

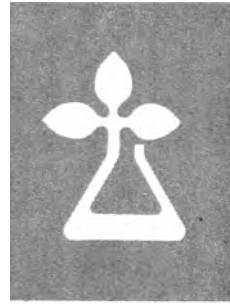
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In Cooperation with the University of Wisconsin

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RESEARCH NOTE

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ADHESIVES FOR ASSEMBLY OF LIGHTWEIGHT WOOD CONTAINERS

ADHESIVES FOR ASSEMBLY OF LIGHTWEIGHT
WOOD CONTAINERS

By

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Abstract

This report discusses the screening of various adhesive and mastic systems for possible use in assembling lightweight wood containers. Results showed that dynamic tests of simulated box corners correlated reasonably well with rough handling evaluations of eight selected systems when used to assemble lightweight wood boxes made from a Group I container wood. Conventionally nailed specimens were used as the control. The impact tests, as well as the rough handling tests, showed that a system should exhibit a certain degree of resilience. Diagonal compression tests indicated that a system should possess minimum creep characteristics.

Introduction

Adhesive and mastic systems exhibit interesting characteristics, worthy of consideration, for use in the assembly of lightweight wood containers. Systems that warrant consideration should have a certain degree of resilience and only minimum creep characteristics. Other factors to be taken into account are lidding or closure, opening, and recoopering.

¹Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

The effectiveness of the joints of a nailed container greatly influence its overall performance, and for the nails to develop adequate performance characteristics, the ends of nailed wood boxes are generally thicker than the sides, tops, and bottoms.² This minimizes chances of excessive splitting, permits some choice in the direction and location of driving the nails, and obtains balanced construction.

A fiberboard box, which has the same thickness material in the sides and ends, is joined by a continuous joint known as the "score." It appeared feasible that for some lightweight fruit and vegetable boxes a continuous joint might have some possibilities in the assembly of the boxes as well as allowing a reduction in end thickness. Recently, the Forest Products Laboratory has been exploring this possibility and also has endeavored to develop a simple method of evaluating the adhesives and mastics so that consideration might be given to only the more promising materials.

Preliminary Study

A considerable amount of preliminary study was conducted to determine the behavior of container joints and fasteners. Results showed that static tests of small simulated box corners did not correlate with the performance of boxes when subjected to rough handling. The simulated box corners, glued with polyvinyl emulsion, outperformed the nailed corners when subjected to a compressive load in a universal testing machine that tended to spread the box corner. Boxes with inside dimensions of 16-1/8 by 11-1/2 by 5 inches deep, which were loaded with approximately 20 pounds and glued with the same adhesive, failed on the first edgewise fall from 6 inches. Similar size boxes nailed with fourpenny fruit box nails, loaded with approximately 20 pounds, averaged 49 edgewise falls from 6 inches.

From this and other preliminary work, two facts became evident. (1) Static tests of simulated box corners are not suitable for predicting rough-handling performance of boxes and thus should not be considered as a means to screen adhesive or fastener systems. (2) Hard brittle glues such as polyvinyl emulsion are not suitable for assembly of conventional wood boxes because this type of adhesive results in too rigid a box. Because of box rigidity, shock at impact causes extremely rapid buildup of stresses that become excessively high at the area adjacent to the glueline, and failure results.

² Forest Products Laboratory. Nailed and lock-corner wood boxes. Forest Products Lab. Rpt. 2129. 50 pp., illus. 1958.

Nailed boxes are not so rigid and become more limber in the joints when subjected to rough handling. This relative movement between box parts during rough handling dissipates some of the shock energy and reduces the rapid buildup of locally high stresses,

Thus, it appears that to produce a wood box, assembled with an adhesive, and capable of withstanding some degree of rough handling, requires a joint capable of providing some relative movement between box parts--a joint that would tend to cushion and absorb the shocks resulting from rough handling. Further, it is evident that some method of test, other than static loading, is necessary to evaluate simulated box joint performance for the purpose of screening adhesives, mastics, and joint systems,

Two minor tests were tried: (a) impact spread, and (b) impact shear. Both utilize simulated box corners (side or top to end assembly) and a falling weight to provide impact type of loading.

To evaluate this method, impact spread and impact shear tests were made on simulated box corners using fourpenny fruit box nails, polyvinyl adhesive only, and a black rubber (electrician's tape) isolator glued to the wood parts with polyvinyl adhesive. Subsequently, boxes with inside dimensions of 28 by 12 by 12 inches deep, assembled in the same manner and loaded with approximately 48 pounds of simulated fruit, were subjected to an edgewise drop test. Each side-end edge was dropped from a height of 2 inches. After the four edge drops from 2 inches, the height was increased to 4 inches and the cycle repeated. This procedure was continued, increasing the drop height by 2-inch increments, and repeating the drop cycle until failure of the box. The following tabulation summarizes the results of the edgewise drop test, giving the minimum and maximum number of drops to failure for five boxes evaluated for each assembly system:

<u>Assembly method</u>	<u>Minimum</u>	<u>Maximum</u>	<u>Average</u>
Polyvinyl adhesive	6	12	9
Sixpenny coated sinkers	29	36	32
Rubber isolator and polyvinyl adhesive	44	53	49

The minor tests, conducted by dropping a weight on the test specimen, started at a 1-inch height and were increased by increments of 1 inch for each subsequent drop height. These results are summarized in table 1.

The bar chart (fig. 1) indicates that the minor impact tests tend to correlate with the rough-handling tests of boxes assembled in a similar manner.

Materials and Methods of Investigation

Screening Evaluation

Thirty-two different adhesives, mastics, or combinations were screened for possible further consideration. The fourpenny cement-coated fruit box nail was used as the control. Some of the systems investigated used the same adhesive but were altered somewhat or used in a slightly different formulation. In other systems, the adhesives were used with an isolator, such as sheet rubber, or with a plastic joint connector.

