JOURNAL OF APPLIED POLYMER SCIENCE VOL. III, ISSUE NO. 8, PAGES 132–142 (1960)

Short-Time Stress Relaxation and Toughness of Rubber-Modified Polystyrene

J. A. SCHMITT and HENNO KESKKULA

Polychemicals Research Department, The Dow Chemcial Company, Midland, Michigan

INTRODUCTION

The importance of measuring the physical properties of plastics at high deformation rates is becoming more and more recognized. Data obtained under static conditions or at low speeds do not satisfactorily characterize those plastics which are subject to impact loading in service.

Several methods for rapidly straining specimens have been reported[1–3] which employ gas-operated pistons, large springs, or other mechanical devices. Watson, Kennedy, and Armstrong[1] described an apparatus in which the compressive force of a large spring is used to obtain rapid extensions. They measured the short-time rates of stress relaxation of several plastics and reported an empirical relationship between "toughness" and these rates.

We have built an apparatus modeled after that of Watson, Kennedy, and Armstrong in order to study toughness. Several modifications were incorporated to extend its usefulness. The short-time, stress-relaxation rates of several types of plastics have been studied, especially rubber-modified polystyrenes. The empirical toughness correlation does not seem to apply to the materials we studied. However, the stress-relaxation results can be used to determine short-time critical elongations or critical stresses as well as high-speed stress-strain curves. A simple modification of the specimen holder has also resulted in a high-speed, flexural-type test which can give a realistic measure of toughness or impact resistance. The mechanism of reinforcement in rubber-modified polystyrene is discussed in the light of observations made during this study.

APPARATUS

The short-time stress-relaxation apparatus is basically the same as Watson's and was built from prints graciously furnished by the Tennessee Eastman Company. Some modifications of the instrumentation were introduced. An Ellis bridge-amplifier meter was used to balance and amplify the strain gage signal from the weighbar. The stress and its decay with time were recorded on one channel of a Sanborn 60 two-channel magnetic oscillograph. The second channel was used to record the strain by means of the type extensometer described by Watson. For records at times shorter than 0.01 sec., the bridge amplifier signals were put into a DuMont 304A cathode-ray oscilloscope equipped with a Polaroid camera. A Hewlitt-Packard 200 CE signal generator furnished a time reference trace.

In the original design we experienced much difficulty in aligning the specimen holders so that all sides of the weighbar would be equally stressed. The thrust bearing between the weighbar and the upper jaw was removed and a ball-type universal joint installed above the weighbar. This permits a more uniform uniaxial force on the load cell. The removal of the thrust bearing also results in a smaller mass for the system. This is important in very high speed work where resonance of the upper jaw and weighbar assembly can produce high amplitude vibrations which mask the stress readings.

For all the stress-relaxation experiments, an injection-molded bar of $^1/_4 \times {}^1/_4$-in. cross section and $2^1/_4$-in. length between shoulders was used. The jaws were shaped to fit the end knobs, and backplates were installed to prevent slippage.

The weighbar was calibrated by hanging weights on the upper jaw, and this calibration was checked and corrected by comparing Instron stress-strain plots with similar curves constructed from the high-speed stress-relaxation data. However, for most experiments this calibration is unnecessary, because relative stress can be used to determine per cent decay rates. The bicycle-clip shaped extensometer was calibrated by making a special jig by use of a micrometer calipers barrel so fitted with clamps that turning the barrel produced a corresponding extension. Except for determining rates of strain, it was unnecessary to measure strain for each experiment, because the spacers set below the springbar accurately predetermined the strain.

The apparatus was not fitted with a constant temperature enclosure, its use being limited to

measurements at room temperature (70 ± 2°F.).

For the high-speed flexural tests, three special rectangular brackets were cut from $^3/_{16}$-in. steel stock and attached to the jaws in such a way that a flat specimen, about $1^1/_2$ in. in length could be flexed by pulling down in the middle of the piece when supported near each end. By installing the proper number of spacers below the springbar, a predetermined deflection could be applied and the resulting load measured. Successively higher deflections would then be applied until the sample broke during loading.

The speed of tensile loading and the strain rate were determined from the oscilloscope records. Watson operated his apparatus at speed of "up to as much as $^1/_8$ inch or more . . . in times of the order of 2 or 3 milliseconds" (2500–3750 in./min.).[1] Our experience indicated that with no force except that of the specimen resistance restraining the spring, the springbar would strike the spacer blocks with such great force that vibrations would be sent through the framework back to the load cell. These vibrations would be superimposed on the records and made it very difficult to analyze the data. Another disadvantage of an unrestrained spring movement is that the springbar and lower jaw accelerate during the movement so that a nonuniform rate of straining occurs which differs for each sample material.

By inserting a hydraulically controlled resistance to this movement, the rate of extension was reduced. Moreover, at the same time, a uniform rate of extension was obtained which was essentially the same for all the plastics tested. The simplest way to accomplish this was to leave the hydraulic jack in place after compressing the spring. Opening of the jack valve allows fluid to escape at a constant rate when the spring is released. In this way, a fairly constant cross-head speed of 300 in./min. was obtained for all the experiments reported here. Other rates could be obtained easily by using hydraulic systems of different characteristics, or by adjusting the fluid relief valve to control the flow of fluid and thus the spring movement. Rates from zero to three or four thousand inches per minute, or more, should be possible.

