SHOCK CUSHIONING BY CORRUGATED FIBERBOARD PADS TO CENTRALLY APPLIED LOADING

USDA FOREST SERVICE
RESEARCH PAPER
FPL 184
1973
Packages are frequently designed so that only the smaller projections of items contact the protective pads, and the package designer is uncertain about the shock-cushioning ability of centrally loaded corrugated fiberboard pads (as happens in cushioning of items having load-bearing projections of different sizes). FPL quantitatively defined this relationship: The optimum effectiveness of partially loaded corrugated fiberboard pads as shock cushions decreases with reduction of the bearing area of the item against the pad. Additionally, the study determined that A-flute pads perform substantially better as shock cushions than B-flute pads when the only difference between the pads involves the geometry of the corrugations.
SHOCK CUSHIONING BY CORRUGATED FIBERBOARD

PADS TO CENTRALLY APPLIED LOADING

By

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INTRODUCTION

Projections of appliances, laboratory apparatus, and various other products serve as concentrated load transfer points for the shock and vibration encountered by packages during shipment. Often these projections bear only against the central portion of larger pads. Thus, cushioning action involves not only the energy absorption mechanism of the pad directly under the projections, but partially that of the adjacent area too. The principal objective of this work, therefore, was to define the performance of A- and B-flute corrugated fiberboard pads under these partial loading conditions.

Behavior of C-flute pads under similar circumstances had been defined previously at FPL in (1) and (2). The entire FPL series of work with the shock-cushioning properties of corrugated fiberboard pads is given in (1) through (2).

TEST SPECIMENS

Test specimens consisted of 12-inch open-ended squares of A- and B-flute corrugated fiberboard fabricated either as two-, three-, four-, five-, or 10-layer pads. The composition and construction details for the pads are given in appendix I and figure 1.

TEST PROCEDURE

The FPL dynamic compression testing equipment, modified to produce partial loading, was used to produce impact tests of the corrugated fiberboard pads. Energy input was varied to produce "bottoming" in each specimen—a requirement in the data computation process. Each specimen was given a single impact and pertinent test data were recorded. For a detailed description of the testing equipment and method refer to appendix II, and figures 2 and 3.

1 Formerly Research General Engineer at the U.S. Forest Products Laboratory. Prior to his retirement, he was actively engaged in the research upon which this report is based.
2 The authors wish to acknowledge the service of J. D. Wiese, who performed the tests and recorded and summarized the resulting data.
3 Maintained at Madison, Wis., in cooperation with the University of Wisconsin.
4 Underlined numbers in parentheses refer to Literature Cited at end of report.
Figure 1.—A representative set of square test specimens and the corresponding disklike control. (M 139 608)

Figure 2.—Dynamic compression test in progress. (M 139 637)

Figure 3.—Loadinghead (simulated item) and various attachments required to achieve different bearing areas. (M 139 636)
RESULTS

Either of two visible failure patterns, depending upon pad thickness, pad type, and the amount of loaded area, occurred during compression of the pads. Shock loading of thinner pads was absorbed principally by the corrugated material directly under the loading head ram (fig. 4, A and B). Additionally, the layers of corrugated fiberboard in the adjacent area were partially loaded by the simulated item in a complex fashion. Because the pads were considerably larger in all instances than the areas directly loaded, the resulting data essentially represented typical “flat crush” behavior.

Thicker pads failed by a more elaborate sequence: Some of the layers crushed initially; then the topmost components tore (coupled with completion of flat crushing of components directly beneath the ram), as shown in figure 4, C and D; and lastly, bottoming occurred (fig. 4, E). Thus, the simulated item tended increasingly to “punch through” thicker pads, as the load-bearing area decreased, and to bypass the additional energy absorption capability of the surrounding area. As might be expected, this condition, most prevalent in 10-layer, A-flute pads, was caused by increased tensile failure of the components along the circumference of the loaded area and reduced the effectiveness of the pads as shock cushions. However, A-flute pads were superior as shock cushions. Components of A-flute pads failed by this manner sooner than comparable B-flute pads because of their greater thickness and the resulting higher tensile stress of components during compression of both types of pads (figs. 4 and 5). From the standpoint of performance, tearing of the periphery around any particular loaded area resulted in a slight decrease of the negative slope of the pad before appreciable compression occurred (fig. 6).

