NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3931

A STUDY OF THE "TOSS FACTOR" IN THE IMPACT TESTING OF CERMETS BY THE IZOD PENDULUM TEST

By H. B. Probst and Howard T. McHenry

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

Washington
February 1957

4141

CA-1

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3931

A STUDY OF THE "TOSS FACTOR" IN THE IMPACT TESTING OF CERMETS BY THE IZOD PENDULUM TEST

By H. B. Probst and Howard T. McHenry

SUMMARY

The energies involved in the Izod pendulum impact test and the two components contributing to the total "toss energy" are considered. The components are recovery of stored elastic energy and kinetic energy contributed directly from the apparatus. A method to determine experimentally the kinetic energy imparted to the free half of a specimen by the apparatus is presented.

A low-capacity Izod pendulum test was used to determine the toss factor for three titanium carbide base cermets. With this apparatus, the toss factor was found to be less than 0.2 inch-pound. The validity of this small value was confirmed by high-speed motion pictures of the test. The study also showed that approximately 97 percent of the total toss energy of a broken cermet test bar is due to recovered stored elastic energy, which is a legitimate portion of the true rupture energy.

Alloys and cermets were tested at room temperature by the Izod pendulum and the results are compared with those obtained with the NACA drop test. It is shown that reliable impact data for brittle materials can be measured by using a low-capacity Izod pendulum.

INTRODUCTION

Cermets, which are mixtures of ceramics and metals produced by powder metallurgy techniques, have certain desirable properties for application as jet engine turbine blades (ref. 1). The principal drawback is their poor resistance to impact failure. In order to study effectively the impact resistance of these materials, some means of reliable impact testing is needed. Conventional testing machines are of too high capacity and the magnitude of extraneous factors is unknown.

Results obtained with conventional impact tests are not always clear cut and free from ambiguities. Even when closely controlled testing conditions are employed, impact data are characterized by wide scatter (ref. 2), and frequently the results do not correlate with service performance (ref. 3).

Extraneous factors may be included in the measured impact energy which, legitimately, should not be included. These factors are the friction loss between specimen and striker and the kinetic energy contained in the broken portion of the specimen (ref. 4). In testing brittle materials, the kinetic energy contained in the thrown half of the specimen or, as it is frequently termed, the toss energy, has aroused 4141
much speculation.

In the field of brittle plastics it has been reported that the toss energy may be of sufficient magnitude to invalidate the results of conventional pendulum tests (ref. 5). New tests were devised for testing plastics in order to eliminate the toss energy. One method is to put the unfractured specimen in motion so that it has a kinetic energy that will cancel the toss energy in the energy balance equations (ref. 6). Another method has been to eliminate toss energy by increment drop tests in which just enough energy is supplied to rupture the specimen. The source of energy is either a freely falling weight or a ball accelerated by gravity along an inclined path (refs. 5 and 7).

Jet engine materials have been compared by the NACA drop test (refs. 8 and 9) which is in use at a number of laboratories (ref. 10). This is an increment test in which toss energy is eliminated by dropping a hammer onto a specimen from increasing heights until the specimen fractures. Only energy sufficient to rupture the specimen is supplied. The drop test shows the differences in impact properties of materials, but, as it was originally conceived, the results were subject to error from nonreproducible gripping force, variations in properties of gripping materials, and the effect of repeated blows. Variations in impact energy due to gripping force and gripping material problems have been eliminated by the use of a stress-free specimen supporting arrangement (ref. 8). The fatiguing action of repeated blows, however, is still a source of error. The magnitude of this effect is not clearly known. The effect of repeated blows may be minimized by a judicious testing procedure but cannot be completely eliminated and still use a reasonably small number of specimens.

Since a single-blow test would eliminate any variations in impact energy due to repeated blows and would also be a more convenient test to operate, a modified Izod pendulum test was investigated. With this test, the toss energy contributed by the apparatus could be determined and, consequently, the true rupture energy of a test material obtained.

MATERIALS

Impact bars measuring $\frac{3}{16}$ by $\frac{3}{16}$ by $1\frac{1}{2}$ inches were tested. The compositions of the test materials are given in table I.