Operation of the apparatus is the same as reported by Watson.[1] Records of stress were usually made for 30 sec. after straining. The majority of the resulting data were plotted as per cent of residual stress versus the logarithm of time.

EXPERIMENTAL RESULTS

It was for the purpose of studying toughness of plastics that this apparatus was built. Our initial study includes three commercial materials with differing impact resistance records. Polystyrene is a relatively brittle, inexpensive material which is not very tough in the general sense. Styrene-acrylonitrile copolymer is also a rigid, relatively brittle material, but it is somewhat tougher or more impact-resistant than polystyrene. The rubber-modified polystyrenes are considered impact-resistant plastics.

The short-time stress-relaxation curves for these three materials are shown in Figure 1, which is a plot of the actual stress against the logarithm of time. When plotted as per cent residual stress versus log

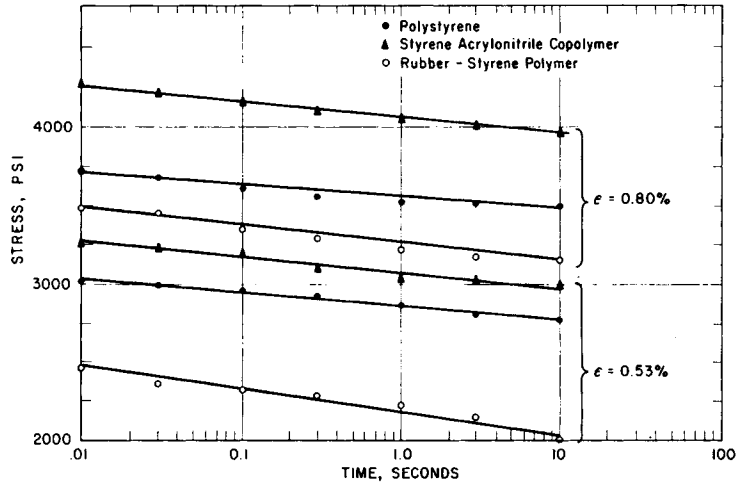

Fig. 1. Short-time stress-relaxation curves at various strains. Specimens were $^1/_4 \times {}^1/_4$ in. injection-molded bars, 2.25 in. between shoulders.

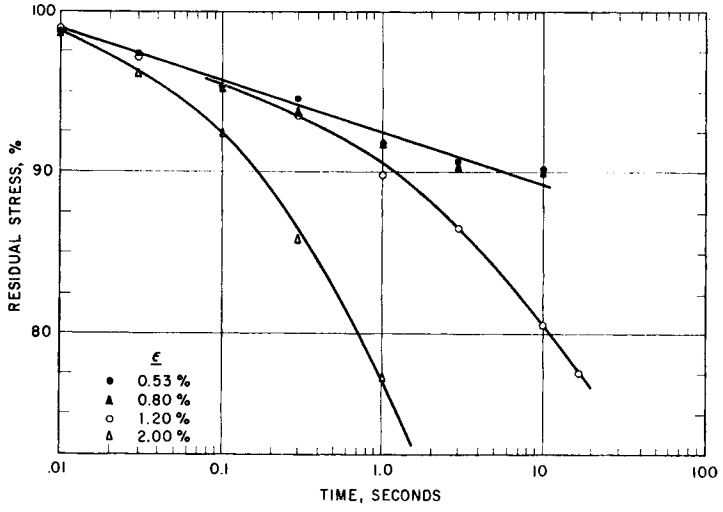

Fig. 2. Stress-relaxation curves for rubber-styrene polymer at various strains.

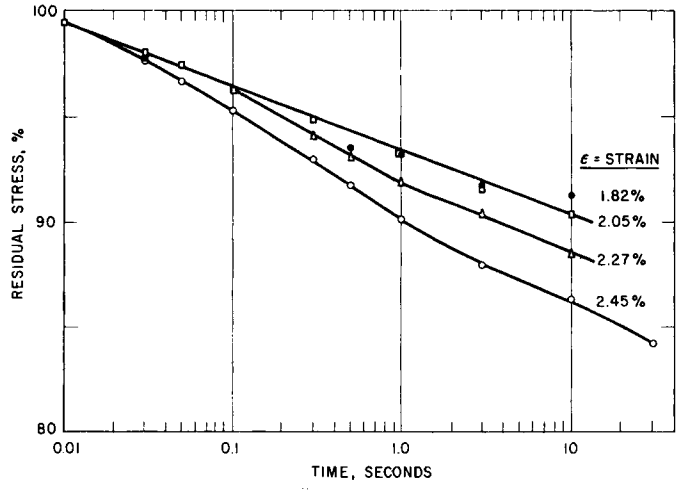

Fig. 3. Stress-relaxation curves for polystyrene at various strains.

time, the points fall on the same line. The straight lines have nearly the same slopes. The slightly greater slope for rubber-modified polystyrene at 0.80% strain may be a reflection of the weaker polystyrene backbone caused by the imbedding of rubber particles in it. The major difference in the stress relaxation curves of these three materials is in the actual stress level recorded. Styrene-acrylonitrile copolymer, with the highest tensile strength, gives the highest stress, and rubber-modified polystyrene the lowest. The data do not seem to rate these materials in their order of toughness or impact resistance.

