



AN INVESTIGATION OF THE NOTCH
SENSITIVITY OF SEVERAL MATERIALS IN
TORSION-IMPACT

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This is to certify that the
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AN INVESTIGATION OF THE NOTCH SENSITIVITY
OF SEVERAL MATERIALS IN TORSION-IMPACT

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1. INTRODUCTION

Many mechanical devices have members subjected to torsional stresses; often the designer is forced to impose discontinuities in the stressed section such as shoulders, grooves, keyways, splines and others. The factor of impact is also usually present.

The purpose of this investigation is to present the features of experiments with notched specimens for several materials in torsion-impact; the DeKoning Torsion-Impact Machine was employed to study certain aspects of notch sensitivity in these materials. Some problems encountered and discussed are the mass production of accurate test specimens, the variation of energy of rupture in torsion-impact with diameter of test section, and the variation of rupture energy with notch angle in some typical ductile and brittle materials.

The DeKoning Machine was recently offered as a new instrument in the field of materials testing. The scope of this investigation was designed to facilitate specimen production and testing technique, standardize the test notch, and indicate the general variation of data that may be expected from this machine in its present state of development. Also, data is presented concerning the behavior of several materials in notched torsion-impact.

II. DESCRIPTIVE MATERIAL

A. Historical Sketch

The general field of impact testing has been recognized as extremely helpful in the selection of the proper material for a given shock loaded member. Shock or impact loading causes a severe increase in stress in a member calculated to resist a nominal static load, often times causing failure. Impact overloads may result from such simple situations as back-lash in a gear, starting and stopping machinery, or even the sudden application of a load to a member without breaking contact.

It follows that there is a decided need for information on a material's ability to resist such loading, enabling the designer to cope with the problems of higher operating speeds, reduced masses, and lower factors of safety. It was with this thought in mind that the American Society for Testing Materials met and published a symposium on impact testing.²² Sam Tour opened the discussion by labeling impact testing as an "art" and "science" and making a plea for utility and the use of non-standard impact tests.

A few years prior to this meeting, two unique and non-standard impact testing machines were developed to rupture a specimen in torsion, rather than the ordinary

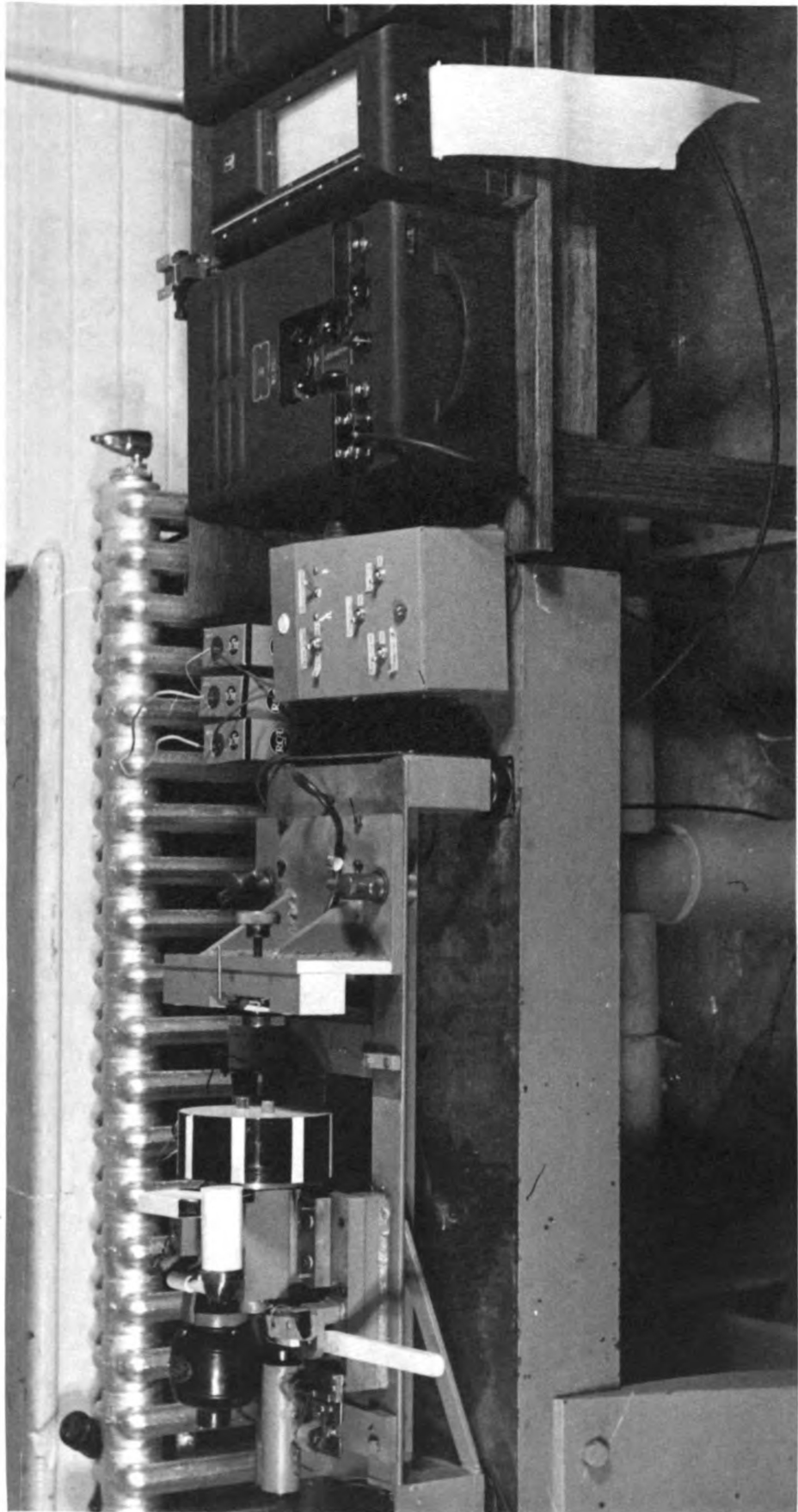
tension or bending type impact. Luerssen and Greene designed and built a torsion-impact machine and tested specimens of plain carbon, and high alloy steels.¹⁰ The final standard specimen was one-fourth inch in diameter with an effective length of one inch, allowing a compromise between energy absorption in rupture and fairly good heat-treatability. The data of their tests showed some substantial peaks in rupture energy indicating that optimum tempering conditions do exist for that particular material. Further, these peaks were not demonstrated in the usual standard Charpy and Izod type impact tests, thus assuring the position of the torsion-impact test.

In 1933, Mititosi Ithihara published the first of a series of articles on the results of **torsion-impact** tests conceived at the Tohoku Imperial University, Sendai, Japan.¹³ The test section was 8 mm. in diameter and 10 mm. long; torque measurements were read from a spring deflection, and twist angles recorded by optical means. The investigation included tests run with a variable shear rate and in general indicated that maximum torque increased with increasing velocity of impact. Impact values offered by Ithihara indicated substantial increases over static values; a 25 percent increase in torque and a 10 percent to 20 percent increase in angle of twist was reported.

B. The DeKoning Torsion-Impact Machine

In 1950, Paul J. DeKoning designed and built a torsion-impact machine embodying several new themes.³ The standard test specimen had a severe notch and an extremely small gage length, where failure occurs. This allowed another variable, notch sensitivity, to be introduced into the test with its subsequent mechanical and metallurgical features. Most shafting, and other members subjected to torsion, have threads, notches, shoulders, and various discontinuities that present the problem of selecting a material with proper strength levels, along with a low notch sensitivity or resistance to stress risers caused by abrupt changes in section.

The DeKoning machine, as pictured in Figure 1, involves a rotating flywheel to produce and measure the energy of rupture, and electrical strain gages, with their related equipment, to measure the resisting torque of rupture exerted in the specimen support. A detailed description of the machine in its present state of development is as follows: the stationary specimen holder, mounted rigidly in the tail-stock of the machine, resists the exerted torque of rupture through two small pillars, equidistant from the central or twisting axis of the test piece. Mounted on these pillars are four SR-4 resistance type strain gages, arranged with two in series in parallel with two in series, and a "dummy" or compensating gage on the other leg of a wheatstone circuit to balance out temperature



The DeKoning Torsion-Impact
Machine and Related Equipment

Fig. 1

differentials. The net result of the four active gages is to give average readings of axial strain on the pillars, without error introduced by bending. The signal from the strain gages is fed through a Brush Strain Analyser, and thence to a Brush Magnetic Pen Oscillograph, recording a "pip" on the oscillograph tape that may be calibrated directly into inch-pounds of torque.