APPARATUS AND PROCEDURE

The low-capacity Bell Telephone Laboratory Izod impact machine (ref. 11) shown in figure 1 was used. The machine was modified so that the pendulum could be released from any position up to total capacity. The specimen gripping arrangement was also altered. Because of difficulties encountered due to variation in gripping load in the original drop test (ref. 8), the specimen in the pendulum test was gripped by a dead weight load applied to the vise. Using a lever system of 6-to-1 ratio allowed a freely hanging 50-pound weight to exert a constant 300-pound gripping force on the specimen. This is within the range of forces resulting from the 20-inch-pound vise torque used in the drop test (ref. 8). The gripping arrangement is shown schematically in figure 2. This arrangement will accommodate the three specimen shapes previously used for testing cermets (ref. 12).

The test has the same gripping geometry as the drop test, that is, 1/2 inch of the specimen is gripped while the point of impact is 1/8 inch from the free end.

The total capacity of the pendulum is 25.5 inch-pounds which may, however, be increased to 62.5 inch-pounds by the addition of lead weights. The striking velocity when the pendulum is released from maximum height is 135.8 inches per second. The striking velocity in the drop test may vary from approximately 60 to 144 inches per second, depending on the height from which the hammer is dropped.

THEORY

Brittle materials fracture in impact with no discernible plastic deformation. At any given velocity of impact, a fixed quantity of energy must be supplied before cracking will initiate and propagate to complete fracture. Until fracture, this energy has the form of stored elastic energy in the specimen. Upon fracture, a portion of this elastic energy is recovered and may contribute to throwing the free portion of the specimen. Additional kinetic energy may also by imparted to the free half by the motion of the pendulum. Thus, the total kinetic energy or toss energy of a broken specimen comes from two sources, recovery of stored elastic energy and energy that may be transferred directly to the broken fragment from the pendulum. The portion of toss energy obtained from stored elastic energy is a legitimate part of the true rupture energy of the materials and, therefore, should not be subtracted (ref. 5). Kinetic energy imparted directly from the pendulum will also register as an energy loss on the scale readings, although it is not a portion of the true rupture energy. This energy value must be subtracted from the total energy lost by the pendulum in order to obtain the true rupture energy of the test specimen.

When a specimen is ruptured by an Izod pendulum, the following energy balance holds:

$$E_O = E_r + E_t + E_f \qquad (1)$$

4141

where

E_O initial energy of pendulum before release

E_r true energy required for rupture of test material

E_t portion of toss energy contributed directly from pendulum

E_f final energy of pendulum

Equation (1) neglects friction of pendulum bearing, windage, shearing and tearing, friction between pendulum and specimen, deformation of pendulum, and absorbtion of energy by machine structure. The latter four factors may be neglected in "fast-breaking" materials (ref. 4). Bearing friction and windage will be considered later. The portion of toss energy contributed directly from the pendulum is the value that must be determined in order to obtain the true rupture energy.

If a broken specimen is replaced in the machine and tossed by the pendulum, the following energy balance holds:

$$E_O' = E_t' + E_f' \qquad (2)$$

where

E_O' initial energy of pendulum (variable with equipment modification previously discussed)

E_t' energy consumed in tossing broken specimen

E_f' final energy of pendulum for this case

If a series of runs is made using a prebroken specimen, E_0' can be adjusted to yield a value of E_t' which is exactly equal to E_t. There will be only a single value of E_0' which yields $E_t' = E_t$. This value of E_0' is the same as the energy possessed by the pendulum just after rupturing a test bar, that is,

$$E_0' = E_0 - E_r \tag{3}$$

Substituting E_t for E_t' in equation (2) gives

$$E_0' = E_t + E_f' \tag{4}$$

Equating the right sides of equations (3) and (4) and substituting equation (1) for E_0 gives

$$E_t + E_f' = E_r + E_t + E_f - E_r$$

or

$$E_f' = E_f$$

Since $E_f' = E_f$, in order to obtain E_t it is only necessary to

(1) Experimentally establish E_f' as a function of E_0' for a given material and test bar.

