DYNAMIC DIRECT-WITHDRAWAL TESTS OF STAPLES AND T-NAILS IN CONTAINER APPLICATIONS

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ABSTRACT

DYNAMIC DIRECT-WITHDRAWAL TESTS OF STAPLES AND T-NAILS IN CONTAINER APPLICATIONS

by Neil Lynn Powers

This study was undertaken to find a technique, equipment, and instrumentation for obtaining information on the behavior of staples, T-nails, and conventional nails when subjected to impact forces that tend to cause direct withdrawal in simulated container applications.

Resistance of several types of staples, T-nails, and conventional nails to direct withdrawal in a dynamic impact test is considered as a basis in determining the suitability of these fastenings for fabricating container panels and similar container applications. Pneumatically driven staples and T-nails were used with 1/4-inch container-grade plywood and nominal 1-inch material to form specimens. These specimens, and control specimens using common nails, were tested to failure under direct-withdrawal impact loading in the Forest Products Laboratory toughness machine and the Tinius Olsen impact machine.

Behavior of the specimens is discussed on the basis of average maximum loads, average energy expended, and average duration of loading to produce failure. Also presented is a comparison of the two techniques, equipment, and instrumentation used with the two testing machines.

Both the Forest Products Laboratory toughness and Tinius Olsen impact machines provide a usable method for obtaining information on the behavior of fasteners when subjected to dynamic impact forces tending to cause direct withdrawal. The selection of one machine over the other depends upon the type of container application being simulated. The Olsen machine generally appears to simulate container impact loads encountered under relatively high impact velocities better than the toughness machine.

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BY

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Lansing, Michigan   Neil L. Powers
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INTRODUCTION

The purpose of this study was to find a technique, equipment, and instrumentation for obtaining information on the behavior of staples, T-nails, and conventional nails when subjected to impact forces that tend to cause direct withdrawal in simulated container applications.

This study was conducted at the U.S. Forest Products Laboratory, Madison, Wisconsin. A manufacturer of pneumatic-type driving equipment provided an assortment of staples and T-nails as well as equipment for driving them.

The development of the instrumentation and technique permits obtaining basic information on the behavior of fasteners when they are subjected to direct-withdrawal impact loading. This information may aid in the design and development of wood containers to withstand normal hazards encountered in shipping, rough handling and accidental dropping (6).

During handling and shipping of wood containers, the fasteners used in their construction are subjected to impact direct-withdrawal forces or stresses that tend to pull the fasteners from a piece of wood. The conditions of container handling under which impact direct withdrawal is important include bending, racking and twisting.

Information, therefore, was obtained on the resistance to direct withdrawal during dynamic impact loading of several types of staples, T-nails, and conventional nails in simulated container applications. Pneumatically driven staples and T-nails were driven into 1/4-inch container-grade plywood and nominal 1-inch white pine material to form specimens. These specimens, and control specimens with common nails, were tested to failure under direct-withdrawal impact loading.

A total of 200 specimens was tested on the U.S. Forest Products Laboratory toughness and the Tinius Olsen impact testing machines. Maximum load and duration of loading were recorded by the use of a load cell and electronic instrumentation that produced a visible trace on an oscilloscope. This trace was photographed with a Polaroid Land camera. Each testing machine permitted an evaluation of the energy expended in testing each specimen.

PREVIOUS WORK

Direct-withdrawal tests of fasteners in the past have been almost exclusively conducted with a universal testing machine. These tests are often referred to as static tests because the fastener is subjected to relatively low rates of impact (1, 6 and 8). Relative simplicity of testing is, no doubt, the major advantage of obtaining data by static means and the equipment for such tests is readily available in many testing laboratories.

Reliance could be placed on the results obtained from conventional static tests if it were known that the performance of the fastener was unaffected by the rate of loading. However, previous work at the U.S. Forest Products Laboratory and by others tends to indicate that dynamic tests may provide useful information unobtainable from static tests. Also, it has been thought that results from impact tests might correlate with the rough handling of a container better than would the results from static tests. This is because containers in common pratice are generally subjected to dynamic external stresses, so that almost all damage occurs when a container is in motion and subjected to dynamic or rapid loads. Fastener failures rarely occur while containers are at rest or in storage (3).

Even though the impact direct-withdrawal resistance of fasteners is an important property which should be considered in the design of wood containers, only limited study has apparently been given to it. There are, no doubt, many methods and techniques of performing dynamic direct-withdrawal tests of container fasteners, but information on such tests is meager.

The U. S. Forest Products Laboratory by 1925 had developed a method for determining the amount of energy required to dynamically withdraw a nail directly from wood (6 and 13). The tests were performed using the Forest Products Laboratory toughness machine (12). The specimen is held against two steel pins with the pendulum in an approximately vertical position. The upper portion of the pendulum bar is attached to a pulley or drum whose center is the axis of rotation, while an adjustable weight is located at the lower end of the pendulum bar. Impact is applied to the fastener through a cable wrapped around the pendulum-supporting rotating steel drum. Using a vernier and tables, the work absorbed in pulling the fastener can be determined.

In 1953, E. George Stern of the Virginia Polytechnic Institute investigated the dynamic withdrawal resistance of fence staples (7). He performed the impact tests with the U. S. Forest Products Laboratory-designed, V.P.I.-built toughness testing machine. He also has performed a number of lateral-impact tests using the same equipment (9).

J.J. Mach of the Commonwealth Scientific and Industrial Research Organization, Australia studied the impact withdrawal resistance of nails in 1960 using a testing machine similar to the FPL toughness testing machine (5). Maximum loads were recorded by use of instrumentation consisting of A.C. strain gauges, amplifiers and a pen recorder. Four strain gauges were mounted on a steel load measuring tension link to form a bridge. The output of the bridge controlled the pen recorder which in turn continuously registered the load on the fastener.

In 1960, R.S. Kurtenacker of the U.S. Forest Products Laboratory developed a lateral-impact test of container fasteners using the FPL toughness testing machine (3). The tests of several types of staples, T-nails and conventional nails recorded maximum loads in addition to energy by use of a capacitance-type load cell and electronic instrumentation that produced a visible trace on a cathode-ray oscilloscope equipped with a Land process camera.

DESCRIPTION OF MATERIALS

The materials used were those generally found in the fabrication of crate panels, panels for cleated-panel boxes, or in any container construction where panel material is fastened to nominal 1-inch cleat material or two pieces of nominal 1-inch material are fastened together.

The withdrawal resistance of nails and other types of fasteners is greatly influenced by such factors as moisture content changes in wood, time the nail remains in the wood, type of nail point, type of shank, surface coatings, direction of driving, type of nail-head, density or specific gravity of the wood, diameter of the nail and the depth of penetration (6 and 11). The holding power of fasteners in wood is also affected by the direction and nature of the grain, defects and decay resulting from growth and mechanical injury and whether the nail is clinched or not.

The above variables affecting the withdrawal resistance were, where possible, eliminated, held constant or isolated before performing any of the tests.