The flywheel contributes the necessary energy to produce rupture. It is brought up to the nominal testing speed, 420 rpm, by a small, 110 volt, A.C. driving motor, connected through a Variac transformer for speed control. The initial energy level is determined approximately with a stroboscopic synchronizing device, consisting of a wheel driven by a rubber belt from the shaft of the flywheel and a neon glow lamp, shining on the wheel rim on the operator's side. Stripes painted on the wheel rim are calibrated to "stand still" when the proper initial test speed is reached. The very accurate speed determination, needed for energy results, is made by means of a unique photocell tachometer. Painted on the flywheel rims are white lines on a black background, suitably spaced, that reflect pulses of energy from an exciter lamp to the photocell. The pulses are then fed through a Brush D.C. Amplifier and thence to the oscillograph tape, causing the deflection of a second oscillograph pen. These deflections may be calibrated in terms of the energy state of the flywheel and will be discussed in detail later. The advantage of such an arrange-

ment is that there is no mechanical connection to the flywheel for an energy measurement and thus no energy loss through friction. The flywheel shaft is mounted in bearings such that the resulting friction energy loss is negligible over a short time interval.

The entire operating apparatus is wired through a central control panel to facilitate testing. The circuit includes a timing switch for proper flywheel engagement, a switch to energize the photocell tachometer, and a switch to start and stop the oscillograph tape for the duration of a test run. Thus, the testing operation is greatly simplified and requires only the clamping of a specimen in a dog and in the tailstock support, moving the tailstock into position, checking the flywheel speed with the stroboscope, and energizing the system with a master starting switch. The completed operation takes less than a minute allowing many tests to be run in a relatively short time.

The energy state of the flywheel, rim, and shaft at any speed, is a function of the mass moment of inertia of the system and the square of the angular velocity.

That is, $E = \frac{1}{2} I w^2$

where $E =$ kinetic energy,

$I =$ mass moment of inertia,

and $w =$ flywheel speed.

If the spacing of white impulse strips on the flywheel rim and the diameter of the flywheel are known, the angular

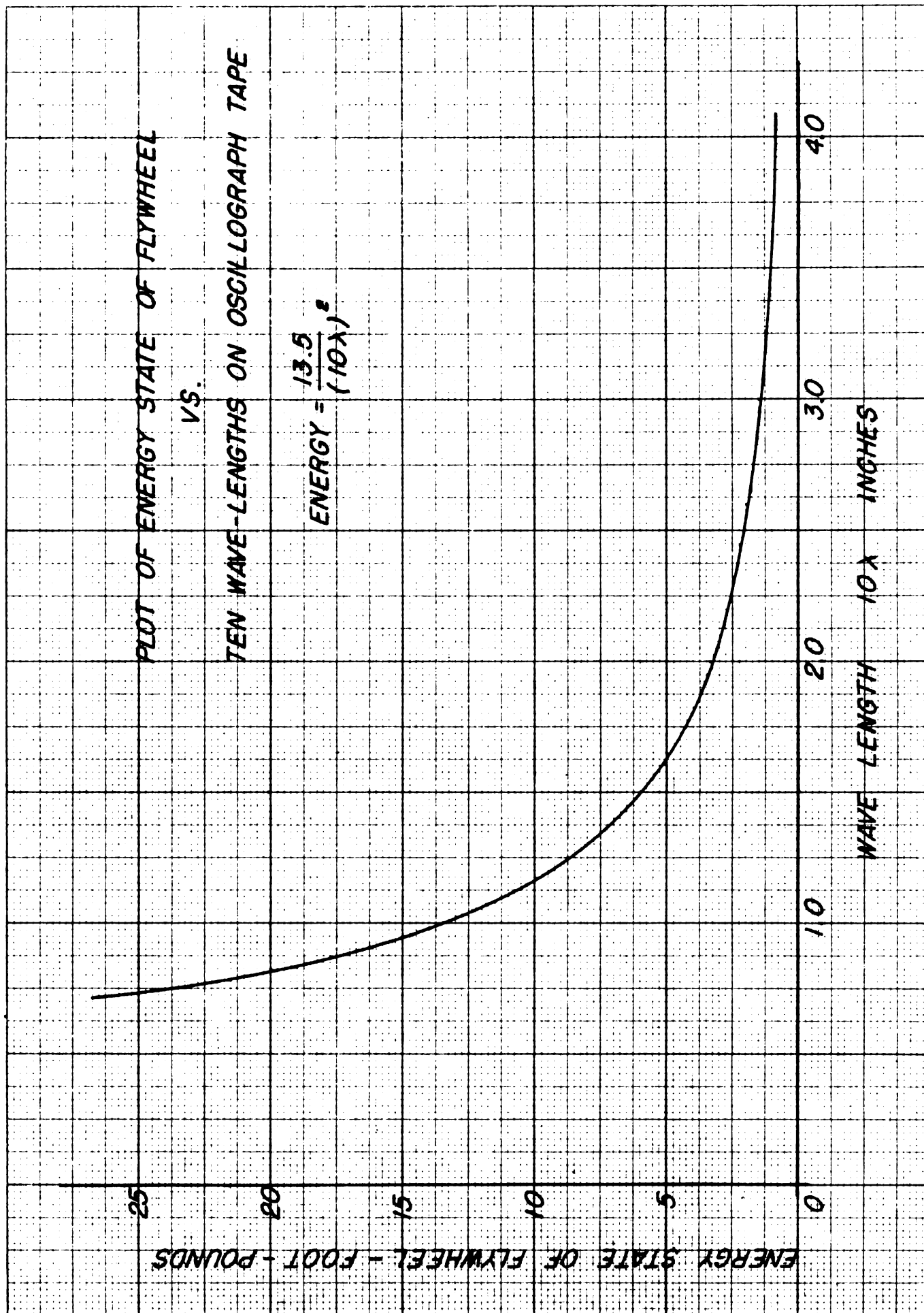


Fig. 2

velocity may be expressed in terms of a linear, peripheral, velocity. Further, since these impulses are transmitted through the photocell to the oscillograph pen and tape, if the tape speed is known, a direct expression results relating the kinetic energy in terms of the wave length of tape pen oscillation. For a tape speed of 125 mm. per second, the energy equation is

$$E = \frac{13.5}{m^2} \text{ in foot-pounds}$$

where 13.5 = machine and circuit constants,
and m = wave length of ten oscillations
in inches.³

The plot of this expression, as shown in Figure 2 , provides a convenient and accurate method of determining the flywheel energy of a given tape measurement of ten wave-lengths. The plot used for energy data for the following tests was made on 24 x 36 inch graph paper, insuring good accuracy to a hundredth of a foot-pound. The initial energy state usually varied only within a small range, but since the curve is rather critical there, it was deemed more accurate to calculate the corresponding energy.

