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MECHANICAL PROPERTIES OF AAR M128-69-B STEEL PLATE SAMPLES TAKEN FROM INSULATED FIRE TESTED TANK CAR RAX 202

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FINAL REPORT

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16. Abstract Studies were undertaken to measure the elevated-temperature mechanical properties and to determine the elevated-temperature fracture behavior of selected AAR M128-B steel plates. In addition, the ambient-temperature mechanical properties were measured to determine if the requirements of specification AAR M128-69-B were satisfied. The NBS results of check chemical analyses, hardness surveys, thickness measurements, macroscopic observations, and metallographic analyses of the plate samples had been reported previously. The results of ambient-temperature tensile tests showed that all plate samples met the strength and tensile ductility requirements of specification AAR M128-69-B. The results of hot-tensile tests showed a continuous decrease in strength properties and an increase in tensile ductility as the test temperature was increased from 1100 F to 1250 F. An analysis of stress-rupture data for specimens from all plate samples in the same temperature range indicated that a straight line in a log-log plot of initial stress versus rupture life reasonably represented the data at each test temperature. In the temperature and stress range studied, a decrease in the initial stress of about 20 to 30 percent resulted in a twelvefold increase in rupture life from 15 minutes to three hours. A comparison of the results of the metallographic analysis of hot-tensile and representative stress-rupture specimens with the previously reported metallographic results on the initial rupture site in the failed shell course indicate the presence of the identical fracture mode. This mode is characterized by many intergranular voids which originate primarily at the proeutectoid ferrite-pearlite boundaries. These results confirm the previously reported finding that the initial rupture of the tank car was a stress-rupture crack.

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1. INTRODUCTION

In recent years, a number of catastrophic failures of railroad tank cars carrying hazardous materials have occurred. These catastropic accidents have prompted the Federal Railroad Administration (FRA) to sponsor research activities with the object of developing knowledge concerning the various factors responsible for causing rupture and failure of tank cars involved in accidents, and to use this knowledge to prevent or minimize the effects of tank car failures.

In one phase of the FRA-sponsored research program, fire engulfment tests were conducted on two full-scale rail tank cars filled with liquified petroleum gas (LPG); uninsulated tank car RAX 201 and insulated tank car RAX 202. The steel plates used in the fabrication of both tank cars were reported to be 5/8 inch-thick, fine-grained steel plate in the as-rolled condition, produced to specification AAR M128-69, Grade B, Flange Quality, by Lukens Steel Company as part of Melt Number CO 485.(1) [a]

The fire tests on both full-scale tank cars were conducted at White Sands Missile Range, New Mexico, under the direction of personnel from the United States Army Ballistic Research Laboratory (BRL). The details of the test procedures and instrumentation used in these fire tests have been reported previously. (2,3) A metallurgical analysis of the failure of the uninsulated tank car, RAX 201, indicated that the initial rupture was the result of a stress-rupture crack which initiated near the top of the tank car. (4)

The FRA requested that the National Bureau of Standards (NBS) conduct a metallurgical evaluation of the failed insulated tank car, RAX 202. The analysis of the failure led to the conclusion that the initial rupture was a stress-rupture crack which formed as a result of prolonged exposure to elevated temperatures. (5)

The results of the two full-scale fire tests and data from other tank car failures (6) suggest that knowledge of the elevated-temperature mechanical properties of tank car steels is essential to any understanding of the failure behavior of tank cars carrying compressed gases subjected to fire environments. At present, however, elevated-temperature data available in the literature for AAR M128-B steel appears limited. Typical of the available data are results from hot-tensile tests on specimens from a failed tank car (7) and from an as-rolled plate (8), and hot-tensile tests and short-time stress-rupture tests on specimens from the fire tested uninsulated tank car, RAX 201 (4).