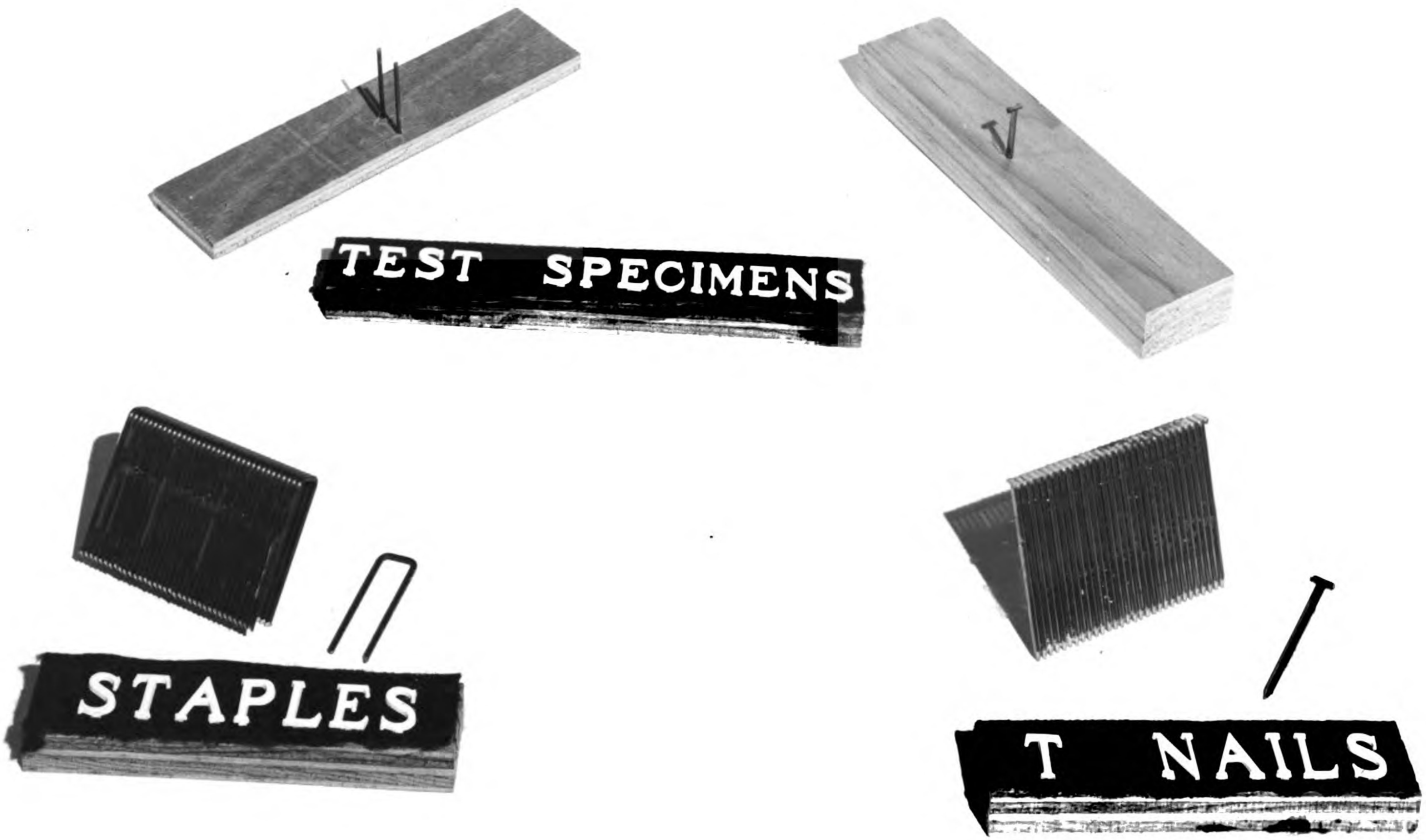
The wood used for this series of tests consisted of nominal 1-inch (25/32-inch-thick) white pine, and 1/4-inch three-ply container-grade plywood made from group III woods complying with the requirements for type III, class 1 of Federal Specification NN-P-515a. All wood was selected from commercially obtained stock. The test specimens had straight grain and minimum number of physical defects. After a sufficient number of pieces were cut and marked, the specimens were selected by a method of randomization. All pieces were then placed in a conditioning room at a constant temperature of 75 degrees Fahrenheit and 65 per cent relative humidity until they reached an equilibrium moisture content of approximately 12 per cent.

Each white pine and container-grade plywood specimen tested in the Tinius Olsen impact machine was 6-1/4 inches long by 1-15/32 inches wide. A single fastener was located 3-1/8 inches from the end and 3/8 inch from the side of the specimen (fig. 1).

Each white pine specimen tested in the FPL toughness machine was 6-1/4 inches long by 1-15/16 inches wide. Each container-grade plywood specimen tested in the FPL toughness machine was 11-1/2 inches long by 1-15/16 inches wide. A single fastener was located in both types of specimens at the center of their length and width. The specimens used in the two machines differed only in size to provide proper fit, apparently having no effect on the test results.

The fasteners used in these tests were common nails, staples, and T-nails. The two types of control

Figure 1.--Representative staples and T-nails used in the direct-withdrawal dynamic impact tests and assembled specimens for test in the Tinius Olsen impact testing machine. FPL toughness machine test specimens were similar but varied in size and location of the fastener.



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nails used were the 1-1/4-inch duckbill and the 2-inch sixpenny common nail selected from commercially obtained stock. The staples were all 16 gage with a 7/16-inch crown width, either galvanized or plastic coated with a divergent chisel point, and varying in leg length from 1-1/8 to 2 inches. The T-nails were all 13-1/2 gage, plain with a shank length of 2 inches (table 1).

Table 1.--Description of fasteners

Fastener	Gage of fastener	Length of shank or leg	Coating of shank or leg	Clinch[1]	Staple crown width	Type of point[2]
		Inch			Inch	
Nail	14	1-1/4	Plain	H	......	Duckbill
Nail, sixpenny, common	11-1/2	2	Plain	H	......	Diamond
Staple	16	1-1/2	Plastic	N	7/16	DC
Staple	16	2	Plastic	P	7/16	DC
Staple	16	1-1/8	Galvanized	P	7/16	DC
Staple	16	2	Galvanized	P	7/16	DC
T-nail	13-1/2	2	Plain	P	......	Diamond

[1]N, no clinch; H, clinched by hand with hammer; P, clinched by driving through specimen against a steel backing plate. Clinch applies to white pine specimens only.

[2]DC, divergent chisel.

EQUIPMENT

The general arrangement of the test equipment for dynamic impact tests in the FPL toughness testing machine is illustrated in figure 2, while that for the Tinius Olsen machine is shown in figure 3. These consist of a resistance strain-gage load cell with a special fastener clamp, a calibration box, a cathode-ray oscilloscope equipped with a Land process camera, two types of triggering devices, the FPL toughness testing machine, and the Tinius Olsen impact testing machine. Both testing machines employed the same load cell, clamping device, and instrumentation except for a minor difference in the triggering devices.

Both machines operate on the pendulum principle but differ radically in the manner in which the load is applied to the specimen. In the toughness machine the load is applied to a stationary specimen by means of a chain fastened around a drum, whereas on the Tinius Olsen machine the load is applied to a moving specimen by direct impact of specimen and base.

The FPL toughness testing machine consists of a steel frame from which is suspended a pendulum. The upper portion of the pendulum bar is attached to a pulley or drum whose center is the axis of rotation, while an adjustable weight is located at the lower end of the pendulum bar. The angle through which the pendulum

Figure 2.--Overall setup for conducting direct-withdrawal impact tests with the FPL toughness machine.

Figure 3.--Overall setup for conducting direct-withdrawal impact tests with the Tinius Olsen impact testing machine.

