

IMPACT RESISTANCE OF THREE CORE MATERIALS AND SIX SANDWICH CONSTRUCTIONS AS MEASURED BY FALLING-BALL TESTS

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IMPACT RESISTANCE OF THREE CORE MATERIALS AND SIX
SANDWICH CONSTRUCTIONS AS MEASURED BY FALLING-BALL TESTS¹

By

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Summary

This report presents data on the impact resistance of three core materials: (1) balsa, (2) hard, synthetic, sponge rubber (a proprietary product), and (3) cellular cellulose acetate, as measured by impact of a falling ball. Each was tested separately and in combination with two facing materials, aluminum and resin-impregnated glass cloth. The ball was dropped from progressively increasing heights and the condition of the materials was observed after each drop. The deflection caused by each drop was also measured. Deflection was found to be proportional to height of drop until a "critical deflection" was reached. Beyond this point, deflection increased much more rapidly.

The observations indicated that the hard sponge rubber and cellular cellulose acetate core materials were about equal in resistance to damage and that the balsa wood was inferior to them; also that the aluminum and the glass-cloth facings were about equal. The heights of drop at the critical deflection indicated essentially the same comparisons.

Introduction

The tests were undertaken to determine the relative resistance of a few core materials to damage by impact. Since the core materials are relatively weak and in a structure are always used with relatively dense facings, the evaluation of the impact resistance of the cores was made on sandwich constructions as well as on the core materials themselves. An evaluation of the relative resistance to damage was made by a qualitative estimate of the degree of damage caused to panels of equal size and thickness mounted in the same way and by consideration of the height of drop of the ball which caused the damage. The falling-ball impact test was intended to cause damage similar to that which occurs to a sandwich construction in service when a wrench, stone, or other object strikes the material.

¹This is one of a series of progress reports prepared by the Forest Products Laboratory relating to the use of wood in aircraft. Results here reported are preliminary and may be revised as additional data become available.

Test Material

The core materials used in the sandwich constructions were balsa wood; hard, synthetic, sponge rubber; and cellular cellulose acetate. The facing materials were aluminum sheets and resin-impregnated glass cloth. The same core materials were tested separately without facings.

The balsa wood was carefully selected to avoid defects and wide variations in density. The density varied between 6 and 9 pounds per cubic foot. For a more specific control of density and strength, the balsa used in the 5-inch central square of all panels was cut from the same plank. The rough wood planks were surfaced and were cut across the grain into 1/2-inch thick blocks. These blocks were glued edge to edge to form the sandwich core. The grain of the balsa was, therefore, perpendicular to the face of the panel.

The hard sponge-rubber core material, a cellular synthetic-rubber product, was cut from 1-1/2- by 20- by 36-inch pieces. The cellular structure of this material was fairly uniform. The cells were irregularly shaped polyhedrons, about 0.04 inch in diameter. The pieces, as received, had a thin skin which was completely removed before the test specimens were made. The density of the finished pieces was 6.3 pounds per cubic foot.

Cellular cellulose acetate, a foamed product extruded in strips approximately 5/8 by 2-5/8 inches in cross section was received in various lengths from 4 to 10 feet. Its cellular structure, like that of the hard sponge rubber, was fairly uniform. The irregularly shaped cells were about 0.01 inch in diameter. The pieces, as received, had a thin skin on the 5/8- and 2-5/8-inch surfaces which was completely removed by machining before the test specimens were made. The machined strips, 1/2 by 2-1/2 inches and cut to a length of 16 inches were glued edge to edge so that the 2-1/2- by 16-inch area became part of the face of the core panel. The density of the finished cores averaged 6.3 pounds per cubic foot.

The glass-cloth facings consisted of a three-ply construction of glass cloth impregnated with a contact-pressure laminating resin to a resin content of about 45 percent, based on total weight of resin and cloth. The lengthwise directions of adjacent layers of glass cloth were placed at right angles to each other in the manufacture of the laminate; that is, a cross-laminated construction was formed. The three layers of impregnated glass cloth were bonded to each other and to their respective cores in one pressing operation. The total thickness of each facing was approximately 0.010 inch.

The aluminum facings were of aluminum sheet designated 24S-H. The sheets, as received, were 0.005 by 20 by 36 inches. The lengthwise or rolled direction was parallel to the 36-inch edge. The bonding procedure used in the attachment of the aluminum to its respective cores was as follows: (1) the aluminum was etched with a sodium dichromate cleaning solution and dried; (2) a rubber, vinyl, phenol composition was applied

to the aluminum and then cured; (3) a room-temperature-setting resorcinol glue was applied to the rubber, vinyl, phenol composition; and (4) the faces were pressed to the cores.

Three sandwich panels, 16 inches square with 1/2-inch cores, of each face-and-core combination were constructed and tested and three panels 1/2 inch thick consisting of core material only were constructed and tested for each core material.

The pressure used in assembling and gluing the sandwich constructions was about 13 pounds per square inch, except for the 0.005-inch aluminum on balsa, which was 100 pounds per square inch.

Test Procedure

The dimensions of the impact test specimens were 9 by 10 inches. They were cut from the center of the 16- by 16-inch panels. The specimens were placed between two frames of 1-1/2-inch thick plywood, in each of which was a central opening 6 inches square. The specimens were securely clamped between the frames by eight 3/8-inch carriage bolts, equally spaced on a circle 8.6 inches in diameter. The specimen and frame were mounted for test, as shown in figure 1, in an impact machine which provided permanent centering and rigid support. A 2-inch diameter steel ball weighing 1.18 pounds was automatically released from the electromagnet at various heights.