Figure 3 shows two sample oscillograph tapes taken as typical for the tests run. Figure 3a is a test run of a leaded, free-machining brass with a square notch and .005 inch corner radii. This type of notch imposes a definite .0625 inch test length and represents the practical upper limit of energy absorption for the machine. Ten wave-lengths before rupture measured 0.87 inches, with an energy of 17.80

Typical Oscillograph Tapes

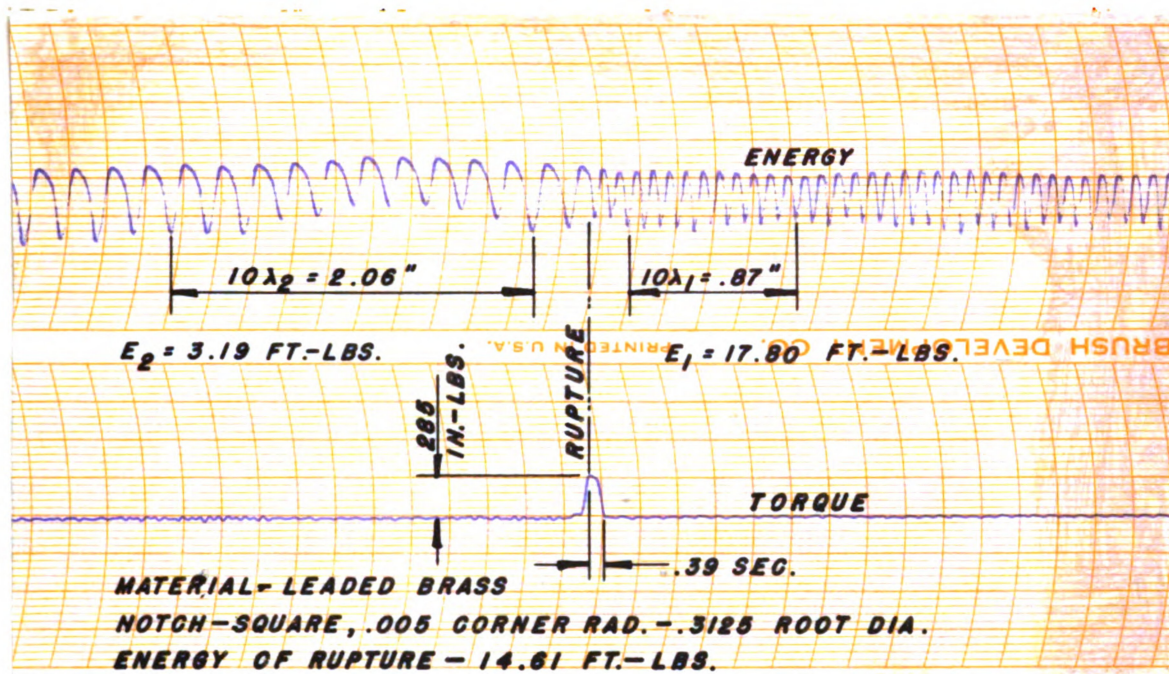


Fig. 3a

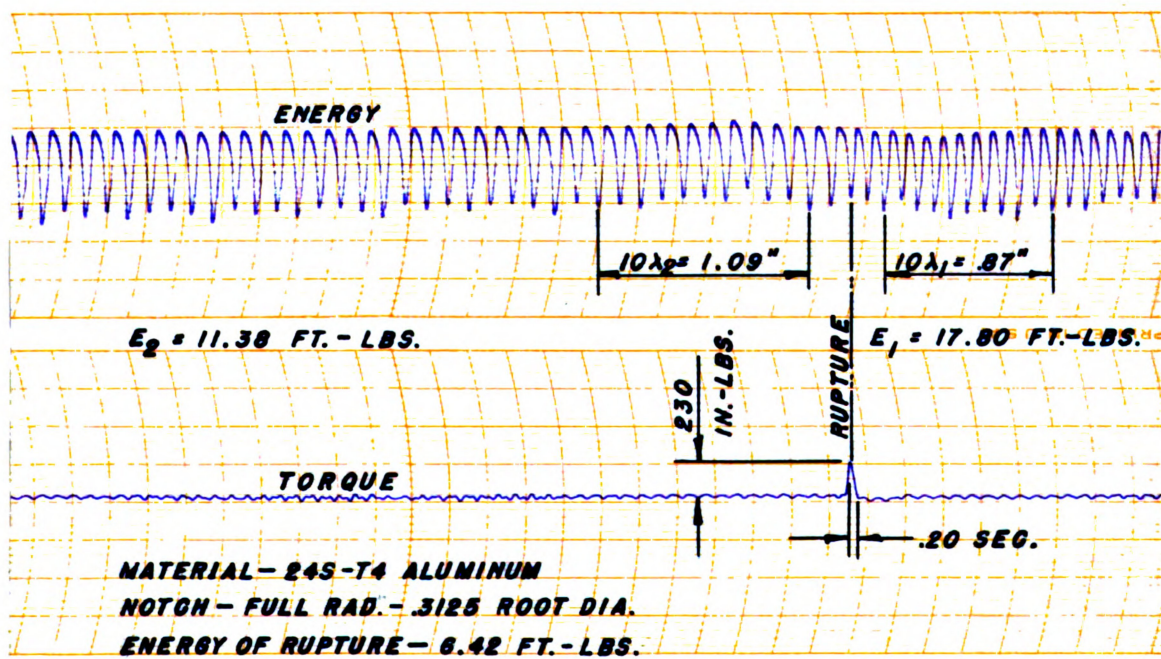


Fig. 3b

foot-pounds; ten wave-lengths after rupture measured 2.06 inches, with an energy of 3.19 foot-pounds. The resultant energy of rupture then, is 14.61 foot-pounds. The torque pip is approximately 5.7 divisions high or representing 285 inch-pounds of torque. The tape length during rupture is 0.08 inches long corresponding to an elapsed time of 0.39 seconds.

Figure 3b is a typical test run of a full radius notch specimen of 24S-T4 aluminum. The energy of rupture was 6.42 foot-pounds with a torque of 230 inch-pounds. The elapsed time during rupture was 0.20 seconds. The full radius notch was later adopted as a control for the series of experiments since it seemed best suited from the standpoint of machineability and tool wear. Over the range of notches investigated, the full radius notch also gave the most consistent data for the materials tested.

C. The Torsion-Impact Specimen

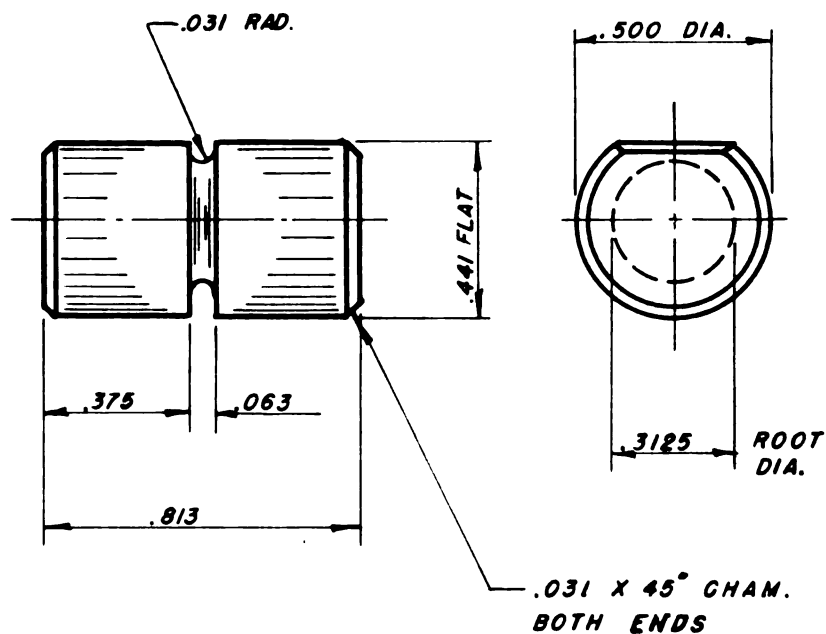
Figure 4a is a view of whole and fractured specimens, adopted as standard for this torsion-impact test. Figure 4b shows a detailed drawing of the specimen. The gross dimensions are .500 inch diameter and .8125 inches long with a milled clamping flat .059 inches deep. The notch is turned in the center of the length to a nominal root diameter of .3125 inches, and a constant width of .0625 inches.



