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Progress Report, Task Group on High Speed Testing, ASTM Committee D-20 on Plastics

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INTRODUCTION

High speed tensile data on various materials have been published in the literature by a number of different authors over the past decade. None has used exactly the same equipment—in fact, in many cases the design of the testing apparatus was purposely quite different from those of other investigators. Even in this symposium, the first paper was concerned with flywheel actuation, the second with pneumatics, while the third cited data in different speed ranges from equipment including hydraulic, pneumatic, and ballistic loading. Others will deal with hydraulic testers as well as a gravity technique.

How does a given type of equipment compare with another similar one or, more importantly, how do the data obtained from one of these testers compare with those produced with another of quite different design? In the belief that progress in high speed testing had reached a sufficiently advanced research stage to make studying these questions worth while, a task group was organized in Section IA (tensile properties) in American Society for Testing and Materials (ASTM) Committee D-20 on plastics in June 1960. Nineteen companies were represented at an organizational meeting at which the following six laboratories agreed to participate in experimental round robins:

1. Plas-Tech Equipment Corp., Natick, Mass. (R. H. Supnik, chairman of the task group).

2. Union Carbide Chemical Co., S. Charleston, W. Va. (R. R. Cosner).

3. E. I. du Pont de Nemours & Co., Inc., Explosives Department, Eastern Laboratory, Gibbstown, N. J. (R. D. Spangler).

4. U. S. Army, Redstone Arsenal, Redstone, Ala. (R. E. Ely).

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Since then, three additional participants have joined in.

The scope of the task group was set down at the organizational meeting as follows: "To establish equipment specifications, speed ranges, and methods of test for characterizing the tensile stress behavior of plastics."

The purpose of this paper is to describe the work done to date, to discuss the significance of the data obtained, and briefly to indicate the program to be undertaken in the immediate future.

The first effort of the task group was to obtain some gross measure of the agreement presently existing among the various types of high speed testing machines. The first round robin involved six laboratories, testing (in the machine direction only) each of two plastic film materials: Mylar polyester film (1 mil thick) and low density polyethylene film (10 mils thick) at each of three different speeds. A cursory examination of the data (Table III) showed that, while tensile strengths are in fairly good agreement, elongation values were quite widely dispersed. It was felt that the large amount of scatter was due to end and edge effects normally associated with testing thin films (failure at grips, slippage, micronicks along edges, etc.). The type of grips had not been specified for the round robin.

TABLE I
Energy and Speed Characteristics of High Speed Testers Used in ASTM Round Robins, 1960–61

		Lab. 1	Lab. 2	Lab. 3	Lab. 4	Lab. 5	Lab. 6
Method of propulsion		Gas	Hydraulic	Gas	Gas	Rotating wheel	Rotating wheel
Max. energy available, ergs		?	?	10^{11}	?	10^{7}	10^{10}
Max. force available, kg.		900	326	3000	>900	>900	90+
Force							
Kg.	Lab.	Equipment Speed Capacities, m./min.					
2.3	5	1–400	0.02–250	1–2500	2.5–125	2–250	6–400
45	100	1–400	0.02–250	1–2500	2.5–125	12–250	25–400
227	500	400	0.02–250	1–2500	2.5–125	—	—
455	1000	200	—	1–2500	2.5–125	—	—
1140	2500	—	—	1–2500	2.5–125	—	—

Rather than attempt immediately to eliminate these sources of difficulty, it was decided to follow the original plan of comparing gross differences attributable to the testing machines by conducting a second round robin on standard copper wire, silver-soldered to steel plates. In this way, results would be independent of end and edge effects. In this case (Table IV) both tensile and elongation values are in fairly good agreement.

A statistical analysis of the data obtained in both round robins was attempted but was hindered because not all laboratories tested the same number of specimens nor did they test at the same speeds (inadvertently). However, an analysis of variance was performed on the least-squares line of each laboratory when the data were plotted as a function of strain rate. The objective here was to show up agreement in the area of rate sensitivity in the speed range studied. No attempt was made to standardize on load cells in this work.

