Drug Development and Industrial Pharmacy, 24(11), 1017–1024 (1998)

RESEARCH PAPER

Advantages of Impact Testing over Hardness Testing in Determining Physical Integrity of Tablets

Kirk E. Wilson[1] and Andrea Potter[2,*]

Procter and Gamble Pharmaceuticals, Process Development Department,
[1]Woods Corners, Route 320, Norwich, NY, 13815,
[2]Rusham Park, Whitehall Lane, Egham, Surrey, TW20 9NW, England

ABSTRACT

An investigation of four different tablet strength tests was carried out on four different placebo formulations (differing in Avicel : Pharmatose ratios). The results analysis compared fatigue failure, work of failure, and impact failure to diametrical compression measurements (hardness). The impact results clearly show how different formulations can have the same hardness, yet their impact resistance can vary by as much as 200%. The impact test used in this work and other tests described are useful in tablet development to understand, compare, and mitigate tablet breakage during subsequent unit operations.

INTRODUCTION

Tablet strength is loosely defined and many different tests exist to measure it (1). The industry standards for determining the tablet strength are the diametrical compression hardness test (2,3) (hardness) combined with the Roche friability test. The hardness test measures the maximum force needed to fracture the tablet. Elastomeric properties vary significantly among materials; some are brittle, whereas some others are ductile. Although two materials may have the same tensile strength, the energy required to break them may be significantly different (4). Many stress-strain responses are also time-dependent effects. For example, under slow deformation, a piece of rubber may break with less force than a piece of glass; however, an impact will fracture the piece of glass with much less force than it will the piece of rubber.

Why is it, then, that tablet hardness is often accepted as the indicator for the physical integrity of a tablet? The answer may lie in the question. The pharmaceutical development goal is to create a robust process and formulation that ensure the tablet dissolution will meet strict

* To whom correspondence should be addressed.

specifications. Often, pharmaceutical development is not interested in the physical integrity of the tablet beyond meeting some minimum hardness and friability. These minimum hardness standards are arbitrary since they will vary for different tablet shapes, materials, and subsequent process steps. To understand the physical integrity and prevent tablet fractures, it is imperative to investigate beyond hardness. The two goals of this research are to present a novel method for impact fracture measurement and to compare available tablet fracture techniques against the standard hardness testing in order to highlight the importance of using the appropriate test to measure physical integrity.

Researchers have instrumented hardness testers and Instrons to track and integrate the force-displacement curves during tablet fracture (5–8). Analyzing the curves or measuring the work to failure instead of the hardness has allowed them to differentiate between brittle and ductile materials with the same hardness.

Several pharmaceutical researchers have looked at the time-dependent behavior and the importance of test time (5,6,9). Both Rees et al. and Patel et al. demonstrated how the strain rate could have an impact on the hardness measurements. The strain rate was not varied enough to produce large changes. The experiments did show that some pharmaceutical materials have time-dependent mechanical behavior.

The effect of cyclical loading on the tablet integrity has also been investigated (7,8,10). Rees et al. discovered a linear correlation between the work to failure and the logarithm of the number of cycles. Patel et al. showed that different materials have different responses to cyclical loading (fatigue failure) depending on their crack propagation energy (plasticity).

It is evident from these pharmaceutical researchers that tablet physical integrity cannot be measured by a single-point determination. Fracture toughness is different for brittle and ductile materials; it is often time dependent, and it is capable of fatigue failure. With all these variables to consider, it is not possible to find one test that is applicable for all situations. It is important, therefore, to design a strength test to emulate the actual process situation.

Most stress encountered by the tablets during processing, handling, packaging, and shipping is from impacts. These are not slow deformations under pressure; these are from free-falling tablets impacting on a surface or a moving surface impacting the tablets. By whatever means the impact is created, it is a rapid transfer of energy that is used to either accelerate the tablet or create fractures. Fractures develop only after the elastic limit is exceeded or after sufficient cyclical strain causes fatigue failure. Therefore, it is important to measure the tablet's physical integrity through impact testing rather than measuring hardness alone. The research presented here shows the importance of using a simple apparatus to measure impact energy to fracture a tablet.

MATERIALS AND SAMPLE PREPARATION

Materials

Materials used in the study were Avicel PH101 (microcrystalline cellulose, FMC Corp., Philadelphia, PA), Pharmactose DC11 (hydrous lactose, DMV International, Veghel, Netherlands), and magnesium stearate (Akcros Chemicals, New Brunswick, NJ).