Torsion-Impact Specimens

Fig. 4a

**STANDARD TEST SPECIMEN
DEKONING TORSION-IMPACT MACHINE**



**DOUBLE SIZE VIEW OF FULL RADIUS
NOTCH, ADOPTED AS CONTROL**



ACTUAL SIZE

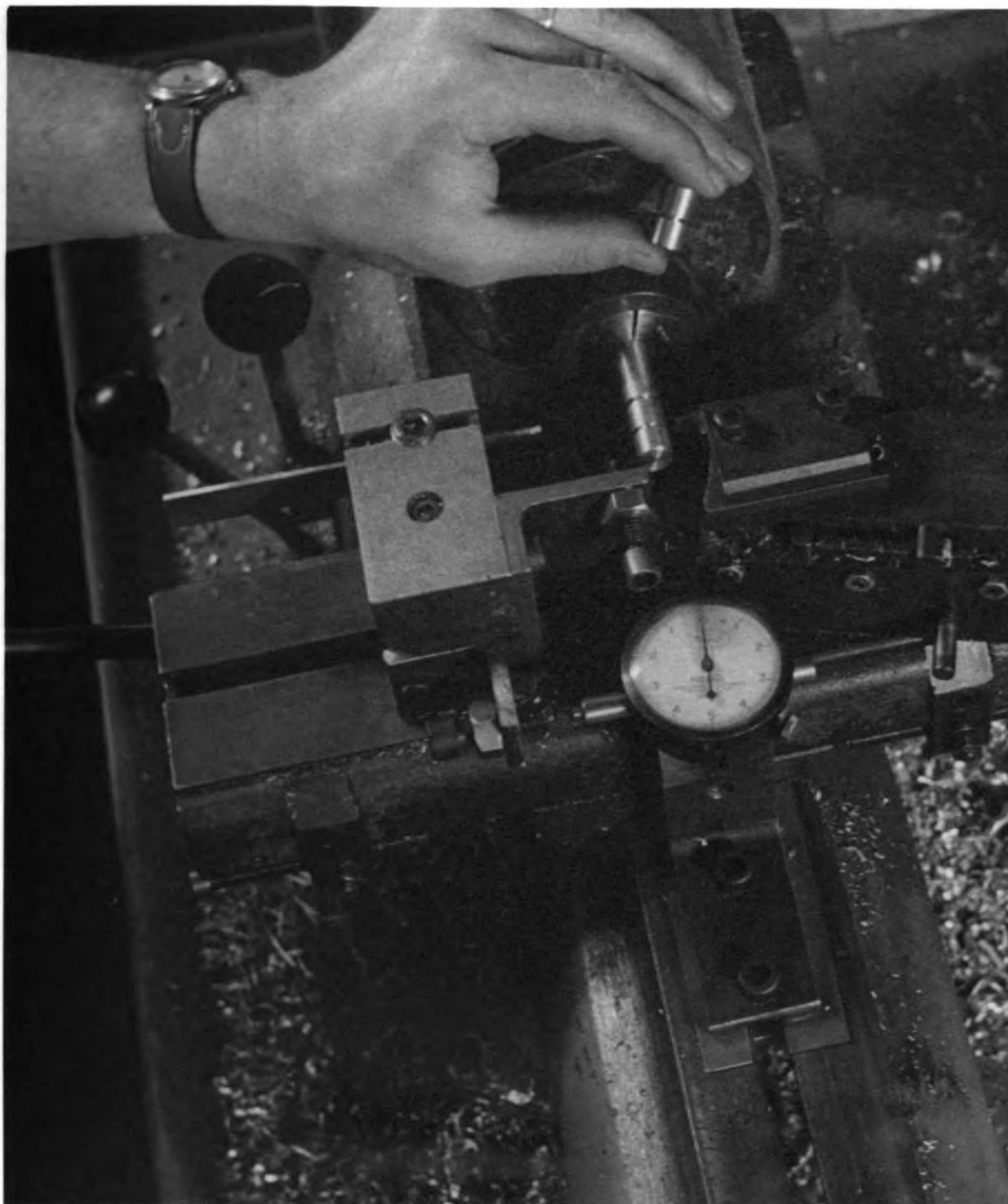
Fig. 4b

To intelligently run a series of tests of this nature, a few hundred specimens are needed. To maintain high standards of dimensional accuracy, a machine-tool setup is needed with an adequate method of checking these dimensions. Figure 5 shows the small Hardinge production lathe selected for the job. The specimens were turned from 1/2 inch O.D. bar stock, with a collet type chuck for good concentricity between O.D. and root diameter. Tool blocks were designed and built specifically for this problem and were keyed and bolted rigidly to the movable cross-slide of the lathe. The machine cycle is as follows:

1. Set depth of grooving tool, mounted on rear tool block, with aid of long-travel dial indicator and adjustable stop
2. Open collet and bring stock out to adjustable length-stop and lock collet
3. Back in grooving tool to depth set on stop
4. Run in cut-off tool, chamfer with a file, and cut off.

After the stops were set properly, the entire cycle took only a few seconds. A vertical milling machine was employed to machine the clamping flat and the specimen was ready to test.

Accurate dimensional control of the cutting tools, notches, and finished root diameters is a necessity if a quantitative test is to be run. An optical comparator or "shadow-graph" was used for checking the profile of the



Production Machine-Tool Setup

Fig. 5

cutting tools and notches. With the aid of an over-sized micrometer screw, a table travel was made for checking root diameters easily to a ten-thousandth of an inch. The comparator was calibrated accurately to give a magnification of 50 to 1 of objects placed in front of the lenses. Thus, with the use of drawings of a given notch on transparent paper, a close check was run on the cutting tools and notches. Consistent with the tools available, a blanket tolerance of .001 inch was imposed on the test specimen.

III. EXPERIMENTAL MATERIAL

A. Variation of Energy of Rupture With Diameter of Test Section

With the problems of mass production of accurate test specimens and the proper calibration of the torsion-impact machine and resulting data satisfactorily overcome, thought was then turned to a test problem. At that time, it was of interest to determine what machining tolerance should be imposed on the specimen, and how this tolerance would affect the resulting measurements of energy and torque of rupture. The initial tests were run partly to answer this question and partly to systematize the total operation, including the test run.

The first material investigated was a leaded, free machining brass chosen for its excellent machineability,

high ductility and moderate strength level which seemed to indicate a fair amount of energy absorption in rupturing. The physical properties of this material were taken as follows:

chemical composition - copper, 61.5 percent;
zinc, 35.5 percent; lead, 3.0 percent;
mechanical properties - tensile strength,
58,000 psi; percent elongation, 25 percent;
elastic modulus, 14×10^6 psi; hardness,
Rockwell "B" 78.

The recommended top rake of cutting tools for machining this type of brass is zero or negative rake, which simplified grinding the compound angle cutting tools.

Approximately thirty specimens were machined at random with respect to root diameter, both over and under the nominal root diameter of .3125 inches. An eighty degree tool-bit was used with a width of .0625 inches and a nose radius of .005 inches. The root diameters ranged from .3047 to .3181 inches and the resultant energy and torque measurements are shown in Figure 6.

Although the scattering of data was rather large, a definite trend was indicated. As the root diameter increased over a small range, the corresponding energy and torque increased, but apparently not in a straight-line manner. The scattering of values was lessened in later experiments by stiffening the cutting tool to reduce chatter and improving the actual test conditions. The imposed tolerance of $\pm .001$

