportation JUN 7 1976 Library</p></div>					
17. Key Words Metallurgical, Tank Cars			18. Distribution Statement Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161		
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 71	22. Price

ABSTRACT

An analysis of the failure of an insulated rail tank car, RAX 202, which had been tested to failure in a fire environment at White Sands Missile Range, New Mexico, was requested by the Federal Railroad Administration, Department of Transportation.

The tank car, filled with approximately 33,000 gallons of liquified petroleum gas (LPG), failed after approximately 94 minutes of exposure to a JP-4 jet fuel fire. The car fractured into four fragments which were examined in the field. Five plate samples from the four fragments were selected for laboratory study at the National Bureau of Standards.

The results of laboratory check chemical analyses of five specimens representing three shell courses indicated that all of the samples tested met the chemical requirements of AAR TC128-B steel. The chemical variability between individual plate samples was low, and the levels of phosphorous and sulphur were notably low in comparison with the levels found in six heats of TC128 steels previously analyzed at NBS.

The results of metallurgical investigations suggest that a region approximately 30 inches in length near the top of the tank car in shell course 3 was the site of the initial rupture of the tank car. This rupture was attributed to the tensile hoop stress due to internal gas pressure, as the crack was aligned with the longitudinal axis of the tank car. The results of stress-relieving experiments conducted on samples taken from the top and bottom of the car indicated that the top of the tank car experienced temperatures of 1200°F to 1250°F for times of between 10 to 15 minutes.

The fracture features of the initial rupture were indicative of failure by a stress-rupture mechanism. It was concluded that this 30-inch stress-rupture crack led to tensile overload, instability and to the onset of rapid crack propagation in a shear mode, with the initial shear fracture propagating as an extension of the original stress-rupture crack. Within a short distance, this shear fracture turned 90° and propagated in the plate rolling direction, a result explained by the anisotropy of the fracture resistance of this steel at the elevated temperatures of the test. This reorientation occurred despite the fact that the hoop stress which promotes fracture in the longitudinal axis of the tank car is twice as large as the stress that promotes fracture along the rolling direction of the plate.

1. INTRODUCTION

A metallurgical evaluation of a full-scale railroad tank car tested to failure was requested by the Federal Railroad Administration, Department of Transportation. A fire test (Fire Test 2) was conducted on tank car RAX 202 on December 6, 1973, at White Sands Missile Range, New Mexico, under the direction of personnel from the United States Army Ballistic Research Laboratory. The tank car tested was similar to a standard 33,000 gallon tank car with the exception of three modifications. One modification was the addition of a second manway to provide access to the interior of the tank car in order to facilitate the installation of temperature and pressure sensors at various locations inside the tank car. Secondly, two ports were added to one side of the tank car through which the instrumentation cables passed, and finally, a white, protective, thermal coating was sprayed over the entire tank car. The steel plates used in the fabrication of tank car RAX 202 were reported to be 5/8 inch-thick, fine-grained steel plate in the as-rolled condition and to have been produced to Specification AAR M128-69, Grade B, Flange Quality, by the Lukens Steel Company as part of Melt Number CO 485.(1)

The tank car, filled with approximately 33,000 gallons of liquified petroleum gas (LPG), was placed in a large pit. A low earth dike that was continuously maintained at a level of about 18 inches of JP-4 jet fuel surrounded the tank car. When ignited, this pool of jet fuel, located beneath the tank car, provided the thermal energy to heat the tank car. Figure 1 shows the tank car positioned in the pit surrounded by the fuel dike prior to the fire test.(2)

The time to failure of the tank car was measured beginning with the ignition of the JP-4. At about 60 minutes into the test, the temperature and pressure recording systems failed. This failure prevented the recording of any temperature or pressure data for the remainder of the test. Approximately 94 minutes after ignition of the JP-4, the tank car failed and fractured into four fragments. Two fragments, constituting almost all of shell course 3, were propelled out of the pit. The smaller of the two fragments remaining in the pit contained the A head plate and shell courses 1 and 2, and the larger fragment remaining in the pit contained the B head plate and shell courses 4, 5, 6, and 7, see Figure 2.

A total of five steel-plate samples from four shell courses were selected, removed by torch cutting, and sent to NBS for metallurgical investigation. The samples, designated TC2-(1), TC2-(3), TC2-(7), TC2-(10)* and TC2-(11)*, were photographed in the as-received condition and are shown in Figures 3 through 7.