The steel ball was dropped upon a single specimen at the center of the opening; first from a 2-inch height, next from 4 inches, and so on increasing the height by 2-inch increments to 72 inches or to failure. The ball was caught after it had struck the specimen a single blow from each of the measured heights. Following each drop on the center of the specimen, the faces of the specimen were examined for signs of failure. The height of fall at which the first failure appeared on the top face, core, or bottom face was recorded. Also the deflection of the panel after each impact, as measured by means of a 1/8-inch diameter steel rod in a brass cylinder, was recorded. The rod was placed in contact with the bottom face, and the panel, under impact, pushed the rod into the cylinder a distance equal to the deflection. The friction of the rod in the cylinder was adjusted to overcome the inertia of the rod and halted its movement at the panel's maximum deflection. When core materials without facings were under test, indentation of the lower face by the rod was avoided by capping the rod with a piece of plywood about 3/4 inch square.

Discussion

In falling-ball or similar tests on sandwich materials and sandwich constructions for use in aircraft, the condition of the panel at some specific stage in the progressive breaking down is the significant result rather than the height of drop or the severity of the blow required for

complete penetration. The heights of drop required to produce some unique or specifically defined condition and the height of drop at the critical deflection, as later discussed, are the numerical results available for comparisons. In this study, comparable conditions or stages of the failure cannot be exactly defined because of the diversity of materials and consequent diverse types of failure or damage that are involved. It was thus necessary to adopt definitions that describe what seem to be comparable degrees of failure as among the several materials and in accordance with whether the materials were tested singly or in combinations.

The adopted definitions, of first failure and of critical deflection that were assumed as being comparable, for which values of height of fall are listed in table 1, are as follows:

(1) Top Facing

The top facing was considered as having failed when visible cracks or tears appeared on the top surface.

(2) Core

(a) Core within the sandwich.--The core material was considered as having failed when a circular bulge appeared on the bottom facing indicating a shear failure.

(b) Core without facings.--The core material was considered as having failed when cracks were visible on either the top or bottom surface of the material.

(3) Bottom Facing

The bottom facing was considered as having failed when cracks appeared on the bottom surface or between the bottom facing and the core material.

(4) Critical Deflection of the Panel

The panel was considered as having failed when the height of drop at which the linear relationship of the height of drop to the deflection changed so that the deflection increased with greater rapidity.

In general, dents appeared on the top face with the first (2-inch) fall, and their size increased with each succeeding fall. This additional form of damage occurred on all the test specimens and was not measurable to any degree of accuracy, therefore no criterion was established or defined in this series of tests.

The individual types of failure conforming to the adopted definitions of first failure or first damage, other than denting, are discussed in the following observations.

The first damage to the top facing, in addition to the dents, was in the form of cracks in the aluminum or white spots on the glass cloth. The white spots were the result of the resin breaking away from the glass fibers and leaving unsupported glass fibers from which cracks emanated. Continued impacts increased the cracks and tears.

The first damage of the core materials within the sandwich panels was defined as the height at which a shear failure first appeared. The shear failure of the core in the sandwiches was indicated on the bottom face of the panel by a circular bulge within which could be seen the outline of a shear failure. This failure in the balsa-core panels had the shape of a rounded plug ranging from $3/8$ to 1 inch in diameter. The hard rubber and cellulose acetate cores were damaged in compression (as shown by the depth of dent) with each increase in height of drop until a failure took place in the top facing of either facing material; then a large, circular plug of the core material caused a projection to appear on the bottom facing. In the aluminum-faced sandwiches the shear was easily identified, but in those faced with glass cloth a separation of the lower facing from the core all around the core plug and beyond it accompanied the shear failure.

The glass cloth on the bottom side separated from its various cores outside the plug area, and the separation finally extended to the frame. This loose face, acting as a hammock, continued to support the pulverized core and additional impact loads to 72 inches of drop, but the panel as a unit was useless after the separation failure occurred. When the glass-cloth facings on the bottom separated from any of the three core materials outside the plug area, no failure was observed on the bottom face; therefore the height at which the bottom glass-cloth facing separated from the core was arbitrarily taken as the first appearance of failure of the bottom face. The glue bond between the aluminum and its core materials appeared to be stronger than the bond between glass cloth and its cores. The aluminum on the bottom side clung to its cores and elongated until it failed in tension.

In the tests on cores without facings, the first failure occurred in the material itself only in the hard rubber. This failure was in the form of cracks beginning at the center of the panel on the bottom side and extending outward to the frame. The cellulose acetate appears to be the toughest of the materials, but in test the glue bonds between the 2-1/2-inch wide strips failed first with later breakage of the material. The balsa likewise failed first at the glue lines between individual blocks and later along radial lines in the wood. Figures 2 through 7 show top and bottom views of samples of the various failures. The core material in the glass-cloth sandwiches is also shown by cutting away the bottom facing after the separation of the facing from the core had taken place.

Graphs of deflection against height of drop showed a linear relationship until a well-defined point was reached after which the deflection

increased much more rapidly. The height of drop at which this change occurred has been defined as the drop at critical deflection. Figure 8 is typical of such graphs.

Figure 9 is a graphical presentation of the results. All parts of the sandwich construction, on which results of the impact test were observed, are plotted individually. The graph shows 10 ways in which the 3 core materials may be compared. In each comparison, there is assumed to be only one variable -- the core material. Individual comparisons of the relative resistance to impact show that the hard rubber resists damage to the top facings to a higher degree than balsa or cellular cellulose acetate, but the cellulose acetate withstands higher impact drops before damage occurs to the bottom facings. Impact resistance of the core materials in the sandwich show hard rubber and cellulose acetate about equal and balsa inferior to them. The comparison of core materials on the basis of the critical-deflection method indicates that cellulose acetate is the most resistant and balsa the least.

Conclusions

In general, the balsa core material, either alone or in a sandwich, was considerably less resistant to damage by impact than either the hard rubber or the cellular cellulose acetate. The hard rubber and the cellulose acetate were about equal with the cellulose acetate having a slight advantage.

