JOURNAL OF APPLIED POLYMER SCIENCE VOL. 19, 2717-2730 (1975)

Autographic Impact Testing with Increased Efficiency and Accuracy

H. GONZALEZ, *Research Laboratories, Tennessee Eastman Company, Division of Eastman Kodak Company, Kingsport, Tennessee 37662*

Synopsis

The objective of this work was to test modifications of an autographic impact device which would make autographic impact testing more suitable for routine work. Autographic impact devices allow the force transmitted to a specimen during impact to be recorded and displayed; thus, a detailed analysis of the impact process is possible. In addition to the measurement of the breaking energy, information on the load at which yielding begins and how the impact energy is absorbed by the specimen during impact can be obtained. Through the use of autographic impact devices, the impact resistance of plastics during an impact test has been shown to be composed of three basic areas of contribution: (1) an elastic deformation stage, (2) a plastic deformation stage, and (3) a tearing stage. The autographic method is not practical for routine evaluations because of the excessive time and effort necessary to set up, calibrate, and interpret each test. The following modifications of the autographic device were made to improve the efficiency of the method: (1) improved triggering technique, (2) improved calibration procedure, (3) elimination of the preloading force, and (4) a computer program to analyze the data much more efficiently. It is expected that these modifications will allow autographic tests to be performed efficiently.

INTRODUCTION

The strength, ductility, and toughness of plastics are modified when impact loads are used instead of static loads. In particular, toughness may be greatly changed under suddenly applied impact loads, and various machines and methods have been developed for testing materials under impact loading. Two of the most widely used tests are the Izod impact test (ASTM-D256) and the tensile impact test (ASTM-D1822).[1] The values reported from these tests are useful in the comparison of various types or grades of a plastic. However, when one plastic is being compared with another, values from these tests are not reliable indicators of overall toughness or impact strength and cannot be closely related to the performance of end products.

The difficulty in the correlation of values for different plastics is due to the fact that the energy required to break a standard test piece is actually the sum of several energies: (1) the energy to initiate fracture of the specimen, (2) the energy to propagate the fracture across the specimen, and (3) the energy to throw the free end of the broken specimen. After a fracture has been initiated in a product, it can be said for all practical purposes that the product has failed; therefore, for end use design the energy in (1) is the most critical. If energy (1) were measurable, a correlation between a material's performance and the end use performance might be possible.

The U.S. Rubber Company autographic impact tester provides a quantitative method for evaluating the impact behavior of materials. In addition to the measurement of the breaking energy, information on the load at which yielding begins and how the impact energy is absorbed by the specimen during impact can be obtained. Preliminary tests[2] indicated that fairly good results could be obtained using the tester. It was concluded, however, that the method was not practical for routine evaluations because of the excessive time and effort necessary to set up, calibrate, and interpret each test.

The objective of this work was to test modifications of the autographic impact tester which would make the tester more suitable for routine testing.

OPERATION OF AUTOGRAPHIC IMPACT TESTER

Basic Operation

The autographic impact tester consists of a standard impact tester (Impact Tester Model 43-1, Testing Machines, Inc.) modified to accommodate a strain gauge transducer (1) in the anvil for Izod impact tests and (2) in the hammer for tensile impact tests, a strain gauge amplifier, a storage oscilloscope, a camera to record the oscilloscope trace during impact, and a triggering mechanism. The force on the specimen is transmitted to the strain gauge transducer, and an electrical unbalance in the transducer is produced. This signal is amplified and displayed on the oscilloscope.

To run tests using this equipment, the following steps are necessary:

1. Install specially modified anvil for Izod impact tests or specially modified hammer for tensile impact tests.
2. Adjust the trigger to ensure that triggering of the sweep of the trace will be timed to the impact.
3. Calibrate transducer, including zeroing and balancing, by the use of dummy steel specimens. A calibrated force gauge is used to apply known forces to each specimen, and the response of the transducer, as shown by movements of the oscilloscope trace, is recorded.
4. Apply a fixed preload or clamping force on the specimen.
5. Integrate the force–time curves and convert the impulse as calculated to more commonly used impact strength.

Theory for Converting Impulse to Energy Values

The conversion of impulse to energy values has been developed by Arends[3] and takes the form

$$E_b = Av_0\left(1 - \frac{v_0 A}{4E_{\max}}\right) \tag{1}$$

where E_b is the energy absorbed by the specimen, v_0 is the speed of the hammer immediately before impact, A is the impulse calculated from the area underneath the force–time curve, and $E_{\max}$ is the maximum energy available from the hammer.

For the testing machine used in this work, v_0 = 11.349 ft/sec. For a 2 ft-lb maximum energy hammer, eq. (1) becomes

$$E_b = 11.349A(1 - 1.419A). \quad (2)$$

For a 10 ft-lb maximum energy hammer, eq. (1) becomes

$$E_b = 11.349A(1 - 0.284A). \quad (3)$$

In both eqs. (2) and (3), A is the impulse calculated from the area underneath the force–time curve of the oscilloscope trace in pound-seconds.