The screening was accomplished by use of impact tests using a falling weight of 3.46 pounds oriented between two vertical guides (fig. 2). The joints were evaluated by subjecting them to the impact spread and impact shear tests. Later, during the investigation, it appeared advisable to incorporate an impact tension test. In fabricating these test specimens, the wood pieces were fabricated from ponderosa pine, a Group I container wood.²

Impact Spread

These specimens consisted of a piece measuring 5-1/4 by 3-1/2 by 9/32 inch thick, simulating top or bottom boards, and a piece 3-1/2 by 4-7/8 by 11/16 inch thick, simulating the end. The thinner piece overlapped the piece representative of the end to form the test specimen (fig. 3).

Each specimen was placed between the guides of the apparatus in an inverted "V" position so that the falling weight would strike the apex of the "V" (fig. 4). The weight was raised 1 inch and allowed to fall freely against the specimen. The height of the weight was increased by a 1-inch increment after each fall until failure of the specimen. In some instances, the falling weight rebounded and when this occurred, no attempts were made to prevent it.

Impact Shear

These specimens consisted of a piece measuring 3 by 3-1/2 by 9/32 inch thick, simulating top or bottom boards, and a piece 3-1/2 by 4 by 11/16 inch

thick, simulating the end. The thinner piece overlapped the thicker piece (fig. 5). The clamp and metal U-shaped support were used to position and hold the specimen in proper relation to the falling weight (fig. 6). The weight was raised 1 inch and allowed to fall freely against the specimens. After each fall, the height of the initial position of the falling weight was increased by an increment of 1 inch until failure of the specimen. No attempts were made to eliminate bouncing of the falling weight.

Impact Tension

As screening of adhesives and mastics continued, an impact tension test was devised. This specimen consisted of two pieces measuring 3 by 3-1/2 by 9/32 inch thick and 6 by 1-3/4 by 11/16 inch thick. The pieces were assembled in the form of a cross with each piece centered on the length of the other (fig. 7). The specimen was supported by two U-shaped support blocks (fig. 8) with the load application block arranged to push the test specimen apart. Again, the weight was allowed to fall freely, with no attempt to eliminate bouncing, from a height of 1 inch with a 1-inch increment increase for each successive impact until failure.

Container Evaluation

Two experimental procedures were selected to evaluate the containers assembled with mastics and adhesives. They were the small (7-foot diameter) revolving drum,³ and the diagonally opposite corner-to-corner compression test.⁴ The boxes subjected to rough handling were loaded with approximately 27 pounds of simulated fruit, while those subjected to the compression test were evaluated empty with the covers in position. The boxes used in this evaluation had inside dimensions of 16-1/8 by 13-1/2 by 5-3/4 inches deep and are referred to in the trade as "L.A. lug boxes."

The control boxes (fig. 9) had sides and bottoms of 1/4-inch-thick resawn white fir and ends of 11/16-inch-thick white fir. The tops were of the cleated unitized construction consisting of 1/10-inch-thick yellow-poplar veneer unitized with two 7/32-inch-thick sawn cleats at each end. These boxes were assembled with fourpenny cement-coated fruit box nails.

³ American Society for Testing and Materials. Tentative method of testing shipping containers in revolving hexagonal drum. ASTM Designation D782-60T. Book of ASTM Standards, Part 15, Philadelphia, 1964.

⁴ American Society for Testing and Materials. Standard method of compression test for shipping containers. ASTM Designation D642-47, Book of ASTM Standards, Part 15, Philadelphia, 1964.

All of the boxes assembled with adhesives or mastics had sides, tops, and bottoms of 1/4-inch-thick resawn white fir. The ends of these boxes were 1/4-inch-thick, three-ply Douglas-fir plywood with the grain of the outer plies parallel to the length of the box part. Plywood was used for the ends to eliminate the problem of splitting when using 1/4-inch-thick ends of white fir in some 'exploratory work. It was believed that the elimination of nails and the use of adhesives or mastics to effect a more or less continuous joint could tolerate a reduction of end thickness over that generally used in conventional nailed assembly.

The assembly systems selected are shown in table 2 and were specifically selected from the performance of the systems in the minor or screening tests. Some systems were selected that performed well in all three screening tests while others were selected that performed reasonably well in one or two of the screening methods to ascertain if all three screening procedures were necessary. Also included was at least one system that performed rather poorly in the screening evaluation to ascertain whether or not the screening methods could detect a system that would tend to result in poor box performance. Some examples of adhesive or mastic assembled boxes before test are shown in figures 10 and 11.

Results and Discussion

A summary of the results of the minor screening tests and the rough-handling and compression tests of boxes is given in table 2. The averages of these evaluations, along with their confidence limits at the 95 percent level, are presented graphically in figure 12. Table 2 and figure 12 show that the fourpenny fruit box nails were less variable in the screening tests than were some of the adhesive and mastic systems, which exhibited a somewhat wide range of variability in at least one of the screening methods. One adhesive system, the copolymer emulsion of vinyl acetate and a long chain acrylate, exhibited little variability in the screening evaluation. However, this adhesive demonstrated a tendency to creep and, as a result, the boxes did not retain their shape sufficiently enough to permit an evaluation. Although this adhesive was less variable than some of the other systems, its performance in the screening tests was generally below that of the fourpenny cement-coated fruit box nails.

Some assembly systems, subjected to rough-handling tests, showed more variability than expected, judging from the variability of the screening tests. The results of the revolving drum test may be highly variable.⁴

The results tend to indicate that if the mastic or adhesive system performs below the level of the control fastener (in this work the fourpenny cement-coated fruit box nail) in any one of the three screening methods, it most likely will perform rather poorly when subjected to rough handling. Conversely, if the performance of the system in the three screening methods is equal to or greater than the control fasteners, the rough-handling performance of boxes assembled with that same system will approach that of boxes with the control fastener.

