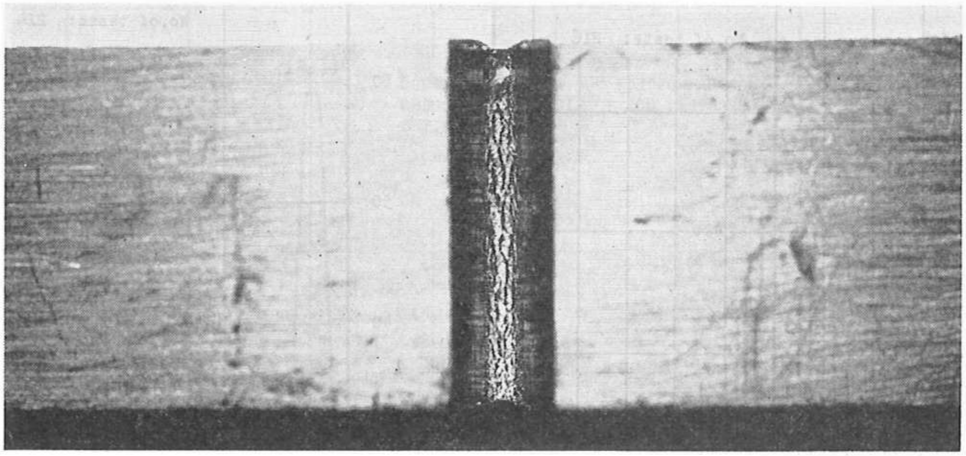

FIG. 20 DUCTILE NOTCH-BEND SPECIMEN AFTER CONSIDERABLE STRAIN BUT BEFORE INITIATION OF A CRACK. "FURROWS" IN NOTCH BOTTOM ARE MACHINING MARKS WHICH HAVE OPENED UP INTO BLUNT GROOVES

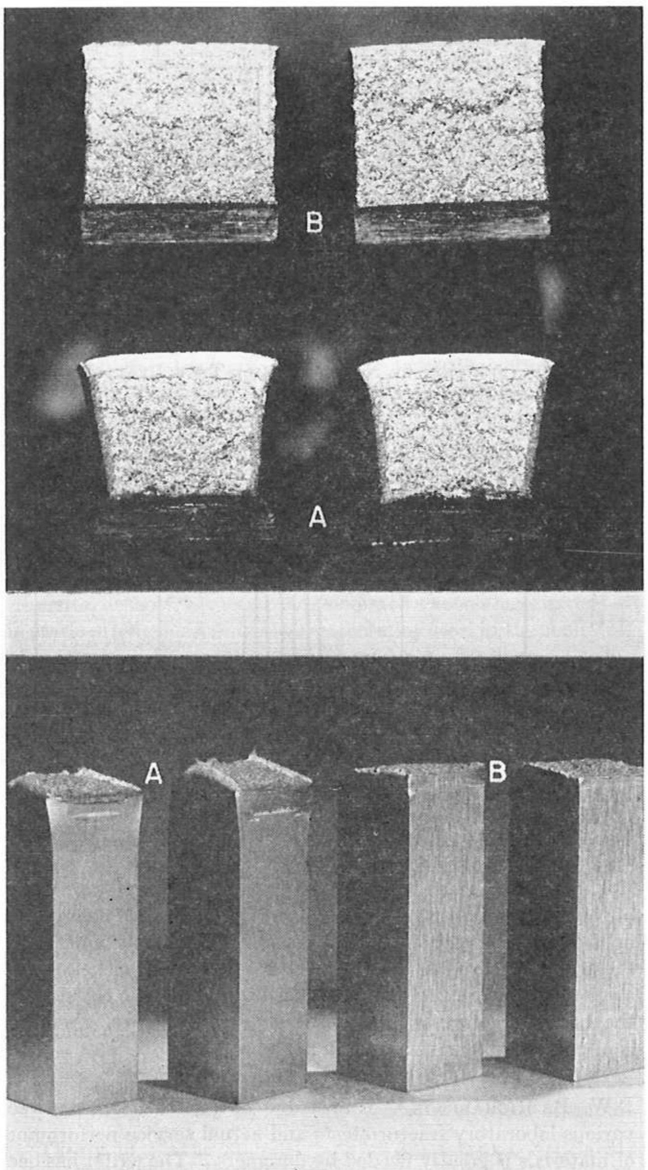

FIG. 21 COMPARISON OF FRACTURE SURFACES OF NOTCHED BEND SPECIMENS FOR HEAT-TREATMENTS A AND B

ing. Thus the energy of crack propagation was less than that stored elastically in the system.