The only calculated values used were tensile strength and per cent elongation at failure. Other computations may be even more meaningful, e.g., modulus of elasticity, tensile stress at yield, and

TABLE II
Measurement Characteristics of High Speed Testers Used in ASTM Round Robins, 1960–61

Lab. no.	Length of grip travel, cm.	Means of monitoring velocity	Type of force gage
1	20	(*a*) Linear potentiometer (*b*) Load vs. elongation on *z* axis	Unbonded strain gage (Dynisco)
2	96	3 magnetic pickups	Bonded strain gage
3	3.2	Capacitance (Photocon)	Capacitance (Photocon)
4	2.5–5	Linear potentiometer	U-1 cells (Baldwin)
5	188	Tachometer on motor	Piezoelectric crystals
6	20	Voltmeter on d.c.-controlled motor; photoelectric monitor of impellent wheel	Unbonded strain gage (Dynisco)

TABLE III
Data from Round Robin No. 1 at High Strain Rates

Lab. No.:	1	2	4	5	6
Polyester Film, Tensile Strength, kg./cm.^{2}					
6.4 m./min.	—	1570	1550 (1)	1420	1670
51 m./min.	1600	1690	1670 (3)	1410	1730
130 m./min.	1430	1810	—	1590	1730
Polyethylene Film, Tensile Strength, kg./cm.^{2}					
6.4 m./min.	—	113	—	106 (2)	137
51 m./min.	144	139	—	127	134
130 m./min.	144	145	—	121	125
Polyester Film, Elongation at Break, %					
6.4 m./min.	—	117	29 (1)	135 (2)	73
51 m./min.	216	113	34 (3)	119	57
130 m./min.	175	113	—	101	36
Polyethylene Film, Elongation at Break, %					
6.4 m./min.	—	495	—	639 (2)	522
51 m./min.	419	492	—	542	563
130 m./min.	471	527	—	523	516

(1) 5.1 m./min., (2) 13 m./min., (3) 25 m./min.; specimen dimensions between grips: 2.5 × 2.5 cm.; no data from laboratory 3; Each figure is average of 3–6 replicates.

TABLE IV
Data from Round Robin No. 2 for Copper Wire at High Strain Rates[a]

	Lab. 1	Lab. 2	Lab. 3	Lab. 4	Lab. 6
		Tensile Strength, kg./cm.²			
1.3 m./min.	2690	2600	2880	—	2840
13 m./min.	2770	2630	2930	2970[b]	2710
130 m./min.	2900	2910	3200	3020[c]	2770
		Elongation at Break, %			
1.3 m./min.	24	33	24	—	29
13 m./min.	28	32	25	26[b]	28
130 m./min.	25	28	27	26[c]	23

[a] Specimens were standard copper wire prepared at one laboratory, silver-soldered to steel plates, 5-cm. effective length; each figure is average of 3–6 replicates; no data from laboratory 5.
[b] 5.1 m./min. [c] 51 m./min.

area under the curve to yield and failure. It is the intent of the task group to study these data in future work.

In the fall of 1961 the task group will engage in a third round robin concerned with the testing of high density polyethylene, impact polystyrene, and polyurethane, all in molded form. Following this it is hoped that specimen geometry, method of gripping, degree of slack, and detailed methods of measurement can be standardized in a comprehensive test method for obtaining high speed data on plastics for use in providing engineering data as well as specifications.

EXPERIMENTAL

Equipment

The equipment used by the participants in the round robins is described briefly in Tables I and II. It can be seen that no two machines exactly duplicate each other in every respect. Machine variables include the following.

1. Means of generating and applying the force necessary for stressing the specimen; and the machine's speed characteristics, e.g., impact loading versus acceleration from a zero velocity.

2. Means of measuring the force involved, including type of load cell and specimen mounting arrangements.

3. Means of measuring the strain.

4. Methods of recording and calculating the data available.

The data already referred to in the first round robin are shown in Table III, and the second in Table IV. It can be seen that discrepancies exist. Clearly there are problems to be resolved, but there are many bright spots of agreement which cannot be considered coincidental.