The individual results of the drum tests of the nailed containers show why the confidence limits are so large. These results were 15, 21, 12, 12, and 46 falls respectively to failure (spilling of the contents). Close examination of the one container that withstood 46 falls did not reveal any abnormalities that would justify eliminating this box from consideration. If this container were eliminated, it can readily be seen that the variability of the nailed containers in the drum test would be considerably smaller. Since there is no valid reason for eliminating the container, it would appear that there were not enough samples. Five samples for this test procedure is the absolute minimum.⁴

Failures of the nailed containers, subjected to rough handling, were characterized by splitting of the full length of one side, usually starting and terminating at a nail location. This splitting, accompanied by either nail pull or shearing from the nails, allowed part of the side to fall off and spill the contents. The boxes, assembled with mastics and adhesives and subjected to the drum test, were characterized by failures that also generally involved the sides. With this type of assembly, the sides generally pulled loose at either or both ends and permitted the contents to spill. Splitting of the sides was not as prevalent as with the nailed assembly and generally the failure involved a separation of the adhesive or mastic with little or no wood failure (figs. 13 and 14).

The correlation between screening tests and rough handling does not appear to hold for diagonal compression of the containers. This is not surprising when it is realized that the diagonal compression test utilizes a static or slowly applied load while the screening tests utilized impact loading. Thus, it seems reasonable to assume that static loading techniques applied to the screening specimens would provide results that would correlate with the diagonal compression performance of the boxes.

It is readily seen that the resistance to distortion of the boxes assembled with mastics and adhesives is generally less than that of the boxes assembled with nails. This is understandable since the adhesive and mastic systems had a certain degree of resilience which resulted in a more flexible or mobile

joint than that afforded by nailed containers, Other types of containers with flexible joints, such as corrugated fiberboard and wirebound boxes, also exhibit a large amount of deformation in diagonal compression,

In the nailed boxes subjected to diagonal compression, there was considerable splitting of the sides, top, and bottom slats and cleats, These splits generally started from a nail and followed the grain of the wood, thus causing permanent racking of the box.

The diagonal compression test of the boxes assembled with adhesives caused distortion of the containers. However, when the load was removed, many of the boxes tended to return to their original shape and did not exhibit a great deal of permanent deformation, Many of the boxes, except those assembled with the elastomer sealing resin, two-part synthetic rubber compound and polysulfide polymer, were still serviceable after the test. In many instances, maximum load was reached without complete separation of the box parts at the joints, The joints did deform and some of them showed signs of partial separation, Complete separation of adhesive joints occurred in some of the boxes in lots 13, 14, and 17 and failures in these groups involved the loss of a side, top, or bottom slat, Typical examples of boxes, after being subjected to diagonal compression, are shown in figures 15, 16, and 17,

Table 3 presents the average net, tare, and gross weights as well as the average moisture contents encountered in the box evaluation. The adhesive systems resulted in a 16 to 23 percent reduction in tare weight over the conventional nailed containers with the exception of lot 16, rubber-base contact adhesive and extruded rubber angle, These containers were only slightly lighter in weight. The weight savings can be attributed to the reduction in thickness of the ends even though 1/4-inch-thick plywood was used in the adhesive assembled containers in place of 11/16-inch white fir as used in the nailed boxes,

The variation in moisture content of the boxes was small and does not appear to be the basis for any abnormal behavior of the boxes during evaluation,

Conclusions and Recommendations

The results of the work discussed in this report indicate that lightweight boxes, such as those used for fruits and vegetables, assembled with suitable adhesives and mastics exhibit a reasonable degree of resistance to rough handling, This method of assembly must incorporate a certain degree of resilience in order

to exhibit rough-handling performance approaching that of containers assembled with nails. The resistance to diagonal distortion of containers assembled in this manner will generally be less than that of similar containers assembled with nails.

The use of static evaluation methods to screen adhesive and mastic systems is not adequate for indicating rough-handling performance characteristics of containers assembled with such systems. Conversely, the use of dynamic loading techniques show promise as a reasonably reliable means of screening systems for consideration in container assembly operations. In general, the performance of the system in the screening evaluations should be equal to or better than the performance of the control fasteners. Further, the system being considered should perform adequately in all three impact screening techniques.

The drum test is considered to be well suited for subjecting a container to a wide range and variety of shocks and stresses, similar to those received in transportation. However, it may not be the most desirable method of evaluating rough-handling performance of lightweight containers, assembled with adhesives and mastics, because of the variability of the test procedure. Many samples are needed when using this method.

Although a certain degree of resilience is necessary, the tendency of some mastic and adhesive systems to creep is detrimental in container applications and should be held to a minimum.

Boxes assembled with adhesive or mastic systems, which exhibit a sufficient degree of resilience to perform adequately when subjected to the shock and vibration hazards of transportation, will generally exhibit a rather low resistance to diagonal distortion.

In this type of application, it is not necessary to demand that the system develop a so-called "fiber" or wood failure. It is the performance of the joint or assembly system that is important, not the type of failure. If the joint performs satisfactorily and failure occurs within the adhesive system, it is better than one that has a low level of performance but develops failure in the wood.

The use of adhesives or mastics for container assembly presents some unsolved problems that could be the basis for additional work. Some consideration needs to be given to providing easy and ready opening of the containers. Consideration should also be given to retooling of damaged boxes. This may not be too large an obstacle since there are other containers used rather extensively that present

similar recoopering problems. In order to realize the full benefits of mechanized assembly, it will be necessary to develop a system that cures rapidly or attains sufficient initial strength to permit the box to be moved immediately after assembly. Perhaps closure or lidding of the box is the largest single obstacle to the use of adhesives or mastics. One solution may be in the use of a minimum number of small fasteners to hold the container in position during curing of the adhesive system. Perhaps a more practical approach would be to consider radical redesign of the nailed wood box, as presently known, to efficiently and economically utilize a promising adhesive or mastic system.