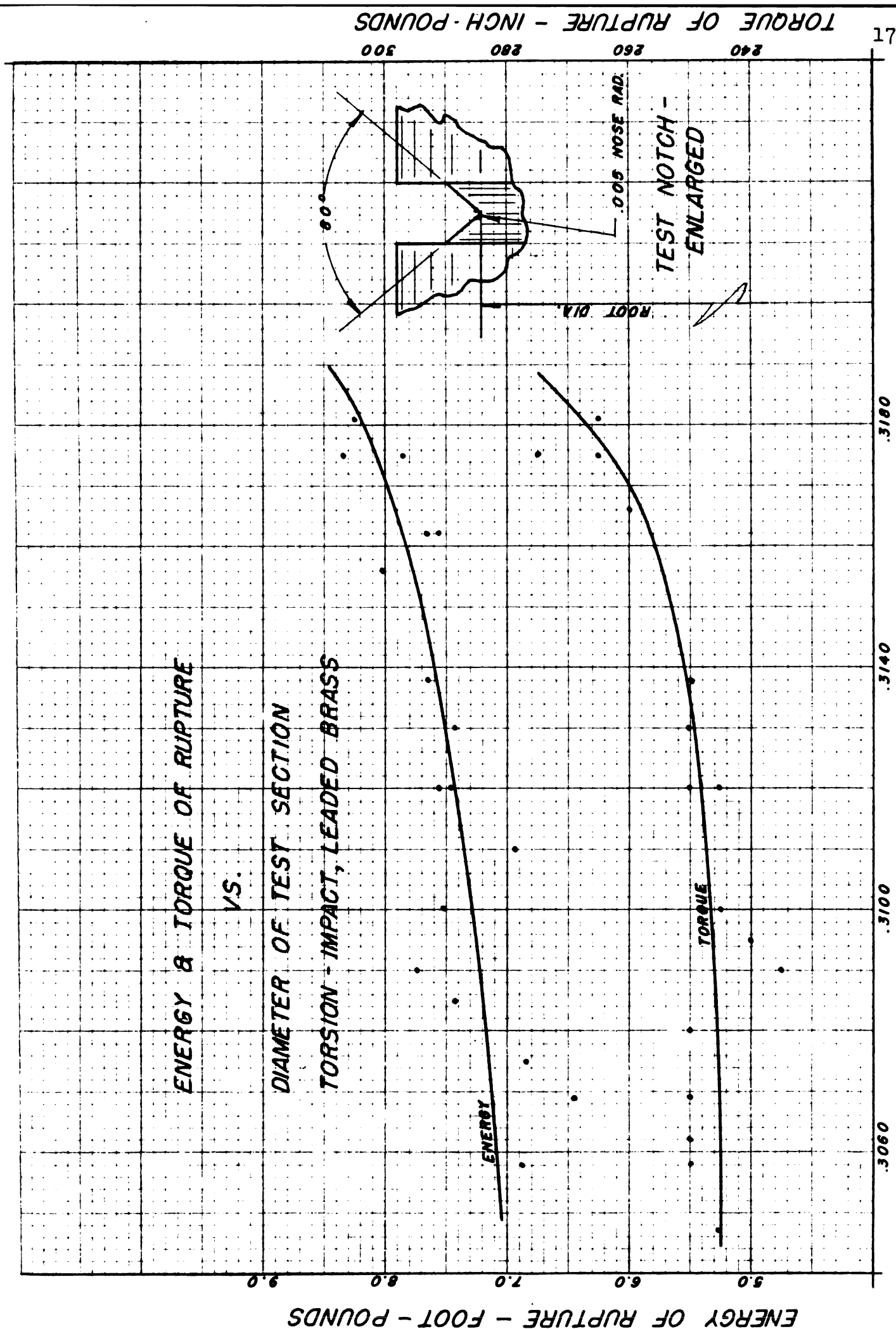
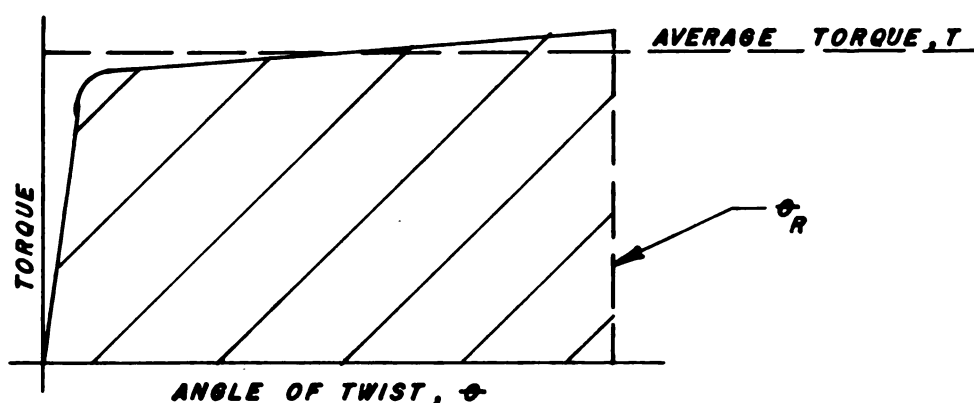


Fig. 6 ROOT DIAMETER OF TEST SECTION - INCHES

inch on the root diameter appeared to have a negligible effect on energy and torque, based on the results of the test run.

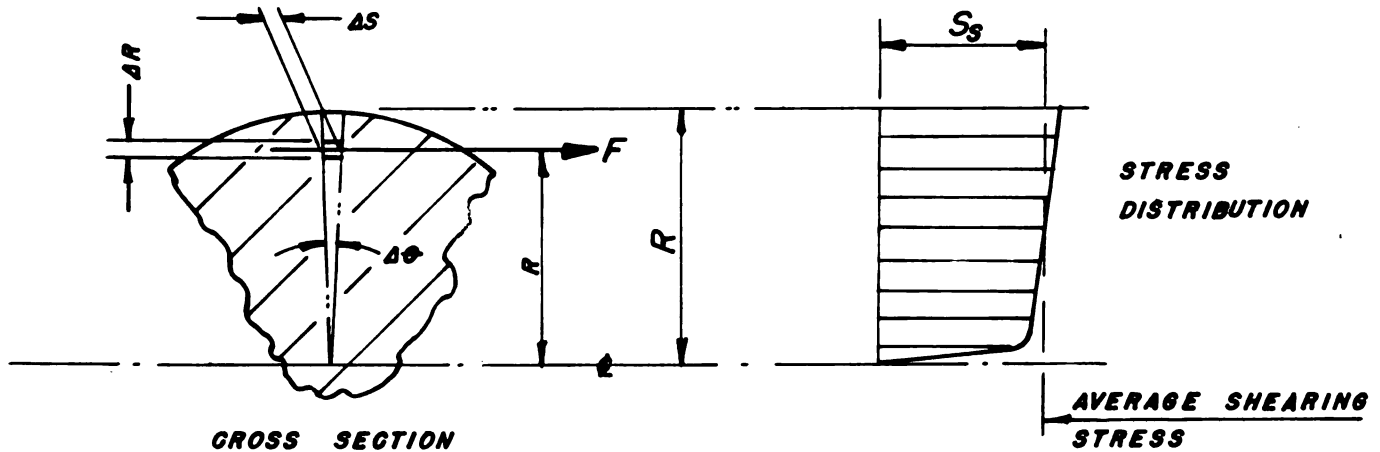
The results of the test shown in Figure 6 posed the question of how the energy of rupture in torsion-impact would vary with the root diameter of the test section. The effect of impact on such a determination is one which cannot be easily predicted, thus restricting the logic to a static condition. A ductile material, such as leaded brass, would exhibit a torque-twist curve that could be idealized as follows:



an exact expression for the energy of rupture would be the area enclosed under the torque-twist curve, but could be approximated by

$$\text{energy, } E = T\phi_R. \quad \dots\dots\dots(1)$$

Assuming an elemental area in the sectional view of the notch root, and a stress distribution across the radius as shown below, an equation may be written for the average torque on the section of diameter "d".



For static torsion, the shearing force on the elemental area is shearing stress times area, and the torque exerted is the force times the "lever arm".

$$\text{i.e.,} \quad F = AS_s \text{ and } T = Fr$$

$$\text{where} \quad F = \text{shearing force}$$

$$A = \text{area in shear}$$

$$\text{and} \quad S_s = \text{shearing stress.}$$

$$\text{Thus,} \quad dT = (S_s dA) (r).$$

$$\text{Since,} \quad ds = r d\theta,$$

$$dA = r dr d\theta$$

and

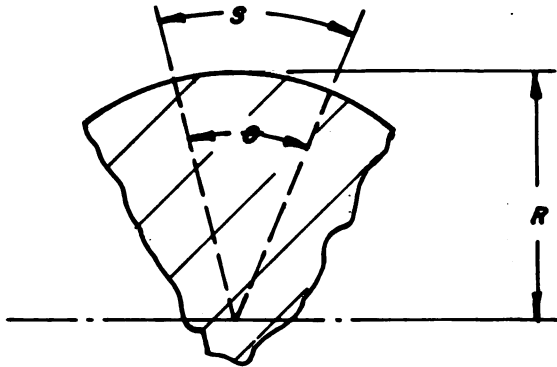
$$T = \int_0^{2\pi} \int_0^R S_s r^2 dr d\theta.$$