(2) Test given material and observe E_f.

(3) Then, since $E_f' = E_f$, this observed value of E_f may now be substituted into $E_f' = f(E_0')$ giving E_0', then E_t may be determined from equation (4).

This calculation is more easily shown graphically as follows. The curves shown in figure 3 can be established experimentally by varying the initial energy of the pendulum. Curve A, at 45°, is for an ideal pendulum (no friction or windage losses) with no specimen. Curve B is for a real pendulum also without a specimen. Bearing friction and windage were accounted for in the usual manner by letting the pendulum swing freely with no specimen in place and noting the energy loss. The separation of these two curves is due to bearing friction and windage. Curve C is for a real pendulum with a broken specimen in place.

These curves for a given pendulum and a particular test material and specimen size having been established, the material may now be ruptured by the pendulum and E_f noted. Since $E_f = E_f'$, E_f may now be located on the abscissa of figure 3. The separation from the intersection of a vertical line drawn from E_f on curve C to curve B is then E_t as shown in figure 3. This value may now be substituted back into equation (1) and the true rupture energy E_r determined.

RESULTS AND DISCUSSION

4141

The experimental curves for determining the value of toss energy for K152B (corresponding to the hypothesized, fig. 3) are shown in figure 4. The cermets K162B and JR-5 were also tested in this manner. The data points for these cermets fall on the same curve as K152B as shown in figure 4. However, for materials with large differences in density, this would not necessarily be true. From this figure it is seen that, with the apparatus and testing conditions used, E_t is less than 0.2 inch-pound and, for all practical purposes, is negligible.

In order to check this unexpectedly small value of E_t, high-speed motion pictures were taken of the Izod pendulum test in operation. A film speed of 5000 frames per second was used to photograph the flights of a K152B specimen after fracture and of the replaced broken half. The rotational and translational velocities of the specimen in each case were obtained and, knowing the moment of inertia and mass of the specimen, the two energy components were calculated. The rotational energy in both cases was extremely small, 0.012 inch-pound when the specimen was fractured, and much less when the broken half was struck. The total toss energy measured when the specimen was fractured was 0.552 inch-pound. When the broken half was replaced and struck, the kinetic energy of the tossed piece was less than 0.017 inch-pound, confirming the conclusion obtained graphically in figure 4. This result shows that for the material tested with this apparatus the total toss energy is considerable, but only a small portion (3 percent) is obtained directly from the pendulum. The use of a conventional, high-capacity pendulum released in normal operation from greater heights would, of course, have increased striking velocity and, consequently, alter toss energy.

Several additional materials of which specimens were available were also tested by the Izod pendulum at room temperature. These results are shown in table I along with values obtained in the drop test. The drop-test values are averages of six specimens each, while the number of specimens for the pendulum tests are entered parenthetically in table I. The values obtained with the Izod pendulum were obtained in the conventional manner, accounting only for bearing friction and windage losses. Toss energy contributed by the pendulum was considered negligible and not subtracted.

The data of table I indicate good agreement for unnotched cermets between results obtained by the two testing methods. A similarly good agreement for notched cermets is indicated but with a lesser amount of data. The data available for alloys are meager, but there does seem to be a fair agreement between test methods. The drop test appears to be more sensitive to the effects of notches than the pendulum test. This apparent increase in sensitivity, however, may be due to a greater sensitivity of notched bars to the effect of repeated blows in the drop test.

CONCLUDING REMARKS

When brittle cermets are tested with the apparatus described in this report, the toss energy contributed by the pendulum is negligible. Although the total toss energy possessed by a broken cermet specimen is considerable, approximately 97 percent of this energy is due to recovered stored elastic energy.

This study shows that by using an Izod pendulum having a suitably low capacity, reliable impact energies can be obtained for brittle materials. This test is more convenient to operate than the drop test, since it is a single-blow test.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, December 13, 1956

REFERENCES

1. Ault, G. Mervin, and Deutsch, George C.: Review of Materials for Jet Engines. NACA-University Conference on Aerodynamics, Construction, and Propulsion. Vol. 1 - Aircraft Structures and Materials. Lewis Flight Propulsion Lab., Nat. Advisory Committee for Aero., Oct. 1954.