Table 1.--Summary of minor impact tests of simulated box corners with different assembly methods

Assembly method	Number of hammer drops					
	Spread test			Shear test		
	Minimum	Maximum	Average ¹	Minimum	Maximum	Average ²
	-----	-----	-----	-----	-----	-----
Polyvinyl adhesive	3	5	4	3	7	5
Fourpenny nails	7	10	9	11	12	11
Rubber isolator and polyvinyl adhesive	11	22	19	18	26	21

¹Average of 7 specimens.

²Average of 10 specimens.

Table 2.--Assembly systems and results of screening and box evaluations

Lot: No.:	Assembly system	Minor tests										Drum tests		Diagonal compression tests								
		Impact spread					Impact shear					Impact tension							Deflection		Load	
		Mini- num drops	Mini- num drops	Mini- num drops	Mini- num drops	Mini- num drops	Mini- num drops	Mini- num drops	Mini- num drops	Mini- num drops	Mini- num drops	Mini- num falls	Mini- num falls	Mini- num inches	Mini- num inches	Mini- num pounds	Mini- num pounds					
1	Two fourpenny cement- coated fruit box nails	7	10	9	10	12	11	8	10	9	12	46	21	0.96	1.28	1.16	387	452	415			
11	Rubber-base contact adhesive and rubber electrician's tape	8	17	12	14	19	16	7	10	8	6	13	10	1.10	1.41	1.20	121	164	135			
12	Synthetic rubber-base contact cement	2	8	4	6	9	8	3	4	3	1	4	3	.56	.69	.61	294	347	315			
13	Elastomer sealing resin	4	6	5	13	27	17	5	8	6	3	12	7	.51	.65	.59	176	198	189			
14	Two part synthetic rubber compound	7	12	10	2	6	4	4	14	9	1	9	3	.60	.69	.64	112	147	138			
16	Rubber-base contact adhesive and extruded rubber angle	36	36	36	4	6	4	9	12	11	10	21	16	.48	.96	.74	112	136	125			
17	Polysulfide polymer	3	24	12	16	40	32	8	19	13	6	14	9	.61	.81	.72	152	190	165			
18	Urethane pre-polymer cured with a castor polyol	4	10	6	5	10	8	5	10	8	1	7	3	.58	.71	.66	386	440	415			
19	Copolymer emulsion of vinyl acetate and a long chain acrylate	2	9	4	3	7	5	4	7	6	(1)	(1)		(1)				(1)				

1--Unable to test boxes due to excessive creep of joints.

Table 3.---Average¹weights and moisture contents

Lot: No.:	Assembly system	Drum tests						Compression test	
		Box weight	Net weight	Gross weight	Moisture content	Box weight	Moisture content		
		<u>Lb.</u>	<u>Lb.</u>	<u>Lb.</u>	<u>Pct.</u>	<u>Lb.</u>	<u>Pct.</u>	<u>Lb.</u>	<u>Pct.</u>
1	Two fourpenny cement- coated fruit box nails:	3.8	26.7	30.5	11.0	3.8	11.7		
11	Rubber-base contact adhesive and rubber electrician's tape	3.2	26.6	29.8	10.8	3.3	11.7		
12	Synthetic rubber-base contact cement	3.0	26.7	29.7	11.0	3.1	11.3		
13	Elastomer sealing resin:	3.0	26.8	29.8	10.8	3.1	10.9		
14	Two part synthetic rubber compound	3.1	26.6	29.7	10.6	3.1	12.1		
16	Rubber-base contact adhesive and extruded rubber angle	3.5	26.6	30.1	11.1	3.5	11.3		
17	Polysulfide polymer	3.0	26.7	29.7	11.0	3.0	12.1		
18	Urethane pre-polymer cured with a castor polyol	2.9	26.8	29.7	10.6	2.9	12.5		
19	Copolymer emulsion of vinyl acetate and a long chain acrylate								
		Not tested				Not tested			

¹---Average of five boxes.