MODIFICATIONS TO IMPROVE EASE OF OPERATION

Triggering

The sweep of the oscilloscope trace is normally triggered by the mechanical contact of the hammer against a trigger. The point of contact has to be continually checked and readjusted so that the trace will trigger immediately before contact of the hammer with the specimen is made. This manner of triggering is very tedious. The oscilloscope used in the autographic tester had the capability of internal triggering. Therefore, the following modified triggering technique was used: The sweep of the oscilloscope trace is initiated through the internal excitation from the input signal (e.g., the trace will sweep whenever a preset force is exceeded, and the preset force is usually set just above the "noise" level).

Calibration of Strain Gauge Transducer

The normal calibration procedure for the Izod strain gauge transducer is as follows: (1) electrically balance transducer under "no load" conditions; (2) insert dummy specimen and apply 50 lb of load by use of a force gauge and a line attached to the dummy specimen at the point of hammer impact; (3) apply 50 lb of preload on dummy specimen and electrically balance the transducer; (4) apply increments of load on dummy specimen and observe deflection of trace.

This procedure is very time consuming and tedious and must be followed whenever the transducer calibration is to be checked. However, a new method of calibration was developed. A new signal conditioner (Series "400" Signal Conditioner, Testing Machines, Inc.) is being used, and calibration is now done by the unbalancing of the transducer output by a known resistor, which corresponds to some preset load. This new procedure requires that the load corresponding to the resistor be determined only one time. The corresponding load is determined in the following manner:

1. Balance the transducer by depressing a zero button of the signal conditioner.
2. Insert the resistor by depressing a calibrate button of the signal conditioner.
3. Adjust the gain so that the deflection of the trace is at some convenient division mark on the CRT chart (e.g., 4, 5, or 6);
4. Remove the resistor by retouching the calibrate button;

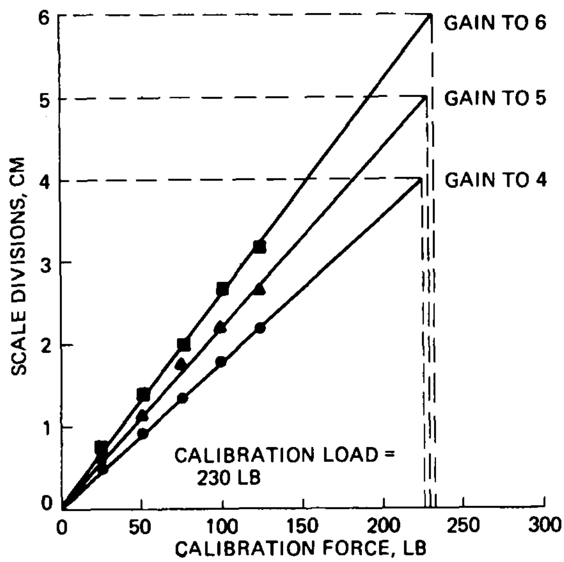


Fig. 1. Calibration of low-range Izod impact transducer.

5. Apply loads to the dummy specimen and observe the corresponding deflection;

6. Plot the load–deflection curve and extrapolate to the preset gain adjustment. This extrapolation corresponds to the load to which the resistor corresponds.

7. Repeat steps 1–6 for different gain settings to get an average of the calibration load. Figures 1–3 show the calibration of the transducers used in this work.

Once the calibration force has been determined, the gain may be easily adjusted to give some convenient force scale on the CRT chart.

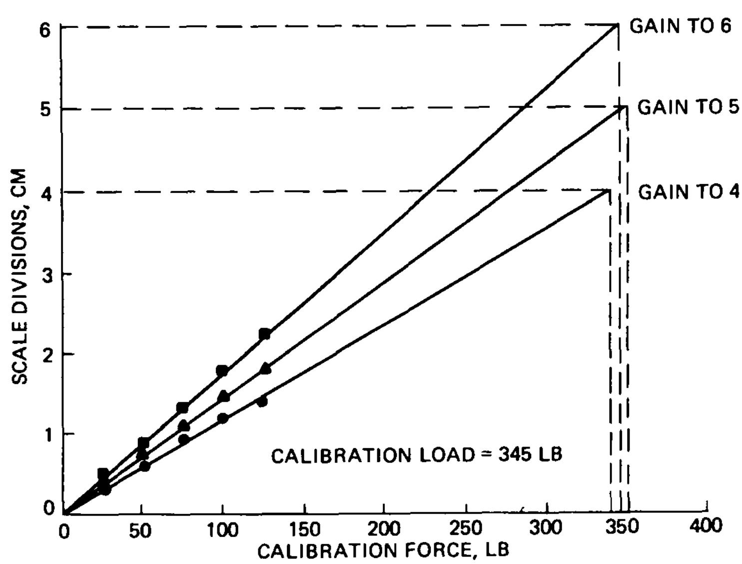


Fig. 2. Calibration of high-range Izod impact transducer.