When the strain was increased to 1.2 and 2.0% the curves for polystyrene and the styrene-acrylonitrile copolymer follow the same slope as at the lower strain levels. However, for rubber-modified polystyrene, the curves are different, as shown in Figure 2. At 1.2% strain the curve breaks away from the straight line at about 0.07 sec. and drops more sharply. At 2.0% strain, the break from the straight line occurs before 0.01 sec. For these samples, a general whitening of the opaque plastic occurred. This effect was quite general for this and other rubber-modified plastics and is probably caused by light being reflected from many fine craze cracks in the polystyrene surrounding the rubber materials. This mechanism will be treated more fully later.

An increased stress-relaxation rate was also observed with polystyrene at higher strains. The curves of Figure 3 show a similar, but less sharp, in-

Fig. 4. Polystyrene test bar after rapid straining showing internal craze planes.

crease in stress-decay rate, which starts earlier as the strain is increased. In these samples, the craze planes appear in the interior or weakest part of the injection-molded bar perpendicular to the force applied, as shown in Figure 4. The initiation of these cracks corresponded with the time at which the stress-decay rate increased, so that the relaxation rate after cracks appear is a function of both molecular relaxation and the growth of these cracks. The styrene-acrylonitrile copolymer does not craze in the time range studied; at higher strains, the bars break during straining.

The strain (or stress) at this point of departure from the straight line appears to be the critical elongation (or critical stress) at the time the increase in rate occurs. Thus, critical elongations can be determined directly from stress-relaxation data for either clear or opaque materials. We have found that the most accurate way of determining the values involves a special plot of the combined data from several experiments in which the strain is varied. At any given time, the per cent residual stress from each experiment is plotted against the strain value. This is repeated for each of several chosen times. The resulting plot for a polystyrene is shown in Figure 5. The per cent residual stress remains quite constant until the critical strain or elongation is reached and then drops. The intersection of two straight lines gives the critical elongation for each time.

This method for determining critical elongations or critical stresses as a function of time should be generally applicable to both clear and opaque plastics. Although this apparatus is limited to short-time measurements, it would be easy to change the instrumentation to cover any desired time range. Compression-molded specimens can be used by making the necessary modifications in the specimen holders.

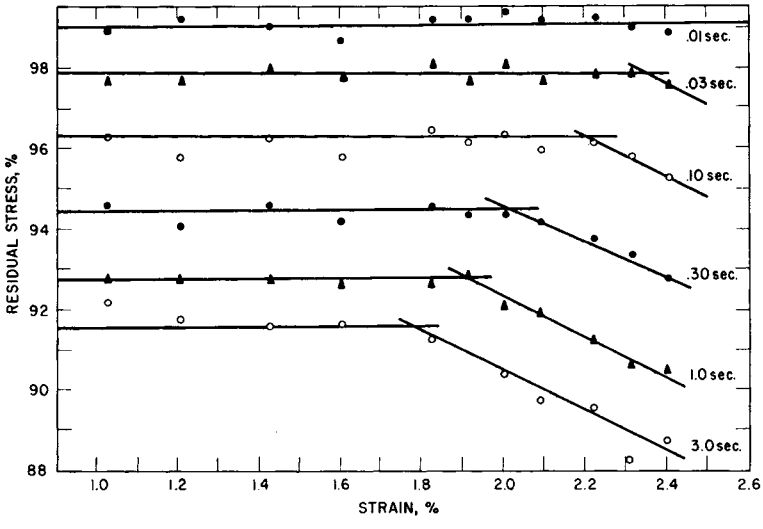

Fig. 5. Method of plotting stress-relaxation data to determine critical elongations. Material is polystyrene.

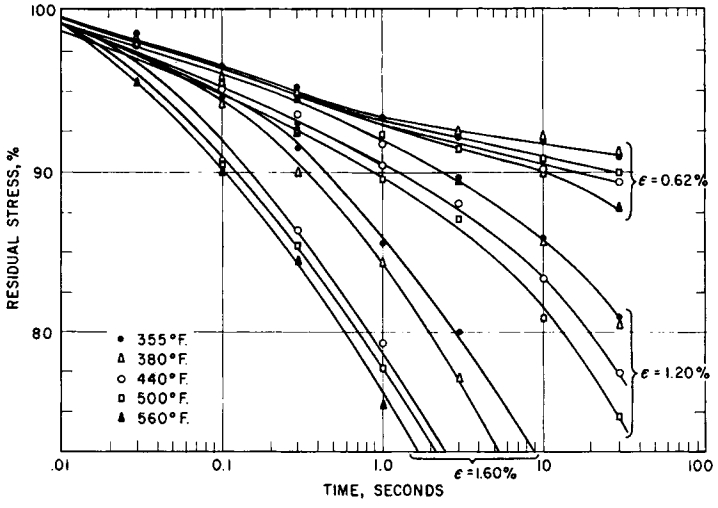

Fig. 6. Curves showing the effect of the molding temperature of rubber-styrene polymer on short-time stress relaxation rates at various strains.