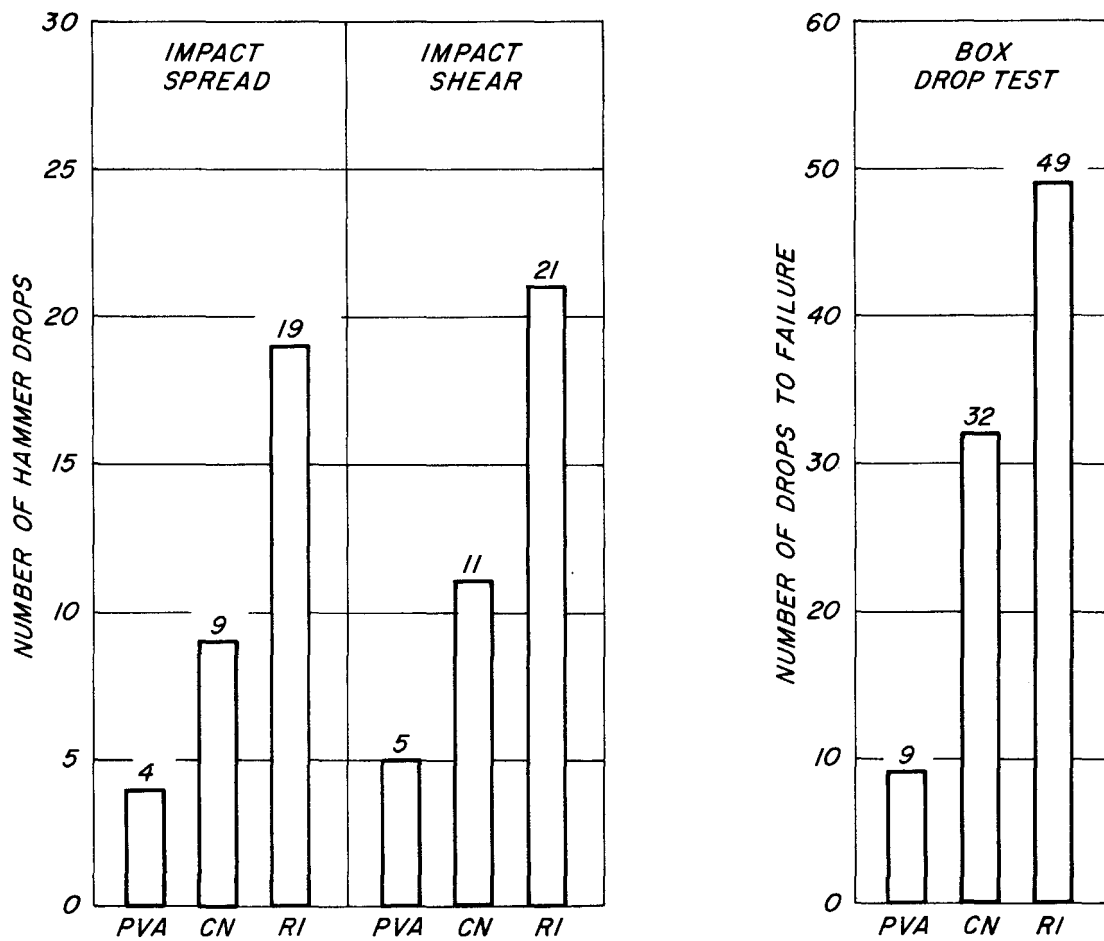


Figure 1.--Bar chart of average results of minor impact and box drop tests (preliminary work),
Legend PVA--polyvinyl adhesive; CN--coated nails; RI--rubber isolator.

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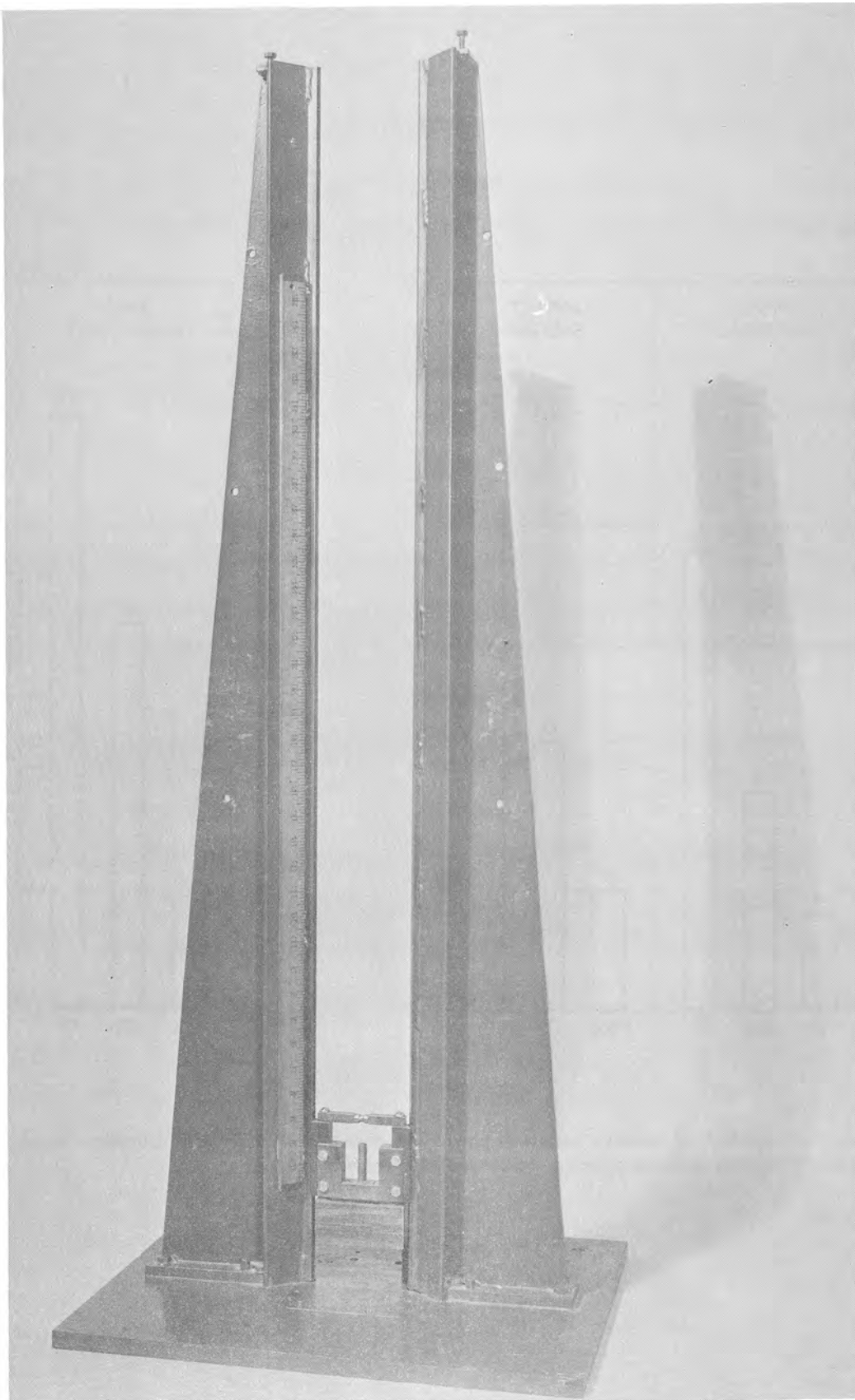


Figure 2.--Mechanism for providing impact loading to specimens simulating container joints. The impact head or falling weight rests at the bottom of the two vertical guides.