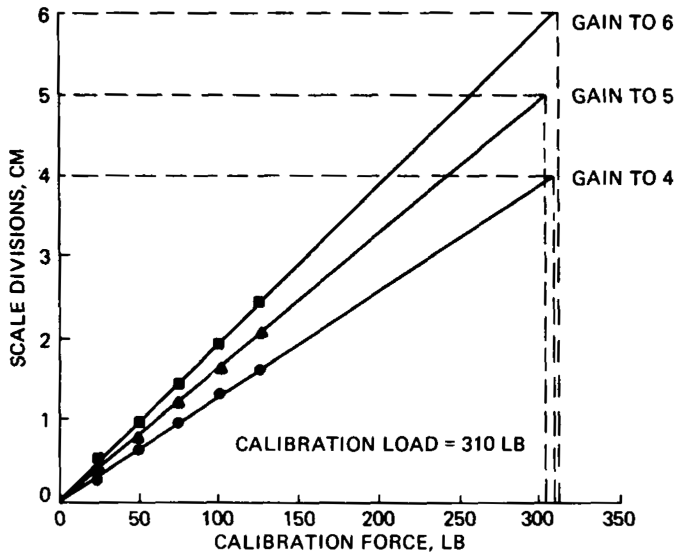


Fig. 3. Calibration of tensile impact transducer.

Preload Force

The operating instructions supplied with the autographic impact tester suggest that a preload force be applied to the specimen–transducer system. After the tester had been used a while, it was discovered that the suggested procedure can lead to great distortions of the load–time trace. If a preload is applied to the system, the distortion may occur because the reactive force on the transducer will have to almost exceed the preload before any force is detected. This distortion is due to the mechanics of deformation, and can be further illustrated in Figures 4 and 5. Figure 4 shows the effect of a known

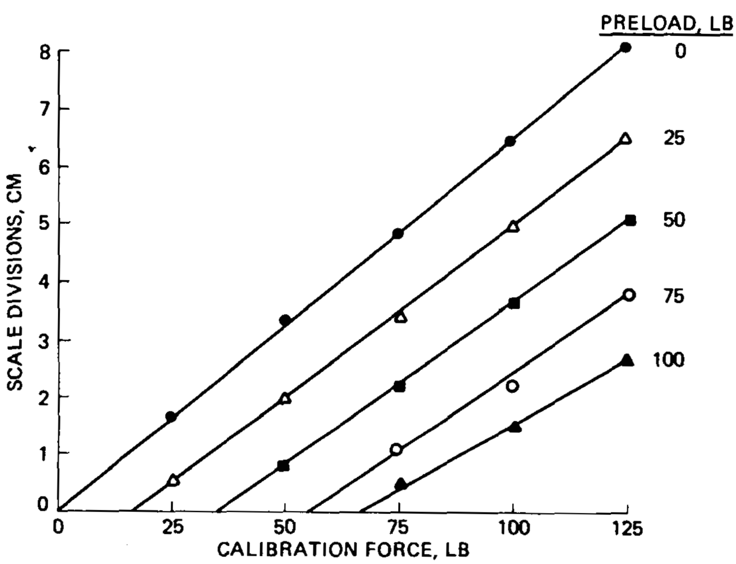


Fig. 4. Effect of preload force on calibration scale.