NOTCH TENSILE TESTS

The notch was a 60-deg annular V-groove cut in a 0.250-in-diam, 1-in-long cylindrical section. The notch had a 0.005-in. root radius. The specimen diameter at the root of the notch was 0.175 in., thus giving a notch depth of 51 per cent.

In most of the tests, only the maximum load and reduction of area after separation were measured. In a few tests on ductile specimens, however, the load-diameter curves were determined, and the point of crack initiation was observed. These latter tests (Table 2) showed that part of the "ductility," measured after separation, is fictitious. It is due to the rim effect (6).

The results of all the tests are given in Table 2. They show that the ductility under notch conditions is much lower for heat-treatment B than for heat-treatment A. However, the ductility in either case apparently is high enough to smooth out the initial stress concentration, because the notch-strength ratio is very high for both A and B heat-treatments. This is not so for heat-treatment C. In this case the notch-strength ratio is far below the ideal value of 1.5. This must be due to a still lower notch ductility for heat-treatment C than for B, although the measured values do not show it. (However, they are too small to be very reliable.)

Discussion

E. P. KLIER,[4] V. WEISS,[4] and G. SACHS.[5] This paper is a very interesting and stimulating contribution to the evaluation of the old standard and of recently developed laboratory tests. It is evident from the paper that a large number of factors is responsible for any failure and, therefore, that the selection of a single test method is not sufficient to establish the fracture characteristics of a material.

The writers would like to present a contribution concerning the accuracy and reproducibility of notch-tension and Charpy impact tests. A great number of tests of these types have been performed on 4340 steel at Syracuse University.[6]

An evaluation of these tests revealed that considerable scatter

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[5] Director of Metallurgical Research, Syracuse University, Syracuse, N. Y. Mem. ASME.

[6] The work was supported by the Bureau of Aeronautics, U. S. Navy, under Contract No. NOas 54-424-c. The steel was hardened to strength levels between approximately 200,000 and 300,000 psi.

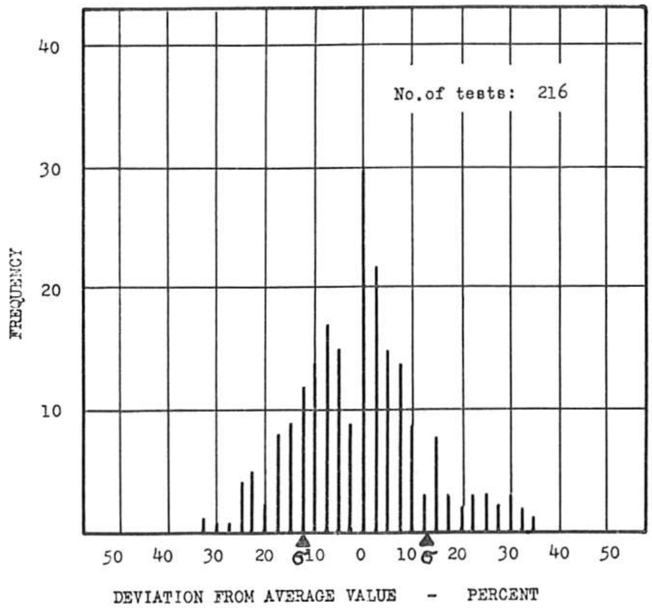

Fig. 22 Distribution of V-Notch Charpy Impact Test Values of 4340 Steel, Tested at Room Temperature

was encountered for impact tests, even at room temperature, while the consistency of the results of notch-tensile tests was very much better.

For a given heat-treatment the maximum number of parallel impact tests in this study was 10 and that of notch-tensile tests was 5. Frequency plots of such a small number of test values, of course, were irregular. Therefore, to achieve the desired statistical comparison, a large number of values was needed. To obtain such an expanded set of test values the following procedure was used:

1 Each set of test data was averaged and the average value was assigned "zero" deviation.

2 The percentage deviation from this value was determined for each test of the set.

3 Such results of a number of sets, differing in heat-treatment, were plotted in the same co-ordinate system.

Frequency plots, such as presented in Figs. 22, 23, and 24, herewith, were thus obtained for the impact test at room temperature, the notch-tension test at room temperature and —100 F and at —320 F. The frequency plots of the data are compared in Fig. 25. In addition, Table 3 of this discussion lists the percentage of test values, as derived from Fig. 25, which lie within the indicated deviations.

TABLE 3 PER CENT OF INDICATED TEST DATA WHICH LIE WITHIN SPECIFIED DEVIATION FROM MEAN VALUE

Deviation, per cent	±2.5	±5	±10
Impact test (RT)	20	39	65
Notch-tensile test (−320 F)	45	64	85
Notch-tensile test (RT, −100 F)	73	93	100

From this evaluation of the test results it is evident that the reproducibility of a notch-tensile test performed at room temperature and at —100 F is considerably superior to the repoducibility of the V-notch Charpy test. The consistency of the notch-tensile test performed at —320 F is intermediate.

