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With the steadily increasing use of fiberboard containers for purposes for which other materials were formerly used, determination of the durability of such containers has become a major problem. This is especially true of the food industry, which is now using over 30% of all fiberboard containers manufactured in the United States- a larger proportion than is used for any other single purpose.(2)

The problem of strength of containers has been accentuated by the recent development of numerous new container materials. How they compare in durability cannot be determined by casual observation. Sometimes the sturdiest looking containers have theleast actual strength. Users must rely on the manufacturers statements that the fiberboard meets certain specifications, or have the materials tested by a commercial laboratory, or conduct the tests themselves. The situation is complicated by the fact that the Railroads are at present giving renewed study to specifications for shipping containers, which have always been a considerable problem for the carriers. For these reasons there is an increasing tendency among large users of fiberboard to adopt means of making their own durability tests.

Hazards to which containers are subject are many and varied. No single test is adequate to determine the ability of the container to withstand all of these hazards successfully.

From numerous studies that have been made, however, it is evident that the damage by puncture is one of the greatest hazards. Several years ago a study was made on large-scale shipments of canned foods which indicated that the number of shipping containers seriously punctured in transit was in the neighborhood of 20% of the total shipped.(2) While this is not an overall average, it does confirm the marked preponderence of punctures over other kinds of damage.

Numerous methods of testing shipping containers were in use before the outbreak of World War 11. Among them were the compression test, the impact test, the vibration test and the bursting test. While all of these methods can give valuable information concerning container strength, none has proved entirely satisfactory for measuring resistance to puncture- the great hazard of transit.

The method ordinarily used to measure the puncture resistance was the bursting test, wherein a small area of the material to be tested was subjected to a uniform hydraulic pressure which was increased steadily untill the material was ruptured. This method has serious drawbacks. Punctures are ordinarily caused by quick blows from sharp objects, as when the corner of a heavy wood crate is thrust against the side of a fiberboard container. This subjects the material to strains quite different from those encountered when it is subjected to a uniform pressure over a sizable area.

During World War 11, the United States found it necessary to ship an unprecedented volume of goods overseas in fiberboard containers. The thousands of items shipped in this way ranged

from delicate instruments to huge quantities of foodstuffs. Because the durability of the containers was of vital importance, the War Department undertook far-reaching studies of container materials. In this work, extensive use was made of a new type of puncture tester developed in the General Electric Laboratory. As a result of its studies, the War Department was able to obtain containers far superior to those used in World War 1.

The new puncture tester originated in the General Electric Company's need for better means of testing its own shipping containers. It was felt that good results could be obtained with a machine striking a blow similar to that which the container was likely to receive in service. In line with this idea an experimental puncture tester was developed by R.L. Beach, in charge of packing in the company's apparatus factories. Use of this apparatus on various kinds of material used on containers was found to give more information than any other kind of test on the material and the quality of its fabrication. Both of these factors are important. No method of fabrication can produce a strong box if the materials are of inferior quality. Similarly, the design of the corrugations and adhesion influence the strength greatly, regardless of the materials used.(2) The puncture tester measured both of these factors and were found to furnish an exdellent guide to the liability of punctures in shipment. As an outcome of this experience, the use of the instrument became part of the company's standard procedure for,testing and now has been adopted by the American Society for Testing Materials(D781-44T)

and The Technical Association of the Pulp and Paper Industry (T803).

The latest type of puncture tester consists of three parts: First is a pendulum from which projects an arm in the form of a 90 degree arc, second is a pointer with appropriate scales for measuring the angle through which the pendulum swings and third is a clamp for holding the specimen in position. The above mentioned arm carries on its free end a triangular, pyramidal point which punctures the specimen. All of these elements are assembled on an iron frame.

The puncture tester was designed with the idea in mind that minor variations would not effect the results. The tester was developed so that it would:

1. Rupture the components of combined materials equally and as far as possible simultaneously.
2. Rupture a considerable amount of material to avoid small variations.
3. Rupture along defined lines so that the rupture would be independent of such factors as grain direction and the direction of the corrugation.
4. Rupture in a sufficient number of directions so that the results would be an average in all directions.
5. Itself be free of relatively small variations because of friction, gages and springs.
6. Be calibrated in definite units of energy, and which could be duplicated and checked without elaborate apparatus.

After the pendulum has been raised to a horizontal position

it possesses a definite amount of energy. When the latch is released the pendulum will swing through its arc of 90 degrees past the vertical, or approximately 180 degrees total. If there is a sample between the plates, its rupture by the puncture point will absorb some of the potential energy of the swinging pendulum. Hence, it will not swing the full 90 degrees past the vertical, and the number of degrees by which,it fails to swing through its full arc is an accurate measure of the energy required to puncture the material being tested.

A lightly held, detachable collar fits around the base of the puncture point. The function of this collar is to hold open the three triangular flaps which will be torn in the sample being tested. Thus the flaps will not rub against the puncture arm and cause frictional error during its swing after the material is ruptured.