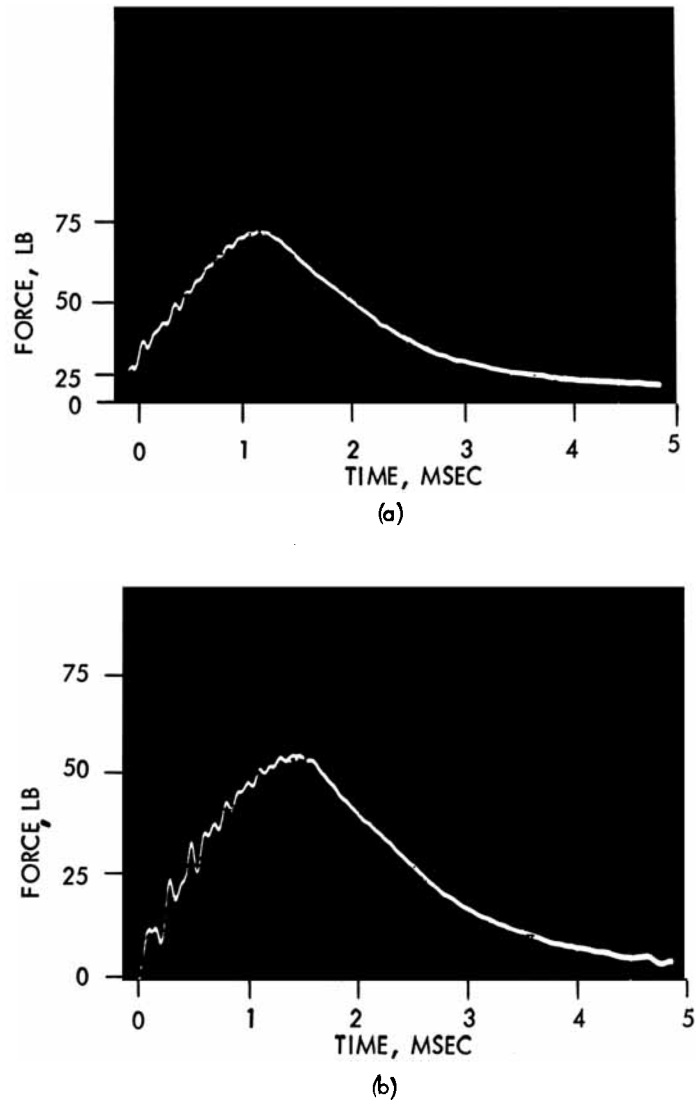


Fig. 5. Autographic Izod impact, Lexan 141 polycarbonate: (a) 25-lb preload; (b) 0-lb preload.

force applied to the dummy specimen under various preloading forces. At 0-lb preload, a linear plot of scale divisions versus calibrating force is obtained, and the plot passes through the origin. At any other preload (e.g., 25, 50, 75, or 100 lb), the plots are again linear and have essentially the same slope as the 0-lb preload plot. They do not, however, pass through the origin. The effects of this distortion are shown in Figure 5. Figure 5a shows that a linear scale of force occurs only above the preload force; Figure 5b shows that a linear scale of force occurs along the entire force axis. Thus, the curve of Figure 5a appears to be much more compressed than the curve of Figure 5b, when in actuality the curves should be the same. This difference means that a calculation of the area under the curve of Figure 5a would be very difficult because of the nonuniform force scale. The difference in impact perfor-

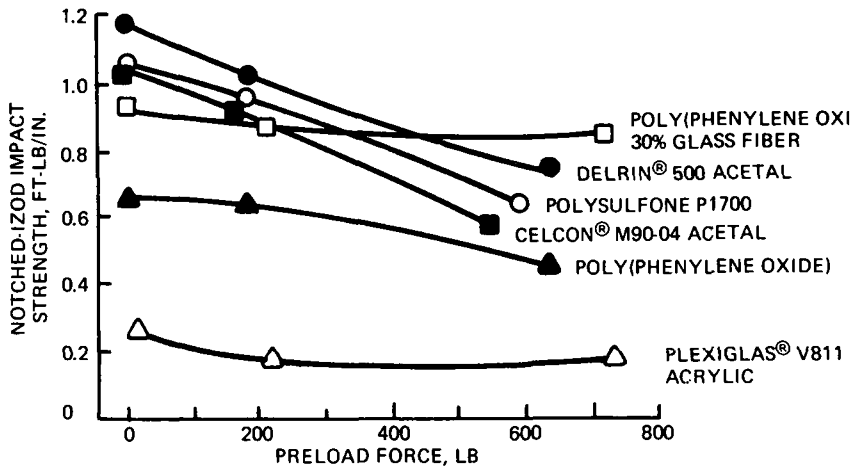


Fig. 6. Preloading effect on Izod impact strength.

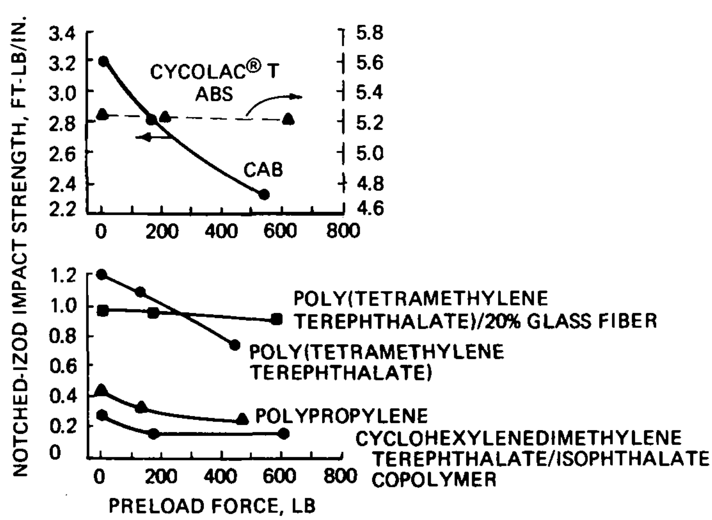


Fig. 7. Preloading effect on Izod impact strength.

mance[4] between a 0- and a 25-lb preload was judged to be insignificant for most materials (see Figs. 6 and 7). Since the difference between a 0- and a 50-lb preload (the amount suggested in the procedure) was also judged to be insignificant (Figs. 6 and 7) and since the curves with a 0-lb preload have no distortion, it was decided that the preload would be eliminated in routine tests.