Comparison of the impact resistance of these core materials is masked by other variables when they are used in a sandwich construction. Some of these variables are: (1) the faces supported the cores to the extent that different types of failure in the core were experienced when the core materials were tested alone as compared to tests in combination with facings to form a sandwich; (2) the strength of the bond between the core and its face influences the impact resistance of the panel as shown (a) by the bonds to the aluminum compared with bonds to the glass cloth and (b) also by the third specimen of glass-cloth, cellulose-acetate sandwich in which the core was damaged at one-fourth the height of drop that caused similar damage to the first two specimens.

The height at which the various parts of the sandwich failed ranges from 2 to 58 inches. No one part can be pointed to as being the most critical.

The deflection method of determining critical height of the falling ball at which a panel fails warrants further consideration, since drops at the critical deflections were a measure of the over-all resistance to impact damage. These observations were based on a limited number of tests, but the critical heights by this method parallel the heights at which damage was observed on the bottom face of the panels.

Table 1.--Results of impact tests (falling ball)

Material		First appearance of failure			Drop at critical deflection ¹	Remarks	
Facing	Core	Top face	Core	Bottom face			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	
		Inches of drop					
	1/2-inch balsa		8.0			Tension cracks perpendicular to annular rings and at glue bond between blocks	
			2.0		8.0		
					12.0		
Av.			4.6		10.0		
Three-ply resin-impregnated glass cloth:	1/2-inch balsa	16.0	8.0	8.0		Shear failure in core, separation of bottom facing from core, cracks in top face but never in bottom face	
		18.0	10.0	10.0	44.0		
		12.0	12.0	14.0	36.0		
Av.		15.3	10.0	10.6	40.0		
0.005-inch aluminum	1/2-inch balsa	26.0	8.0	26.0		Early shear failure in core; top and bottom facings failed in tension	
		26.0	10.0	30.0	22.0		
		32.0	12.0	36.0	36.0		
Av.		28.0	10.0	30.6	29.0		
	1/2-inch hard rubber ²		6.0			All cracks were radial from the point of impact	
			12.0		12.0		
			4.0		14.0		
Av.			7.3		13.0		
Three-ply resin-impregnated glass cloth:	1/2-inch hard rubber ²	22.0	24.0	24.0		Top face developed cracks followed by shear in core and separation of bottom facing from core but no failure in bottom facing	
		26.0	42.0	42.0	42.0		
		20.0	58.0	58.0	58.0		
Av.		22.6	41.3	41.3	50.0		
0.005-inch aluminum	1/2-inch hard rubber ²	32.0	34.0	34.0		Top-face cracks followed by shear in core and tension failure in bottom facing	
		40.0	40.0	42.0	42.0		
		24.0	28.0	30.0	28.0		
Av.		32.0	34.0	35.3	35.0		
	1/2-inch cellulose acetate		2.0			Failures first occurred in bond between strips	
			8.0		16.0		
			2.0		18.0		
Av.			4.0		17.0		
Three-ply resin-impregnated glass cloth:	1/2-inch cellulose acetate	24.0	56.0	58.0		Cracks in top face followed by shear in core and separation of bottom facing from core except last panel which had separation of bottom facing from core first	
		22.0	52.0	52.0	52.0		
		16.0	14.0	10.0	48.0		
Av.		20.6	40.6	40.0	50.0		
0.005-inch aluminum	1/2-inch cellulose acetate	20.0	24.0	52.0		Top-face cracks in tension followed by shear in core and bottom face tension failure	
		26.0	34.0	38.0	38.0		
		30.0	34.0	50.0	50.0		
Av.		25.3	30.6	46.6	44.0		

¹Deflections were measured only on two of each group of three specimens.²Hard synthetic sponge rubber (a proprietary product).