The general condition of pad components after compression is indicated in figure 7, wherein equivalent five-layer, A-flute pads are shown after loading by various sized rams having bearing areas of 35.8, 19.2, 9.6, and 4.9 square inches. Typically, the components remained intact (though stretched) after loading with the largest bearing area, but the loading ram with the least area punched through the pad without much compression of the surrounding material. Component tensile failure first appeared in material centrally loaded with a 9.6-square-inch ram (fig. 7, C).

Figures 8 and 9 are a brief summary of the boundary conditions for the shock isolation performance of five- and 10-layer A- and B-flute pads when loaded by different sized rams at 136 inches per second (equivalent to a flat drop after a 24-in. free fall).

Typically, the peak acceleration—static Stress (G\textsuperscript{m}—W/A) graphs for the fully Loaded specimens were similar in shape and quantitative magnitude, when compared with similar pads that differed only in the degree of loading. It’s noteworthy that the graphs for the controls occurred at markedly lower static stress. This implied directly that larger pads would be required for similar shock cushioning, if they were fully vented over their entire surfaces. The quantitative magnitude of this effect was uncertain, however, because of the partial loading of areas immediately adjacent to that under compression.

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This behavior differed from the “tipping and rolling” of corrugations often observed during tests of fully loaded pads (4, 5).

According to a recent estimate by the Technical Committee of the Fibre Box Association, these represent the extremes of the range of pad layer thicknesses most commonly used for shock isolation purposes in packages.
Figure 4.—A typical series of cutaway sections (after rebound) of multilayer A-flute pads after loading by the 4.9-square-inch cylindrical projection of a simulated fragile item: (A) two--; (B) three--; (C) four--; (D) five--; and (E) 10-layer pads. (M 139 829)

Figure 5.—A typical series of cutaway sections of multilayer B-flutes pads loaded by the same apparatus as in figure 4. (M 139 830)
Figure 6.—$GW/A$ graphs for different thicknesses of A-flute pads centrally loaded over 4.9 square inches by simulated items with an initial velocity of 136 inches per second. (The number of pad layers is indicated for each curve.)

Figure 7.—The condition (after rebound) of five-layer, A-flute pads after loading by various-sized rams; (A) 35.8, (B) 19.2, (C) 9.6, and (D) 4.9 square inches.
Figure 8.--The shock loading performance of five- and 10-layer, A-flute pads centrally loaded at 136 inches per second by simulated items having different bearing areas.
Figure 9.--The shock loading performance of five- and 10-layer B-flute pads centrally loaded at 136 inches per second by simulated items having different bearing areas.
Details of the shock-cushioning performance of these and various other partially loaded pads are presented quantitatively in the peak acceleration–static stress ($G_m$–$W/A$) graphs shown in appendix III, figures 10 through 47.2

**CONCLUSIONS**

1. The optimum effectiveness of partially loaded corrugated fiberboard pads as shock cushions decreases somewhat with reduction of the bearing area of the item against the pad.

2. A–flute pads perform substantially better as shock cushions than B–flute pads, if they differ only in geometry of cross section.

3. As with all package cushioning materials, the package designer must relate variation of pad bearing area, thickness, and type of item fragility, if damaging acceleration is to be avoided during handling and shipment. Therefore, these design graphs are essential for quantitatively accurate design of this nature.

**LITERATURE CITED**


2Note: Tests of this nature were not conducted with 20-layer pads loaded by a 35.8-square-inch head, because this exceeded the energy delivery capability of the apparatus.
APPENDIX I - PREPARATION OF TEST SPECIMENS

The basic material used to make the test specimens was commercially made, double-faced, single-wall, A- and B-flute fiberboard. The first step in the preparation process was to cut 12-inch squares drawn by systematic random selection. The squares were bonded with flutes aligned parallel as two-, three-, four-, five-, and 10-layer pads, using water glass (sodium silicate) and a pressure of 1.0 pound per square inch, figure 1.

As shown in figure 1, disks having a 6.75-inch diameter were also cut from the same materials, aligned, and bonded as five-layer pads in a similar manner to serve as comparative controls with previous work (1,4-8).

The average thickness of the two liners was 0.115 and 0.117 inch. The corresponding basis weights were 40.7 and 40.9 pounds per 1,000 square feet. The average thickness of the corrugating medium was 0.0094 inch, and its basis weight was 26.5 pounds per 1,000 square feet.

Because the same rolls of liner and corrugating medium were used to make both kinds of fiberboard, this work allowed a true comparison of performance differences attributable solely to the geometry of the cross section of corrugated fiberboard.