Integration of Force–Time Curve

The most time-consuming aspect of autographic impact testing is the integration of the force–time curve. The ideal way to accomplish this integration would be to connect the output of the transducer directly to a computer which would accept the electrical output of the transducer in real time and then compute the desired property data. However, this method is not possi-

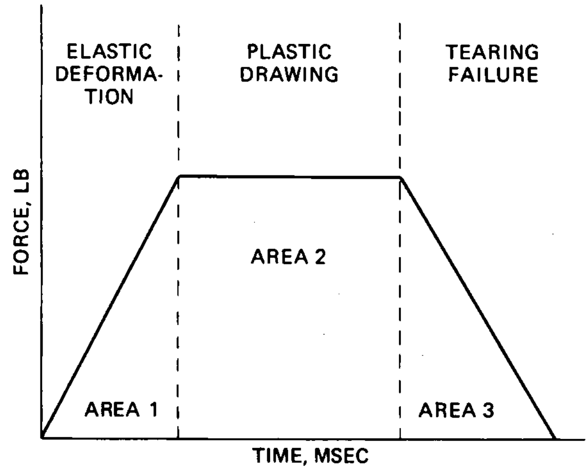
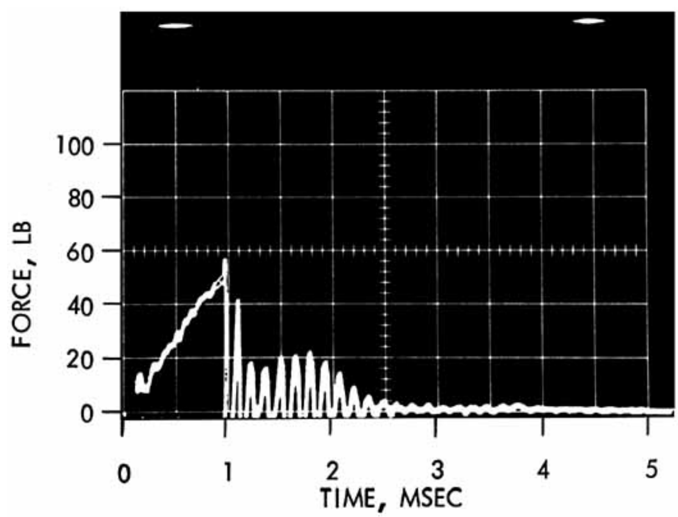


Fig. 8. Typical force-time curve.

ble at present. Another approach would be to compute the area under the curve with a planimeter, but this is again very time consuming; therefore, the following method was used.

The output from an autographic impact test may usually be represented by the trace shown in Figure 8. Area 1 is usually a triangular area and corresponds to elastic deformation where the sample deforms uniformly under the impacting blow until a peak force is reached right before yielding begins. Area 2 is usually rectangular and corresponds to plastic drawing at constant



Energy section	Energy calcd.	% of Total energy calcd.	Geometric shape of energy section
Elastic	2.3	100	triangular
Plastic	0.0	0	
Tearing	0.0	0	

Fig. 9. Autographic notched-Izod impact test, 10 mil; cellulose acetate butyrate. Energy from impact scale, 2.3 ft-lb/in., complete break; total energy calcd., 2.3 ft-lb/in.; per cent difference, 0.

force yielding. Area 3 is usually triangular and corresponds to tearing after yielding but no plastic drawing. All samples will have area 1, but not all samples will have areas 2 and 3. Some samples will have (1) only area 1, (2) areas 1 and 2 but not area 3, (3) areas 1 and 3 but not area 2, or (4) areas 1, 2, and 3.

A computer program was written for an IBM Model 1130 computer which allows the areas under the force–time curves to be analyzed. A typical result from the use of this program is shown in Figure 9. The computer program provides for the following: (1) specification of type of test, e.g., notched-Izod, reversed notched-Izod, unnotched-Izod, and tensile impact; (2) specification of hammer used, e.g., 2 ft-lb or 10 ft-lb; (3) calculation of normal impact energy from scale reading; (4) calculation of impact energy in each of the three areas from the force–time curve; (5) calculation of the total impact energy from the force–time curve; (6) calculation of the division of the total impact energy into each of the three areas; (7) difference between the impact energy as calculated from the force–time curve and the scale reading.

DISCUSSION OF RESULTS

Triggering

Figure 9 shows that only a very small portion of the force–time record is lost when the internal triggering technique is used, and even this loss is not significant since the exact point of specimen contact can be determined by the extrapolation of the initial linear portion of the trace to zero force. This procedure greatly reduces the tedium previously involved in setting up the proper triggering sequence.