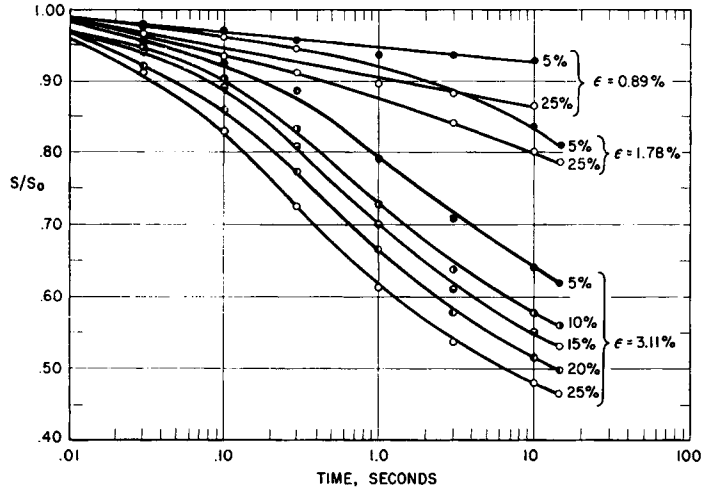

Fig. 7. Curves showing the effect of rubber content of mechanical blends of styrene and rubber on the stress relaxation rates at various strains.

Short-time stress-relaxation data can also be used to study the effects of composition and molding variables. For example, the curves in Figure 6 show how the stress decays as a result of changing the molding temperature of rubber-modified polystyrene. The temperatures of molding are as indicated, 355–560°F. At 0.62% strain, not much difference in relaxation rates is seen, except that the 560° sample appears to start dropping more rapidly at about 20 sec., probably due to crazing. At 1.2% strain the effect is more pronounced. At 1.6% there seems to be a large difference between the 380 and the 440°F. moldings. This might indicate some degradation of the styrene-rubber interaction.

The short-time stress-relaxation rates of mechanically blended, hydrocarbon-insoluble, styrene-butadiene rubber and polystyrene are shown in Figure 7. Again, at a low strain (0.89%) the curves are nearly straight. As the strain is increased and exceeds the critical value, the stress decays more rapidly, especially as the rubber content increases.

Besides the regular short-time stress-relaxation plots obtained from the use of this apparatus, stress-strain curves can be constructed for a high

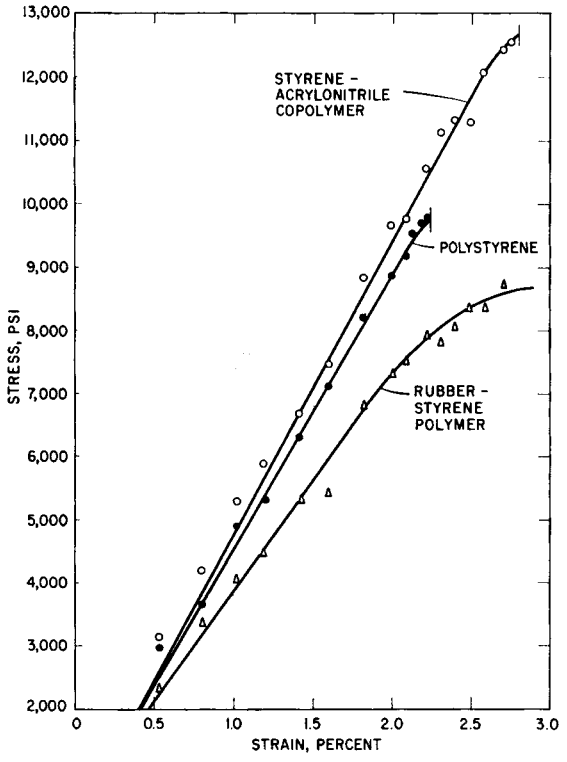

Fig. 8. Stress–strain curves for polystyrene, styrene-acrylonitrile copolymer, and rubber-styrene polymer, as obtained from the short-time stress-relaxation data for strain rate = 133 in./in.-min.

straining rate. The strain rate was 300 in./min. or 133 in./in.-min. The strain was increased for each succeeding sample until instantaneous breaking occurred. By plotting the initial, or maximum, stress against each strain setting, a stress–strain curve is obtained where each point comes from a separate sample and experiment. Figure 8 shows the results obtained in this manner for polystyrene, styrene-acrylonitrile copolymer, and rubber-reinforced polystyrene, where the strain for each new specimen was increased until instantaneous breakage occurred. Clear differences show up for these materials, but even with this kind of comparison, the prediction of toughness does not seem feasible.

Figure 9 shows the high speed stress-strain curves for a series of polystyrene-rubber mechanical blends where a crosslinked styrene-butadiene rubber was used. The elongation improves considerably as the rubber content increases, while the stress decreases. An interesting fact might be brought out here. If one plots the high-speed elongation at breakage against the per cent rubber, a curve of the type shown at the lower portion of Figure 10 results. However, the Instron elongations obtained at the much slower speed of 0.125 in./in.-min. show a peak at about $12^1/_2\%$ rubber. If the Instron speed is increased to 2.5 in./in.-min., the peak occurs at about 22% rubber. Thus, it appears that the peak shifts with the speed of straining to a higher rubber content. The peak for the high straining rate would apparently occur at a somewhat higher rubber concentration than 25%. The notched Izod-impact values for these materials correlate better with the high speed elongations. This is to be expected since the Izod test is a high-speed test and the breakage is similar,