Tablet Compression

Tablet blends were prepared by mixing 4 kg of different ratios of Avicel to Pharmactose along with 0.25% w/w magnesium stearate in a V-blender (Patterson Kelly, Stroudsburg, PA) for 20 min. The percentages of Avicel in the formulations were 0%, 20%, 80%, and 100%. The blend formulations were compressed on an instrumented press (Manesty Beta Press, Liverpool, England) fitted with one set of 12.7-mm plain-faced convex punches. The press was set to produce 500-mg tablets at three different compression forces (500 lbf, 1500 lbf, and 2500 lbf). At each compression force, samples were taken. The samples were stored in sealed polyethylene bags prior to testing.

TEST METHODS

Hardness Testing (Diametrical Crushing Strength)

Sample tablets from each of the three compression forces for each of the four formulations were tested in a hardness tester (Schleuniger Model 6D, Manchester, NH). The average hardness of 10 tablets was recorded for each sample.

Fatigue Failure

Rees and Rue used a tap density machine that would repeatedly tap a tablet placed under the arm attached to

Table 1

Combined Testing Results

Formulation (% Avicel)	Compression Force (lbf)	Average Gauge (mm)	Average Hardness (N)	Work to Failure (mJ)	Log Taps to Failure	Impact Energy to Fracture (mJ)
0	500	6.8	8	0.19	0.00	0.07
0	1500	6.0	42	1.60	0.48	0.15
0	2500	5.7	97	1.39	0.48	0.33
20	500	7.1	5	0.07	0.00	0.11
20	1500	6.0	54	2.02	0.74	0.33
20	2500	5.6	102	1.94	0.85	0.58
80	500	7.6	39	1.21	0.54	0.44
80	1500	6.0	180	3.93	2.19	2.11
80	2500	5.5	268	5.37	4.31	3.30
100	500	7.7	59	1.76	0.89	0.65
100	1500	5.9	229	5.80	4.04	2.47
100	2500	5.5	343	6.96	>4.5	4.00

the tapping disc (8). For the fatigue failure results reported here, a slightly different apparatus is used. A tablet is placed at the bottom of a slotted tube (3-cm diameter and 10-cm tall), which is fixed onto a tap density machine (Stampfvolumeter STAV 2003, Ludwighaven, Germany). A weight is placed in the tube, on the tablet, and the tap machine is started. The average number of taps required to fracture was obtained for each sample using 5 individual tablets. Advantages of this setup over the device used by Rees and Rue was that it can accommodate any size tablet, and any deformation of the tablet under stress does not change the impact force.

Normalized Work of Failure

Five tablets from each sample were tested using an Instron to determine the work of failure (the area under the force/displacement curve). Using a platen speed of 25.4 mm/min, the Instron was able to calculate the work required to fracture the tablet:

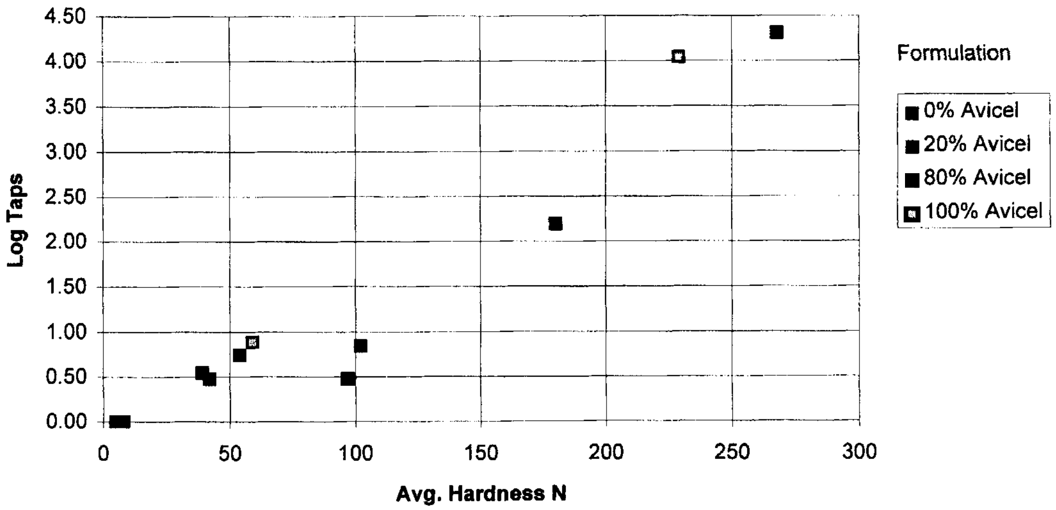

Figure 1. Fatigue failure as a function of hardness for different formulations.