Plate sample TC2-(1), including the additional manway and encompassing the top of shell course 3, was torch-cut along the line BG (Figure 3). The fracture surface follows the line BCDEFG. Sample TC2-(3) was torch-cut from the bottom of shell course 3 and contains a portion of the fracture surface along HIJ (Figure 4), which is the continuation of the fracture BC in TC2-(1).

Plate sample TC2-(7), containing a portion of the girth weld which originally joined shell plates 3 and 4, was torch-cut from shell course 4, located in the larger remaining fragment in the pit, at the bottom of the tank car. A small piece of shell course 3, seen at the lower left front of the sample (Figure 5), contains part of the fracture surface, MNO, which is also an extension of the fracture surface BC in TC2-(1).

The last two plate samples, TC2-(10) and TC2-(11), were torch-cut from the smaller remaining fragment of the tank car in the pit. Sample TC2-(10), taken from the top of the tank car, and TC2-(11), taken from the bottom of the tank car directly opposite from TC2-(10), were selected for removal because they were from a relatively undeformed region of the tank car. A schematic of a portion of the tank car, Figure 8, shows a representation of the plate samples in their approximate location.

2. PURPOSE

The principal purpose of this metallurgical investigation was to determine the cause and location of the initial rupture which led to the fracture of the tank car. Another purpose of the investigation was to make observations of the fracture characteristics and the elevated-temperature mechanical behavior of this type of steel.

* Each of plate samples TC2-(10) and TC2-(11) contained portions of shell courses 1 and 2. Tests and observations of these two plate samples are reported here based on the particular shell course involved; TC2-(10A) and TC2-(11A) are from shell course 2 and TC2-(10B) and TC2-(11B) are from shell course 1.

5. SUMMARY

1. An insulated tank car (RAX 202), which was fabricated from plates from a single heat of TC128-B steel, was tested to failure in a JP-4 fire environment. Five steel samples selected for this investigation were taken from the failed tank car and were designated TC2-(1), TC2-(3), TC2-(7), TC2-(10), and TC2-(11).
2. The plate samples selected for investigation were taken from four shell courses. Two samples were taken from shell course 3, the only shell course that failed in the fire test, TC2-(1), which contained what is believed to be the site of the original rupture near the top of the car, and TC2-(3), which was located at the bottom of the tank car in this failed shell course. Sample TC2-(7), contained portions of shell course 4 and the girth weld that joined shell courses 3 and 4. Portions of shell courses 1 and 2 were contained in each of two samples, TC2-(10) and TC2-(11), taken from relatively undeformed regions at the top and bottom of the tank car, respectively.
3. The chemical compositions of the samples taken from shell courses 1, 3, and 4 met the chemical requirements of AAR TC128-69, Grade B steel. The chemical variability on an elemental basis was low, both between individual plate samples and between the check chemical analyses of the plates and the ladle analysis of the heat.
4. Macroscopic examination of the outside plate surfaces of the samples indicated that exposure to the JP-4 fire was apparently insufficient to completely burn-off the protective thermal coating from samples located at the bottom of the tank car but the fire exposure was sufficient to completely burn-off the thermal coating from samples located at the top of the tank car.
5. Three of the five plate samples contained portions of the fracture surfaces. Examination of these fracture surfaces indicated that two distinct fracture modes are present. The fracture mode in one region near the top of the tank car in shell course 3, was rough and irregular with the fracture surface nearly perpendicular to the plate surfaces. This region is believed to be a 30-inch long stress-rupture crack and the origin of the failure of the tank car. Essentially all of the balance of the fracture occurred predominately by a shear mode with the fracture plane at an angle of about 45° to the plate surfaces.