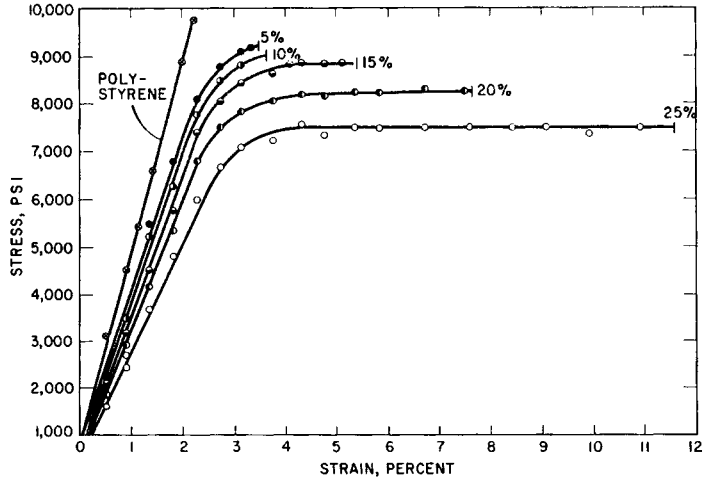

Fig. 9. High-speed stress–strain curves showing the effect of the rubber content of mechanical blends of polystyrene and crosslinked butadiene-styrene rubber.

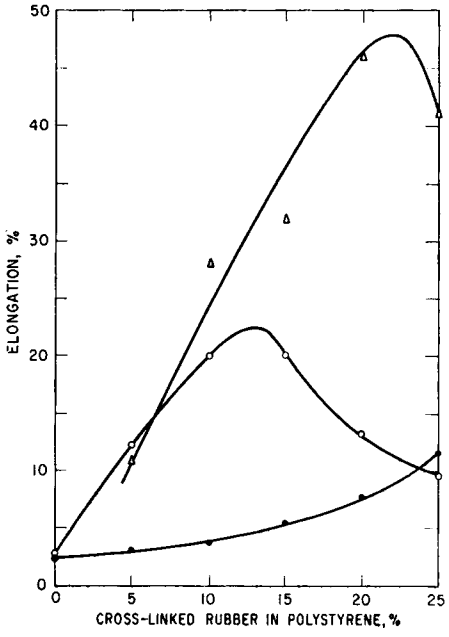

Fig. 10. Curves showing the effect of strain rate on the measured elongation (at breakage) of polystyrene-rubber blends: (○) 0.125 in./in.-min.; (△) 2.5 in./in.-min.; (●) 133 in./in.-min.

that is, it is primarily a tensile break of a specimen in which the polymer chains are preferentially oriented in the long direction. We should conclude, in general, that elongations, to be a measure of quality, should be measured at a speed of deformation near that expected in ultimate use. This idea is compatible with the shift of T_g to higher temperatures with speed of deformation.

As shown earlier, the short-time stress-relaxation rates did not correlate with toughness or impact resistance. However, it was found that a simple modification of the apparatus gives a test which more closely approaches this objective. A study of the orientation produced in a molded object and the type of deformation occurring during impact indicated that a high-speed, flexural-type test would give results more closely related to practical toughness. A simple modification of the jaws was made so that a small flat strip of plastic, $^1/_2$ in. wide and about 2 in. long could be supported near its ends and flexed rapidly in the middle at a speed of 300 in./min. Such strips were cut from injection-molded dinner-plate covers, both parallel and perpendicular to the flow of plastic in the mold. The dinner-plate cover is edge-gated and measures 8 × 8 × 1.25 in. and is 0.092 in. thick. It is molded on a 12-oz. Lester machine. Orientation produced during flow strengthens the plastic in the parallel to flow direction and weakens it in the perpendicular direction. An impact blow will cause breakage in the weaker direction. Thus, one would expect the results from the perpendicular-to-flow specimens to correlate better with actual impact resistance.

Figure 11 shows the results obtained with the high-speed flexural test on specimens of polystyrene and rubber-reinforced polystyrene. Stress was plotted against the deflection, which was increased

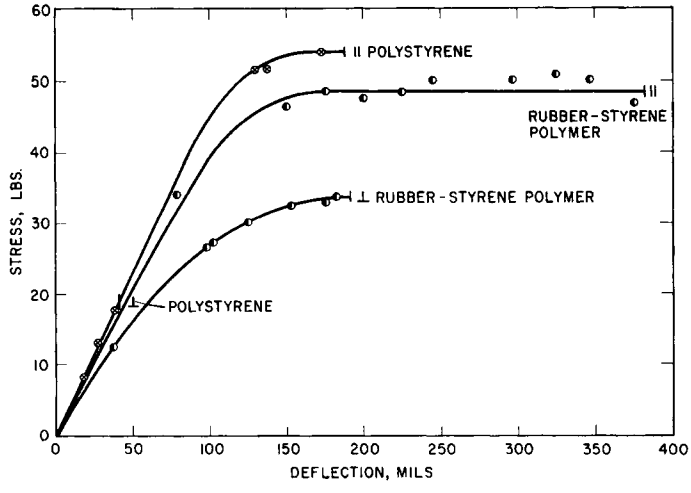

Fig. 11. Results of high-speed deflection test on $^1/_2$ × 2-in. strips cut parallel (||) and perpendicular (⊥) from a molded dinner-plate cover to the flow of plastic in the mold. The vertical line at the end of the curve indicates the deflection above which breakage occurs on deformation.