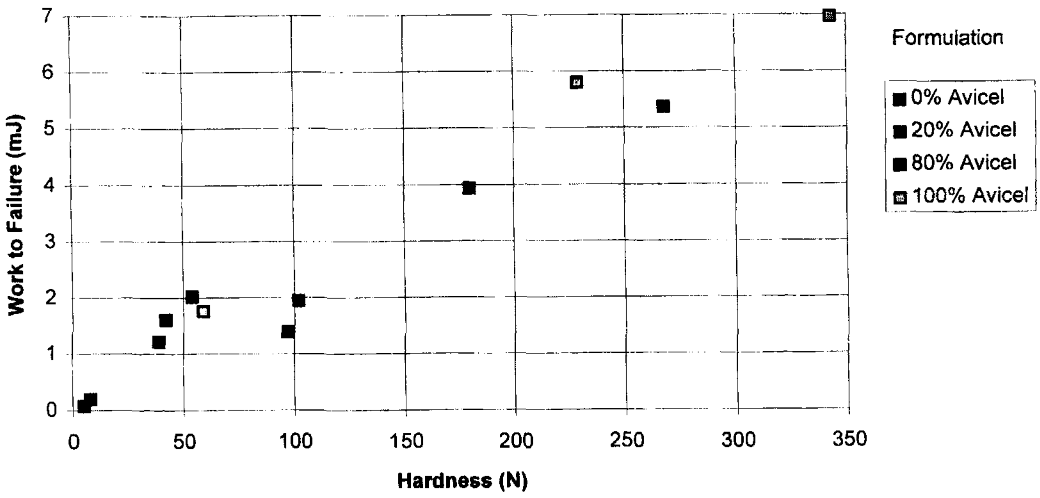

Figure 2. Work to failure (mJ) for different formulations as a function of hardness (N).

$$NWF = [\text{integral}] F dx \quad (1)$$

where F is the force at the given displacement, and x is the displacement of the platens.

Impact Testing

For impact testing (11), using the same tube as for the fatigue failure testing, a tablet is placed at the bottom of the tube, and a weight (called a *tup*) is dropped onto it from a measured height. If the tablet does not break, the drop height is raised for the next tablet placed in the tube until a tablet cracks from the impact. The drop height is then progressively lowered (using a new tablet each time) until no fracture occurs. At least 10 tablets are used to determine the drop height causing impact fractures (similar to ASTM D 3029). In most cases, this was determined within 5% of the overall drop height.

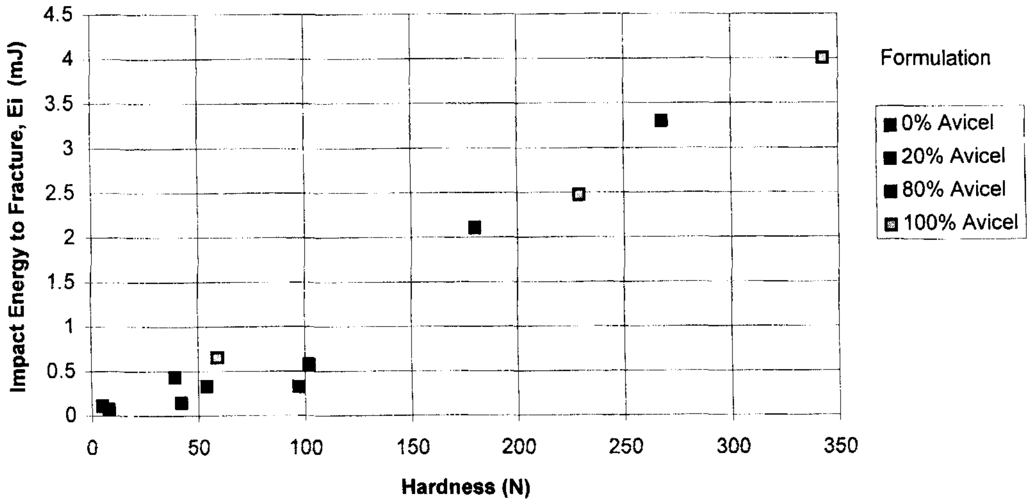

Figure 3. Impact energy for different formulations as a function of hardness (N).