The potential energy possessed by the bare pendulum when in the horizontal position is not sufficient to puncture heavy material. It is therfore necessary to increase the energy of the pendulum by adding weights when heavier grades of materials are being tested. These weights are added at the point at which they will increase the energy of the pendulum without increasing the velocity.(2) Different scales are provided, corresponding to the auxiliary weights used.

The puncture tester scale is calibrated to give readings in the range of the numerical values in common usage. Values read on the scale are actually the inch-ounces of energy divided

by the theoretical length in inches of the tear caused by the projected length of the three tearing edges. The units on the scale are therefore inch-ounces per inch of tear.(4) The theoretical length of the tear is taken as 4.24 inches.

For measurement of thin material a modified test is used. Because the puncture tester was designed for measuring a wide range of corrugated and solid board, the regular numerical scale is too condensed to permit accurate readings on extremely light material. To facilitate the testing of wrapping paper and materials of that nature, an auxilliary scale is provided and the pendulum can be released from an elevation of only 45 degrees. When released from this height, the energy of the pendulum is only one third of normal, which permits the scale to be greatly opened up.(2)

The puncture tester can also be used to measure the strength of wrapping paper. For ordinary Kraft wrapping paper it has no particular advantages as tensile and tear tests give satisfactory results. For waterproof papers, on the other hand, the puncture tester is especially useful as other means of testing are not availible. These waterproof papers usually consist of one or more sheets of kraft paper and a layer of asphalt. Sometimes they are reenforced with scrim or sisal threads. Often they are crinkled or creped to conform to regular shaped objects. These papers are extensively used for the lining of boxes to be shipped overseas and also for the covering of machinery and other apparatus shipped in open crates. The cheaper grades, consisting only of kraft

paper laminated with asphalt, have a resistance to puncture of from 10 to 15 puncture test units(P.T.U.'s). The addition of scrim reenforcement between the laminations raises the resistance to puncture to the values of between 20 and 35 P.T.U.'s. If the process of lamination is accompanied with creping, the resistance to puncture will be increased to values between 45 and 55 P.T.U.'s.(2)

The puncture tester provides a quick and accurate means of determining the resistance to puncture of corrugated board, fiberboard, wallboard, vulcanized fiber, plywood or very heavy paper or liner. It is therefore an ideal method of testing fiberboard containers for domestic use and also water resistant boxing used for export shipping.

The tester not only provides a means of establishing the requirements of fiberboard to meet both moderate and severe service and rejecting grades unfit for their intended purpose, but also is useful in evaluation of design, material, and fabrication, and their relation to the serviceability of the container.

There are six main advantages of the puncture tester worth noting, namely:

1. Capable of testing liner board above .014 inch thickness to solid kraft fiberboard of .140 inch thickness, or corrugated board from niminal nontest grade to the heaviest grade of double wallboard.
2. Will test varied materials, such as thin plywood, vulcanized fiber and wallboard.

3. Measures resistance to both puncture and bending.

4. Requires no skill or experience on the part of the operator and has only one moving part- a pendulum.

5. Shows the strength of the material over a considerable area, the measured value being anaverage of both the strongest and the weakest directions of the grain, thus making the measurements proportional to the fiber strength of the material itself.

6. Calibrated in definite units of energy.

Material under test is held rigedly between two clamping plates at the level of the axis of the pendulum. The springs which act upon the clamping plates are not heavy enough to crush the material. As the pendulum swings, puncturing the material, the absorbed energy prevents the pendulum from swinging the full 180 degrees. In actual practice the pointer is set slightly above the anticipated value, so it will travel only a few degrees, thereby further decreasing the almost negligible friction loss.

A clear plastic guard is mounted above the plates and a release latch is provided on the trigger latch to prevent personal injury.

Imbedded in the base is a small level to facilitate positioning of the puncture tester on a firm foundation.

Several punctures are taken on a sample and the average result reported. As in most tests of this nature, the more punctures made, the nearer the value of the true puncture will be obtained.

The Institute of Paper Chemistry recently made an

instrumentation study of the variables affecting the bursting strength with the model "C" Mullen tester.(6) It was found that the various diaphrams used influenced the results to some extent. As the clamp load is increased, the magnitude of the bursting strength decreased. However, at high clamp load, the curve levels off to give a maximum change in bursting strength with changes in clamp load. It was decided that any air in the hydraulic system should be eliminated. Special precautions should be taken to remove all air from the Bourdon tube of the gage.

From this it can be seen that there are many places where errors can enter the burst test. Even the rate of loading in the case of hand-operated machines can cause erroneous results. Likewise, with very thick board there is likely to be a shearing effect before the sheet breaks.

Variables such as these, and the comparable ones for the other test usually run on board, are eliminated by using the puncture tester, either as the complete test or as a supplement test to the others. The element of human error is reduced to a minimum so that results may be duplicated quite accurately.