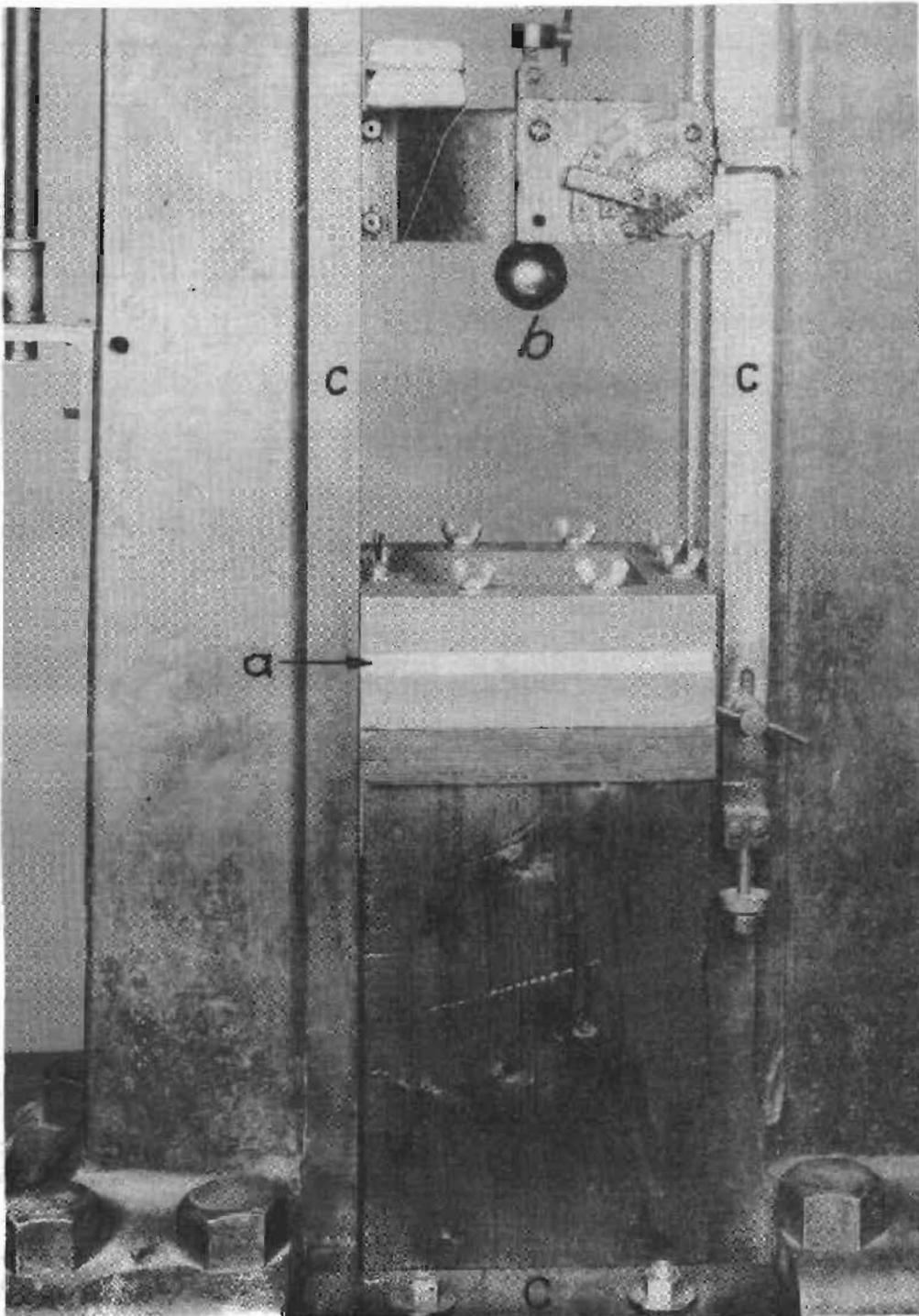
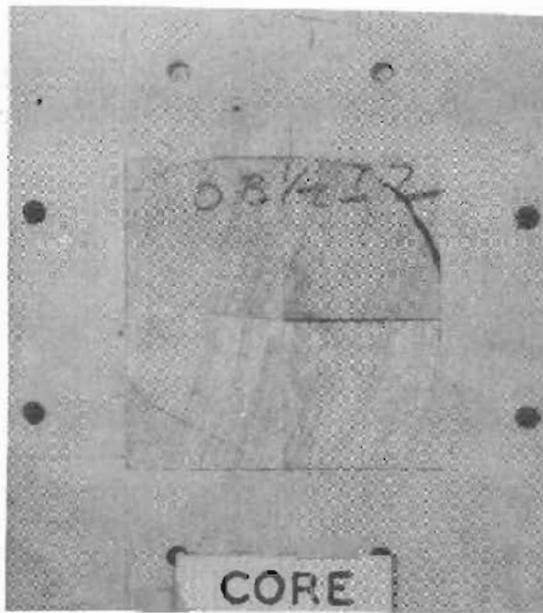
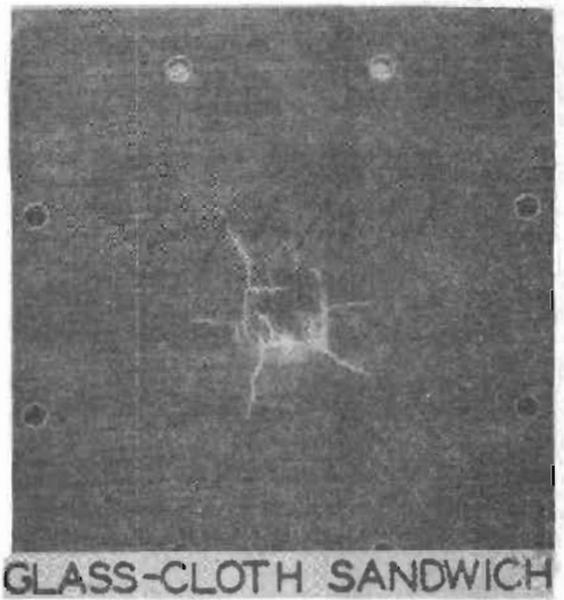


Figure 1.--Apparatus for impact test (falling ball), showing:
(a) test specimen in plywood frame; (b) 2-inch diameter steel ball held by electro-magnet; (c) base and vertical guide rails of machine normally used for impact-bending tests.



A



B



C



D



Figure 2.--Top view of impact specimens with balsa wood cores. A, failure of core without facings; B, cracks in the top face of glass-cloth sandwich; C, first cracks in aluminum sandwich; and D, additional damage to top face in aluminum sandwich.

