REPORT NO. FRA-OR&D 75-51

IMPACT PROPERTIES OF STEELS TAKEN FROM FOUR FAILED TANK CARS

JUNE 1976

FINAL REPORT

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VIRGINIA 22161

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

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FRA-OR&D 75-51		

4. Title and Subtitle	5. Report Date
IMPACT PROPERTIES OF STEELS TAKEN FROM FOUR FAILED TANK CARS	June 1976
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
C.G. Interrante	NBSIR 75-656
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
National Bureau of Standards Washington, D.C. 20234	
	11. Contract or Grant No.
	DOT-AR-40008
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	FINAL REPORT
U.S. Department of Transportation Federal Railroad Administration, Office of Research and Development Washington, D.C. 20590	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

An overview of the results and metallurgical analyses of the findings of impact tests conducted at the National Bureau of Standards on samples of tank-car materials submitted by the Federal Railroad Administration is presented. The submitted samples were taken from tank cars which had been involved in service accidents during the period January 1970 to January 1971. One of these tank cars had been fabricated from ASTM A212 steel and the remaining four tank cars from AAR TC128 steels. The impact test data were reported earlier in four tank-car addicent reports.

17. Key Words	18. Distribution Statement
Metallurgical, Tank Cars	Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	160	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

1. PREFACE

An overview of the results and metallurgical analyses of the findings of impact tests conducted at the National Bureau of Standards on samples of tank-car materials submitted by the Federal Railroad Administration is presented. The submitted samples were taken from tank cars which had been involved in service accidents during the period January 1970 to January 1971. One of these tank cars had been fabricated from ASTM A212 steel and the remaining four tank cars from AAR TC128 steels. The impact test data were reported earlier in four tank-car accident reports.

It is recognized that the analyses given here are based on only a limited number of plates, which cannot be considered a sufficiently large number of samples to justify a definitive comparison of the impact properties of the various grades of steel from which the cars were constructed. However, as a data compilation detailing the characteristics of tank car steels, this report can serve as a basis for further analysis and as an example of how impact data can be handled to derive a general understanding of the fracture characteristics of these materials. The data do allow a comparison of longitudinal, transverse, and short transverse properties in these plates, and they illustrate impact toughness trends as they relate to chemical composition, grain size and cleanliness of the specific plates studied. Further, they illustrate the comparative results that are expected from Charpy-V-notch tests vis-a-vis those from Dynamic Tear tests for the steels tested. When these various findings on the impact properties and on the metallurgical factors affecting them are considered along with the observed behaviors of those materials in service and with the service requirements which can be developed from larger numbers of service failures, recommendations as to approaches to improved materials and improved specifications for such materials can be formulated. Although some general conclusions (based upon results of the program and of the analyses of the available data) are given here, what is needed are specific recommendations on materials requirements for tank-car applications and on the various approaches that can be taken to meet these requirements economically.

Impact Properties of Steels Taken
From Four Failed Tank-Cars

2. INTRODUCTION

The Federal Railroad Administration (FRA) has sponsored research studies aimed at the development of knowledge that could be used to prevent or minimize the sometimes catastrophic effects of tank-car failures. As part of these studies, the FRA has requested that the National Bureau of Standards (NBS) conduct metallurgical analyses on steel samples taken from failed tank cars involved in four accidents. The results of the NBS analyses are given in four reports(1-4),and in a summary report(5) titled "Analysis of Findings of Four Tank-Car Accident Reports". With minor exceptions, the summary report analyzes all findings of the other four reports except for the results of impact tests. The impact test results are analyzed in the present report on the "Impact Properties of Steels Taken from Four Tank-Car Accidents", and so this report is complementary to the summary report.

This report deals with impact-test results of samples of six steel plates and three weldments taken from four failed tank cars, each from a different tank-car accident site. The six plate steels include four produced to specifications of AAR-TC128 and two produced to specifications of ASTM A212-B; three of these plates represent head plates and three represent shell plates. The weldments represent shell-to-shell and head-to-shell weldments of TC128-B steel plates.