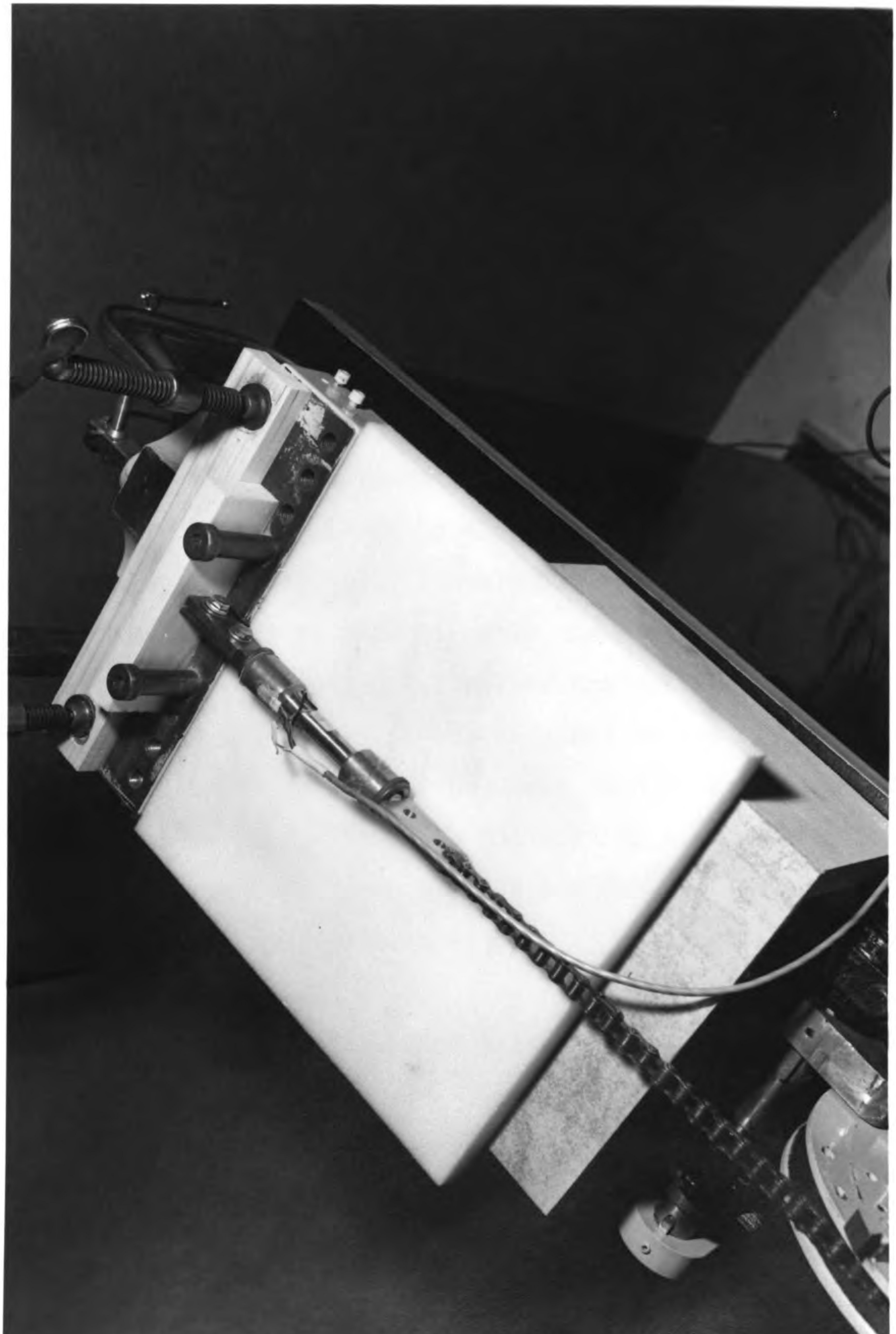
swings can be read from a fixed graduated scale and a vernier operated by the drum.

The energy necessary to withdraw a fastener from a specimen can be determined by reading the final angle which the pendulum makes with the vertical position. The final angle of the pendulum was used with the conversion tables employed with the toughness machine to obtain a value in inch-pounds that was an indication of the energy expended in causing failure of the specimen (12).

A quick-acting latch and trigger is provided for releasing the pendulum at a constant height. Weight position one on the pendulum was used in these tests, and provided a capacity of 673 inch-pounds at approximately 1 foot-per-second impact velocity.

A slight modification of the toughness tester allowed the equipment to be located on the frame and the test specimen to be held in place. The resistance strain-gage load cell was mounted in such a way that the load was applied directly through the cell. To accomplish this, the load cell was connected by a special clamp between the test specimen and a flexible chain, which in turn was fastened around the drum of the pendulum (fig. 4). To prevent the load cell from contacting the frame of the testing machine, a thin piece of polyether based-urethane foam cushioning material was inserted between the chain and the machine frame. This cushioning ma-

Figure 4.--Closeup of load cell and specimen in the FPL toughness machine.



terial did not contact nor interfere with the load cell or chain until completion of the impact test.

The Tinius Olsen impact testing machine consists of a vertical steel column or frame which serves as the axis of support for a pendulum. The upright section of the machine is connected to a base which is firmly bolted to the floor. A pendulum head or hammer is connected to the lower end of the pendulum arm and carries the specimen prior to impact. The pendulum head-holding devices were modified somewhat to carry the load cell with the same special clamp used in the toughness machine and the specimen (fig. 5). A scale is provided on the face of the machine to read directly the energy in foot-pounds expended in causing failure of the specimen.

In general, energy values obtained on the toughness machine had greater accuracy than those on the Tinius Olsen machine, which did not provide a vernier. The Tinius Olsen tests used about 6 per cent of the machine's energy capacity in comparison to about 15 per cent for the toughness machine.

A quick-acting latch and trigger released the pendulum at a constant height. The lower position of the latching mechanism provided a capacity of 120 foot-pounds at 11 feet-per-second impact velocity and was used in these tests.

Friction and windage losses were compensated for

Figure 5.--Closeup of load cell and specimen from beneath the pendulum head of the Tinius Olsen impact testing machine.

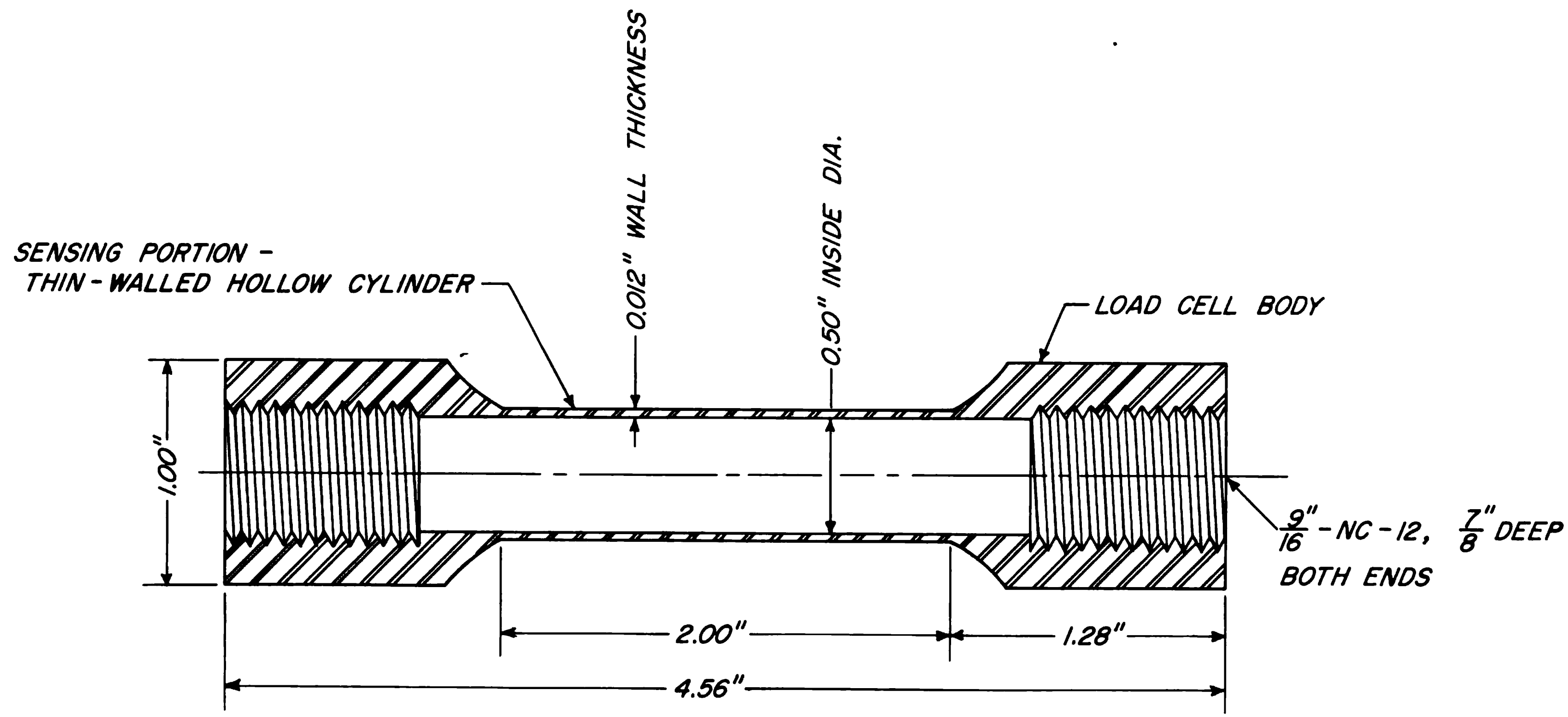
by suitable adjustments in both machines before making tests.