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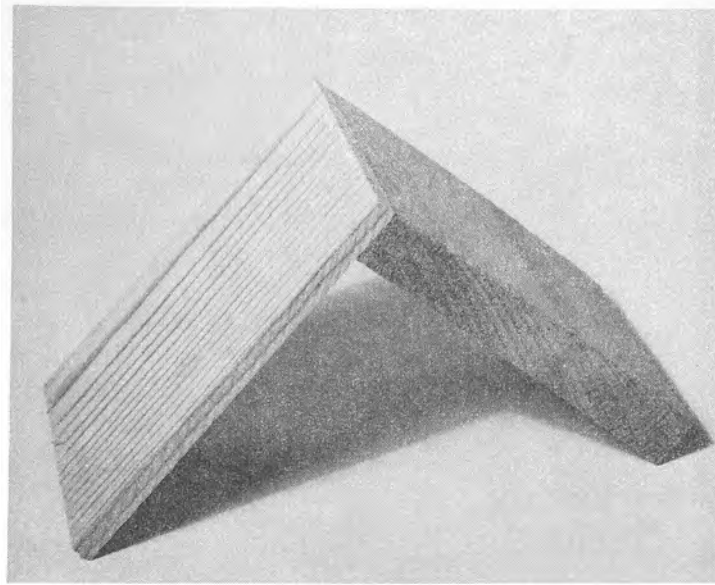


Figure 3.--Specimen assembled for impact spread test.

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Figure 4.--Impact spread specimen in position shows manner in which impact head strikes apex of specimen.

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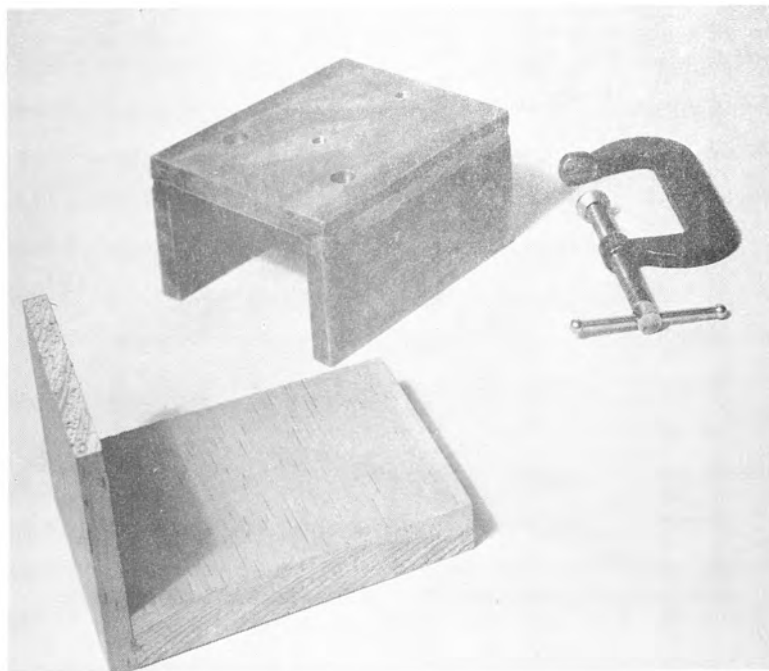


Figure 5.--Impact shear specimen clamp and support block.

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Figure B.--Method of locating shear specimen to receive impact force from falling weight.

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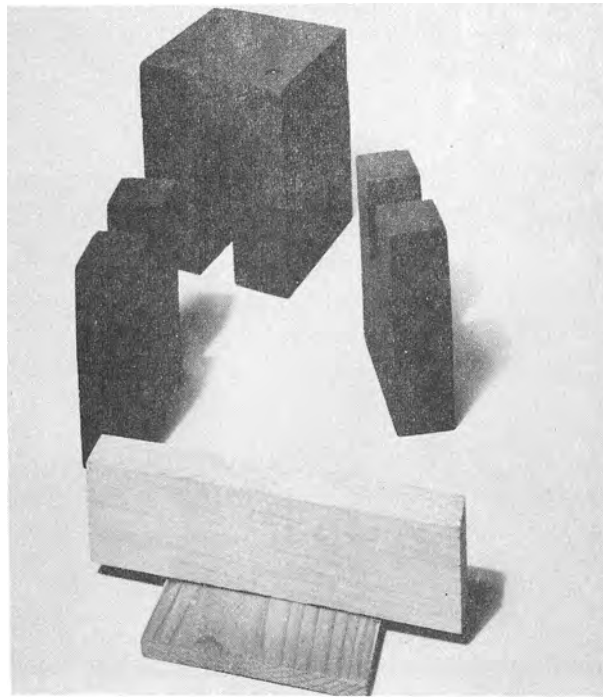


Figure 7.--Impact tension specimen (front) ready for evaluation using support blocks and loading block (back).

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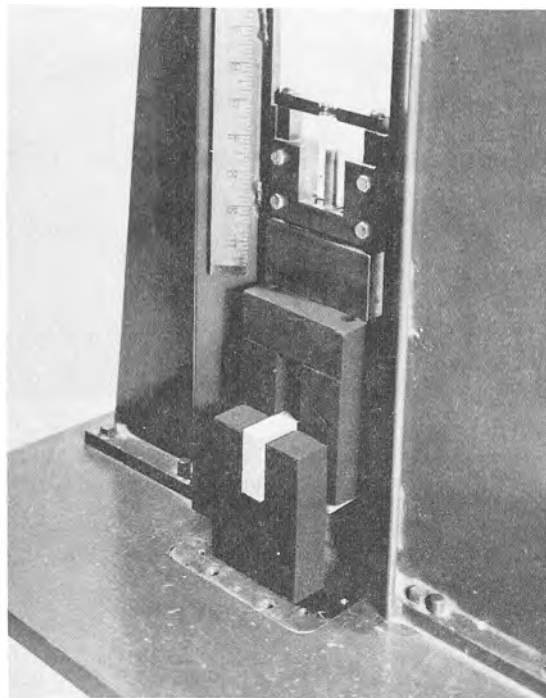


Figure 8.--Location of impact tension specimen between vertical guides in order for impact load from falling weight to be applied through loading block.