Accordingly, a program was initiated at NBS to measure the elevated-temperature mechanical properties of AAR M128-B steel plates used in the insulated tank car, RAX 202. Three plate samples, previously

[a] The isolated numbers in parentheses refer to references listed at the end of the report.

designated TC2-(1), TC2-(3) and TC2-(11B)[b], representing two shell courses, were selected for this investigation. The NBS results of check chemical analyses, hardness surveys, thickness measurements, macroscopic observations, and metallographic analyses of these three plate samples have been previously reported. (5)

Plate sample TC2-(1), taken from the top of the failed shell course in the region experiencing the highest temperature during the fire test, contained a portion of the stress-rupture crack believed to have been the site of the initial rupture of the tank car. Plate sample TC2-(3) was removed from the bottom of the failed shell course in the region heated the least during the fire test. Plate sample TC2-(11B), taken from the bottom of the tank car in an unfailed shell course, was selected because it was located in an undeformed and relatively unheated region of the tank car. After the fire test, the bottom of the tank car still contained a portion of the original thermal protective coating which indicated that this region was heated the least during the test. A schematic of a portion of the tank car, Figure 1, shows a representation of the plate samples in their approximate locations, as viewed from the outside of the tank car.

2. PURPOSE

The principal purpose of this investigation was to determine the hot-tensile and short-time stress-rupture properties of AAR M128-B steel plates used in the fabrication of insulated tank car RAX 202 which had previously failed in a fire engulfment test. Another purpose was to determine the ambient temperature mechanical properties of these plates and to compare the properties with the requirements of specification AAR M128-69-B.

3. EXPERIMENTAL PROCEDURES

Forty-five specimens taken from plate samples TC2-(1), TC2-(3) and TC2-(11B) for ambient-temperature and hot-tensile tests, and for stress-rupture tests, were prepared in accordance with ASTM E8-69, Tension

[b] Plate sample TC2-(11) contained portions of the shell courses 1 and 2. Tests and observations on this plate sample are reported for the particular shell course involved; TC2-(11A) from shell course 2 and TC2-(11B) from shell course 1.

mode in both hot-tensile and stress-rupture specimens is not unexpected, since most of the stress-rupture tests were conducted at initial stress levels that were close to or above the yield strength of the steel at the test temperature.

The characteristics of the fracture mode observed in both the hot-tensile tests and the stress-rupture tests are the same as those observed in specimens taken from what is believed to be the initial rupture site in the insulated tank car, RAX 202. These results further support the earlier findings (5) that the features of the initial rupture region in the insulated tank car are characteristic of failure by a stress-rupture mechanism.

5. SUMMARY

1. For this investigation, three steel plate samples, designated TC2-(1), TC2-(3) and TC2-(11B), were taken from an insulated tank car, RAX 202, which failed while subjected to a fire environment. Test specimens were taken from these plates for ambient-temperature tensile tests, hot-tensile tests, and stress-rupture tests. Metallographic observations were made on selected specimens after testing.

2. These plate samples were removed from two shell courses. Two samples were taken from shell course 3, the only shell course that fractured: TC2-(1), which contained what is believed to be the site of the original rupture near the top of the tank car; and TC2-(3), located at the bottom of the tank car, which was relatively unaffected by the fire exposure. The third sample, TC2-(11B), was taken from a relatively undeformed and unheated region at the bottom of the tank car in a shell course that did not fail, shell course 1. Plate sample TC2-(11B) was believed to be representative of the as-fabricated steel plates used in tank cars RAX 201 and RAX 202, which were reportedly produced from the same heat of steel.

3. Ambient-temperature tensile tests conducted on longitudinal specimens from plate samples TC2-(1), TC2-(3) and TC2-(11B) showed that all three plate samples met the ultimate tensile strength, yield strength, and percent elongation requirements of specification AAR M128-69-B. Yield strength values for specimens from TC2-(3) were approximately 30 percent higher than the levels for plate samples TC2-(1) and TC2-(11B). The increase is believed to be the result of a small amount of plastic deformation which occurred in this plate sample as a result of the failure of the tank car and the expulsion of shell course 3 out of the test pit.

4. Ambient-temperature tensile tests conducted on longitudinal and transverse specimens from plate sample TC2-(11B) showed little anisotropy in the strength properties in the plane of the rolling direction. Tensile ductility values, as measured by percent elongation, showed that the longitudinal elongation values were approximately ten percent higher than the transverse elongation values.