A statistical analysis of this experimental design was attempted, and some significant conclusions may be reached. Each set of data from each laboratory was tested against four models relating tensile strength or elongation to speed. The four models were

$$(1)\ y = a + bx$$

$$(2)\ \log y = a + bx$$

$$(3)\ y = a + b \log x$$

$$(4)\ \log y = a + b \log x$$

where y is the tensile strength or elongation in kilograms per square centimeter or per cent, respectively. x is the speed, b is the slope, and a is the intercept. In all cases, model 1 (a straight line on an arithmetic

TABLE V
Significance of Rate Dependance of High Speed Data
(Figures are b in the equation $y = a + bx$, where x = m./min.)

	Lab. 1	Lab. 2	Lab. 3	Lab. 4	Lab. 5	Lab. 6
			Tensile Strength[a]			
Polyester film	−2.13[b]	+1.93[b]	—	+6.03[b]	+1.55[b]	+(0.36)
Polyethylene film	+(0.019)	+0.22[b]	—	—	+(0.11)	−0.097[b]
Copper wire	+0.0014[b]	+0.0025[b]	+0.0025[b]	+(0.0014)	—	−(0.00019)
			Elongation[c]			
Polyester film	−(0.52)	−(0.031)	—	+(0.24)	−0.190[b]	−3.60[b]
Polyethylene film	+(0.676)	+(0.276)	—	—	−0.88[b]	−0.14[b]
Copper wire	+(0.008)	−0.04[b]	+(0.016)	—	—	−0.040[b]

[a] Where y is in units of kg./cm.².
[b] Indicates significance at the 95% confidence level; parentheses indicate no significance.
[c] Where y is in units of per cent at break.

scale) was found to be mathematically as good or better than any of the others.

Hence, Table V slows the slopes (b in the equation $y = a + bx$) for the six laboratories. Those figures which were found to be *not* significant at the 95% confidence level are in parentheses. The figures indicated by superscript b have >95% significance.

It may be noted first that laboratory 1 is unusual in finding a significant negative slope for the polyester film tensile strength. (It also obtained unusually high elongations for this film.) There is a similar quandary with regard to the polyethylene tensile strength, where only two laboratories obtained significance on the slope, and they were opposite in sign. It is difficult at this time to find reasons for this among the obvious differences in the testers used (e.g., impact versus nonimpact loading). It is probable that specimen gripping problems and edge defects may be playing an important role. The presence or absence of slack in the specimens and the variability in actual strain rate during the test are also worth further evaluation. On the other hand, the data on the copper wire do show some agreement wherever the slopes found significant.

The story on the rate dependence of elongation at break is more satisfactory. All slopes showing significance were negative, although their magnitudes varied. It may be interesting that the three laboratories using pneumatically driven machines (laboratories 1, 3, 4) found no trends in elongation having significance at the 95% confidence level.

The presence of so many nonsignificant slope values and blanks in Table V suggests the need for better experimental design, giving more data over wider strain rates under more completely defined testing conditions. It may be that alternative specimen geometries and improved gripping techniques will contribute to reducing the variability.

Table VI shows the zero intercepts for tensile strength and elongation (each mathematically extrapolated to zero strain rate using the slopes noted in Table IV). There is no clear division among classes of testing machines. It is probable that careful study of the measuring instrumentation, as well as the gripping methods already mentioned, will be useful.

It may be said that the work with copper wire (in spite of the work-hardening variations possibly present, even with gentle handling of such material) was reassuring in the agreement obtained on elongation, considering the readability of the oscilloscope traces involved. On a relative basis, the agreement on the copper tensile strengths is still better. This tends to allay doubts about the performance of these machines at this level of reproducibility. The disagreement on the presence of measurable strain rate dependence might disappear if this work were repeated with all machines run under impact conditions.

The use of dog-bone (or dumbbell) thicker samples of greater length in the third series of round robins should produce data confirming the indicated general reproducibility shown in the work with the copper wire.