The wire strain gage type of load cell was used in all tests because of its adaptability, small size and weight, and reasonable stability and accuracy (4). It produced a high enough output to be effective with the loads encountered in these tests.

The sensing portion of the load cell, which was used with both machines, consisted of a thin-walled hollow steel tube with an inside diameter of 1/2 inch, and a 0.012-inch-thick-wall 2 inches long with four SR-4 resistance strain gages bonded to the outside wall of the cylinder (fig. 6). The set of four resistance strain gages are electrically connected to form a Wheatstone bridge. When the load cell was exposed to a strain in tension within the elastic limit, a change in the electrical resistivity of the wire occurs. A change of resistance in the two active gages will cause an unbalance of the bridge and produce a direct current output signal that is in proportion to the strain imposed upon the load cell. To compensate for temperature, lead length, and other variables, the two passive gages are mounted at the same location, but only the active pair of gages are exposed to the displacement under investigation.

Calibration is accomplished by shunting one leg of the Wheatstone bridge with a calibration resistor. This

Figure 6.--Sketch of load cell assembly.


SENSING PORTION -
THIN-WALLED HOLLOW CYLINDER
0.012" WALL THICKNESS
0.50" INSIDE DIA.
LOAD CELL BODY
9/16" - NC - 12, 7/8" DEEP
BOTH ENDS
1.00"
2.00"
1.28"
4.56"

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produces an unbalance of the bridge equal to that produced by a given load imposed on the load cell.

The direct current output signal was fed into the vertical deflection circuit of a cathode-ray oscilloscope. A Land process camera was used to record the load-time relationship.

In order to trigger the oscilloscope, which was set for a single sweep operation, an external trigger signal was provided for both machines by means of a metal contact that was closed by the testing machine just prior to impact of the specimen.

Horizontal sweep rate of the oscilloscope was calibrated with respect to time, enabling a measurement to be made of duration of test or loading.

The load cell was calibrated by applying loads of known magnitudes in a universal testing machine.

METHOD OF TEST

All wood pieces were removed from the conditioning room as needed and assembled as soon as possible into specimens with a nail, T-nail, or a staple. Similar tests involving the same combination of fasteners and wood specimens were made on each of the testing machines (tables 2 and 3). In any lot or combination of variables, there were 10 replicates.

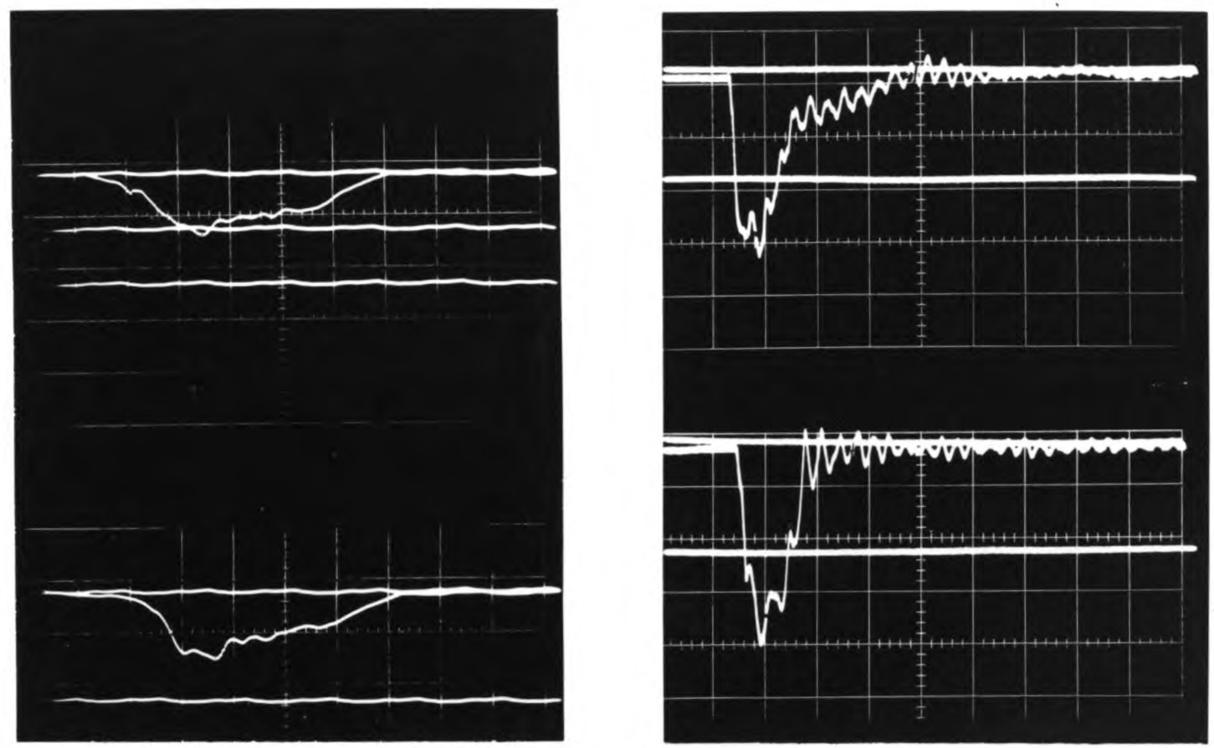
Fasteners in containers when subjected to direct-withdrawal impact loading either pull out of the cleat stock or through the panel material. For this reason the fasteners in the white pine were assembled in such a way that they were pulled out of the wood specimen, while in the plywood the fastener was driven so that the head or crown would be pulled through the plywood from the backside. In the plywood specimens, staple crowns and T-nail heads were driven perpendicular to the grain and flush with the surface of the outside ply. In the white pine, nails, staples, and T-nails were clinched parallel with the grain of the wood to give minimum withdrawal resistance.

The assembled specimens were immediately subjected to direct-withdrawal dynamic impact loading. Common nails used as controls were driven and clinched by hand with a hammer. All staples and T-nails were driven by means of a compressed air-type driving gun. Clinched fasteners were driven through the specimen and against a steel backup plate to give up to a 1/4-inch clinch. Unclinched fasteners were driven into the specimen in such a way that their points were approximately 1/16 inch from the opposite surface.

To perform the test on the FPL toughness machine, the adjustable weight on the pendulum was placed in the first position provided and the pendulum raised to an initial angle of 60°. The fastener was attached to the load cell with the special clamp and the specimen was mounted on the toughness machine. To reduce the possibility of bending during impact, particularly with the plywood, two additional clamps with a backup block were used to brace the backside of the specimens as shown in figure 4. The pendulum, when released, pulled the chain taut and applied a direct-withdrawal impact load to the fastener.

By means of the instrumentation previously described, a load-time pulse was recorded (fig. 7) and the final angle that the pendulum swung was recorded by the vernier and scale. The energy in inch-pounds expended in causing failure of the specimen was obtained directly from conversion tables provided with the toughness machine (12). From the calibration information and the load-time pulse, the maximum load in pounds and the load duration in milliseconds was computed.

To perform the tests with the Tinius Olsen impact machine, the specimen was attached to the load cell and the head of the pendulum, and the pendulum was raised until it



A

B

Figure 7.--Typical load-time pulses obtained with load cell and instrumentation setup for direct-withdrawal impact tests of fasteners. A shows examples of tests performed in the FPL toughness machine, and B shows examples of tests performed in the Tinius Olsen impact machine. Note shock wave superimposed on the main load pulse.

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was held by the latching mechanism. The pendulum was then released and the specimen impacted the base of the machine at the vertical position and was held firm while the pendulum head with clamped fastener continued to swing to a final angle (figs. 8 and 9).

Setup time in both machines was about the same, although clamping of the specimens was accomplished more readily in the toughness machine. Both machines required the operator to lift and latch the pendulum in position before making a test, and they both provided a means of release from a fixed height in order to give reproducible results independent of the operator. Both machines also provided a moving mass of kinetic energy great enough to cause failure of test specimen with one blow.