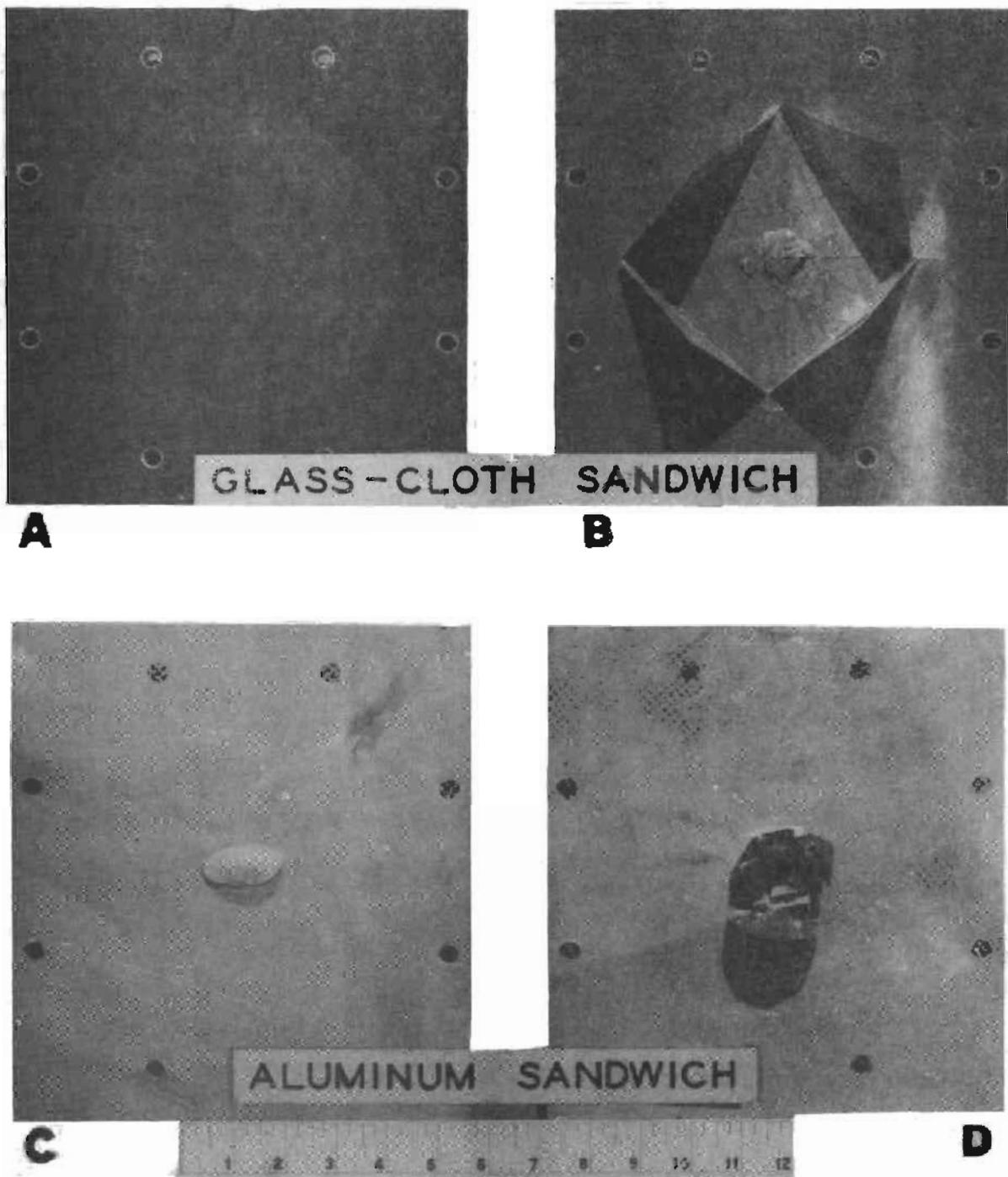
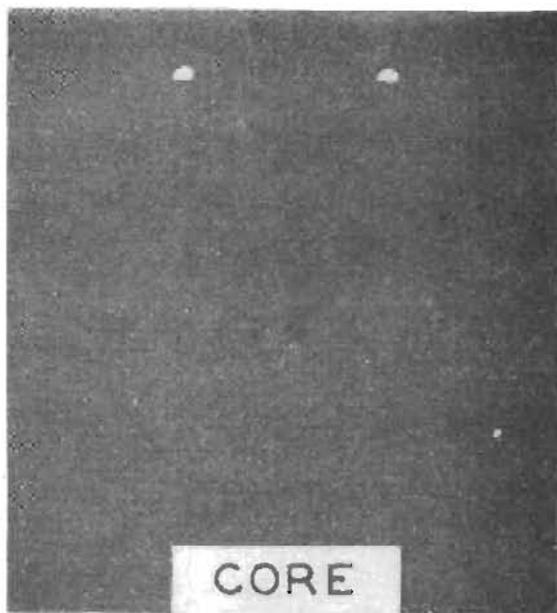
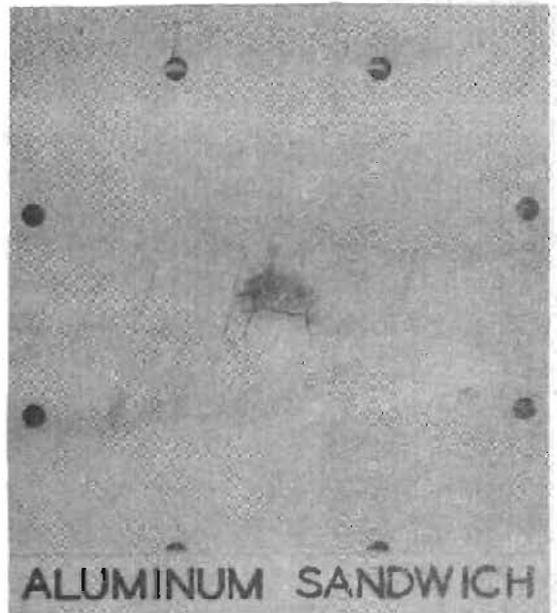


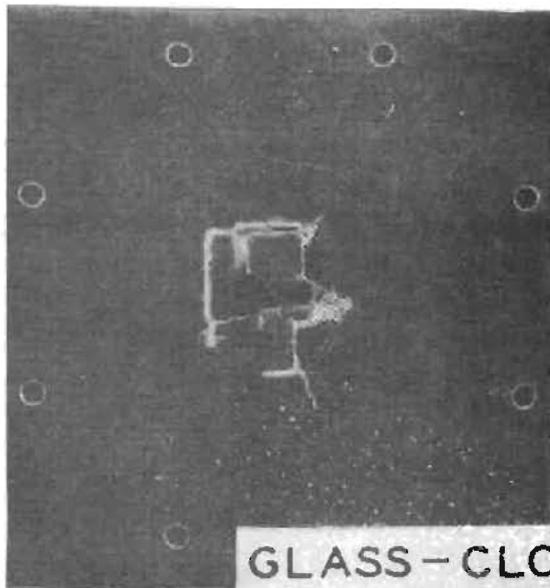
Figure 3.--Bottom view of impact specimens with balsa wood cores. A, separation of facing from core (light-colored circular area) of glass-cloth sandwich; B, core failure beneath a separation between glass-cloth facing and core; C, impression of first balsa plug and first crack on the aluminum face; and D, additional damage to bottom aluminum face.