Performing the integration and substituting $d/2$ for R

$$\text{yields} \quad T = \frac{\pi S_s d^3}{12} \quad \dots\dots\dots(2)$$

It now remains to obtain an expression for angle of twist in terms of test diameter. For a rather ductile material, failure should occur after a certain critical

angular deformation has taken place, as opposed to a critical torque since the torque increases only slightly after the elastic limit of the material is reached.



$$s = \theta R = \text{a constant, } k$$

or $\theta = \frac{2k}{d} \dots\dots\dots(3)$

If s is the arc length to failure, the product of θR may be a constant for a ductile material. The results of the following experiments were rather inconclusive on this point, but indicate that such an equivalence may be possible. Further instrumentation is needed to clarify the situation. Substituting equations (3) and (2) in equation (1) and simplifying yields,

$$E = C d^2 \dots\dots\dots(4)$$

where $C = \frac{\pi S_s k}{6}$

To substantiate the diameter-energy variation, an expression was written

$$E = C d^n.$$

Taking the logarithm of both sides of the equation,

$$\log E = \log C + n \log d.$$

This expression corresponds to the general equation of a straight line where n is the slope and $\log C$ is the energy

intercept. A test run was then devised for two relatively ductile materials using a full radius notch and a range of root diameters from .200 to .320 inches as the independent variable. The first material investigated was leaded brass, previously described, and the second was 17S-T4 aluminum with physical properties as follows:

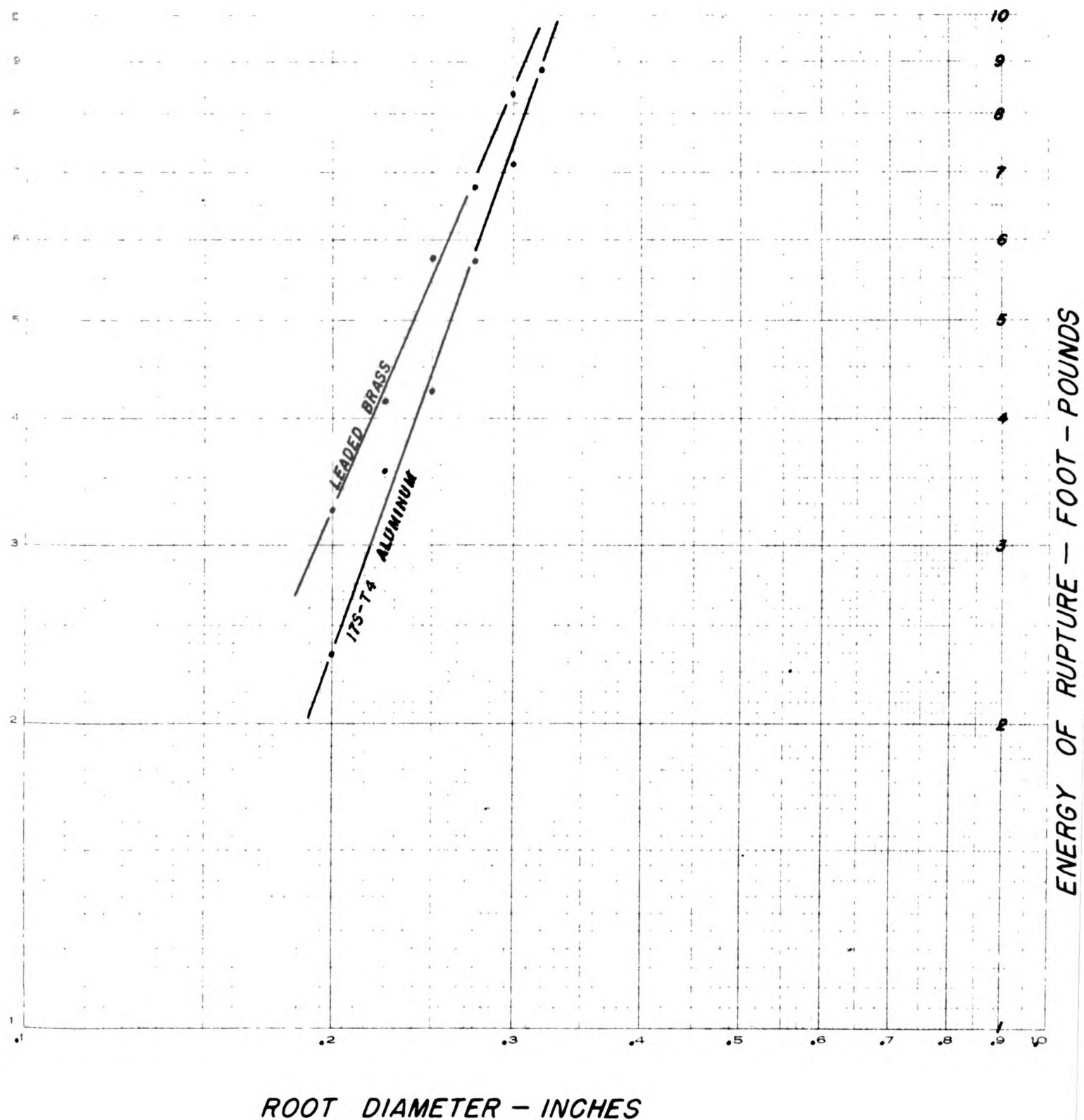
chemical composition - copper, 4.0 percent;
manganese, 0.5 percent; magnesium, 0.5 percent;
aluminum, remainder.

mechanical properties - tensile strength,
55,000 psi; percent elongation, 16 percent;
elastic modulus, 10.5×10^6 psi; hardness,
Rockwell "B" 68.

The results of this test run were as shown in Figure 7. The slope of the log-log plot was approximately two and one-half for the brass and two and three-fourths for the 17S-T4 aluminum. This constitutes a rather large divergence from the previously calculated slope of two and indicates that energy-diameter variations are not quite as simple as reasoned.

There are several contributing factors. The equation as derived was based on a two-dimensional system, where actually a three-dimensional system is more suitable since the stress at the extreme root of the notch differs from the stress in a section immediately adjacent due to discontinuities imposed by the notch. Rupture probably begins at the surface of the test section and proceeds rapidly

ENERGY OF RUPTURE VS. ROOT DIAMETER
FOR TWO DUCTILE MATERIALS.
TORSION-IMPACT, FULL RADIUS NOTCH.



ROOT DIAMETER - INCHES

Fig. 7

inward. Since the diameter of the root is a variable in this experiment the surface speed, and hence, rupture speed is also varying. William H. Hoppmann⁶ presented data for hard copper in tension-impact showing a sizeable variation of rupture energy and elongation with impact velocity. The results of this work tended to substantiate the theoretical calculation of a "critical velocity" as derived by Theodore von Karman²³. At impact velocities greater and less than the critical, there was a pronounced drop in energy absorption from impact. If the logic based on tension-impact is extrapolated to torsion, where a fifty percent change in surface speed is encountered through the range of root diameters investigated, approximately twenty percent of variation in rupture energy could be accounted for. The elimination of this variable would be possible if an adjusted initial test speed of the flywheel were used. Another source of variation in data is the effect of changing geometric stress concentration imposed by the range of root diameters. Stress concentration factors for static and fatigue torsion are available.^{8, 13} The stress concentration factor may be defined as the ratio of actual stress in a section to the nominal stress as calculated by simple theory. If this variable is accepted as applying to impact-torsion, a decrease in root diameter would be accompanied by an increase in stress concentration, and hence, a decrease in energy of rupture. Taken literally, the energies obtained at the lower root diameters would be lower than nominal with

a resulting increase in slope of the log-log plot. A factor of indeterminable magnitude is impact. M. Ithihara¹⁸ reported dynamic torques and twist angles considerably higher than static values, and in general, the maximum torque increased as the velocity of deformation increased for materials investigated in torsion-impact.

An attempt was made at this point to evaluate the shearing stress as it appears in equation (4). Assuming a point on the log-log plot for brass, the angle of twist was approximated from equation (1). The subsequent calculation of stress yielded a value of 42,000 psi. The shearing strength of this material in static torsion is about 30,000 psi showing a forty percent increase. If the slope of the plot was two, as calculated, the experimental value for stress in impact would more closely approach the static value.