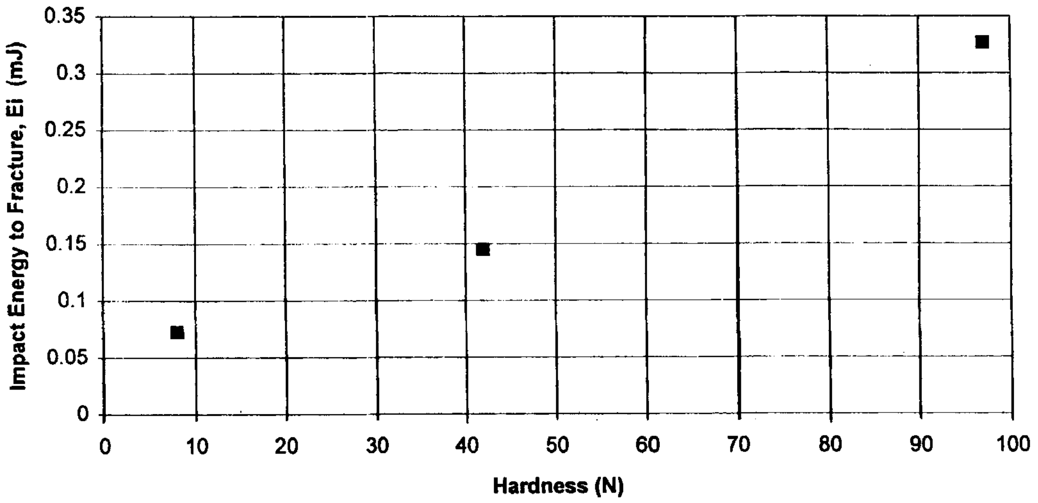

Figure 4. Impact energy versus hardness for 0% Avicel formulation.

From the drop height, it is possible to calculate the corresponding energy imparted *Ei* from the tup to the tablet, assuming negligible friction or rebound:

$$Ei = m \times g \times h \quad (2)$$

where *m* is the mass of the tup, *g* is the gravitational constant, and *h* is the drop height.

Another ASTM method for determining impact resistance is the Izod impact test (ASTM D256). It uses a pendulum weight raised to a measured height and released. At the bottom of the swing, it impacts the sample, which is half-fixed to a stage (half exposed), and energy is dissipated in breaking the sample. The pendulum continues its swing to the other side, and the maximum height attained is measured. From the difference in heights, it is possible to determine the impact energy required to break the tablet. This method has an advantage over the previous method in that each sample gives a numerical value rather than a yes/no result; therefore,

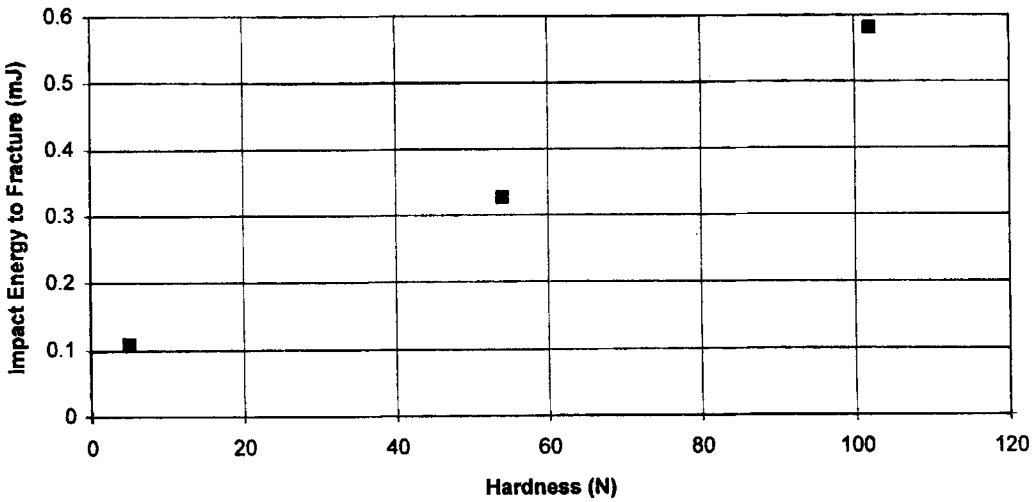

Figure 5. Impact energy versus hardness for 20% Avicel formulation.