Calibration of Transducer

The unmodified calibration procedure for the autographic impact device requires that the calibration equipment be assembled and the calibration procedure be carried out each time the transducers are used. When the same calibration procedure is used, it is impossible to check the calibration of the transducer without reassembling all of the calibration equipment, i.e., force gauge, dummy specimen, and loading train. This process of reassembling is, of course, very inconvenient when tests are in progress. With the new calibration procedure, calibration is now essentially a two-step operation (after the transducers have been initially calibrated, that is): (1) depress the zero button of the signal conditioner and zero the transducer, and (2) depress the calibrate button of the signal conditioner and adjust the gain to some convenient force scale. No assembling and disassembling of calibration equipment is necessary. Also, with the new calibration system, it is only necessary to depress the calibrate button of the signal conditioner to check the calibration while tests are in progress.

Preload Force

Elimination of the requirement for a preload force made it possible to calculate the area under the force-time curve without concern for distortion of scales.

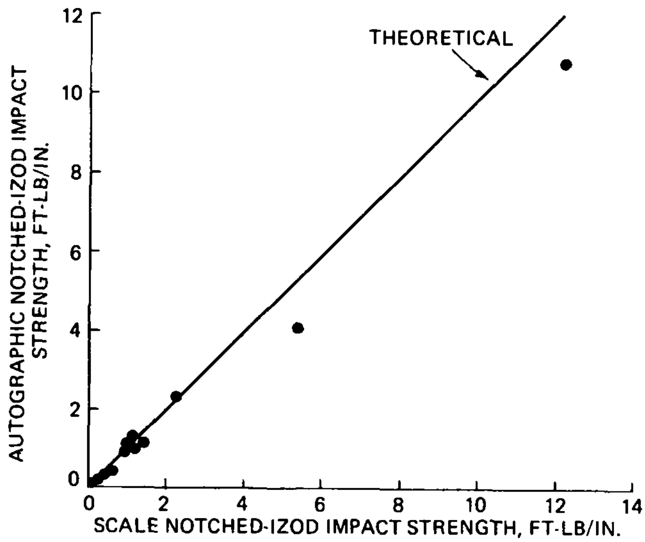


Fig. 10. Comparison of scale and autographic notched-Izod impact strength.

Integration of Force–Time Curve

The new integration technique of area determination previously described (i.e., dividing the area into a triangular section, a rectangular section, and finally another triangular section) allows for a fairly good correlation between energy values determined from the tester scale reading and the energy determined from the impulse calculated from the area under the curve. This correlation is shown in Figures 10–12, where the autographic energy value is plotted versus the scale energy value. In general, agreement between the two values is within 10%, supporting both the theory of conversion of impulse values to energy values and the method of impulse determination.

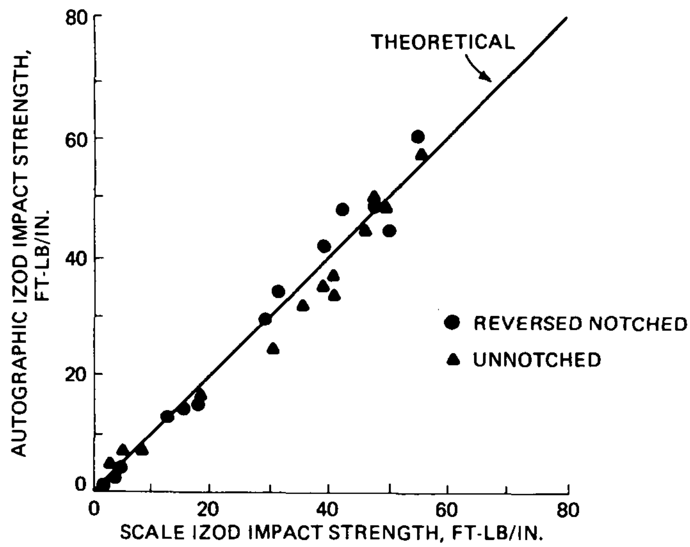


Fig. 11. Comparison of scale and autographic reversed notched-Izod and unnotched-Izod impact strengths.