J. M. Lessells.[7] This paper is of engineering interest since it gives a summary of the various tests which may be used in determining the suitability of a particular steel.

[7] President, Lessells and Associates, Inc., Boston, Mass.; Associate Professor of Mechanical Engineering, Emeritus, Massachusetts Institute of Technology, Cambridge, Mass. Fellow ASME.

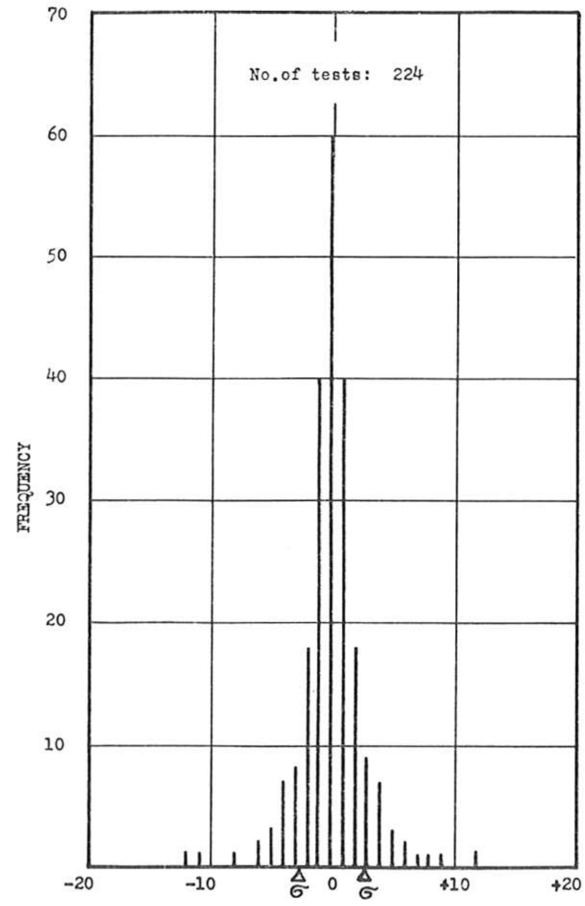

Fig. 23 Distribution of Notch-Tensile-Test Results of 4340 Steel, Tested at Room Temperature and −100 F

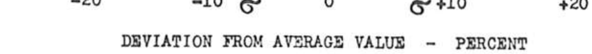

Fig. 24 Distribution of Notch-Tensile-Test Results of 4340 Steel, Tested at −320 F

The authors seem to be a little severe regarding the utility of the notched bar-impact test. While the values of energy cannot be applied directly to design, the test was capable of detecting the notch brittle conditions associated with certain nickel-chrome steels and more recently has been used a great deal in the study of the brittle fracture of ship plate steels. The test, therefore, is of considerable engineering importance.

W. B. Richardson.[8] Knowledge of the relations between various laboratory fracture tests and actual service performance of materials is greatly needed by designers. The writer has been

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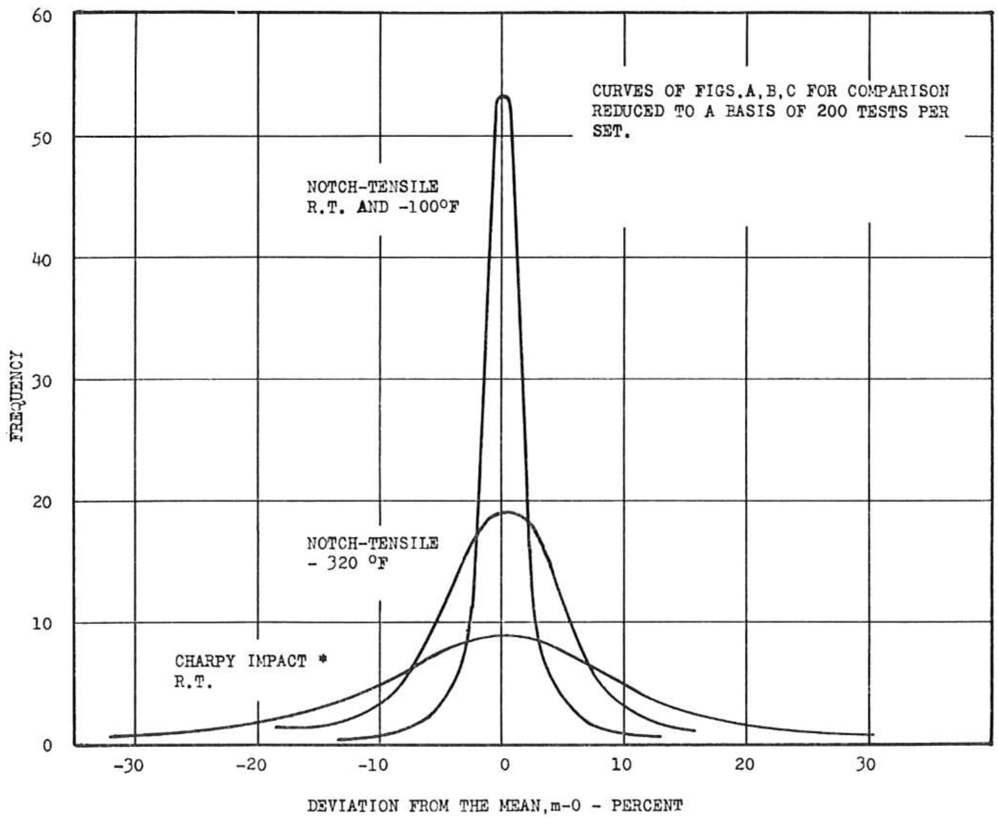