6. Macroscopic observations revealed that, on both surfaces of the plate near the fracture face of the stress-rupture crack, numerous small cracks were present and they were aligned parallel with the stress-rupture crack.
7. Thickness measurements indicated that substantial plate thinning (20% to 40%) occurred only in and nearby the region of the stress-rupture crack. Reductions in plate thickness of between 10 and 20 percent were measured in the shear fracture regions, except that reductions in thickness of less than 10% were measured where the fracture surface followed a weld HAZ.
8. Results of metallographic examinations indicated that the stress-rupture crack was initiated by intergranular voids which formed primarily at interfaces between proeutectoid ferrite and pearlite. Scanning electron microscope fractographs indicated that this fracture surface was formed by void coalescence which led to ductile dimpled rupture throughout the cross section of the plate.
9. Metallographic examinations indicated that in the failed shell course (no. 3) a greater degree of iron-carbide spheroidization had occurred in the sample taken from the top of the car when compared with that for the sample taken from the bottom. In an unfailed shell course (no. 1), the exposure to elevated temperature was insufficient to cause significant differences in the level of iron-carbide spheroidization between samples taken from the top and bottom of the tank car.
10. The results of hardness measurements showed that the plate samples taken from the bottom of the tank car (in shell courses 1 and 3) had higher hardness values than those taken from the top of the tank car in these shell courses. The plate sample from the top of the tank car in the failed shell course (no. 3) had the lowest average hardness. Further, the plate sample from the top of the tank car in shell course 1, which did not fail, had only a slightly lower average hardness than the sample taken from the bottom of the tank car in this course. These hardness results are consistent with results of the metallographic observations of the relative levels of iron-carbide spheroidization.
11. The results of stress-relieving experiments on specimens from the failed shell course, shell course 3, indicated that with a heat treatment at 1221°F for 15 minutes, the average hardness of specimens from the tank car bottom

could be decreased by 2 R_B points, which is slightly less than the 2 1/2 R_B hardness difference measured between specimens taken from the top and bottom of this shell course. Similar experiments on specimens from an unfailed shell course, shell course 1, indicated that on specimens taken from the bottom of the car, heat treatments of 1215°F for 10 minutes and 1257°F for 15 minutes, respectively decreased the average hardness by 1/2 and 1 1/2 R_B points, whereas the average difference in hardness measured between specimens from the tank car top and bottom was 1 R_B point.

12. Extension of the initial rupture occurred by shear fracture which initially was aligned in the same direction as the stress-rupture crack, transverse to the plate rolling direction. Within a short distance from either end of the stress-rupture crack, the ends of this propagating shear crack turned 90° and propagated (still by shear fracture) in the plate rolling direction. During this reorientation process, from transverse to longitudinal, one edge of each of the two shear fracture planes reached the HAZ of a girth weld and propagation continued near to and parallel to these girth welds until the fracture circumscribed the tank car.

6. CONCLUSIONS

1. The insulated rail tank car failed by rupture of the third shell course after extended exposure to fire, with the initial rupture being a stress-rupture crack of about 30 inches in total length that was oriented parallel to the longitudinal axis of the tank car.
2. Growth of this stress-rupture crack occurred by a shear mode initially in the same direction as the stress-rupture crack, transverse to the plate rolling direction. After propagating a short distance, the shear fracture plane began to turn and the shear crack propagated in hoop direction of the tank car, parallel to the plate rolling direction.
3. This shear-fracture plane reorientation behavior is believed to be due to the anisotropy of the fracture resistance of this steel at elevated temperatures.
4. Hardness values of samples from the top and bottom of shell course 3 differed by a wider amount than did hardness values between specimens from the top and bottom of shell course 1 and this observation is consistent with the

microstructural observation that a larger degree of iron-carbide spheroidization occurred in the specimens from the top of shell course 3 than occurred in specimens from the top of shell course 1.

5. In both shell courses 1 and 3, the average hardness of specimens taken from the top of the tank car was less than that for specimens from the bottom of the car and this can be explained by differences in temperature and time-at-temperature experienced by these regions as a result of the fire exposure. The top of the tank car probably experienced temperatures between 1200°F and 1250°F for times of between 10 and 15 minutes. The bottom of the tank car is believed to have received insufficient high temperature exposure to cause a measureable decrease in the strength of the steel.
6. Shell course 3 would probably fail by a stress-rupture mechanism before shell course 1 at a given temperature of exposure due to the relative strengths of these two plates. The stress-relieving test results indicate that at temperatures above 1000°F shell course 3 specimens would be softer and thus weaker than the shell course 1 specimens.

7. ACKNOWLEDGEMENT

The author wishes to thank Dr. J. H. Smith for his comments and suggestions, and Mr. D. E. Harne for his able assistance in the metallographic and photographic portions of this report.