TABLE VI
Extrapolated Intercepts at Zero Speed
(Figures are a in the equation $y = a + bx$, where x = m./min.)

	Lab. 1	Lab. 2	Lab. 3	Lab. 4	Lab. 5	Lab. 6
	Tensile Strength, kg./cm.²					
Polyester film	1720	1570	—	1520	1370	1690
Polyethylene film	142	118	—	—	110	137
Copper wire	2740	2600	2880	2950	—	2810
	Elongation, %					
Polyester film	242	116	—	28	138	85
Polyethylene film	385	487	—	—	624	195
Copper wire	26	33	24	26	—	29

The authors acknowledge the cooperative participation by the individuals and companies in this task group. Samples were provided by T. D. Mecca (Mylar polyester film), R. R. Cosner (polyethylene), and J. K. Owens (copper wire).

The authors and the committee invite written comments or suggestions on this work and wish to advise that data published herein are preliminary and should not in any way be construed as useful for specification or design purposes. Published with the permission of ASTM Committee D-20 on Plastics.

Synopsis

Interlaboratory comparisons on several materials are being conducted among a half-dozen laboratories having high speed tensile testers of widely different mechanical design and instrumentation. This progress report gives results from the first two round robins, the first on two plastic films and the second on copper wire. These materials were tested at several speeds in the range of 1.3 to 130 m./min. (50 to 5000 in./min.). Preliminary conclusions and plans for future work are offered.

Résumé

On a effectué des comparaisons sur plusieurs matériaux dans une demi-douzaine de laboratoires possédant des équipements d'essais de tension, à grande vitesse, de modèle mécanique et d'instrumentation fort différents. Ce rapport donne les résultats à partir des deux premiers échantillons arrondis l'un sur deux films plastiques et le second sur un fil de cuivre. On a testé ces matériaux à diverses vitesses allant de 1.3 à 130 m/min (50 à 5.000 pouces/min.). On propose des conclusions préliminaires ainsi que des projets pour le travail futur.

Zusammenfassung

Von einem halben Dutzend Laboratorien, die mit Hochgeschwindigkeits-Zugprüfgeräten von weitgehend verschiedener Konstruktion und Ausrüstung ausgestattet sind, wurden Vergleichsmessungen an mehreren Stoffen ausgeführt. Der vorliegende Fortschrittsbericht enthält Ergebnisse der ersten zwei internen Berichte, des einen über zwei Kunststoffilme und des zweiten über Kupferdraht. Diese Stoffe wurden bei mehreren Geschwindigkeiten im Bereich von 1,3 bis 130 Meter/Minute getestet. Vorläufige Schlussfolgerungen und Pläne für zukünftige Versuche werden mitgeteilt.

Discussion

Question: What percentage of failures took place at the grips?

Answer: In the case of copper wire there were no failures at the grips. In the case of the plastic films with parallel edges at least one third were failures and probably, in some laboratories, as much as two thirds. It is interesting to note, although we have not made a statistical study of this point, that neither the elongation nor the tensile strength appears to be affected by a grip failure. The values we obtained in almost every case in which there was grip failure seem to be in the same range as the data we obtained on the other samples which have center breaks. This is barring really foul balls, of course. That is, once in a while, particularly in polymers which have a sharp yield point, we will get what is obviously a premature break where the failure occurs at yield. I am sure that at still higher strain rates we would get failure at yield always. Of course, this is probably what happens at a critical strain rate. We are far below the critical strain rates for the material in the first two round robins.

Question: Did you take any steps to avoid the ringing of the load cells referred to in the paper?

Answer: I can't speak for the committee, but I can speak for my own testing. The ringing which we get is not limited to the load cell alone: it is ringing in the whole system. We have reduced this problem about fivefold by improving the tightness and changing the mass and the general geometry of the upper (stationary) grip and its connection to the load cell itself. If you eliminate motion between parts, and if you do things to alter the natural frequency of the system, you eliminate a good deal of this trouble.