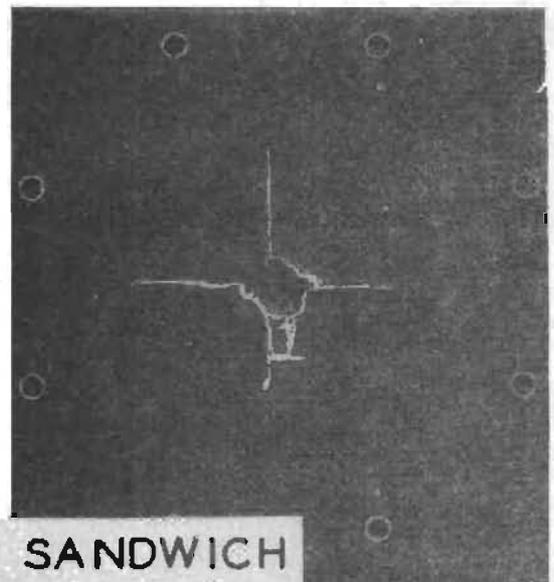
A



B



C



D

GLASS-CLOTH SANDWICH

1 2 3 4 5 6 7 8 9 10 11 12

Figure 4.--Top view of impact specimens with hard sponge-rubber cores. A, pie-shaped failure of core without facings; B, first cracks in top face of aluminum sandwich; and C, D, cracks in top face of glass-cloth sandwiches.

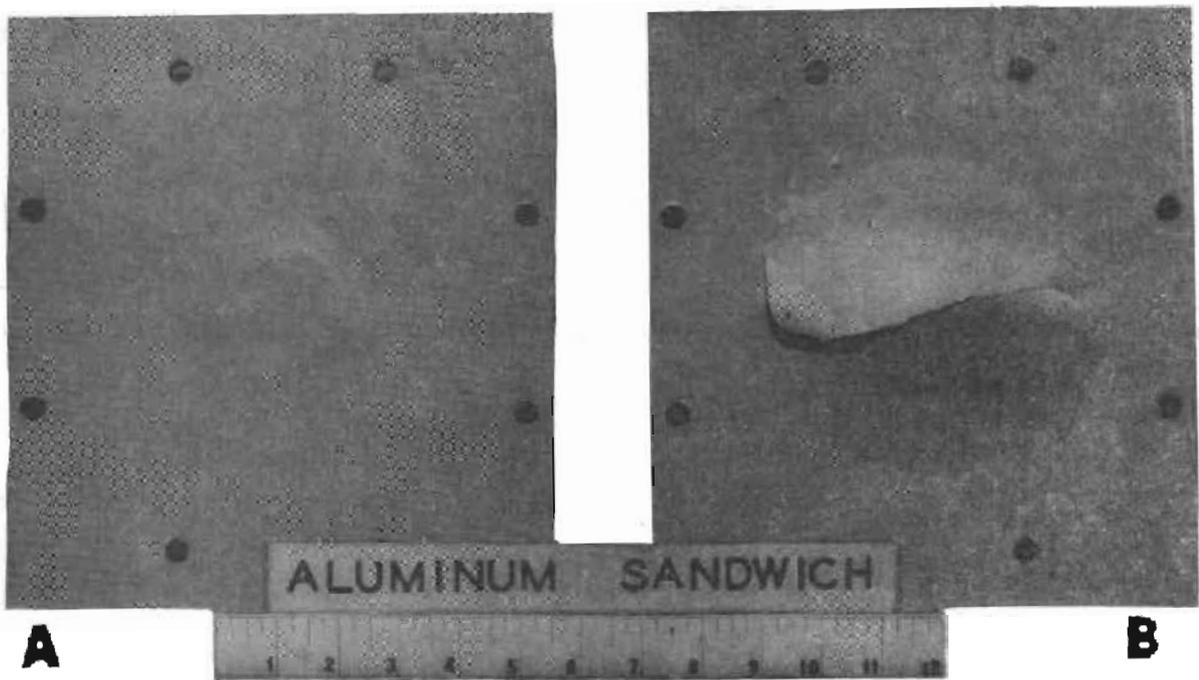
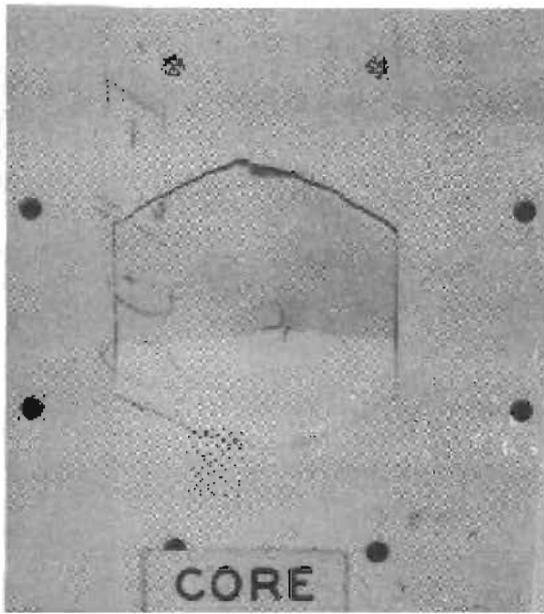
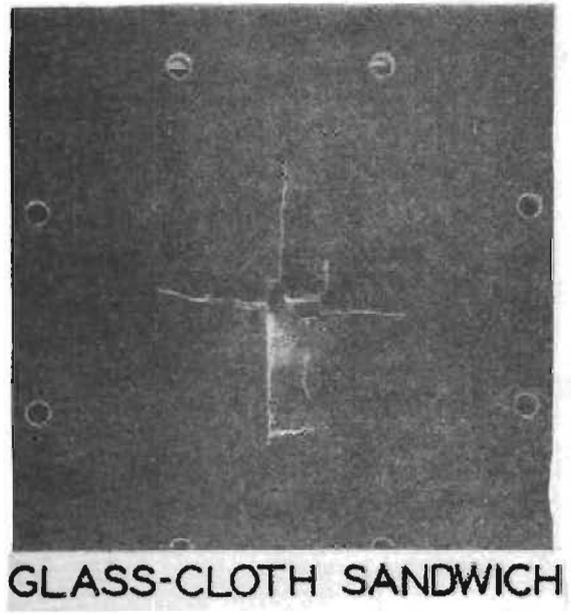