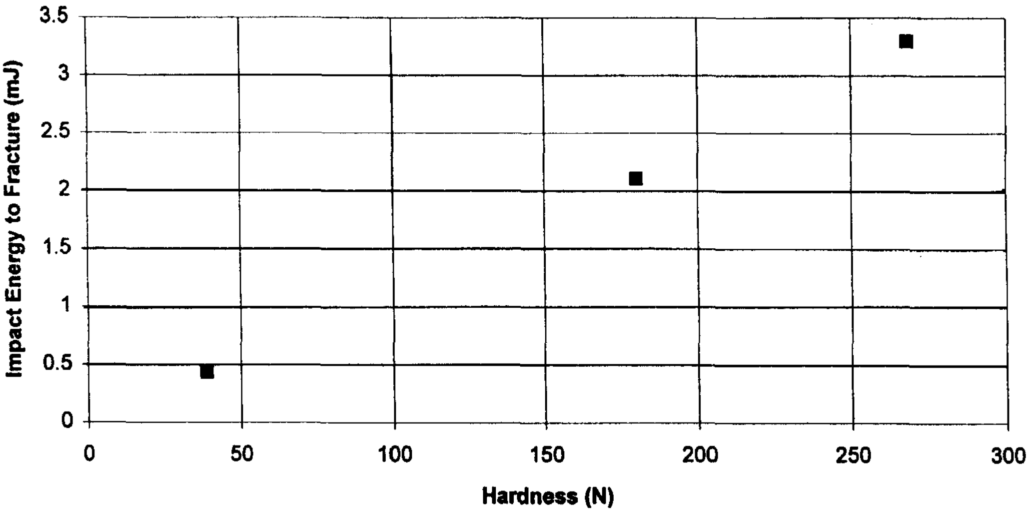

Figure 6. Impact energy versus hardness for 80% Avicel formulation.

fewer samples are required to get a statistical average impact energy.

RESULTS AND DISCUSSION

The results of the different tests are given in Table 1. Friability for all samples compressed at 1500 lbf or 2500 lbf was less than 0.5%. As anticipated, all tests show improved tablet hardness with higher compression force and higher Avicel content. Comparison between the hardness results and the other measurement techniques reveals novel correlations.

Hardness and Fatigue Failure

The correlation between the fatigue failure and hardness or work to failure was shown by Rees et al. to be a direct correlation between the work to failure and the

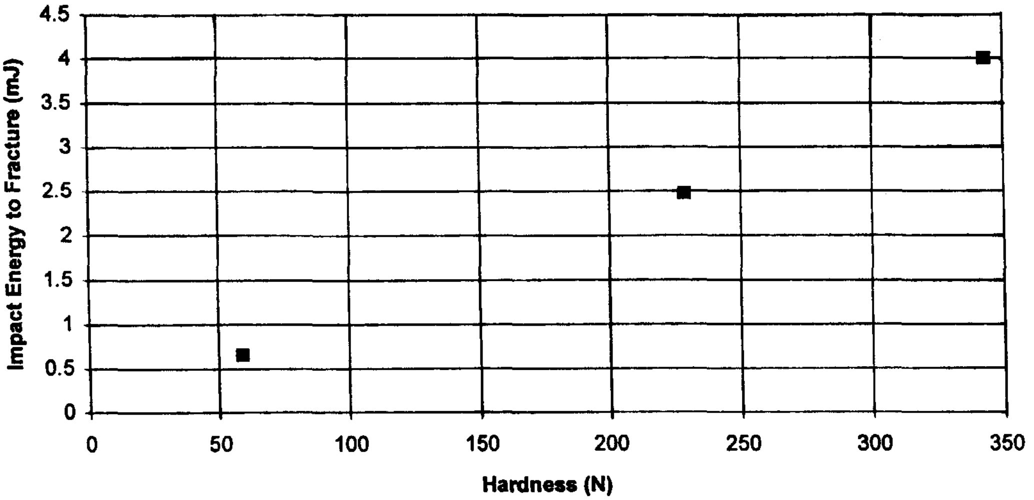

Figure 7. Impact energy versus hardness for 100% Avicel formulation.

Table 2

Regression[a] *of Individual Impact Energy* Ei *Versus Hardness Graphs*

Formulation (% Avicel)	Fitted Line (R^2)	Slope × 10^2 (mJ/N)	Estimated *Ei* (mJ) for a 100 N Tablet
0%	0.94	3.41	3.41
20%	0.94	5.80	5.80
80%	1.00	12.01	12.01
100%	1.00	11.40	11.40

[a]Regressions were done with a zero intercept.

logarithm of the number of cycles (7,8). Shown in Fig. 1 is the correlation between the logarithm of cycles and the hardness for all samples. A 240-g weight was chosen for the testing, which was appropriate for the widest range of samples. Even though the weight was chosen for the widest range, there was a significant number of samples that crumbled in the first few cycles and some samples that did not fracture even after 30,000 cycles. This is a shortcoming of this method since it is not possible to use different weights and then quantitatively compare results. For these samples, the predicted linear correlation, for the hardness to logarithm of cycles, holds true ($R^2 = 0.92$), although the correlation is dominated by the 80% and 100% Avicel blends, which have the largest hardness range.