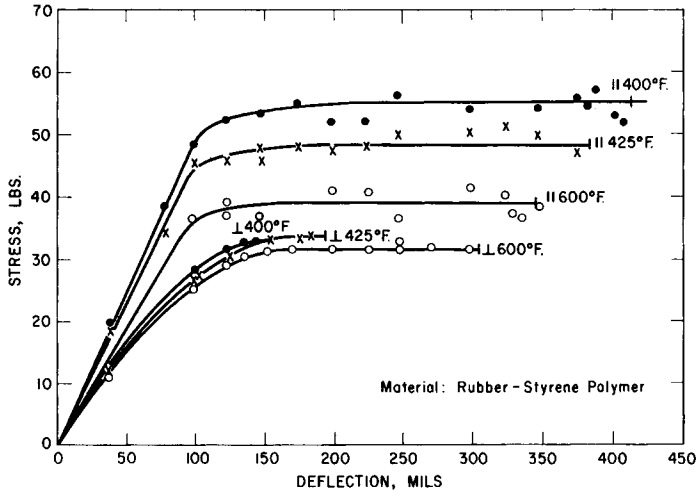

Fig. 12. Results of high-speed deflection test on strips cut from a dinner-plate cover showing the effect of molding temperature of rubber-styrene polymer.

with each new specimen until instantaneous breakage occurred. The deflection and stress at breakage of polystyrene is much lower in the perpendicular direction than in the parallel-to-flow direction. This weaker value, however, determines the resistance of such a flat sheet to impact blows. For rubber-modified polystyrene there is less difference between the values; however, if the perpendicular-to-flow properties are compared with those for polystyrene, it is obvious that the rubber-styrene polymer should be somewhat more resistant to impacts. Both the stress and deflection at breakage are higher.

Figure 12 shows the results of this high-speed flex test on rubber-modified polystyrene molded at three different temperatures, 400, 425, and 600°F. Again, the perpendicular-to-flow specimens broke at lower deflections. However, at the higher molding temperatures, the plastic flowed more easily into the mold so that less orientation was produced in the finished part. This is demonstrated by the much smaller differences in deflection and stress at breakage between directions of flow for the specimens molded at 600°F.

In order to compare these results with a practical-type impact test, we used a dart-drop impact experiment. The specimens were injection-molded dinner plate covers on which a weighted dart was dropped. The data of Table I can be plotted as breaking deflection of the perpendicular-to-flow samples versus log energy to break in the dart-drop test. Such a plot shows a probable correlation. However, this high-speed flex test is not very practical for measuring impact strengths. The dart-drop test is much simpler and gives just as good or better indication of impact resistance of toughness.

TABLE I
Correlation of High-Speed Flexural Test and Dart-Drop Impact Data

Material	Energy to break (dark-drop test), ft.-lb.	Deflection at break (high-speed flex test), mils
Polystyrene	0.13	38
Styrene-acrylonitrile copolymer	0.23	86
Lucite	0.27	83
Rubber-modified polymers	0.20	147
	0.72	170
	4.2	293
	5.2	303
	10.1	371

DISCUSSION

Toughness is a term often applied to plastics, but it is subject to many definitions. We have used it in the general sense of the ability of an object to resist breakage from impact type blows. In this sense, we have limited our study to plastics which are rigid or nonductile, yet have varying degrees of toughness.

As shown in a previous section of this paper, short-time relaxation rates do not give a measure of toughness for all plastics. There is no particular reason why the short-time relaxation rates should be greater for tough materials. Materials which do

not flow could yet be considered tough. For example, a very elastic, high-tensile steel or a heavily crosslinked rubber could be very tough, but neither would have a high rate of stress decay and might show none. However, a material that yields, or is ductile, will creep or relax when a stress or strain is applied.

It is possible that our slower rate of strain or the exclusive use of injection-molded specimens may have prevented us from obtaining a toughness correlation. However, it is more probable that the choice of materials had a greater effect, for there can be different mechanisms which result in impact resistance. Thus, if an object, such as a dart, strikes a plastic specimen and does not cause breakage, it may be for one of several reasons. The energy of the impact may follow any of the following several routes.

(*1*) It may be transmitted entirely back to the object and make the object bounce (high-tensile steel or some rubbers).

(*2*) The specimen may receive much of the energy in the form of vibration, which eventually subsides from air resistance and/or internal damping mechanisms.

(*3*) The plastic may yield or flow, causing temporary or permanent distortion (ductile materials) and give high stress-relaxation rates.

(*4*) The energy may be absorbed by formation of a large number of fine cracks around filler particles, as in rubber-modified polystyrene (to be discussed in more detail below).

(*5*) There may be any combination of these and/or other mechanisms.

Although materials like rubber and leather are tough, in our use of the word, many applications call for rigidity as well. Rubber-modified plastics have been developed to give this combination. However, the mechanism of rubber reinforcement has not been very well understood. During the course of our studies on these systems, we have observed several types of breakage and also the effects produced when impacts do not cause rupture. Some of these observations have led to a proposal for the mechanism of rubber reinforcement to give impact resistance.