The test specimens following fabrication were preconditioned at 80° ± 3° F. and 32 ± 2 percent relative humidity. They were then brought to equilibrium with 73.5° ± 3.5° F. and 50 ± 2 percent relative humidity.
APPENDIX II - TEST EQUIPMENT AND METHOD

All dynamic compression tests were conducted with the FPL dynamic compression testing equipment shown in figure 2. The test in progress represents the partial loading action of a rigid object against a freely ventilated test specimen mounted vertically against a 2-ton steel-concrete abutment. The loading head (simulated item) swung against the specimen at a predetermined impact velocity, and the resulting acceleration-time response was recorded for this set of experimental conditions. The test was repeated with other test conditions to provide data required for the conditions being explored.

The bearing area of the loading head projection was adjustable from 35.8 square inches (full size) to 4.9 square inches (minimum) by attaching with double-coated tape the maple devices shown in figure 3.

Essentially, the acceleration history of the loading head was converted into an electrical analog as a function of time by an attached strain gage accelerometer. The electrical analog representing acceleration was fed at 15 inches per second through DC preamplifiers into an FM magnetic tape recorder. Later, in sequence the sets of pulses were played back at 1-7/8 inches per second through galvanometer amplifiers and recorded by an optical oscillograph. The resulting pulses were displayed on an oscillograph printout chart at 40 inches per second, and this provided a suitably amplified record for subsequent manual digitization.

Input energy, a varied factor during the tests, was chosen by trial drops on extra pads so that the resulting acceleration-time pulses just reached "bottoming" of the pad under compression. This allowed maximum accuracy in the manual integration of area under acceleration-time pulses recorded at these conditions and subsequent calculation of design criteria by the computer.

Following manual digitization the data were (1) computed by an IBM 1620 digital computer, (2) plotted as "peak acceleration-static stress" graphs, and (3) analyzed.

Frequency Response of the System

The limiting frequency response of the different recording components in the system was the 0 to 1,000 Hertz of the strain gage accelerometer used. This particular type of accelerometer was selected because of its accuracy of reproduction down to 0-Hertz, together with only slight signal attenuation of significant high-frequency components.

Velocity Measurement

Because the suspension wires of the pendulum were 10 feet long, the velocity of the loading head was approximately constant where pad loading occurred at the bottom of the arc. This permitted measurement of the time interval required by a fixed, projecting area of the loading head to traverse the nominal 1-inch distance between the fixed reference points. Specifically, the time elapsed between interruption of the two narrow collimated light rays (1.008 in. apart at comparable points) was recorded by a digital counter, and the velocity at impact was calculated by

\[ \text{velocity at impact} = \frac{1.008}{t \times 10^{-3}} \]