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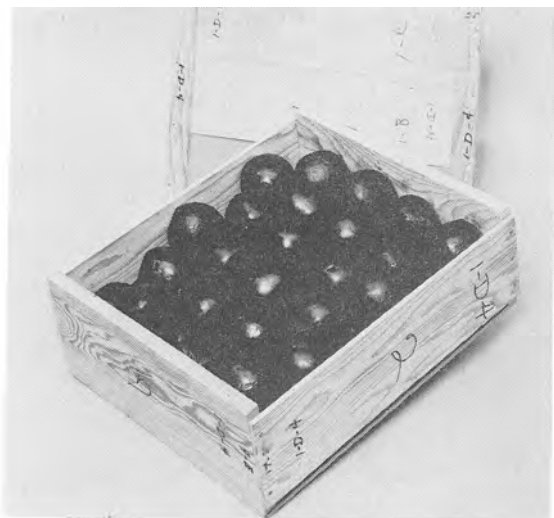


Figure 9.--Representative control box, loaded with simulated fruit and ready for lidding, before rough-handling test in 7-foot-diameter revolving drum.

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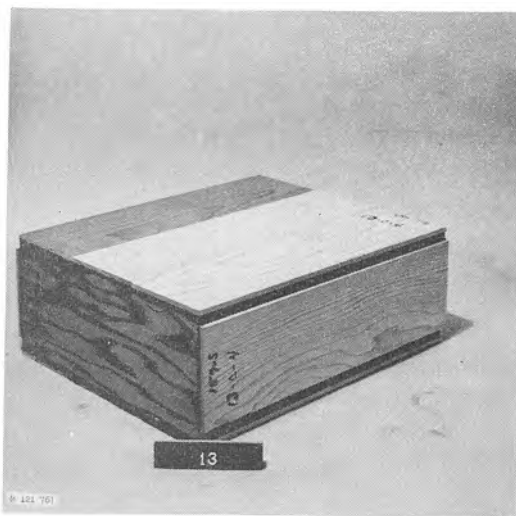


Figure 10.--Example of mastic or adhesive assembled box. The box is assembled with an elastomer-sealing resin.

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Figure 11.--Box assembled with rubber-base contact adhesive and extruded rubber angles.

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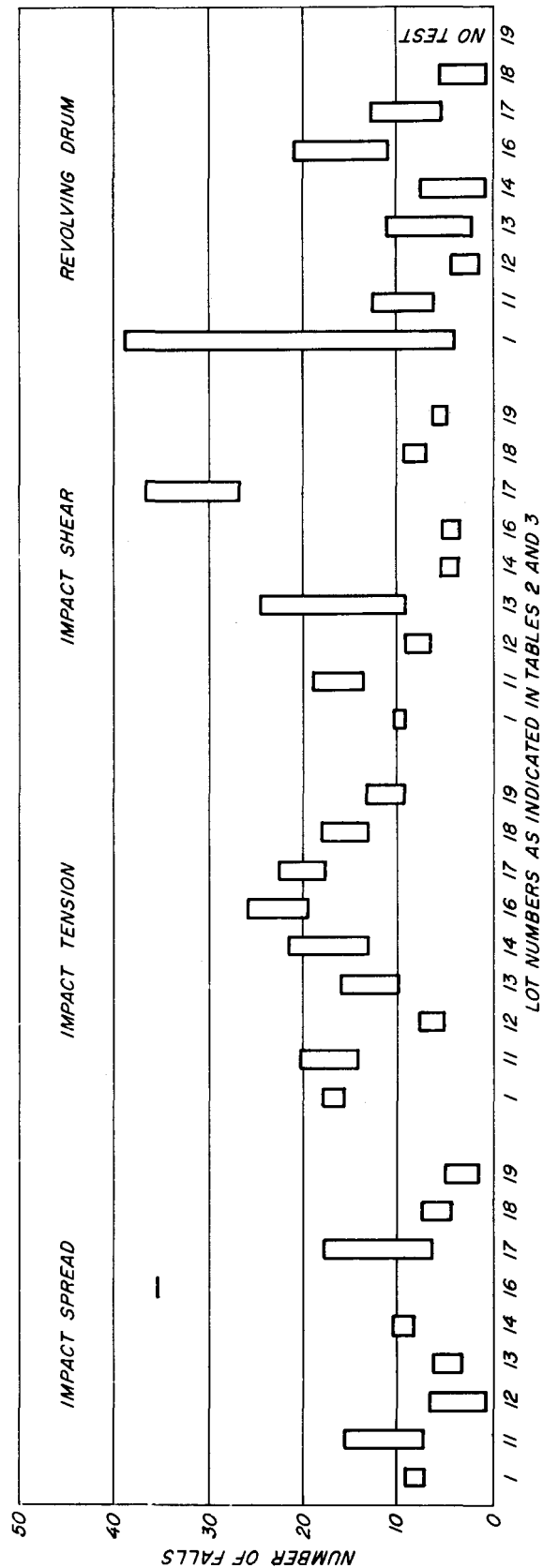


Figure 12.--Confidence limits at the 95 percent level for screening and assembled box evaluation of various assembly systems. Legend: 1--fourpenny cement coated fruit box nails; 11--rubber base contact adhesive and rubber electricians tape; 12--synthetic rubber base contact cement; 13--elastomer sealing resin; 14--two part synthetic rubber compound; 16--rubber base contact adhesive and extruded rubber angle; 17--poly-sulfide polymer; 18--urethane prepolymer cured with castor polyol; 19--co-polymer emulsion of vinyl acetate and long chain acrylate.