The load-time pulses obtained from tests performed in the Tinius Olsen impact machine were smoothed out to reveal the main force trace for approximating maximum loads. This was accomplished by locating the midpoint between the minimum and maximum value of each vibration and then connecting the midpoints with a curve which represented the main load pulse.

Figure 8.--Closeup of pendulum head carrying specimen before impact with base of the Tinius Olsen impact testing machine.

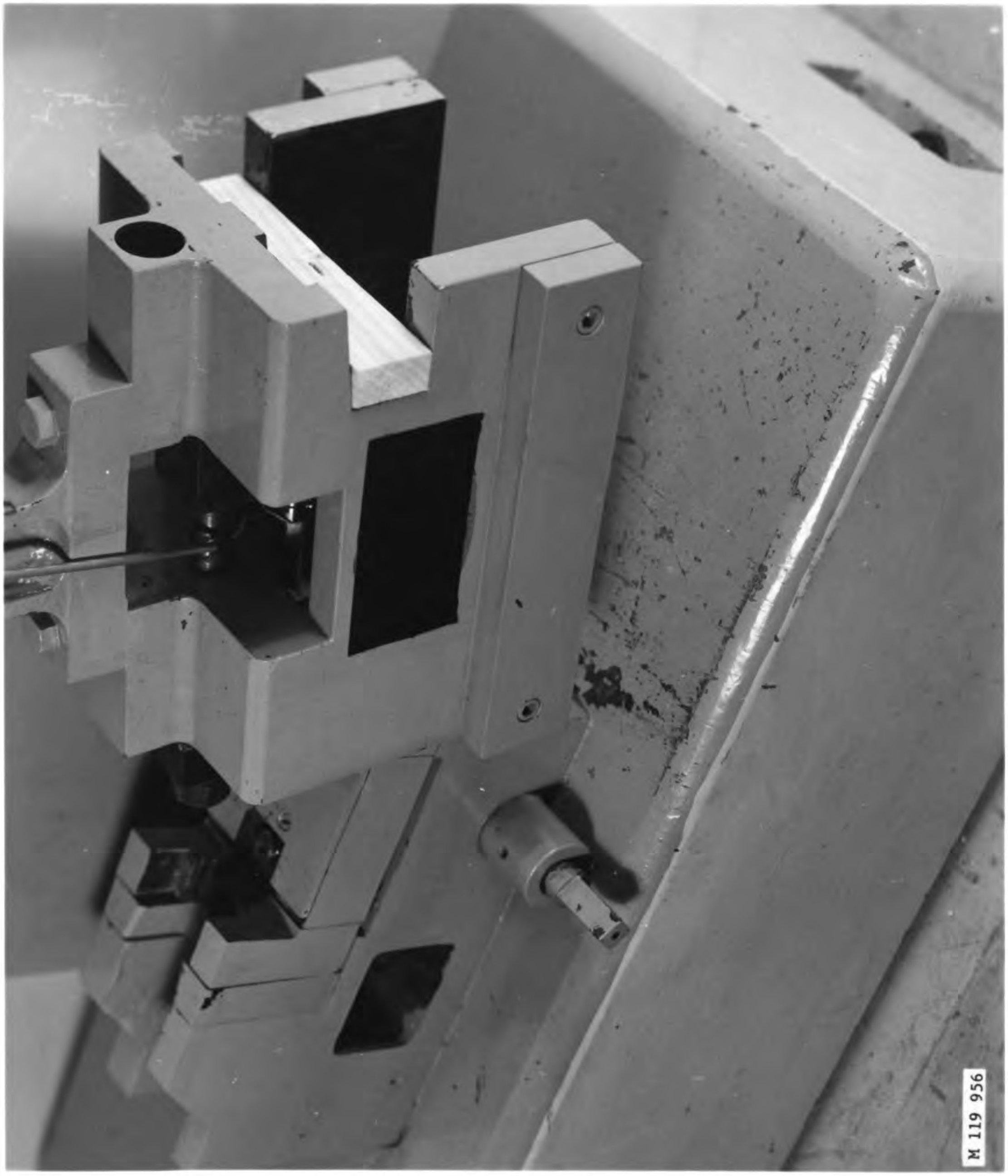
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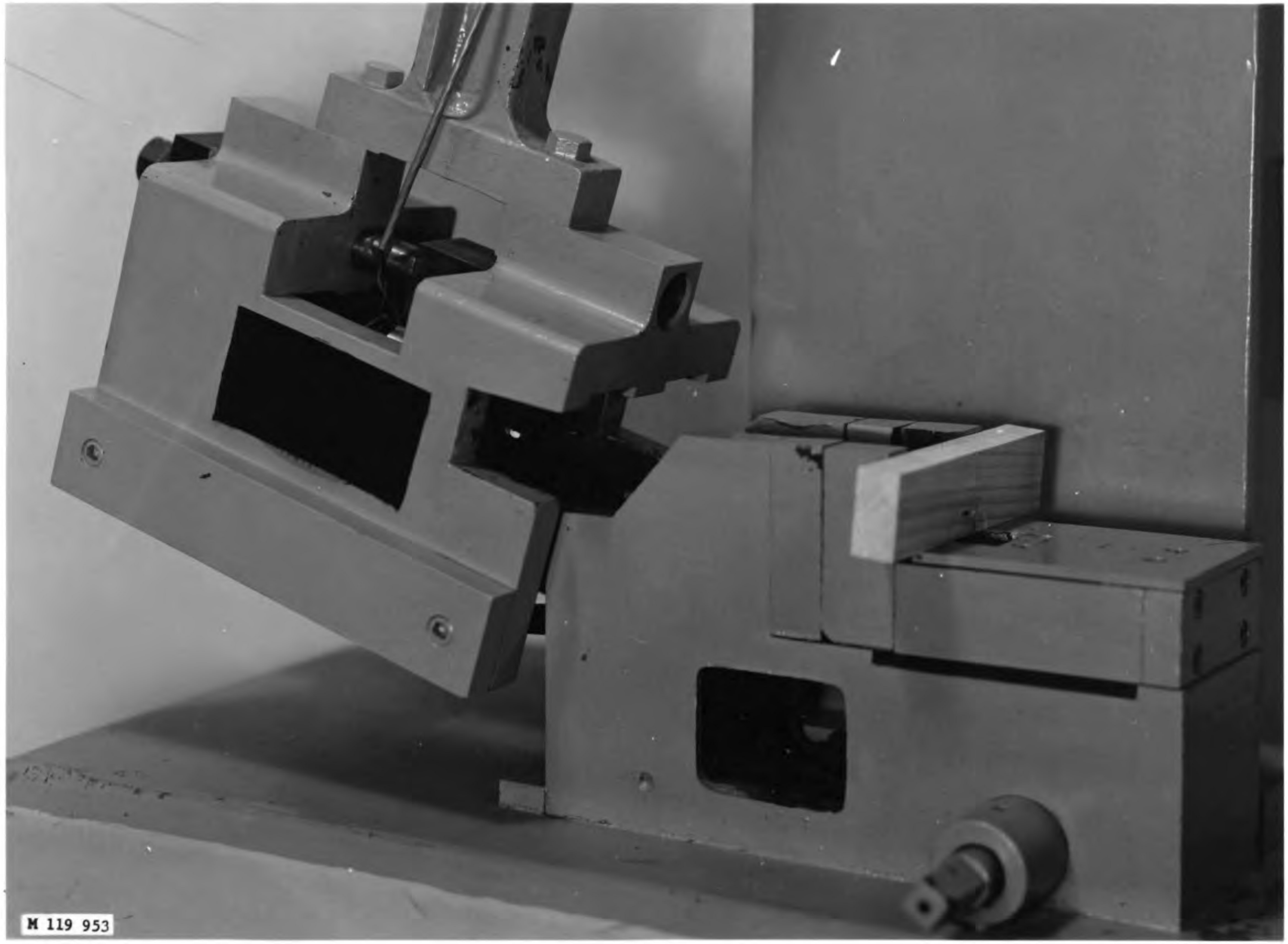
Figure 9.--Closeup of specimen immediately after impact, and pendulum head with fastener withdrawn from wood specimen.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RESULTS AND DISCUSSION

The average maximum load and the average duration of loading as determined from the load-time pulse, and the average energy expended in causing failure of the specimen for each lot of 10 tests using various fasteners with the two machines are given in tables 2 and 3.