2. Metallurgical and Research Committee of the Forging Manufacturers Association: How Accurate is the Impact Test? Metal Prog., vol. 60, no. 6, Dec. 1951, pp. 69-71; cont., p. 176.

3. Hazen, T.: Toughness of Molding Materials. Modern Plastics, vol. 21, no. 2, Oct. 1943, pp. 103-106; 144.

4. Lamb, E. H.: Discussion of Notched-Bar Impact Tests. Inst. Civil Eng., Minutes of Proc., pt. I, vol. 211, 1920-1921, p. 185.

5. Callendar, L. H.: New Methods for Mechanical Testing of Plastics. British Plastics, vol. 13, Apr. 1942, pp. 445-458.

6. Maxwell, Bryce, and Rahm, L. F.: Impact Testing of Plastics: Elimination of the Toss Factor. A.S.T.M. Bull., No. 161, Oct. 1949, pp. 44-47; discussion, pp. 47-48.

7. Stock, Charles R.: A Ball Impact Tester for Plastics. A.S.T.M. Bull., No. 130, Oct. 1944, pp. 21-26.

8. Probst, H. B., and McHenry, Howard T.: A Study of the Impact Behavior of High-Temperature Materials. NACA TN 3894, 1957.

9. Barr, Robert: Behavior of Unalloyed Molybdenum and Some Molybdenum-Base Alloys in a Special Impact Test. Rep. No. 3180, Climax Molybdenum Co., Dec. 22, 1953.

10. Soxman, E. J., Curran, M. T., and Tinklepaugh, J. R.: Impact Testing of Cermets. Prog. Rep. No. 2, July 1 to Oct. 1, 1954, The New York State College of Ceramics, Alfred Univ., Alfred (N.Y.). (Contract No. AF33(616)2380.)

11. Anon.: The Bell Telephone Laboratories Impact Machine. Tech. Bull. No. 180, Baldwin Locomotive Works.

12. Pinkel, B., Deutsch, G. C., and Katz, N. H.: A Drop Test for the Evaluation of the Impact Strength of Cermets. NACA RM E54D13, 1955.

4141

TABLE I. - COMPARISON OF IMPACT DATA OBTAINED USING LOW-CAPACITY

IZOD PENDULUM AND NACA DROP TEST

Material	Nominal composition, weight percent	Impact resistance, in.-lb			
		Drop test		Izod pendulum test	
		Notched	Unnotched	Notched	Unnotched
X-40	25.5 Cr, 5-10 Ni, 7.5 W, balance Co	48.1	----	[a]>61.5 [b](2)	---
Inconel 550	0.05 C, 15 Cr, 0.73 Mn, 6.6 Fe, 1.16 Al, 2.5 Ti, 0.007 S, 1.03 NbTa, 0.28 Si, 0.03 Cu, balance Ni	[a]>62	----	[a]>61.5 [b](2)	---
35-100	35 Ni, 28 Cr, 31 Fe, 1.5 Mn, 0.5 Si, 7.9 Mo, 6-1.1 C, 1-2 B	1.6	1.9	----	3.6 [b](2)
73-J	23 Cr, 6 Ni, 6 Mo, 0.7 C, 1.0 Mn, 2.0 NbTa, balance Co	5.1	----	3.7 [b](3)	---
Guy Alloy	12-15 Cr, 0.5 Mn, 0.5 Si, 5-6 Mo, 5.5-7 Al, 2 Nb, 0.5 B, 4-5 Fe, 0.1 C, balance Ni	12.9	16.7	11.5 [b](2)	---
K152B	30 Ni, 8(NbTaTi)C, balance TiC	2.1	4.1	2.4 [b](6)	2.5 [b](6)
K162B	25 Ni, 5 Mo, 8(NbTaTi)C, balance TiC	3.3	6.3	----	7.5 [b](1)
JR-5	27 Ni, 10.2 Mo, 218 Al, 6(NbTaTi)C, balance TiC	1.7	3.6	2.7 [b](3)	3.1 [b](3)
JR	33.8 Ni, 12.7 Mo, 3.5 Al, 8(NbTaTi)C, balance TiC	2.3	5.5	----	5.2 [b](1)

[a]Maximum capacity of test.