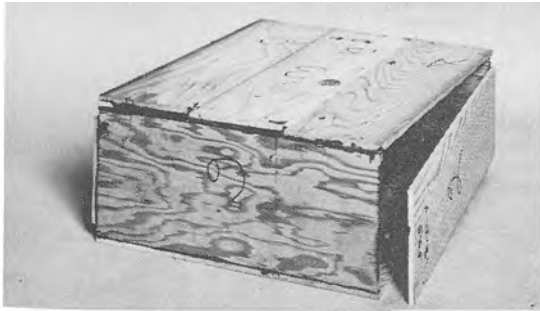


Figure 13.--Failure of adhesive-assembled container subjected to drum test. The lack of wood fibers at the failed joints indicates a separation of the adhesive or mastic system

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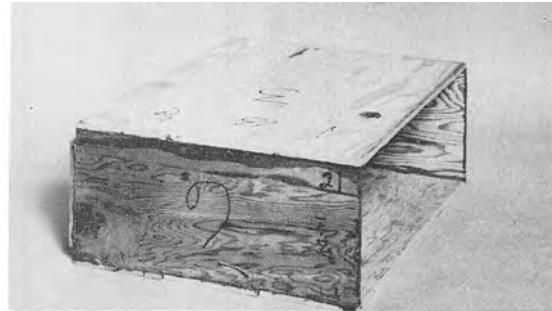


Figure 14.--Failure of adhesive-assembled container subjected to drum test. The lack of wood fibers at the failed joints indicates a separation of the adhesive or mastic system

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Figure 15.--Example of adhesive-assembled box shows relatively little permanent racking and some joint separation, sustained during diagonal compression test.

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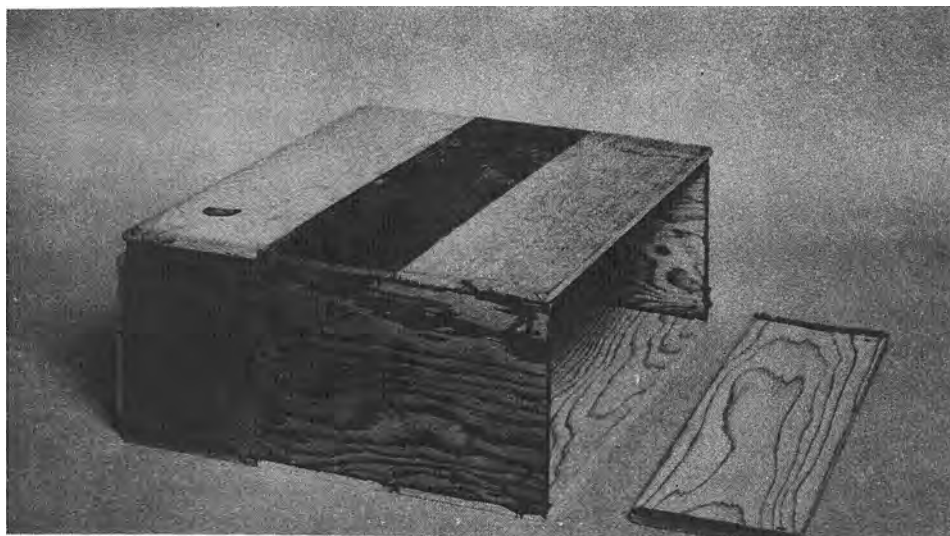


Figure 16.--Typical example of adhesive-assembled box, after diagonal compression test caused failure at joints and loss of one side slat.

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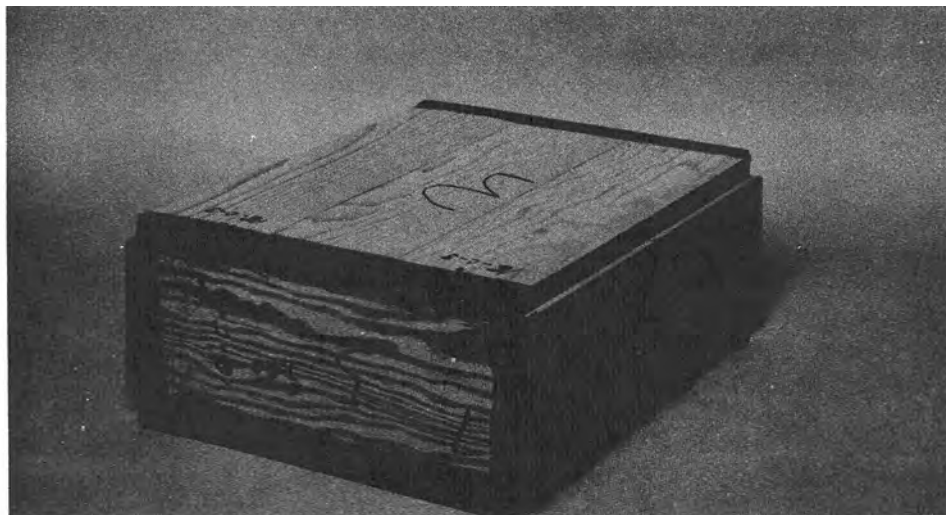


Figure 17.--Typical example of adhesive-assembled box, still in apparent serviceable condition, after diagonal corner compression test.

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Furniture Manufacturers,
Woodworkers, and Teachers
of Woodshop Practice

Logging, Milling, and Utilization
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Mechanical Properties of Timber

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