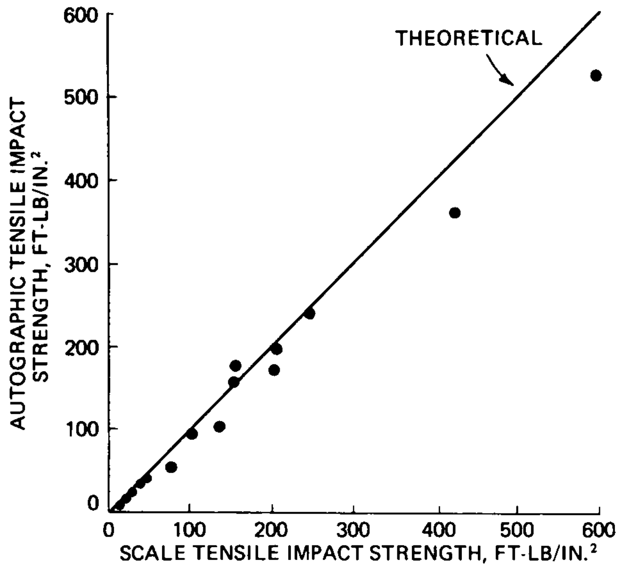


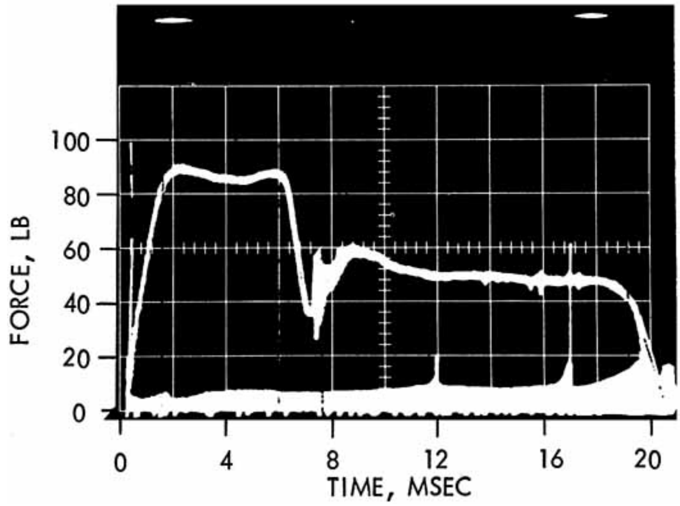
Fig. 12. Comparison of scale and autographic tensile impact strength.

It is no longer necessary to record photographically all the oscilloscope traces of force–time for each test. It is only necessary to store the force–time trace on the CRT chart long enough to pick off the critical points of the trace, transfer them to a data coding form, and process the data using the computer program. This greatly reduces the amount of data reduction.

Unnotched-Izod and Reversed Notched-Izod Discrepancy

All previous autographic impact testing in our laboratories had been done on notched-Izod and tensile impact tests. In this investigation, it was decided to include autographic reversed notched-Izod and unnotched-Izod impact tests. In both reversed notched and unnotched tests, correlations between scale energy values and autographic energy values were very good as long as the specimens were "complete break." However, when a reversed notched or an unnotched sample had a "no break," a very large discrepancy between the scale energy value and the autographic energy value occurred. This may be seen in Figure 13. Because of the uncharacteristic nature of the force–time traces in this figure, the area under each curve was divided into more than the usual three sections.

The characteristic shape of these curves is shown in Figure 14. The characteristic deformation of a "no break" sample is shown in Figure 15. The following is an explanation for the discrepancy between the scale energy value and the autographic energy values: At time t_0, the hammer just strikes the specimen and the deformation process begins. By time t_1, the specimen has deformed elastically and experienced plastic drawing, and it has reached about the maximum in deformation. From time t_1 to t_2, the hammer is sliding along the specimen. As the hammer slides along the specimen, it exerts a force against the specimen and the specimen exerts a reactive force against the hammer. The reactive force on the hammer may be resolved into two components: one aligned radially to the direction of the hammer swing and



Energy section	Energy calcd.	% of Total energy calcd.	Geometric shape of energy section
1	6.2	7	triangular
2	31.8	34	rectangular
3	6.4	7	triangular
4	46.1	49	rectangular
5	3.2	3	triangular

Fig. 13. Autographic unnotched-Izod impact, cellulose acetate butyrate. Energy from impact scale, 45.5 ft-lb/in., no break; total energy calcd., 93.7 ft-lb/in.; per cent difference, −105.

one aligned tangentially to the direction of the hammer swing. It may be concluded that (1) before time t_1, the tangential component of the reactive force on the hammer is much greater than the radial component, and (2) after time t_1, the radial component of the reactive force is much greater than the tangential component. Only force components in the tangential direction appreciably slow the hammer (therefore indicating energy absorbed). Force

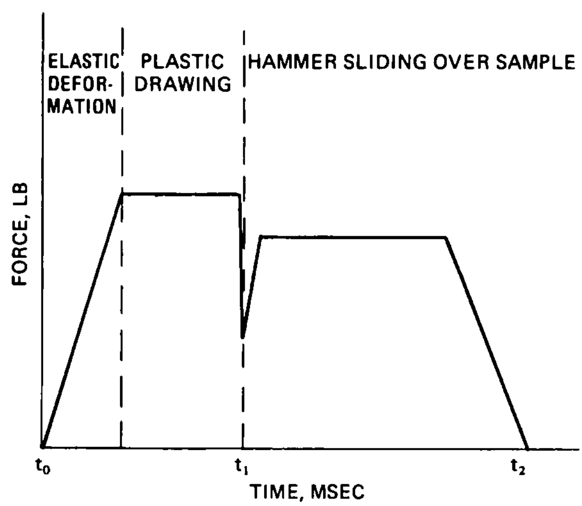


Fig. 14. Typical autographic "no break" reversed notched-Izod or unnotched-Izod sample.