Figure 5.--Bottom view of impact specimens with hard sponge-rubber cores.
A, the impression of the core failure (circular plug) on the aluminum face; and B, aluminum failure.

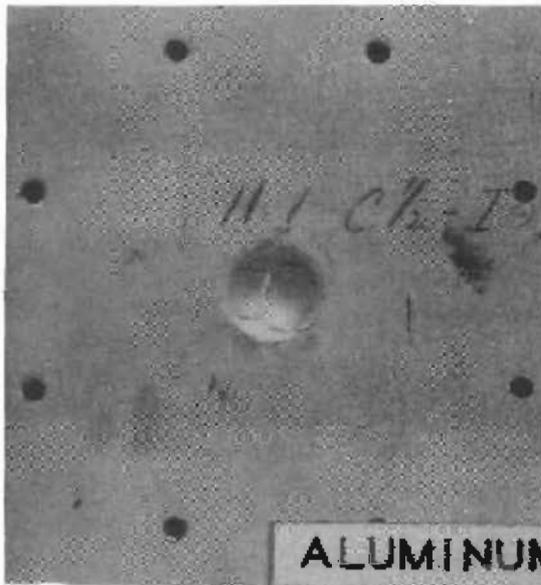
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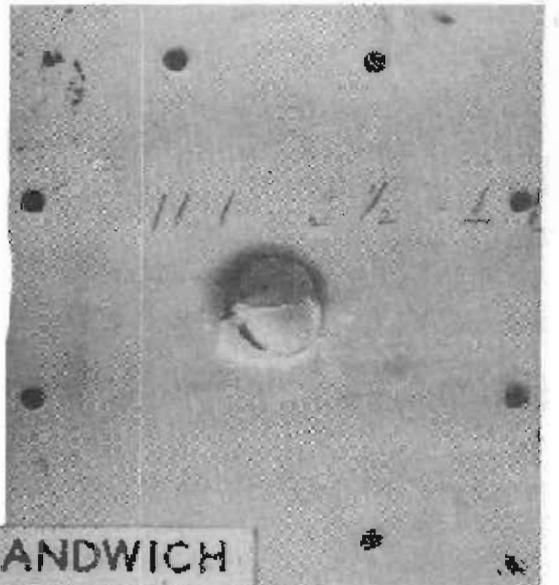
A



B



C



D



Figure 6.--Top views of impact specimens with cellular cellulose acetate cores. A, failure of core without facings; B, face cracks in glass-cloth sandwich; C, face crack in aluminum sandwich; and D, additional damage in aluminum sandwich.