Hardness and Net Work to Failure

Other researchers have indicated that there is a linear correlation between net work to failure (NWF) and hardness that is influenced by the plasticity of the material. In this study, a good linearity of all data points was obtained (Fig. 2; $R^2 = 0.94$). This correlation is again dominated by the 80% and 100% Avicel blends, which have a much wider range. The Instron showed a high degree of variability in computing the breaking point and NWF for the softer tablets. This is evident in the scatter for the 0% and 20% Avicel blends. However, probably because of the scatter, it is difficult to draw any conclusion.

Hardness and the Impact Energy for Fracture

The drop height for fracture was determined to within 5% of the total height, except for the softest samples. The use of different tups was tested and showed that the same impact energy *Ei* was required for fracture regardless of the tup weight (110 g or 240 g). Drop heights of 1 mm to 50 mm were possible, and increments of 0.5 mm were measurable.

The results plotted in Fig. 3 show a similar pattern to the results in Figs. 1 and 2, with the 80% and 100% Avicel formulations showing strong linear correlations. Figures 4–7 are the individual formulation results plotted separately. The results (see Table 2) show that the formulations have significantly different linear correlations between hardness and impact energy to fracture. The lower slope for Pharmactose tablets than that for Avicel tablets indicates that, for a given hardness, Pharmactose's impact energy to fracture is less than that of Avicel. Pharmactose tablets are significantly more brittle than Avicel tablets. The impact results show that the mechanical impact strength increased with the Avicel content in the formulation (up to 80% Avicel), even when compressed to the same hardness.

SUMMARY

The studies have shown how different test methods can provide information on the physical integrity of the tablets beyond hardness testing. The results of the fatigue failure and information about the tablet mechanical strength, but did not distinguish between brittle and ductile properties. Impact testing emulates the process conditions and time frame, thereby eliminating time-dependent behavior effects. Impact testing provided an accurate test to distinguish brittle and ductile failure that is not directly correlated to hardness measurements. For tablet development and process investigations, impact testing should be included in addition to current hardness testing to ensure physical integrity able to withstand the processing subsequent to tableting.

ACKNOWLEDGMENTS

The authors would like to thank Ed Schuurman, P&G Packaging Development, for his work in developing and testing the net work to failure on the Instron.

REFERENCES

1. M. Celik, Overview of compaction data analysis techniques, Drug Dev. Ind. Pharm., 18(6,7), 767–810 (1992).
2. J. M. Newton, G. Rowley, J. T. Fell, D. G. Peacock, and K. Ridgway, Computer analysis of the relation between tablet strength and compaction pressure, J. Pharm. Pharmac., 23(Suppl.), 195S–201S (1971).
3. J. T. Fell and J. M. Newton, Determination of tablet strength by the diametral-compression test, J. Pharm. Sci., 59(5), 688–691 (May 1970).
4. H. Schubert, Powder Tech., (11), 107–121 (1975).
5. C. I. Patel and J. N. Staniforth, Determination of the apparent failure viscosity of tablets, J. Pharm. Pharmacol., 39, 647–650 (1987).
6. J. E. Rees and P. J. Rue, Elastic and visco-elastic properties of compressed tablets, J. Pharm. Pharmacol, 29(Suppl.), 37P (1977).
7. J. E. Rees, P. J. Rue, and S. C. Richardson, Work of failure measurements on formulated tablets, J. Pharm. Pharmacol, 29(Suppl.), 38P (1977).
8. J. E. Rees and P. J. Rue, Work required to cause failure of tablets in diametral compression, Drug. Dev. Ind. Pharm., 4(2), 131–156 (1978).
9. J. E. Rees, J. A. Hersey, and E. T. Cole, The effect of loading rate on the strength of tablets, J. Pharm. Pharmac., 22(Suppl.), 64S–69S (1970).
10. C. I. Patel, J. N. Staniforth, and M. Lindley, Fatigue failure behaviour of direct compression excipients, Int. J. Pharm, 39, 93–99 (1987).
11. A. F. Yee, Impact Resistance, in: *Encyclopedia of Polymer Science and Engineering*, 2nd ed., vol. 8, pp. 36–68.