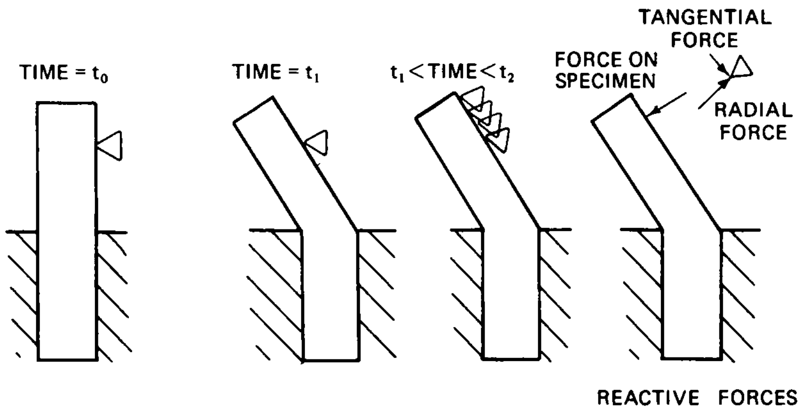
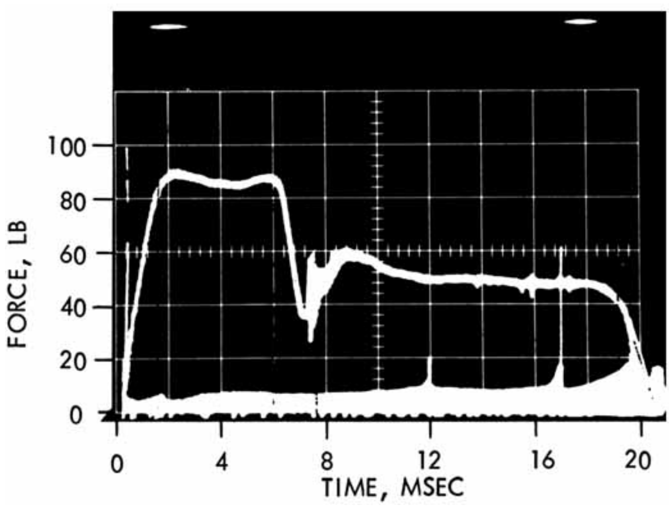


Fig. 15. Deformation of a "no break" sample.

components in the radial direction tend to slow the hammer but to a much smaller extent than tangential components (due mainly to an increase in friction). In this "sliding along" region, a force is sensed by the force transducer, but this force does not necessarily take an appreciable amount of energy away from the hammer. Thus, in the correlation of scale energy with autographic energy, only the autographic energy up to time t_1 should be considered.

The sample shown in Figure 13 was reanalyzed by the new approach, and the result is shown in Figure 16. The use of this new approach in the interpretation of "no break" impacts leads to a much better correlation between scale energy and autographic energy. Generally, it would be expected that this technique would slightly underestimate the scale energy since no energy



Energy section	Energy calcd.	% of Total energy calcd.	Geometric shape of energy section
Elastic	6.2	14	triangular
Plastic	31.8	72	rectangular
Tearing	6.4	14	triangular

Fig. 16. Autographic unnotched-Izod impact, cellulose acetate butyrate. Energy from impact scale, 45.5 ft-lb/in., no break; total energy calcd., 44.4 ft-lb/in.; per cent difference, 2.

values past time t_1 are calculated even though some hammer energy is absorbed because of the slight increase in friction.

CONCLUSIONS

The following modifications were made to the autographic impact tester to improve its efficiency:

1. A new triggering technique which uses the internal triggering of the oscilloscope. This eliminates the mechanical triggering technique.
2. A new calibration procedure which utilizes a new signal conditioner. This eliminates much of the tedious work of calibrating the transducers; it also allows the transducers' calibration to be checked while a test is in progress, which was previously impossible.
3. Elimination of the requirement for preloading Izod impact test specimens. In the past, this requirement has led to distortion of the force–time trace which made integration very difficult.
4. A computer program to allow the results from a test to be analyzed much more efficiently than previously. The computer program was based on certain assumptions of the shape of the force–time trace; the results of this work have demonstrated the validity of the assumptions.

It is expected that these modifications to the autographic impact tester will allow autographic tests to be performed very efficiently.

The author is grateful to R. E. Whipple for writing the computer program to analyze the data and to G. M. Armstrong for helpful discussions.

References

1. *Annual Book of ASTM Standards,* Part 27, Methods D256 and D1822, American Society for Testing and Materials, Philadelphia, 1973.
2. D. W. Abee, unpublished results.
3. C. B. Arends, *J. Appl. Polym Sci.,* **9**, 3531 (1965).
4. Henry Gonzalez, unpublished results.

Received February 6, 1975