where \( v_i \) is velocity at impact in inch per second and \( t \) is the time in seconds required to traverse 1.008 inches (the distance between the midpoints of the slits).
Figure 10.--Dynamic compression behavior of two-layer, A-flute pads when centrally loaded by a 4.9-square-inch ram at impact velocities equivalent to various drop heights.
Figure 11.--Dynamic compression behavior of three-layer, A-flute pads when centrally loaded by a 4.9-square-inch ram at impact velocities equivalent to various drop heights.
Figure 12.—Dynamic compression behavior of four-layer, A-flute pads when centrally loaded by a 4.9-square-inch ram at impact velocities equivalent to various drop heights.
Figure 13.--Dynamic compression behavior of five-layer, A-flute pads when centrally loaded by a 4.9-square-inch ram at impact velocities equivalent to various drop heights,
Figure 14.—Dynamic compression behavior of 10-layer, A-flute pads when centrally loaded by a 4.9-square-inch ram at impact velocities equivalent to various drop heights.
Figure 15.—Dynamic compression behavior of two-layer, A-flute pads when centrally loaded by a 9.6-square-inch ram at impact velocities equivalent to various drop heights.
Figure 16.—Dynamic compression behavior of three-layer, A-flute pads when centrally loaded by a 9.6-squareinch ram at impact velocities equivalent to various drop heights.
Figure 17.—Dynamic compression behavior of four-layer, A-flute pads when centrally loaded by a 9.6-square-inch ram at impact velocities equivalent to various drop heights.
Figure 18.—Dynamic compression behavior of five-layer, A-flute pads when centrally loaded by a 9.6-square-inch ram at impact velocities equivalent to various drop heights.
Figure 19. --Dynamic compression behavior of 10-layer, A-flute pads when centrally loaded by a 9.6-square-inch ram at impact velocities equivalent to various drop heights.
Figure 20.—Dynamic compression behavior of two-layer, A-flute pads when centrally loaded by a 19.2-square-inch ram at impact velocities equivalent to various drop heights.
Figure 21.--Dynamic compression behavior of three-layer, A-flute pads when centrally loaded by a 19.2-square-inch ram at impact velocities equivalent to various drop heights.
Figure 22: Dynamic compression behavior of four-layer, A-flute pads when centrally loaded by a 19.2-square-inch ram at impact velocities equivalent to various drop heights.
Figure 23.--Dynamic compression behavior of five-layer, A-flute pads when centrally loaded by a 19.2-square-inch ram at impact velocities equivalent to various drop heights.
Figure 24.—Dynamic compression behavior of 10-layer, A-flute pads when centrally loaded by a 19.2-square-inch ram at impact velocities equivalent to various drop heights.
Figure 25.—Dynamic compression behavior of two-layer, A-flute pads when centrally loaded by a 35.8-square-inch ram at impact velocities equivalent to various drop heights.
Figure 26. Dynamic compression behavior of three-layer, A-flute pads when centrally loaded by a 35.8-square-inch ram at impact velocities equivalent to various drop heights.
Figure 27.--Dynamic compression behavior of four-layer, A-flute pads when centrally loaded by a 35.8-square-inch ram at impact velocities equivalent to various drop heights.
Figure 28.--Dynamic compression behavior of five-layer A-flute pads when centrally loaded by a 35.8-square-inch ram at impact velocities equivalent to various drop heights.
Figure 29.—Dynamic compression behavior of two-layer, B-flute pads when centrally loaded by a 4.9-square-inch ram at impact velocities equivalent to various drop heights.
Figure 30.--Dynamic compression behavior of three-layer, B-flute pads when centrally loaded by a 4.9-square-inch ram at impact velocities equivalent to various drop heights.
Figure 31.--Dynamic compression behavior of four-layer, B-flute pads when centrally loaded by a 4.9-square-inch ram at impact velocities equivalent to various drop heights.
Figure 32.—Dynamic compression behavior of five-layer B-flute pads when centrally loaded by a 4.9-square-inch ram at impact velocities equivalent to various drop heights.
Figure 33.—Dynamic compression behavior of 10-layer, B-flute pads when centrally loaded by a 4.9-square-inch ram at impact velocities equivalent to various drop heights.
Figure 34.—Dynamic compression behavior of two-layer, B-flute pads when centrally loaded by a 9.6-square-inch ram at impact velocities equivalent to various drop heights.
Figure 35.—Dynamic compression behavior of three-layer, B-flute pads when centrally loaded by a 9.6-square-inch ram at impact velocities equivalent to various drop heights.
Figure 36.--Dynamic compression behavior of four-layer, B-flute pads when centrally loaded by a 9.6-square-inch ram at impact velocities equivalent to various drop heights.
Figure 37.--Dynamic compression behavior of five-layer, B-flute pads when centrally loaded by a 9.6-square-inch ram at impact velocities equivalent to various drop heights.
Figure 38.—Dynamic compression behavior of 10-layer, B-flute pads when centrally loaded by a 9.6-square-inch ram at impact velocities equivalent to various drop heights.
Figure 39.--Dynamic compression behavior of two-layer, B-flute pads when centrally loaded by a 19.2-square-inch ram at impact velocities equivalent to various drop heights.
Figure 40.--Dynamic compression behavior of three-layer, B-flute pads when centrally loaded by a 19.2-square-inch ram at impact velocities equivalent to various drop heights.
Figure 41.—Dynamic compression behavior of four-layer, B-flute pads when centrally loaded by a 19.2-square-inch ram at impact velocities equivalent to various drop heights.
Figure 42.--Dynamic compression behavior of five-layer, B-flute pads when centrally loaded by a 19.2-square-inch ram at impact velocities equivalent to various drop heights.
Figure 43.--Dynamic compression behavior of 10-layer, B-flute pads when centrally loaded by a 19.2-square-inch ram at impact velocities equivalent to various drop heights.
Figure 44.—Dynamic compression behavior of two-layer, B-flute pads when centrally loaded by a 35.8-square-inch ram at impact velocities equivalent to various drop heights.
Figure 45.--Dynamic compression behavior of three-layer, B-flute pads when centrally loaded by a 35.8-square-inch ram at impact velocities equivalent to various drop heights,
Figure 46.--Dynamic compression behavior of four-layer, B-flute pads when centrally loaded by a 35.8-square-inch ram at impact velocities equivalent to various drop heights.
Figure 47.—Dynamic compression behavior of five-layer, B-flute pads when centrally loaded by a 35.8-square-inch ram at impact velocities equivalent to various drop heights.