We observed, as mentioned earlier, that the start of crazing can be determined by the stress relaxation results. Also, a general whitening of the opaque rubber-modified brittle plastic occurs whenever the critical elongation is exceeded. It is extremely difficult to study the cause of this whitening under the microscope, because preparation of the sample affects the resulting picture. However, P. A. Traylor[6] of our Analytical Laboratories was able to cut a thin section of a rubber-styrene polymer and stretch it while viewing it under the microscope. Figure 13 is a phase-contrast picture of such a sample before and after stretching. Around a number of the rubber particles can be seen a large number of fine craze cracks. The cracks are radially distributed in three dimensions rather than all being perpendicular to the force applied. They do not appear to start in the polystyrene to be stopped at a rubber particle; rather, the cracks appear in all directions around the rubber particle and surround the whole rubber sphere. This would account for the whitening effect by scattering of light from the many planes of reflection, just as, e.g., salt appears white even though each crystal is clear.

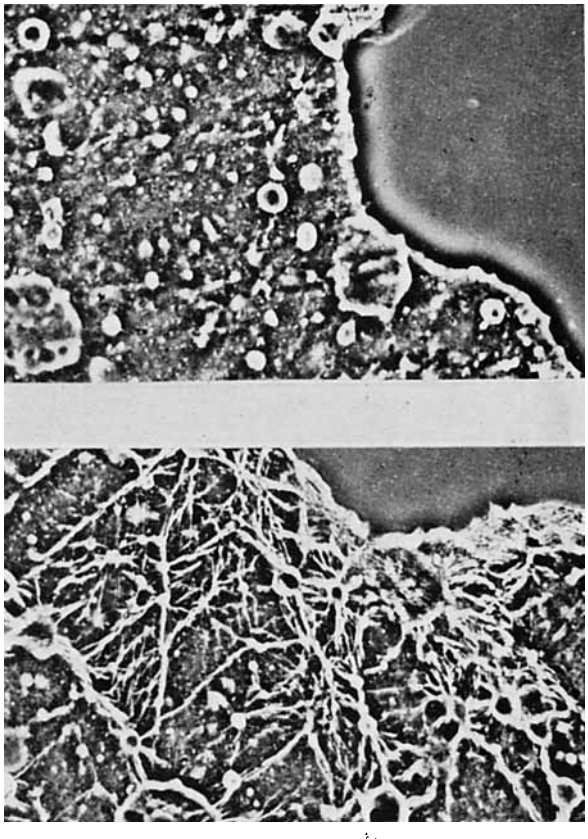

Fig. 13. Phase-contrast photomicrographs of rubber-styrene polymer: (upper) normal specimen and (lower) stressed specimen (before and after pulling apart a thin slice). Magnification 1105 ×.

From these observations we conclude that the rubber does not act simply to stop a crack from growing, but rather introduces points of stress concentration or lines of weakness in the polysty-

rene around its whole surface. Then, if a nondestructive force is applied, its energy is used up in generating many short cracks around the rubber particles. The energy is thus distributed in a small volume instead of propagating a large crack which would cause gross rupture. At sufficiently low temperatures or at high rates of straining, the rubber may be in its glassy state so that it acts like a brittle material. A crack will then propagate as though the plastic were one brittle material.

An analogy to this mechanism can be seen in a recent paper on the rupture strength of rubber which is increased by addition of carbon particles.[4] The carbon introduces new points of easy tear so that the energy of a tear is distributed. Here, too, we are introducing preferred and scattered weaknesses so that the energy of rupture is limited to a small region of the specimen.

This mechanism furnishes a new approach to the study of rubber reinforcement of polystyrene. It may point out which variables to study in order to improve these materials. For example, the type of interface may be more important than the rubber composition.

Other points related to this topic, especially concerning the dart-drop testing of plastics and the effect of orientation on impact resistance, are taken up in a separate paper by Keskkula and Norton.[5]

CONCLUSIONS

Although short-time stress-relaxation rates did not, as hoped, give us a measure of toughness, we have found the apparatus to be a valuable and versatile tool. It furnishes a method for applying a strain or deflection to specimens at speeds more closely approaching impact speeds, under conditions where the resulting stress and its decay with time can be measured. High-speed stress strain curves can be obtained, and short-time critical elongations can be measured. A high-speed flexural test can be used to measure impact resistance if orientation in the specimen is considered.

General results of this study lead to a mechanism for the role of rubber reinforcement of polystyrene.

The authors wish to thank the Tennessee Eastman Company for supplying the prints for the apparatus, and P. Montague for being instrumental in many of the modifications and building of the apparatus. We would also like to thank P. A. Traylor for the photomicrographic work and S. G. Turley for many valuable suggestions and discussions.