5. Hot-tensile tests conducted at 1100 F, 1150 F, 1200 F and 1250 F on longitudinal specimens from plate sample TC2-(11B) showed a continuous decrease in ultimate tensile strength and yield strength, and an increase in percent elongation as the test temperature was increased. The percent reduction-in-area values were less temperature dependent than the percent elongation values, showing a pronounced increase only above 1200 F.

6. Results of tests at a testing rate of 0.05 inches per minute showed increases in ultimate tensile strength and yield strengths and decreases in percent elongation and percent reduction-in-area values, when compared with the values found for tests at an initial testing speed of 0.005 inches per minute.

7. If the effects of testing speed and differences in ambient-temperature strengths are taken into account, the results of the hot-tensile tests from this study are in good agreement, with one exception, with the results from other studies of AAR M128-B steel plates.

8. Stress-rupture data measured at 1100 F, 1150 F, 1200 F and 1250 F on longitudinal specimens from plate samples TC2-(1) and TC2-(3) and on longitudinal and transverse specimens from plate sample TC2-(11B) were analysed by at least-squares technique. A single-slope line in a log-log plot of initial stress versus rupture time represented the data at each test temperature. This result appears to be independent of the plate sample or specimen orientation.

9. The results of the stress-rupture tests indicate that in the temperature and stress range investigated, decreases in the initial stress level of approximately 20 to 30 percent result in a twelvefold increase in the rupture lifetime from 15 minutes to three hours.

10. Stress-rupture tests conducted with a resistance tube furnace (RTF) to heat the specimens indicated that tests conducted with an internal-resistance-heating (IRH) technique gave reliable time-to-rupture data at the stress levels and temperatures used in this study.

11. Little stress-rupture data on AAR M128-B steel were found in the literature for comparison with the results of this investigation. In the one instance where comparable data were found, reasonable agreement was obtained in a comparison of the present results with data from a related tank car steel, ASTM A212, which was tested at 1000 F.

12. A comparison of results from hot-tensile and stress-rupture tests on a plate sample taken from the uninsulated tank car, RAX 201, with those taken from the insulated tank car, RAX 202, showed substantial disagreement. Tne steel plates used to fabricate both tank cars reportedly were produced from the same heat of steel, and thus the origin of the wide variance in elevated-temperature properties between these samples is not explainable.

13. The results of the metallographic analysis of hot-tensile and representative stress-rupture specimens and the previously reported results on the initial rupture in the failed shell course, all from tank car RAX 202, indicate the presence of the identical fracture mode in all three types of metallographic samples. This mode is characterized by the presence of many interphase (intergranular) cracks or voids in the region immediately behind the fracture surface. The voids originate primarily at the proeutectoid ferrite-pearlite boundaries. SEM fractographs revealed the generally ductile character of the fracture surface by the presence of dimples which resulted from void nucleation and coalescence. These results confirm the previously reported findings that the initial rupture of tank car RAX 202 was a stress-rupture crack.

6. CONCLUSIONS

1. The variation in the ambient-temperature ultimate tensile strength allowed by specification AAR M128-B and the effect of the rate of testing can result in a significant variation in the elevated-temperature strength properties. The lack of substantial elevated-temperature mechanical property data in the literature appears to preclude the development, at the present time, of a design or trend curve for the variation of burst pressure with temperature for AAR M128-B steel. Knowledge of the lower bound to the burst pressure-temperature curve for AAR M128-B would be useful in the evaluation of existing relief-valve design.

2. The rupture life of AAR M128-B steel, as measured by uniaxial stress-rupture tests in the temperature range of 1100 F to 1250 F, is a strong function of both temperature and applied stress. Therefore, modifications of tank car technology which would either reduce the temperature dependence of the properties of the steel or reduce the maximum stresses and/or time at maximum stress experienced by the pressurized tank cars, could be important in efforts to reduce the possibility of a tank car failing catastrophically when subjected to a fire environment.

3. The results of the hot-tensile tests indicate that dynamic strain ageing in AAR M128-B steel is not significant in the temperature range and at the testing speeds used in this investigation.

4. In general, there were few differences in the measured ambient- and elevated-temperature mechanical properties between plate samples regardless of whether or not the plate sample was from the most or least heated regions of tank car RAX 202.

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