Although the samples were taken from tank cars that had failed in service, it is believed that the samples were judicously selected so that the impact properties reported in the four reports that are here summarized and reanalyzed are germane to the plates in the tank cars in service, except where noted otherwise.

The results of tests of transverse head-plate specimens indicate that the magnitude of the decrease in upper-shelf energy-absorption values at elevated temperatures can be greater than 50-percent of the maximum energy absorption that is obtained over the usual range of impact test temperatures. Although the significance of these results has not been clearly established, they indicate that TC128-B steels can be embrittled at elevated temperatures in a manner that permits propagation of a crack at temperatures near 1050 F to occur with relatively small levels of energy absorption. The cause of this embrittlement has not been established and it is uncertain as to whether these results may be relevant to the slow-deformation strength or to the creep-rupture properties at these elevated temperatures.

5. SUMMARY

Results obtained from impact tests of two plates of ASTM A212 steel, four plates of AAR TC128 steel, and two weldments of TC128 steel can be summarized as follows:

5.1 Anisotropy of the impact properties of the steels tested was three dimensional. The upper-shelf values and the transition temperature (TT) values were affected by orientation of specimen and notch, but the 50-percent SFA value was not affected.

5.1.1 For the six orientations tested, upper-shelf values of energy absorption and lateral expansion varied widely with orientation and tended to decrease in the order LS, LT, TS, TL, ST, SL; the corresponding values for 15-mil and 15-ft-lb transition temperatures also varied widely and they tended to be in inverse order to the level of their upper-shelf values.

5.1.2 For the six steels tested, SFA values are not greatly affected by orientation of specimen and notch; the 50-percent SFA criteria is shown to have an invariant character for all orientations tested for a given steel with the mean value for various orientations being generally within 10 F of the value for any individual orientation.

5.1.3 The 50-percent SFA TT value for combined data of the six steels was 68 F for either longitudinal or transverse specimens, but this fracture criterion varied widely for the six individual steels tested, as for example, for longitudinal (LT) specimens the values range from -11 to +138 F.

5.1.4 The temperature at which 50-percent SFA obtains was approximately the same as the temperature at which 50-percent of maximum energy absorption obtains. This was true for any individual data set as well as for any combined data set. Consequently, the 50-percent SFA criteria was shown to be generally satisfied at a considerably higher temperature than the temperatures at which the 15-mil or 15-ft-lb criteria were satisfied.

5.2 For a given orientation of specimen and notch, upper-shelf energy-absorption values for the six steel plates varied widely. The results indicated that shelf-energy absorption tended to decrease with increases in the inclusion content and the strength level of the steels, with this strength level dependency reflecting the strength level dependency of ductility. In addition, the shelf-energy absorption values for LT and TL specimens indicated that the head plates were cross rolled to a greater extent than were the shell plates.

5.2.1 Shelf-energy absorption values for the combined data from the six steel plates were about 67 and 41 ft-lb, respectively, for longitudinal (LT) and transverse (TL) specimens.

5.2.2 Shelf-energy absorption values for the six steels varied widely: For longitudinal (LT) specimens they ranged from 46 to 81 ft-lb, and for transverse specimens they ranged from 25 to 55 ft-lb.

5.2.3 When compared with a published trend line, three of the six steels tested had relatively low values of shelf-energy absorption for their respective yield-strength levels. These three steels were TC128-A and -B steels that contain vanadium and have either high or intermediate inclusion contents. These results indicate that increased inclusion content levels and the strengthening effect due to vanadium tended to sharply decrease shelf-energy absorption values.

5.2.4 The anisotropy index values derived from shelf-energy levels of CVN and DT impact tests indicated that each of the three head-plate steels were cross rolled to a greater extent than were any of the shell-plate steels. The indices derived from DT tests compared favorably with those derived from CVN tests.

5.3 Transition temperatures of the six steels tested varied widely, due to wide differences in the ferrite grain size and the contents of carbon, manganese, and phosphorous. Only one of these steels was produced to TC128-A specifications and it had fine ferrite grains and a fine pearlite colony size, both of which may be attributed to the presence of vanadium and the rolling practice. This steel had the lowest transition temperatures of the six steels tested. Transition temperatures of the three steels producted to TC128-B specifications were lower than those of the A212-B steels, and the A212-B steel produced to fine-grain practice had lower TT values than the one that was not produced to fine-grain practice.