[b]Number of specimens tested.

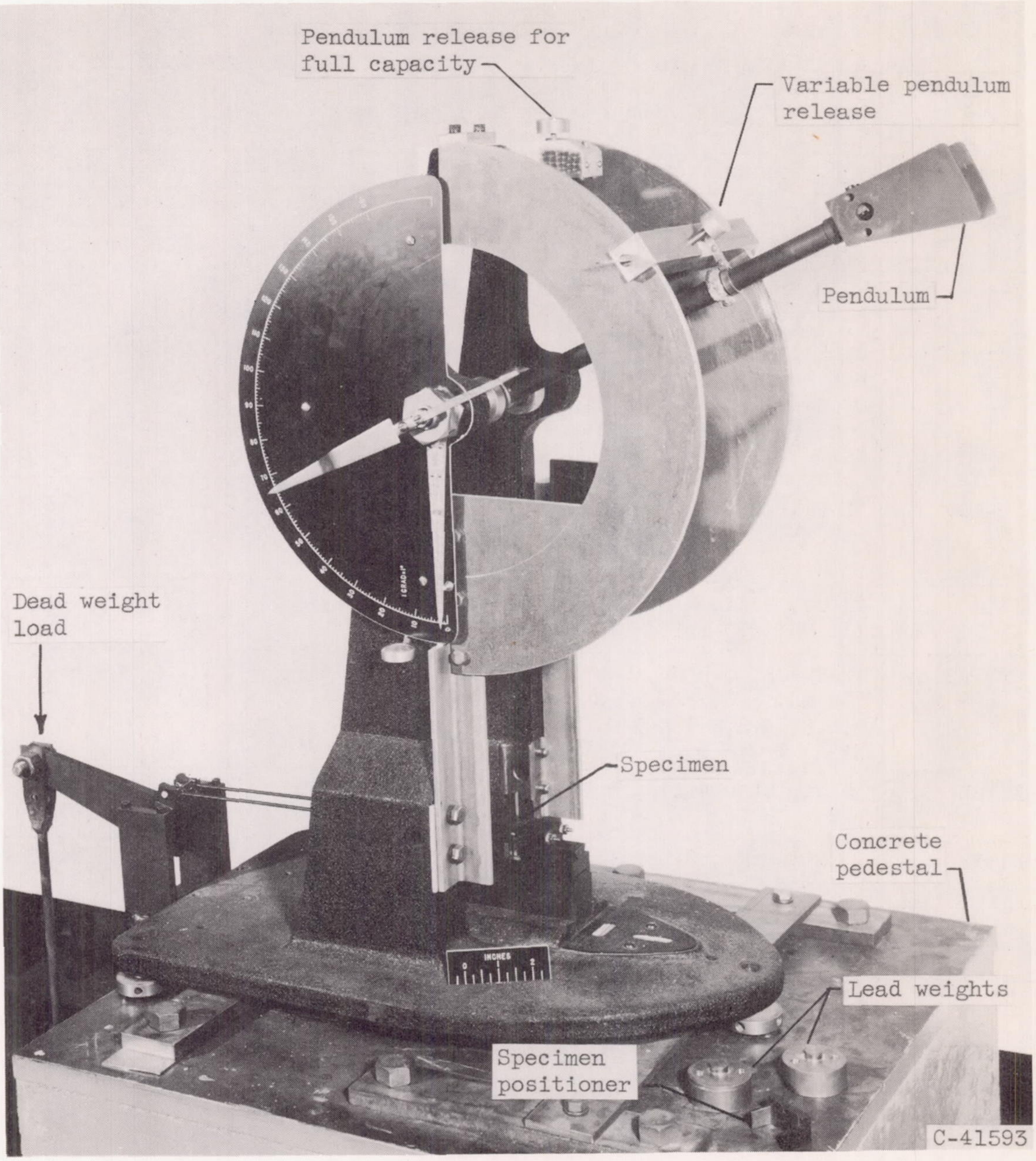

Figure 1. - Modified Izod impact-test apparatus.