Toughness Machine -- Plywood

The average maximum load, energy values, and duration of loading given in table 2 for plywood specimens tested in the FPL toughness machine show the following: (a) The control fasteners generally performed better than all the others, and (b) there was little or no difference discernible between the plastic-coated staple, the galvanized staple, or the T-nail.

Tinius Olsen Machine -- Plywood

The average values of maximum load, energy, and duration of loading in table 2 for the plywood specimens show that: (a) the control nails (duckbill and sixpenny) were only sightly better than the other fasteners, except that the sixpenny nail had a considerably longer duration of load than any of the other fasteners, and (b) among the alternate fasteners, the T-nails had higher average maximum values with little or no difference between the plastic-coated staple and the galvanized staple.

Table 2.--Direct-withdrawal impact resistance of fasteners in 1/4-inch, group III, container-grade plywood using the FPL toughness and Tinius Olsen impact machines

Fastener	Maximum load				Energy expended				Load duration			
	Average[1]	Minimum[2]	Maximum[2]	Range[3]	Average[1]	Minimum[2]	Maximum[2]	Range[3]	Average[1]	Minimum[2]	Maximum[2]	Range[3]
	Lb.	Lb.	Lb.	Percent	In.-lb.	In.-lb.	In-lb.	Percent	Msec.	Msec.	Msec.	Percent
					FPL Toughness Machine							
14-gage duckbill nail	242	217	276	24	103.0	85.5	127.6	41	60	39	78	65
Sixpenny common nail	254	174	307	52	73.6	60.0	91.3	43	42	34	54	48
1-1/2-inch plastic staple	[4]184	142	278	74	43.4	26.3	66.0	92	[4]24	19	32	54
1-1/8-inch galvanized staple	195	111	271	82	43.6	18.2	71.9	123	27	20	38	67
T-nail	195	103	286	94	41.6	18.2	68.0	120	32	21	42	66
					Tinius Olsen Machine							
14-gage duckbill nail	266	238	308	26	70.1	50.4	90.0	57	5.1	4.0	7.2	63
Sixpenny common nail	244	187	283	39	51.2	15.6	72.0	110	5.1	3.4	7.0	71
1-1/2-inch plastic staple	213	167	281	54	35.0	25.2	42.0	48	3.8	2.1	4.6	66
1-1/8-inch galvanized staple	201	168	224	28	33.8	24.0	42.0	53	3.3	2.3	4.6	70
T-nail	236	194	283	38	37.9	24.0	49.2	67	4.7	3.2	7.5	91

[1]Each value represents the average of 10 specimens.

[2]The minimum and maximum value in each lot of 10 specimens.

[3]The range in percent of average value.

[4]Value represents the average of 8 specimens because of no picture.

Table 3.--Direct-withdrawal impact resistance of fasteners in 25/32-inch white pine using the FPL toughness and Tinius Olsen impact machines

Fastener	Maximum load				Energy expended				Load duration			
	Average[1]	Minimum[2]	Maximum[2]	Range[3]	Average[1]	Minimum[2]	Maximum[2]	Range[3]	Average[1]	Minimum[2]	Maximum[2]	Range[3]
	Lb.	Lb.	Lb.	Percent	In.-lb.	In.-lb.	In.-lb.	Percent	Msec.	Msec.	Msec.	Percent
FPL Toughness Machine												
14-gage duckbill nail, clinched	100	61	132	71	45.4	28.3	62.1	74	54	38	62	44
1-1/2-inch plastic unclinched staple	143	89	178	62	14.4	10.1	18.2	56	15	10	22	80
2-inch plastic clinched staple	174	121	216	55	46.0	38.2	52.2	30	65	56	72	25
2-inch galvanized clinched staple	110	84	129	41	50.4	42.3	58.2	32	63	55	73	29
T-nail, clinched	107	87	124	35	70.1	58.2	79.7	31	69	65	72	10
Tinius Olsen Machine												
14-gage duckbill nail, clinched	139	95	204	78	50.9	36.0	60.0	47	6.5	4.7	9.2	69
1-1/2-inch plastic unclinched staple	85	57	108	60	10.0	2.4	18.0	156	2.1	1.7	2.7	48
2-inch plastic clinched staple	143	97	204	75	28.3	24.0	38.4	51	6.8	4.4	8.2	56
2-inch galvanized clinched staple	97	76	138	64	30.4	24.0	43.2	63	8.0	6.8	9.6	35
T-nail, clinched	102	80	145	64	55.1	45.6	69.6	44	7.0	6.4	7.7	19

[1]Each value represents the average of 10 specimens.

[2]The minimum and maximum value in each lot of 10 specimens.

[3]The range in percent of average value.

Toughness Machine -- White Pine

The average maximum load, energy, and duration of loading results for the white pine specimens tested in the FPL toughness machine show the following: (a) All fasteners with the possible exception of the unclinched plastic staple had average values greater than for the duckbill control nail. In some instances the differences were slight, but for other combinations the differences were considerable. (b) There was little difference between the duration of load for the clinched staples and T-nails, but the unclinched plastic staple was considerably lower than the other alternate fasteners. (c) There were some differences between the other values, notably the low energy value for unclinched plastic staples and the comparatively high average load value for the clinched plastic staple.

Tinius Olsen Machine -- White Pine

The average maximum load, energy, and duration of loading results for this combination revealed the following: (a) The unclinched plastic staple had consistently low average values as compared to all the other fasteners. (b) There was no definite trend tending to indicate a superior fastener performance among the duckbill control, the clinched plastic-coated or galvanized staple, or T-nail with the possible exception that the energy values for the T-nail were definitely higher than for the staples, and the average maximum load for the clinched plastic-coated staple was higher than for the galvanized clinched staple and T-nail.

An investigation of the specimens that showed abnormally high or low test values revealed no apparent reason for their occurrence. A possible explanation for the variation in test values might include variations in the assembled specimens due to some difficulty in attaching fastener to the wood specimen. Also, there was the possibility of moving the fastener while clamping it to the load cell. The variation in test values is apparently charateristic due to the variability of the specific gravity of wood within the same species since specific gravity is directly related to fastener direct withdrawal (10 and 11).

Further examination of the results indicated that on the basis of the average values for maximum load, energy, and duration of loading both testing machines generally ranked the fasteners as follows when tested with the plywood specimens: The sixpenny common nail and the 14-gage duckbill nail produced the highest values. These were followed by the T-nail, the plastic-coated staple, or galvanized staple with an occasional variation in the ranking.

Although ranking of the fasteners on the basis of their results with the white pine specimens was more erratic than with the plywood specimens, both testing machines tended to orient the fasteners in the same general fashion as regards average values for maximum load, energy, and duration of loading.