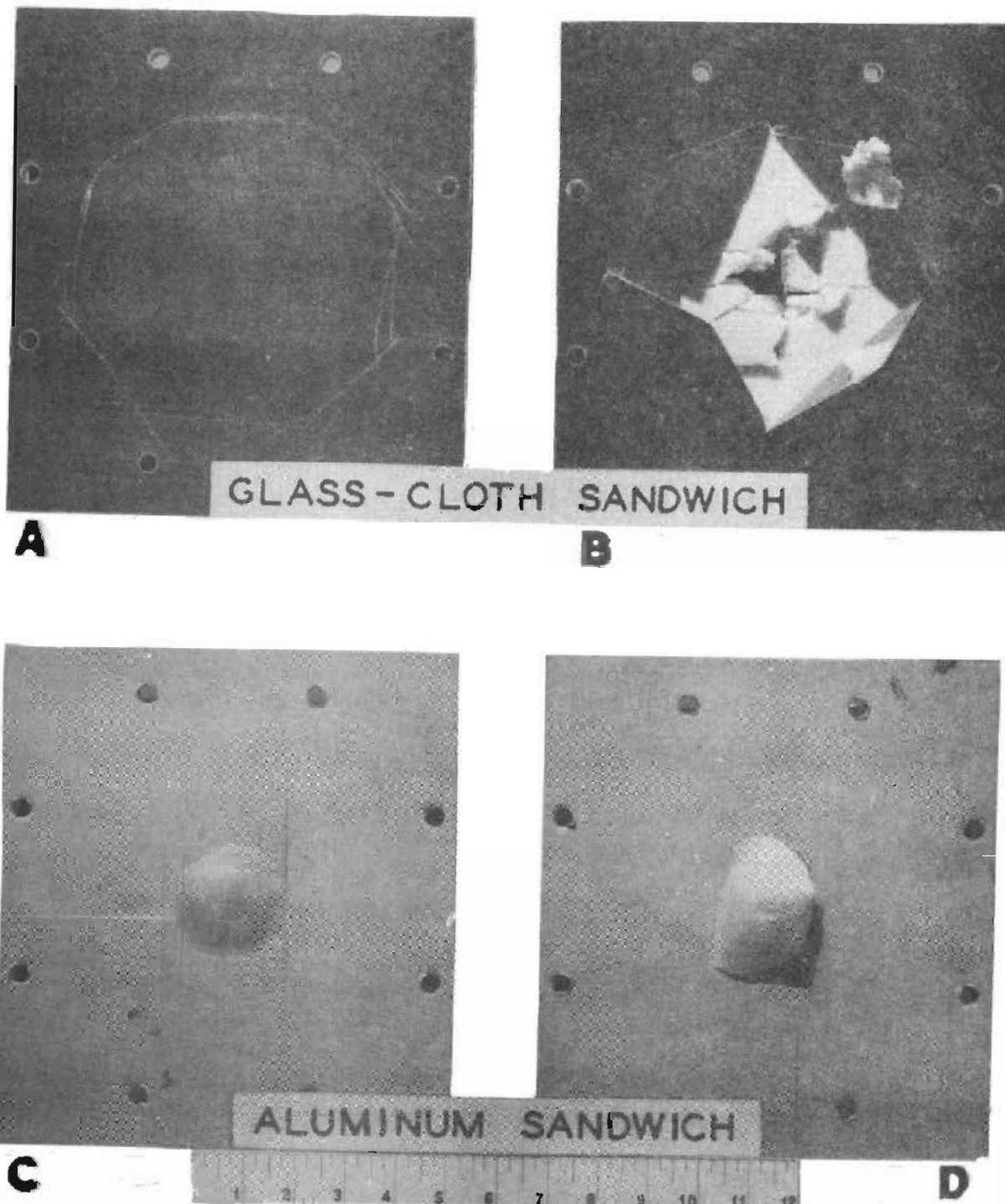


Figure 7.--Bottom view of impact specimens with cellular cellulose acetate cores. A, outline of bulge caused by the core failure in a glass-cloth sandwich; B, core damage in a similar sandwich; C, outline of bulge in an aluminum sandwich before a bottom crack appears; and D, failure in the aluminum face.

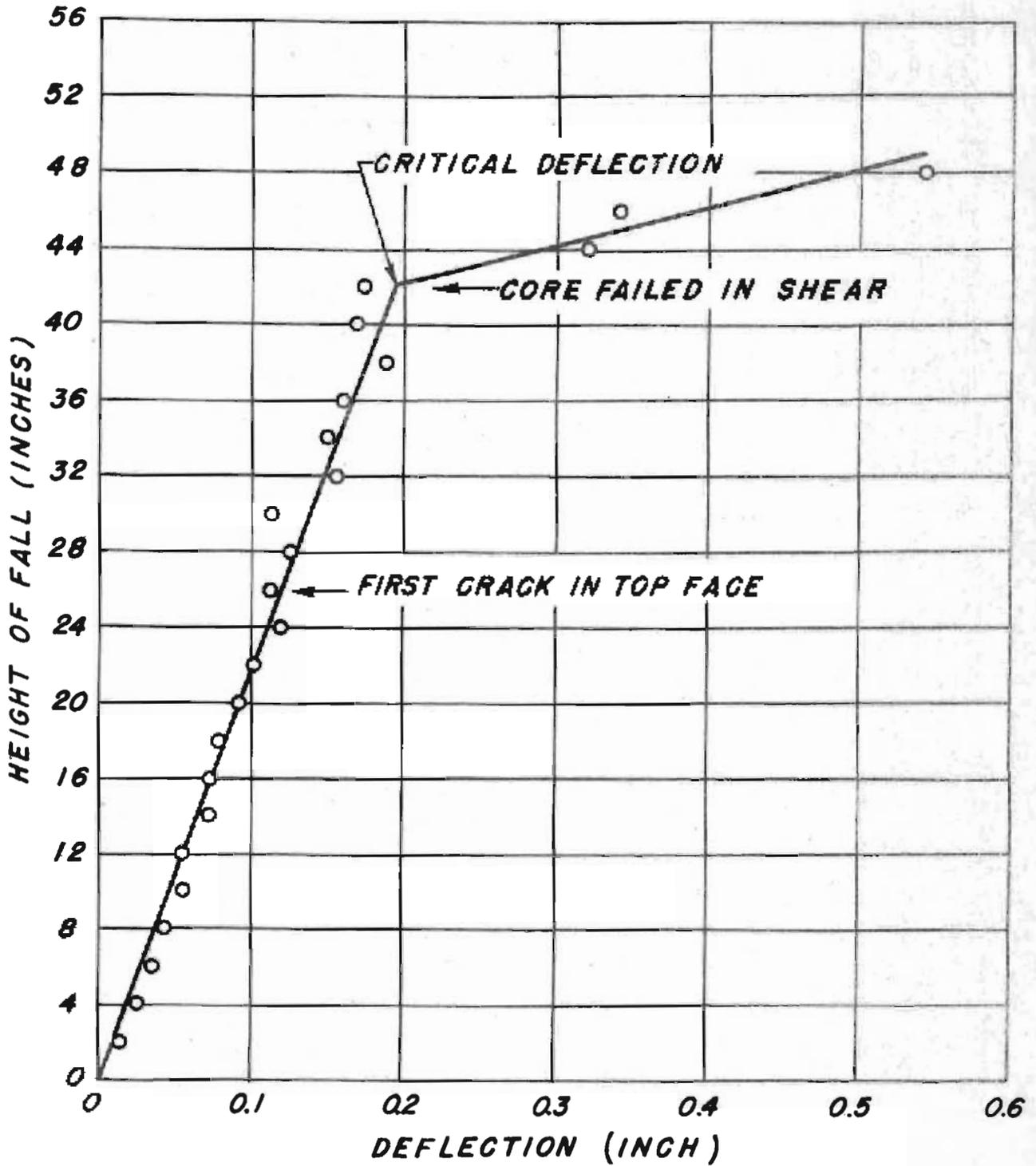


Figure 8.--Typical height-deflection curve as determined by impact of a falling ball on a sandwich panel.