In addition to puncture, the puncture tester may be used to measure stiffness. This is done by making knife cuts in the form of a "Y" in the board, with each leg of the "Y" slightly longer than the tear would be made by the point in its usual puncture. A template with the "Y" cut out is furnished with the puncture tester so that the cuts are uniform.

In this way the puncture test may be divided up into its two components, namely stiffness and toughness. The toughness value is closely related to the tearing properties of the flat board from which the built-up boards were made. The Elmendorf tearing tests on the flat board gives values that are substantially proportional to the toughness as derived from the difference between the values for total puncture and the stiffness values.(8)

Investigations of the puncture tester by the Institute of Paper Chemistry showed that "The results obtained by the puncture tester coordinate most closely with the serviceability of the boxes," and that "The standard error is remarkably low."(2)

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Experimental Investigation

The laboratory work was carried out to find a correlation between the General Electric Puncture Tester and the Mullen Tester and in addition tests were performed on the Taber Stiffness Tester to see if this stiffness compared to stiffness as performed on the General Electric Puncture Tester.

Since the General Electric Puncture Tester is designed mainly for heavier grades of board, single face and double face corrugated board was used for all tests. When availible, the individual components were likewise tested.

In all this work, the average of forty tests was taken as being the true value of the test. To keep the testing procedure standard, the single face corrugated board was tested such that the rupture occured from the liner side to the corrugated side. In the double faced corrugated board, the tests were made so that the rupture occured from the outer liner to the inner liner. In addition, all Mullen tests were run with the clamp snugly turned but not to the point that the sample was crushed at all.

The work was carried out as four separate experiments; two sets of single face and two sets of double face corrugated board. All of the samples were conditioned one week at 73°F. and 50 per cent relative humidity before testing. When possible Taber stiffness was taken, both machine and cross direction and an average taken since the General Electric stiffness is an overall stiffness.

As the author was only trying to get a correlation among the instruments, basis weight, caliper, etc. were not taken into account.

Experiment 1—Double face corrugated board. Numbered H_2H_2

Only the built-up board was tested in this experiment. The results of the tests were: General Electric Puncture 367, General Electric Stiffness 173 and Mullen 452. The stiffness was approximately one-half of the puncture value. The mullen was approximately one hundred units higher. The individual values for puncture and mullen were quite uniform but the stiffness values were highly irregular with a minimum of 118 and a maximum of 221.

Experiment 2—Double face corrugated board. Numbered Menasha

	GE Puncture	GE Stiffness	Mullen	Taber Stiffness
Kraft liner	27	2	102	502
Corrugating medium	1	too low	34	13
Built-up board	192	111	250	—

The results of this experiment agree very closely with those of experiment 1. The values of experiment 1 are approximately one and one-half times the corresponding values of experiment 2. The stiffness-puncture ratio was about one to and the mullen about fifty points higher for the built-up board. For the kraft liner, the corresponding values were one to fifteen and seventy points higher.

Experiment 3—Single face corrugated board. Numbered 1V

	GE Puncture	GE Stiffness	Mullen	Taber Stiffness
Kraft liner	29	2	103	67
Corrugating medium	2	too low	35	15
Built-up board	86	24	86	—

The corrugating medium was entirely too weak to be tested on the General Electric Puncture Tester and the General Electric Stiffness for the kraft liner was so small that its value is nenligible. However it is worth noting that the Mullen and the General Electric Puncture were the same. For the built-up board the General Electric Puncture was about three and one-half times the stiffness value. The stiffness-puncture ratio for the Kraft liner was one to fifteen, the same as in experiment 2.

Experiment 4-- Single face corrugated board. Numbered lVa

	GE Puncture	GE Stiffness	Mullen	Taber Stiffness
Kraft liner	185	7	146	310
corrugating medium	2	too low	35	15
built-up board	148	51	129	—

The corrugating medium in experiments 3 and 4 came from the same roll, the Kraft liners being different. For the Kraft liner the puncture value was about twelve times the General Electric Stiffness and the Mullen about one and three quarters that of the puncture. The stiffness of the built-up board is about one-third of the puncture value and the Mullen is nineteen points lower than the puncture. It is worth noting that in experiments 3 and 4, both single face board, the Mullen of the built-up board is less than the Mullen of the Kraft liner alone. However, there is insufficient data to prove this is always true with single face corrugated board.

The author found that although the puncture tests were done with fair rapidity, the General Electric Stiffness tests took much more time since it is necessary to make three cuts in the sample before testing. The double face corrugated board was extremely difficult to cut as

specified.

From this limited data the author can draw no definite conclusion as to a direct correlation among the instruments used in the testing. In one case the Mullen was lower than the Puncture and in one case the same as the Puncture but in all other cases it was higher than the Puncture. This gives a correlation factor of .77. With additional investigation an exact correlation may be found to exist. No correlation could be arrived at between the Taber stiffness and General ELectric stiffness as the weights availible with the Taber stiffness tester were not heavy enough for the corrugated board and with the individual components the General Electric stiffness was so loe as to be negligible.

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