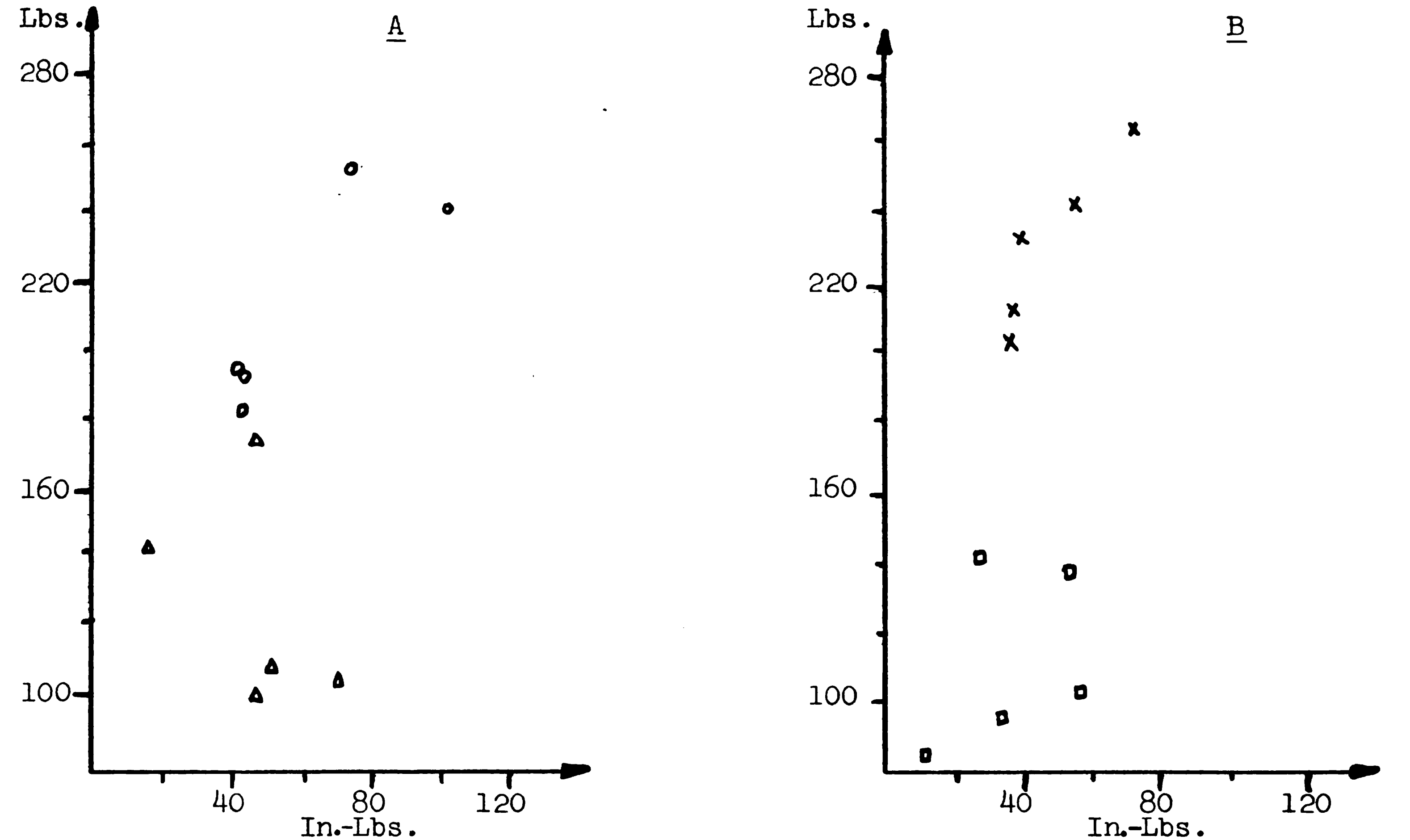
The plywood, when tested in both machines, developed considerably higher average maximum loads than the white pine, However, in general, there was no definite indication of greater energy for either type of wood in the two machines. The white pine, regardless of test machine, developed longer duration of loads than did the plywood.

Plots of average maximum loads against average energy expended in causing failure of the specimens with the toughness machine revealed no apparent relationship (graph 1-A). In the Tinius Olsen machine, the plywood showed a fair direct relationship of maximum load and energy, but the white pine revealed nothing (graph 1-B). Plots of average energy against average load duration revealed an apparent direct relationship in the white pine and plywood in both testing machines (graph 2). An examination of the pictures of the load-time pulses substantiated this fact because fasteners that developed higher energy generally had longer test times.

Regardless of the testing machine, plots of average maximum load against average load duration revealed an apparent direct relationship in the plywood but not in the white pine (graph 3).

An examination of the range in test values indicates that no apparent difference exists between the two machines, except that the Tinius Olsen machine appears to show more variation in load duration than the toughness

GRAPH 1



Showing relationship between average maximum load versus average energy expended.

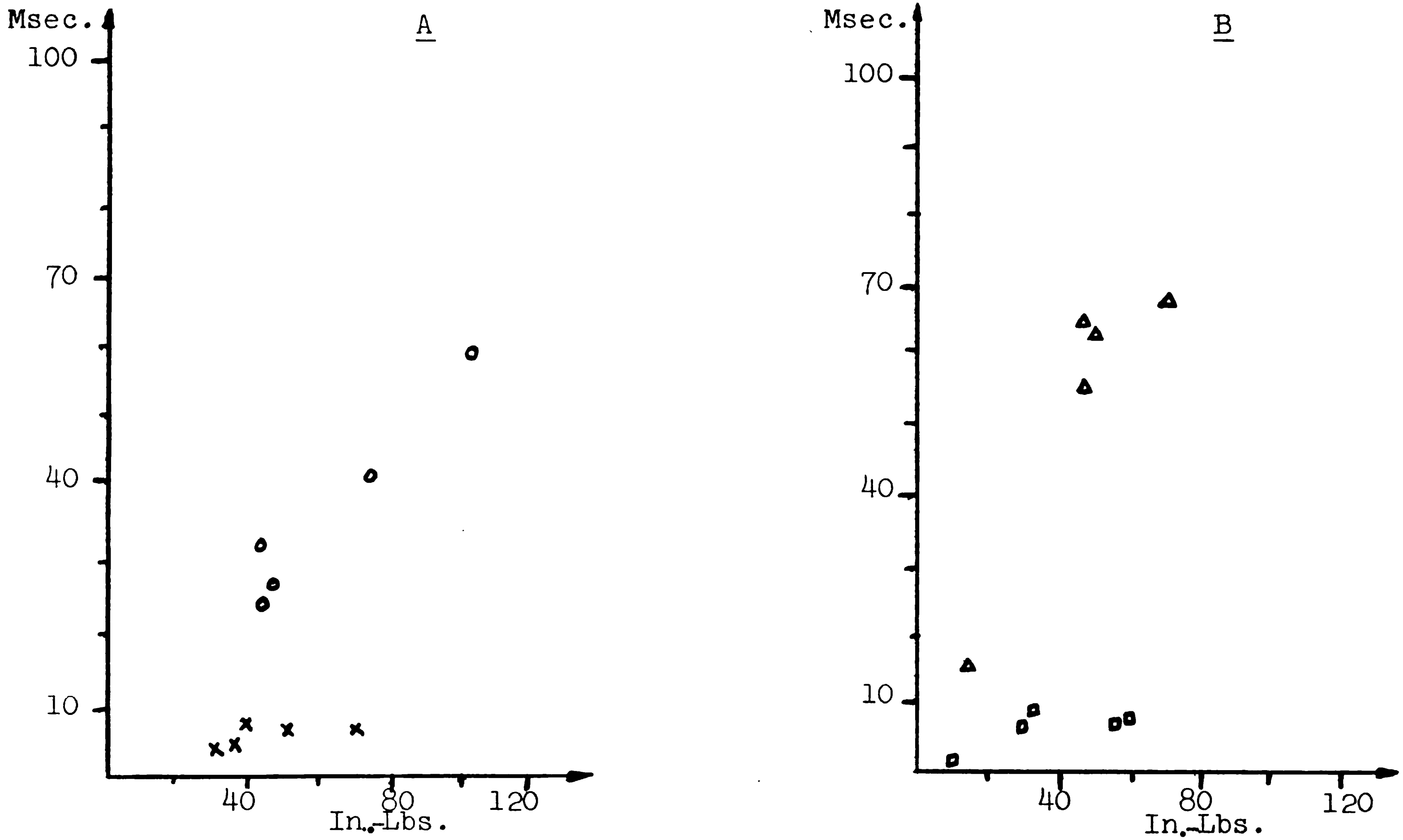
o = Plywood specimens tested in the FPL toughness machine.

Δ = White pine specimens tested in the toughness machine.

x = Plywood specimens tested in the Tinius Olsen machine.

□ = White pine specimens tested in the Tinius Olsen machine.

GRAPH 2



Showing relationship between average load duration versus average energy expended.