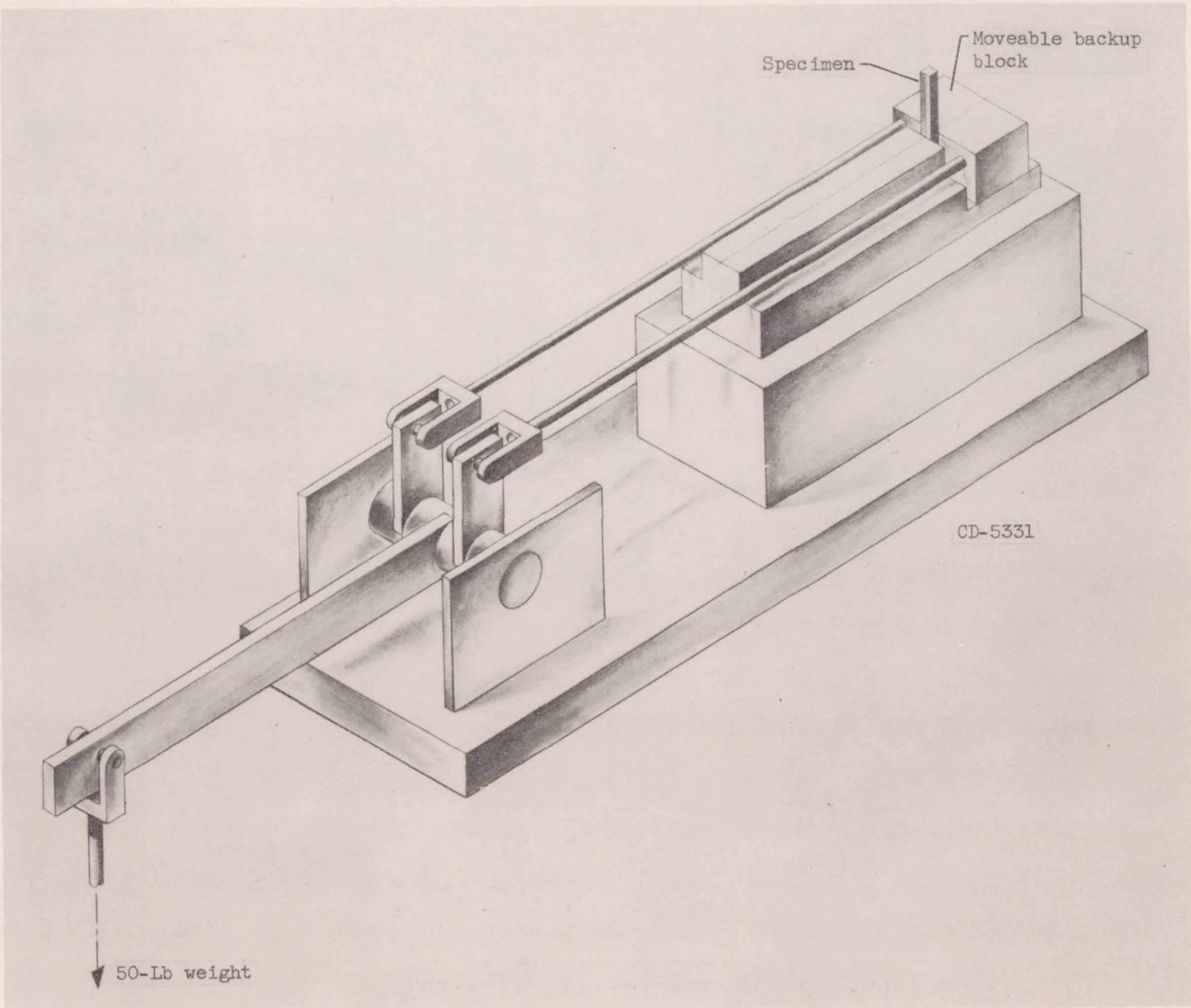

Figure 2. - Specimen gripping arrangement.