References

1. Watson, M. T., W. D. Kennedy, and G. M. Armstrong, *J. Appl. Phys.*, **26**, 701 (1955).

2. Dorsey, J., F. J. McGarry, and A. G. H. Dietz, *ASTM Bull.*, No. **211**, 34 (1956).

3. Spangler, R. D., *Bull. Am. Phys. Soc.*, [2], **2**, 124 (1957).

4. Andrews, E. H., and A. Walsh, *J. Polymer Sci.*, **33**, 39 (1958).

5. Keskkula, H., and J. W. Norton, *J. Appl. Polymer Sci.*, **2**, 289 (1960).

6. Traylor, P. A., private communication.

Synopsis

A short-time stress-relaxation apparatus similar to that of Watson, Kennedy, and Armstrong was built. A large compressed spring is used to attain high strain rates which were kept constant at 300 in./min. by controlling the spring motion hydraulically. Measurements were made at room temperature on injection-molded bars of polystyrene, styrene-acrylonitrile copolymer, and a rubber-styrene polymer. No correlation could be seen between the short-time stress-relaxation rates and impact resistance or "toughness." The apparatus, however, has proved to be very useful, because it furnishes a means of straining a specimen rapidly and recording the stress and its decay with time. Stress-strain curves for a high straining rate have been constructed from the data. A high-speed flexural test can be made by modifying the specimen holders. This flexural test has shown a correlation between the dart-drop impact strength of an object and the deflection at breakage of specimens cut perpendicular to the flow of plastic in the mold. In addition, it was found that stress relaxation data can be used to measure critical elongation (or critical stress) as a function of time, without observing the formation of craze cracks. A mechanism of reinforcement of polystyrene by rubber particles is proposed. A phase-contrast photomicrograph is presented as evidence that the energy of nondestructive impact is used up in forming many short cracks radiating out around the rubber particles. A general whitening in the specimen results which is caused by reflection and scattering of light from the many planes.

Résumé

On a construit un appareil à temps court de tension-relaxation, semblable à celui du Watson, Kennedy et Armstrong. On emploie un grand ressort comprimé pour obtenir des valeurs élevées de la tension, qui sont maintenues constamment à 300 pouces/minute par controle hydraulique du mouvement du ressort. Des mesures ont été faites à température de chambre sur des barres de polystyrènes, de copolymères styrène-acrylonitrile et du polymères caoutchouc-styrènes fondus. On n'a pas trouvé de relation entre les valeurs de tension-relaxation à temps courts et la résistance à l'impact. L'emploi de l'appareil, cependant, a été trouvé très utile, car il fournit un moyen de mettre rapidement un échantillon sous tension et d'en mesurer la résistance ainsi que d'enregistrer la décroissance en fonction de temps. Des courbes tension-rélaxation pour de hautes vitesses d'étirement ont été construites au départ de ces résultats. Un test de flexion à vitesse élevée peut être fait en modifiant les pinces pour tenir les échantillons. Ce test de flexion indique une corrélation entre la force d'impact d'un objet et la déflection lors du bris des échantillons coupés perpendiculairement à l'écoulement du plastique

dans le moule. En outre, on a trouvé que les résultats de tension-rélaxation peuvent servir à mesurer l'élongation critique (ou la tension critique) en fonction de temps, sans observer la formation de crevasses en surface. Un mécanisme de renforcement du polystyrène par des particules de caoutchouc est proposé. Une photomicrographie à contraste de phases prouve que l'énergie d'impact non-destructif, est utilisé à la formation de nombreuses crevasses, disposées radialement au départ des particules de caoutchouc. Il s'en suit un blanchissement général de l'échantillon qui est dû à la réflexion et à la diffusion de lumière au dépens des nombreux plans.

Zusammenfassung

Es wurde ein Apparat zur kurzzeitigen Messung der Spannungsrelaxation, ähnlich dem von Watson, Kennedy und Armstrong angegebenen, konstruiert. Eine grosse, gespannte Feder dient zur Erreichung einer hohen Verformungsgeschwindigkeit, welche durch hydraulische Kontrolle der Bewegung der Feder konstant bei 300 in./min. gehalten wurde. Messungen wurden bei Raumtemperatur an im Spritzguss hergestellten Stäben aus Polystyrol, Styrol-Acrylnitrilcopolymeren und einem Kautschuk-Styrolpolymeren ausgeführt. Es konnte keine Beziehung zwischen der Geschwindigkeit der kurzzeitigen Spannungsrelaxation und der Stossfestigkeit oder "Zähigkeit" erkannt werden. Der Apparat erwies sich aber denooch als sehr brauchbar, da er eine Möglichkeit bietet, eine Probe rasch zu verformen und die Spannung und ihren zeitlichen Abfall aufzuzeichnen. Spannungs-Dehnungskurven für hohe Verformungsgeschwindigkeit wurden aus den Versuchsergebnissen erhalten. Ein Biegetest für hohe Geschwindigkeit kann nach einer Abänderung des Probenhalters ausgeführt werden. Dieser Biegetest liess eine Beziehung zwischen der Fallkörper-Stossfestigkeit eines Körpers und der Bruchbiegung von Proben, die senkrecht zur Fliessrichtung in der Form aus dem Material geschnitten wurden, erkennen. Ausserdem wurde gefunden, dass die Befunde bei der Spannungsrelaxation zur Bestimmung der kritischen Dehnung (oder kritischen Spannung) als Funktion der Zeit ohne Beobachtung von Sprüngen und Rissen benützt werden können. Ein Mechanismus für die Verstärkung von Polystyrol durch Kautschukpartikeln wird vorgeschlagen. Zum Beleg dafür, dass die Energie eines nicht zur Zerstörung führenden Stosses zur Bildung vieler kurzer, rund um die Kautschukpartikel ausstrahlender Risse verbraucht wird, wird eine Phasenkontrast-Mikrophotographie vorgelegt. Es entsteht eine allgemeine weissliche Verfärbung der Probe, die durch Reflexion und Streuung des Lichtes an den vielen Grenzflächen verursacht wird.

Received October 27, 1959