A more sensitive instrumentation of torque values would perhaps shed some light on the variation of twist with root diameter. The product $\frac{\theta d}{2}$ was assumed to be constant. If the variation was exponential, i.e., $\theta (d/2)^n = \text{a constant}$, careful determinations of twist and diameter should yield a more exact expression with the use of a log-log plot and augmenting equation (4) to fit the results.

B. Variation of Energy Of Rupture With
Notch Angle For Two Ductile Materials

If the torsion-impact machine is to be accepted as a materials testing machine, some effort should be made to standardize a notch and determine the general sensitivity that could be expected for a range of notches. In the initial tests, it became evident that size would impose definite limitations on a notch variable, since the notch is only .0625 inches wide. For this reason, the notch angle was chosen as an independent variable in the subsequent tests, with notch width, nose radius, and root diameter remaining constant. The full radius notch was well established as a control, due to its rather high energy absorption level in the materials investigated and low effect of tool wear.

A range of notches from 60° to 160° was investigated for two ductile materials, as shown in Figure 8. The tool bits were ground and honed in 20° increments and carefully checked on the comparator for size and shape. Of the two materials, the brass has been previously described and the properties of the 24S-T4 aluminum were taken as follows:

chemical composition - copper, 4.5 percent;

manganese, 0.6 percent; magnesium, 1.5 percent;

aluminum, remainder.

physical properties - tensile strength, 65,000 psi;

percent elongation, 10 percent; elastic modulus,

10.5×10^6 psi; hardness, Rockwell "B" 75.

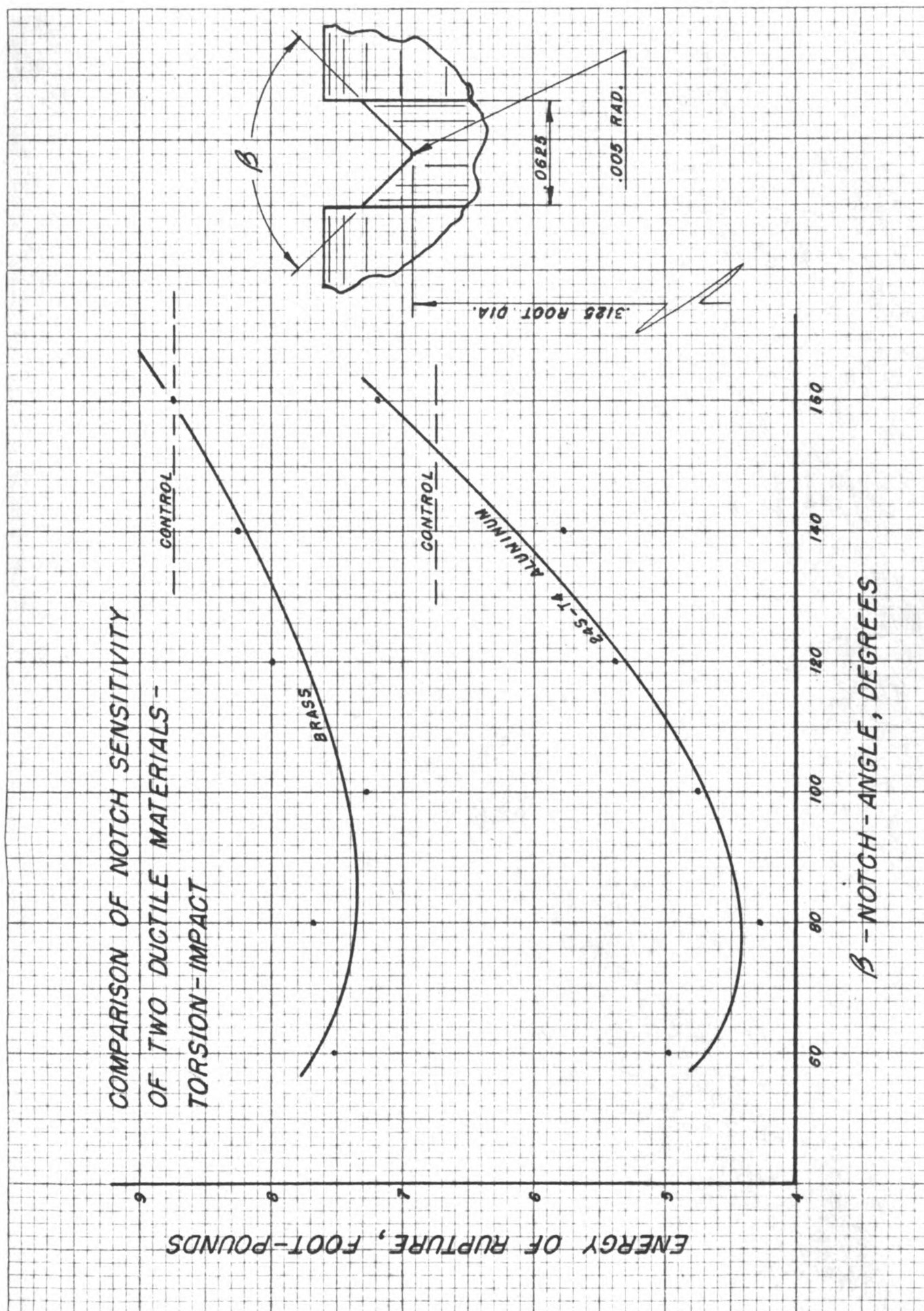


Fig. 8

Eight specimens were prepared for each of the six points in Figure 8, or 48 specimens per material. In addition to the notches shown, a square notch with .005 inch corner radii was also investigated for both brass and 24S-T4 aluminum and gave energies of rupture of 14.39 and 8.78 foot-pounds respectively. This represents a substantial increase in energy absorption over the vee-notches tested, but is logical since there was a definite test length. The length of material in torsion affects the final angle of twist and hence the area under the torque-twist curve or energy of rupture.

In general, as the notch angle increased, the energy of rupture increased, although apparently not in linear fashion. The curve for the two ductile materials investigated seemed to have a characteristic shape with a minimum energy level at a notch angle of approximately 90° . The curve for aluminum is shifted slightly to the left with respect to the brass. To eliminate tool chatter in machining, it was necessary to grind a top rake of 12° on the tools cutting aluminum. Effectively, this compounded the notch angle on the tool-bit, and increased the actual notch angle in the specimen by a few degrees. Thus, the points obtained are nominal and to be truly accurate should be moved slightly to the right.

The energy absorption level for the leaded brass was shown to be higher than the 24S-T4 aluminum. Although the

aluminum has a 12 percent higher tensile strength, the brass is 150 percent more ductile, as indicated by the percent elongation. The aluminum appeared to be more sensitive to a change in notch angle by virtue of the larger range of energy values encountered. This notion is fairly well established metallurgically, that is, higher strength materials are more notch-sensitive than lower strength, more ductile materials.

The full radius notch, used to establish a control level, had energy values comparable to the 160° notch in both cases. It would be possible to calculate stress-concentration factors based on this control notch for the range investigated. An analogy could then be made to static torsion energies of rupture if a testing machine could be built with extremely low torque ranges, say 40 to 50 foot-pounds, with very accurate determinations of angle of twist. Thus a specimen of the same size and shape as impact could be ruptured slowly and energies calculated. The net effect would be an evaluation of the factor of impact in torsion, and the relation of changing notch angles to a control notch.

C. Variation of Energy of Rupture With Notch Angle For Two Irons

It was of interest at this point to investigate the variation of energy absorption in torsion-impact of two

brittle materials. Two samples of iron were available of almost identical chemical composition, but different physical characteristics by virtue of their graphite distributions. The first or "normal" iron had carbon and silicon contents of 2.87 percent and 2.26 percent respectively and had been inoculated in the ladle with calcium-silicon to assure proper graphite distribution. Normal graphite distribution in gray iron is a random, unoriented, distribution of graphite whorls in a matrix of pearlite. The second or "abnormal" iron had 2.89 percent carbon and 2.26 percent silicon, and showed a patterned, dendritic, graphite distribution with resulting planes of weakness.