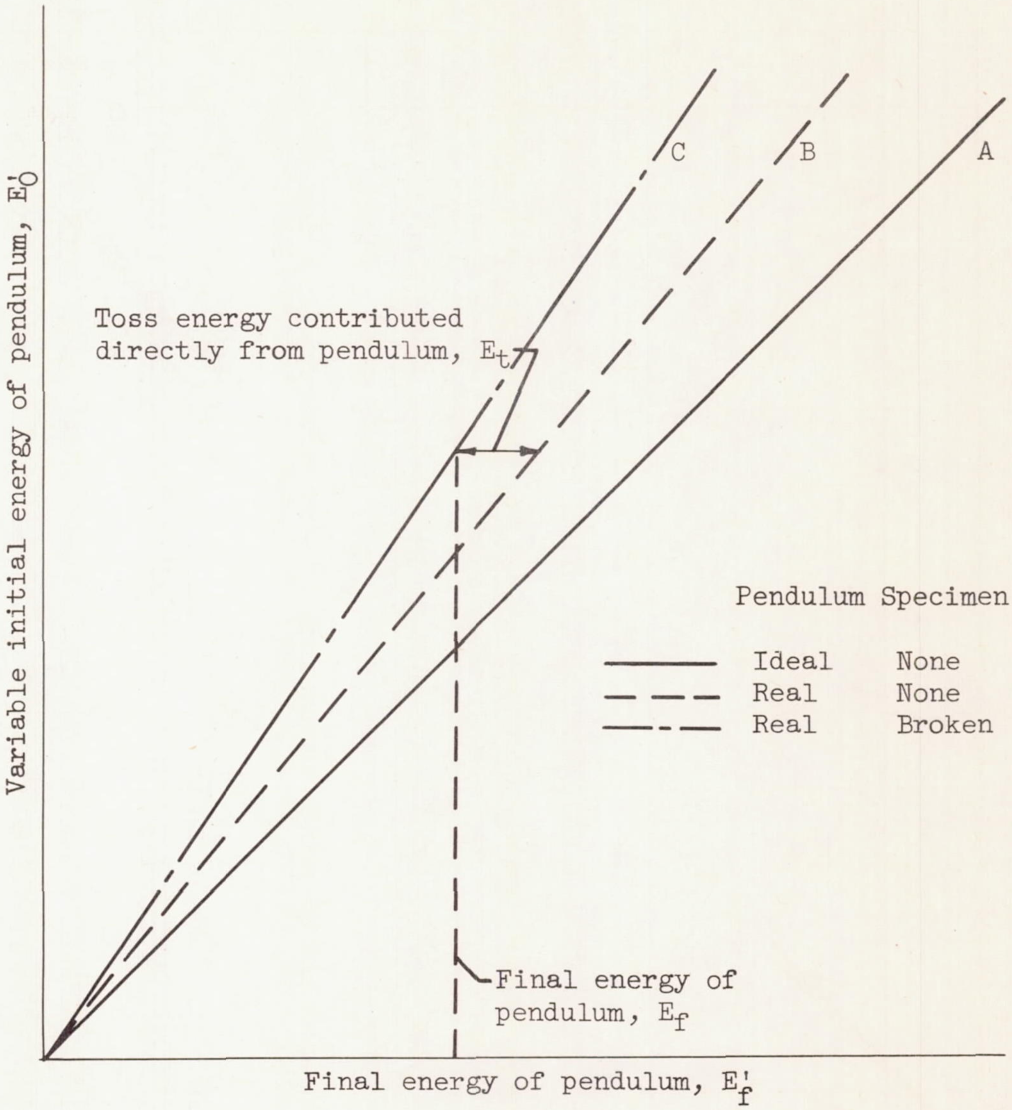

Figure 3. - Hypothetical curves relating initial and final energies of pendulum.