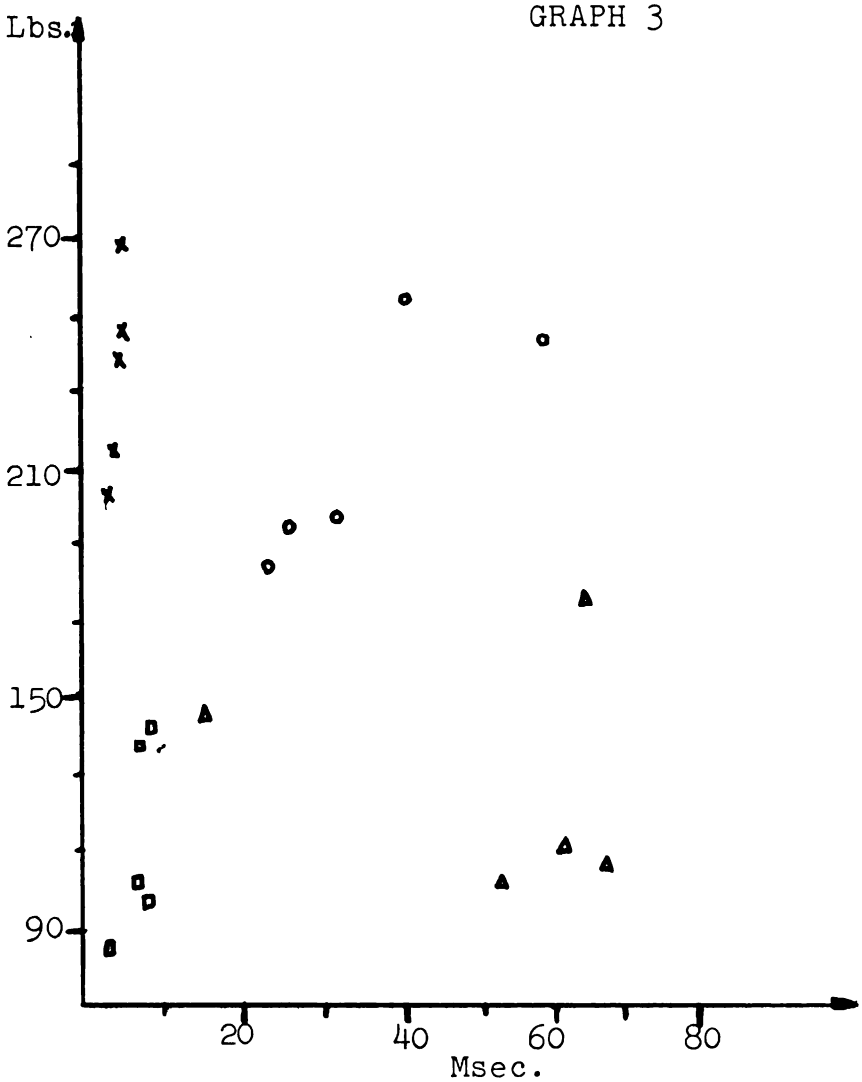
x = Plywood specimens tested in the Tinius Olsen machine.

o = Plywood specimens tested in the FPL toughness machine.

□ = White pine specimens tested in the Tinius Olsen machine.

Δ = White pine specimens tested in the FPL toughness machine.

GRAPH 3



Showing relationship between average maximum load versus average load duration.

o = Plywood specimens tested in the FPL toughness machine.
x = Plywood specimens tested in the Tinius Olsen machine.
△ = White pine specimens tested in the FPL toughness machine.
□ = White pine specimens tested in the Tinius Olsen machine.

machine. Furthermore, when considering all test results, the majority of the white pine specimens showed greater variation in terms of range when tested in the Tinius Olsen machine compared with the toughness machine.

When using the toughness machine, there is the possibility of the chain "whipping" when it is drawn taut just before impact. This action may cause force components to be produced on the fasteners that are not strictly direct withdrawal. It would be desirable to investigate this possible effect further since the test results do not show an apparent effect. The possibility of this type of error is eliminated when making similar tests in the Tinius Olsen impact machine.

The load cell in the Tinius Olsen machine was supported at both ends before and during impact, whereas the load cell in the toughness machine was supported only at the end connected to the fastener. Apparently there was less likelihood of lateral force components being produced in the cell when using the Tinius Olsen machine because there was no looseness in any part being subjected to direct impact. Also, in the toughness machine, there was the possibility of the chain elongating slightly during impact, and producing error in the test results.

The plywood, when tested in the Tinius Olsen machine, appeared to have a greater chance of bending during impact than it did in the toughness machine since it had no bracing on the backside with clamps.

One of the major differences in the two machines was that the Tinius Olsen machine provided a much faster impact velocity than the toughness machine. The impact velocity of the Tinius Olsen machine was about 11 feet per second in comparison to approximately 1 foot per second in the toughness machine. Since a container, when dropped from a height of 30 inches, reaches an impact velocity of about 12-1/2 feet per second at impact, the Tinius Olsen impact machine simulates actual container use conditions more closely than the toughness machine.

Even though the same load cell was used in both machines, the difference in impact velocity seems to have an adverse effect on the load cell in the Olsen machine but not in the toughness machine. Apparently, shock waves were produced in the load cell because of the high-speed loading conditions imposed by the Tinius Olsen machine. These intense stress transients produced at high impact rates superimpose on the main voltage output of the force gage and are superimposed on the load-time trace of the oscilloscope (fig. 7). A publication on high speed testing indicated that this superposition is characteristic enough to permit smoothing out the impact pulse to reveal the main force trace for approximating maximum load (2). It also indicated that tensile and compressive elastic waves produced by an impact pulse have received considerable theoretical attention, but their superposition is yet little understood. This publication also stated that impact tests can be performed at "...high distortion rates only at the cost of sacrificing test rate linearity."

A comparison of the pulse traces taken of the load cell under impact alone and when an actual specimen was loaded revealed the same vibratory wave pattern that was superimposed in actual tests. This indicated that the shock wave was produced in the load cell and not in the test specimen.

The amplitude of the shock wave imposed on the load-time trace is related to the impact velocity of the pendulum; the frequency is related to the modulus of elasticity, length of load cell, and mass density of the load cell. It follows that the natural frequency of the load cell should be high to eliminate confusion of the shock wave produced in the load cell with the desired signal. In this respect, the length of the load cell when employed in the Tinius Olsen machine was too great.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions may be drawn from the results of this study on the direct-withdrawal impact tests:

1. There is no apparent relationship between the load-carrying ability of the fasteners and the energy required to cause failure of the specimen.

2. A direct relationship is apparent between the load-carrying ability of the fasteners and the duration of loading in the plywood, but not in the white pine.

3. There is apparently a direct relationship between the energy required to cause failure of a specimen and the duration of loading.

4. Because the fasteners in the plywood developed greater loads than similar ones in the white pine, fasteners subjected to dynamic direct withdrawal in container applications would generally pull out of the white pine cleat stock rather than through the plywood.

5. The white pine generally produced longer load durations than did the plywood.

6. Generally, staples or T-nails would tend to pull through 1/4-inch container-grade plywood more readily than conventional nails.

7. A plastic-coated staple is generally better than a similar galvanized staple in white pine but not necessarily in plywood.

Both testing techniques differentiated the various fasteners consistently in terms of load, energy and duration of loading. There was no apparent difference in the way the two machines ranked the various fasteners. Generally, the white pine test results varied less when using the toughness machine, but the plywood results varied about equally in the two machines.

The Forest Products Laboratory toughness machine has a more accurate method of measuring energy values than the Tinius Olsen machine. Duration of loading was considerably less when using the Tinius Olsen impact machine because it imparts a faster impact velocity to the specimen and therefore is a faster impact test.

An advantage of the Tinius Olsen machine over the toughness machine is that there is no chain that could "whip" and elongate during testing. Further, the Olsen machine provides better support for the load cell tending to reduce the development of lateral force components.

The wire strain gage type of load cell can be used effectively in both machines. However, the length of the load cell when used in the Olsen machine should be smaller if possible in an effort to reduce shock excitation.

Both the FPL toughness and Tinius Olsen impact machines provide a usable method for obtaining information on the behavior of fasteners when subjected to dynamic impact forces tending to cause direct withdrawal. The selection of one machine over the other depends upon the type of container application being simulated. The Olsen machine generally appears to simulate container impact loads encountered under relatively high impact velocities better than the toughness machine. However, containers subjected to relatively low impact velocities generally would be simulated best in the toughness machine.

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