Both samples of iron were cast into round bars, 1.2 inches in diameter and 20 inches long, suitable for a transverse bending test. The bars were mounted as simple beams in a testing machine and center-loaded over an 18 inch span to failure. Rupture occurred in the normal iron under a load of 3010 pounds and a maximum center deflection of 0.408 inches. The abnormal iron failed under a load of 2250 pounds with a maximum center deflection of 0.185 inches. These results illustrate the generally inferior physical properties of the abnormal irons.

Bending stresses have a similarity to torsional stresses in that both are proportional to the distance from a neutral axis; thus the maximum stress occurs at the outer fiber under both types of loads. A series of tests was devised to demonstrate the difference in strength-deflection

characteristics of the two irons in torsion-impact and investigate the variation of rupture energy with notch angle. Five specimens were machined for each condition and gave results as shown in Figure 9. Again, as the notch angle increased, the energy of rupture also increased in both irons, although not over such a large range as was encountered in the more ductile materials investigated. The normal iron was superior in energy absorption for all the notches tested and tended to give more uniform results. The erratic behavior of the abnormal iron might be attributed to the random orientation of the planes of weakness, induced by the graphite formation, with the twisting axis of torsion. Thus, failure could occur in a random manner across the test section and give varying results, not necessarily representative. A check of the test section after failure showed an irregular fracture for the abnormal iron. All the other materials investigated, including the normal iron, showed a straight, rather clean, fracture across the base of the root diameter.

IV. DISCUSSION AND CONCLUSIONS

The DeKoning torsion-impact machine represents a new unique instrument in the field of materials testing. The initial quantitative investigations with this machine as presented in this study are designed primarily to expedite specimen production, testing, and standardization,

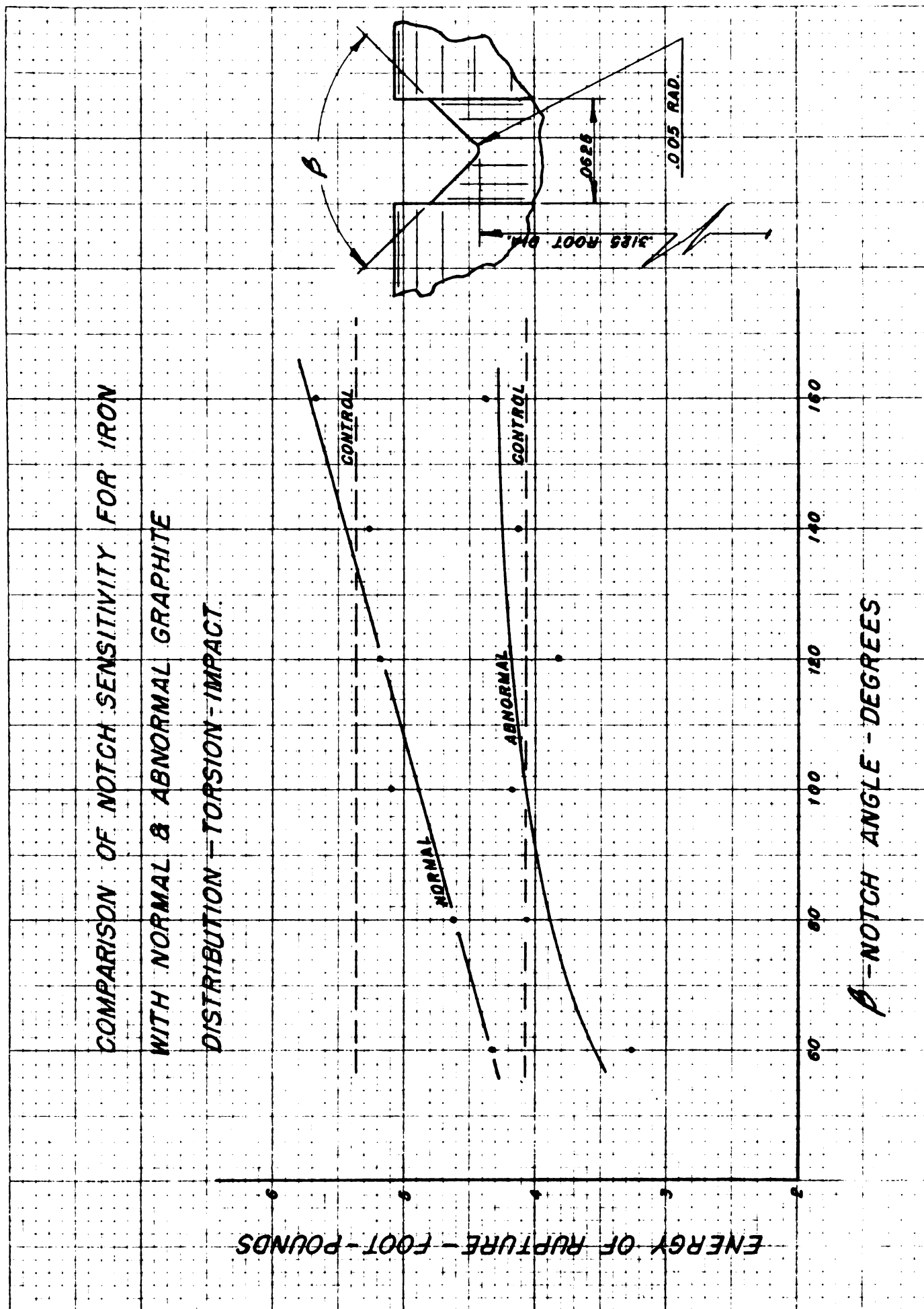


Fig. 9

and indicate the path of further experimentation in torsion-impact.

The machine-tool setup that was designed and built specifically for the mass production of test specimens, has successfully turned out hundreds of accurate pieces. The optical comparator proved to be a valuable device for maintaining proper dimensional limits on cutting tools and specimens. Both instruments are stored and available for future work in torsion-impact.

The testing technique is vitally important for consistent quantitative results. A system for analyzing the data obtained on an oscillograph tape was devised and the suitable energy curve drawn. General accuracy of one hundredth of a foot-pound of energy and five inch-pounds of torque was maintained in the experiments run.

An equation was derived relating the variation of rupture energy with diameter of test section and investigated for two rather ductile materials. The energy of rupture in torsion-impact varied to the 2.5 power of the diameter for a typical leaded brass and to the 2.75 power of the diameter for a 17S-T₄ aluminum. The possible effects of variable stress concentration and rupture speed along with the factors of impact and three dimensional stress were offered as explanations for the lack of complete agreement between calculated and experimental results. Nevertheless, the order of magnitude was indicated, and perhaps most important, the diameter of test section was shown to vary exponentially

with rupture energy since the log-log plot was linear for the two materials tested. Further more delicate instrumentation is indicated for this study to ultimately yield an expression relating the exact variation of energy and diameter calculations of members subjected to impact-torsion.

A study of the notch sensitivity of four materials in torsion-impact was devised and run with the following results:

1. Energy of rupture increased with an increase in notch angle for all materials investigated
2. A leaded brass showed a higher level of energy absorption than a stronger, less ductile, aluminum
3. An iron with normal graphite distribution showed a higher level of energy absorption than an abnormal iron of the same composition
4. A 24S-T4 aluminum showed more notch sensitivity, or spread of energy absorption, than any of the materials tested
5. The two irons tested showed less notch sensitivity than either of the two more ductile materials
6. Generally, the abnormal iron gave more erratic results, attributed to a patterned graphite distribution
7. All specimens tested ruptured at the base of the root with the exception of the abnormal iron which failed randomly across the notch
8. A critical notch angle was indicated for the two ductile materials investigated at approximately 90°

9. The full radius notch was established as a control and is recommended as a standard notch for future investigations.

An interesting future study with the DeKoning machine would be a plot of the variation of rupture energy with tempering temperature of alloy steels. Luerssen and Greenell detected an optimum tempering temperature for steel with a definite test length. Perhaps the additional factor of notch sensitivity would yield valuable information for notched steels in torsion-impact. A higher energy of rupture is required and thus a more massive flywheel with the resulting recalibration of the machine. Other problems of heat-treatment and notch production would also be encountered.

The DeKoning Machine with its related instruments and specimen production machine and tools are available for future research on a material's behavior in notched, torsion-impact.

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