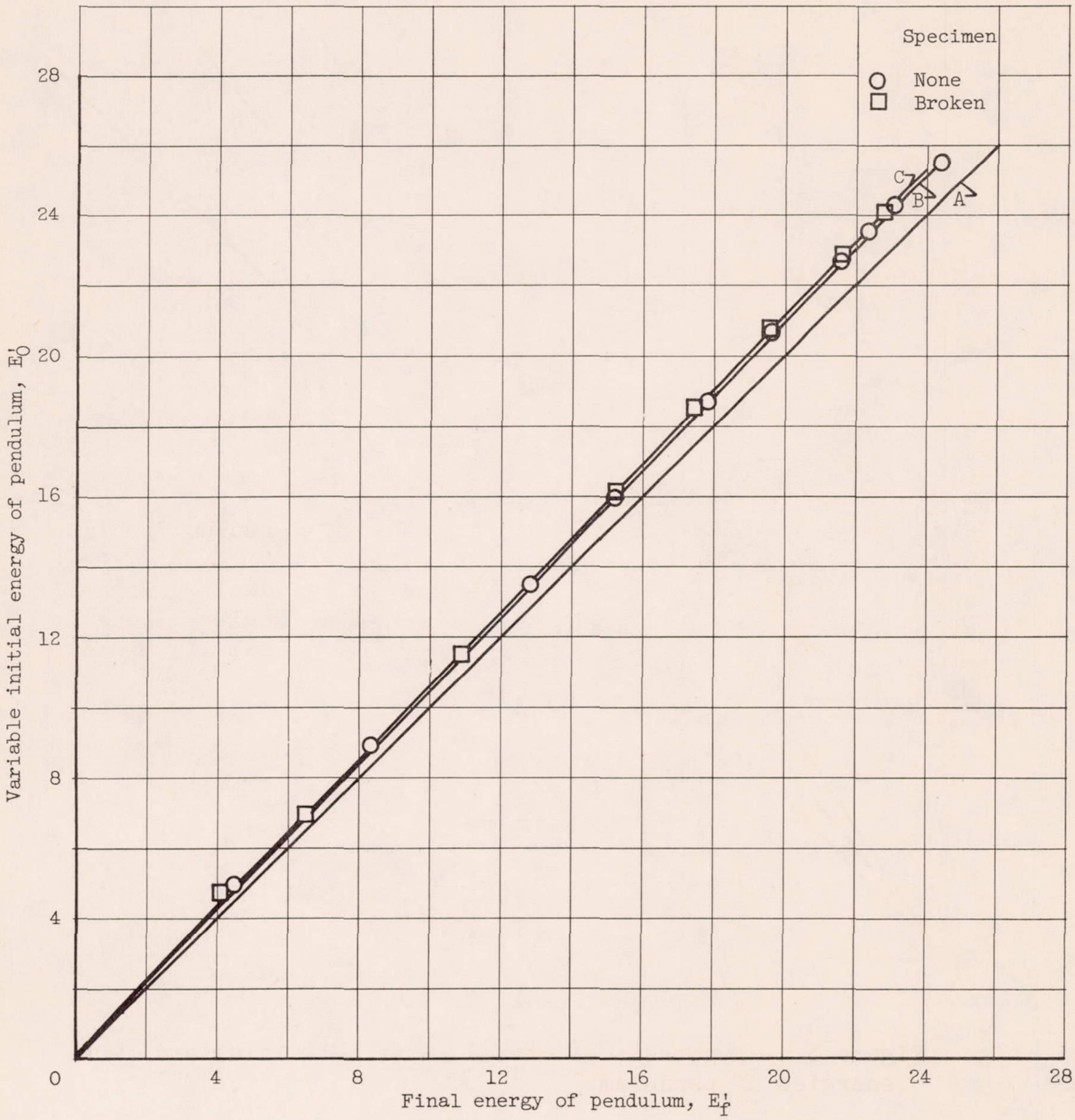

Figure 4. - Experimental curves relating initial and final energies of pendulum for K152B.