5.3.1 Transition temperatures of the combined data for the six steels tested in both LT and TL orientations averaged 14 and 20 F, respectively for the 15-ft-lb and 15-mil criteria.

5.3.2 Transition temperatures for the six individual data sets of the six plates tested varied widely, especially those for the head-plate steels. The 15-ft-lb (LT) values ranged from -47 to +92 F for the head plates and from -5 to +32 F for the shell plates, while the values for the combined data were similar, being +13 and +7 F respectively for the head plates and the shell plates.

5.3.3 The six steels tested were catagorized into four classes of steels. These classes can be ranked on the basis of transition temperature, beginning with the class of lowest TT values: TC128-A, TC128-B without vanadium, TC128-B with vanadium, and A212-B.

5.4 Results from combined data sets indicate that the two A212-B steels tested had higher values of upper-shelf energy absorption but inferior (higher) TT values when compared with the values for the four TC128 steels tested. In addition, the variability in the test results for the four TC128 steels was large and much larger than that for the two A212-B steels. The higher values of shelf energy of the two A212-B steels may be attributable to their cleanliness. Their relatively high TT values may be attributed to comparatively less favorably levels of carbon to manganese when compared with that of the TC128 steels.

5.5 The results of CVN impact tests of specimens taken from weldments of TC128-B steels indicated that the impact characteristic of the weldments tested are much more favorable than those of the base metals of these welded steel plates. For example, the 15 ft-lb TT values of the steels averaged 38 F (for TL specimens) whereas those of the weld metal were -37 F and those of the weld-HAZ region tests (TL) averaged -48 F. The transition temperatures and the shelf-energy absorption values of the weldments tested were believed to reflect good welding practice.

5.6 A comparison of results of DT and CVN tests results for a head-plate steel and a shell-plate steel indicated that the DT test gives more conservative estimates (by about 45 F) of transition temperatures and the CVN test gives more conservative estimates (by a factor of 1/2) of the upper-shelf energy-absorption per unit area. However, for the Callao head plate (k-1) this relationship between the transition temperatures as determined by the two test methods was not observed to hold, and this finding was attributed to the microstructural variability of this head plate, which had fine ferrite on one side and coarse ferrite on the other side of the plate thickness, and to the fact that the CVN specimens were taken only from the coarse-grained half of the thickness of this plate, whereas the DT specimens represented the full thickness.

the inverse order to that of the shelf-energy absorption values for various orientations. Thus, longitudinal specimens tend to have the highest upper-shelf energy absorption and the lowest transition temperatures, and transverse specimens have significantly poorer impact properties. Hence, failure is promoted in the direction of final rolling of the plate--this was shown to be especially true for the shell-plate steels but it is also true for the head-plate steels tested. The result is that fracture in the circumferential direction of the tank car is promoted in shell plates and this can and does sometimes[2] lead to rocketing of large tank car sections.

6.5 The elevated-temperature embrittlement demonstrated by TC128-B steel should be studied further and the results should be interfaced with the elevated-temperature requirements of steels used for plate materials of tank cars. The results of elevated-temperature DT impact tests indicate that upper-shelf energy-absorption values are a function of temperature and that, at temperatures near 1050 F, the energy absorption in DT tests can be less than 50-percent of the value measured at temperatures slightly above the temperature of ambient air. These results indicate that at these temperatures an elevated-temperature embrittlement of the steel occurs by a mechanism that has not yet been established. The decrement in the energy-absorption capacity at elevated temperatures has been observed for two TC128-B steel plates tested after exposure at various temperatures for about 25 minutes in air. The effect of time at temperature on this decrement is not now known, and the susceptibility of AAR TC128-A steels or that of ASTM A212-B steels or other steels used as plate materials of tank cars is not known nor is the most important effect of strain rate known. Thus the significance of this embrittlement is now open to question.

7. ACKNOWLEDGEMENT

The author would like to thank Messrs. G. E. Hicho and T. P. Royston for their assistance in the preparation of the tables and figures of this report.