Fig. 25 Comparison of Distribution Curves for Respective Sets of Data

trying to collect data in this field for use in design of missiles and projectiles. Lack of correlation between various tests, as discussed by the authors, makes development of rational design procedures difficult.

One of the factors governing failure of materials used in projectiles is the rapid rate and short duration of loading. It is not true shock, since the loading pulse may last about 15 millisec in a medium-caliber gun. In most cases the actual design is based on the static strength of the material, using impact and ductility values to check for unusual brittleness. In some experimental designs, however, the calculated stresses have exceeded the static strength of the heat-treated alloy steel in the shell wall by as much as 15 per cent with no evidence of failure. For instance, one specimen of Aircraft Quality AISI 4340 quenched and tempered to a hardness of R_c 42-44 was fired from a gun. The compressive stress in the aft portion of the hollow cylinder reached a maximum of at least 225,000 psi. The specimen was recovered and showed a slight plastic deformation of a form discussed by Timoshenko.[9] A tensile specimen of the same material had a yield point of 175,000 psi and tensile strength of 187,000 psi.

As usual with simulated service tests, the foregoing test had several features which make complete analysis difficult, such as the fact that the load was compressive and also varied from a maximum at the base to a minimum in the nose. Our experience with various types of loading leads us to the belief that the short duration of the load is probably the most important single factor causing the increases in strength which we commonly find.

There has been a considerable amount of research on the effects of dynamic loads on the mechanical properties of materials.[10,11,12,13] Most of the results show somewhat less increase in the strength of the heat-treated medium carbon-alloy steels than our results seem to show. Freudenthal[14] has a good general discussion of the problems involved, stressing the fundamental requirement for more detailed knowledge of the complete equations of state relating stress and strain with time and temperature.

The writer would like to see the authors continue their efforts to correlate results of the various laboratory fracture tests. It also might help if they could include a more explicit study of the time and temperature variables.

Authors' Closure

Professor Lessells' point, that impact tests are useful for comparing materials, is well taken. In general, a steel which has a higher impact strength will also exhibit better performance in service.

The authors did not intend to criticize the impact test from the viewpoint of material selection, but rather from the viewpoint of its usefulness for design purposes. The designing engineer is usually concerned with such quantities as load or deflection at fracture. In only a few cases does energy to fracture enter into design calculations.

[9] "Theory of Elastic Stability," by S. Timoshenko, Article 81, p. 439, "Symmetrical Buckling of Cylindrical Shell Under Uniform Axial Compression," McGraw-Hill Book Company, Inc., New York, N. Y., 1936.

[10] "The Effect of Axial Dynamic Loads on the Mechanical Properties of Certain Steels," by R. C. Smith, T. E. Pardue, and I. Vigness, Naval Research Laboratory Report 4468 (unclassified), Washington, D. C., 1954.

[11] "Analysis of Plastic Deformation in a Steel Cylinder Striking a Rigid Target," by E. H. Lee and S. J. Tupper, *Journal of Applied Mechanics*, Trans. ASME, vol. 76, 1954, p. 63.

[12] "The Tensile Impact Properties of Some Metals and Alloys," by D. S. Clark and D. S. Wood, Trans. ASME, vol. 42, 1950, pp. 45–74.

[13] "Explosive Impact Tests," by P. R. Shepler, Proceedings of The Society for Experimental Stress Analysis, vol. 5, no. 1, 1947, pp. 1–25.

[14] "The Inelastic Behavior of Engineering Materials and Structures," by A. M. Freudenthal, John Wiley & Sons, Inc., New York, N. Y., 1950, pp. 167–170.