CYLINDRICAL SHEAR SPECIMEN FOR QUALITY CONTROL TEST ON GLUE BONDS IN LAMINATED TIMBERS

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CYLINDRICAL SHEAR SPECIMEN FOR QUALITY CONTROL TEST ON GLUE BONDS IN LAMINATED TIMBERS[1]

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Synopsis

The quality of the glue joints in laminated beams can be evaluated by removing round plugs (with their axes perpendicular to the glue lines) from noncritical areas of the beams, such as the end trims, and testing them in shear. A standard block shear tool was modified to facilitate testing glue joints in round plugs, and comparison of results from such plugs and standard shear blocks are presented. Pros and cons of the test are discussed.

Introduction

A cylindrical specimen and a method to test it were developed at the Forest Products Laboratory to meet a need that sometimes occurs for making tests on glue joints of structural laminated wood members in service. This test also offers considerable promise as a method for quality control in production.

Because of improper exposure during erection, severe drying conditions after enclosure of the building, or other causes, checking and joint separation

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[1] Presented at the Symposium on Timber--A Tested Material for the Engineer, Fourth Pacific Area National Meeting, American Society for Testing and Materials, October 3, 1962, at Los Angeles, Calif.

[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

sometimes develop on the surfaces of laminated timbers. When joints separate an appreciable amount at the surface, the quality of the glue bond in other parts of the timber is always questioned, and a need for some means to determine this has been evident for some time. It should be kept in mind, however, that surface checking in the wood is no indication of weak glue joints but rather the contrary; careful examination, often by use of a magnifying lens, is required to distinguish between joint separation and failure or checking in the wood.

As a possible solution to this problem, the Forest Products Laboratory has developed a test by which a check on the quality of the glue bond in various parts of a laminated member can be made without impairing the structural quality of the member. For quality control, the specimens could also be taken from the end trimmings that usually are removed in squaring up the ends of the members. Cylindrical shear specimens of various types have been used previously,[3,4] but none of them appeared applicable to this particular problem.

Description of Test

The method is a modification of the glue block shear test (ASTM D 905-49).[5] The major difference is that the specimens used are cylindrical, about 1 inch in diameter, and with the glue joints perpendicular to the axis of the cylinder.[6]

The shear tool used in most of the development work was a modified glue block shear tool (figs. 1 and 2). The movable and stationary members that apply the shearing force have cylindrical holes of about the same diameter as the specimens. These holes coincide with each other when the movable shearing member is in the correct position for insertion of the specimen. Figure 2 shows a specimen in the shear tool ready for testing. The plane of the glue joint must coincide with the interface between the stationary and the movable shearing members. This was accomplished by making a fine pencil line on

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[3] Twiss, S. B. and Clougherty, L. B. A Disk Shear Test for Adhesives. ASTM Bull. Sept. 1958, p. 57.

[4] Rhude, M. J. A Survey of Methods for Making Shear Tests of Wood. Thesis submitted in partial fulfillment of the requirements for the Degree of Master of Science (Civil Engineer), University of Wisconsin, 1950.

[5] American Society for Testing and Materials. Test for Strength Properties of Adhesives in Shear by Compression Loading. ASTM D 905-49.

[6] An earlier description of the method was published in the February 1962 issue of the Forest Products Journal (Vol. XII, No. 2). Some important modifications in the method have been made, however, since the earlier publication.

the periphery of the specimen, parallel to the glue joint and at a distance from the joint equal to the thickness of the frontal shearing member. When the specimen was inserted for testing, this pencil line coincided with the frontal face of the front shearing member. A small block of steel of exactly the same thickness as the frontal shearing member, and with a hole through it of the same diameter as that of the specimens, was used for marking the distance from the glue line equal to that of the thickness of the shearing member on the specimens.

The direction of the shearing force must be parallel with the grain direction of the adjoining laminations.

Cylindrical Plug Cutter

Various types of plug cutters were considered, and three types were tried. The one that produced the plug having practically no cutter marks or torn grain is shown in figure 3. This cutter is available commercially in sufficient length to produce about a 2-inch plug. To produce plugs about 4 to 5 inches long, this cutter was cut at the base of the half cylinder, and a cylinder or barrel extension was welded to it (fig. 4).

The inside diameter of the plug cutter measured 1.015 inches. A number of plugs that were cut from laminated Douglas-fir and southern pine at approximately 12 percent moisture content were measured for length of diameter along and across the grain. This was repeated on plugs cut from materials that were at about 6 percent moisture content. The results are shown in table 1. The plugs averaged from 0.001 to 0.002 inch less in diameter than the cutter except for those cut from the pine at 6 percent moisture content, which averaged the same as the cutter. The ranges were from 1.013 to 1.015 inches for the individual pine specimens and from 1.012 to 1.014 inches for the Douglas-fir specimens.

The plugs were cut with a drill press, and various cutter speeds and feed rates were tried. When the cutter turned at 295 revolutions per minute and with axial feed rate in the range of 0.004 to 0.020 inch per revolution (equivalent to a cutting speed of about 80 feet per minute), the smoothest plugs were obtained.

Reasonably smooth plugs were also obtained at 475, 715, and 870 revolutions per minute with feed rates of 0.004 to 0.020 inch per revolution. Slight burning developed on dense wood at 870 revolutions per minute, and at 1,335 revolutions per minute both burning and rough plugs resulted when dense wood was involved. The smoothness of cut will vary somewhat, depending on the type of grain involved, and a few trials may be required to obtain the smoothest cut.

No portable equipment was developed, but this would be needed for taking plugs from laminated members in service.

Comparisons of Shear Results from Shear Blocks and Round Plugs

Two Douglas-fir boards and two southern yellow pine boards 1 by 6 by 24 inches in size at about 12 percent moisture content were laminated with phenol-resorcinol adhesive, using a 2-minute assembly period. Similar boards were glued using 45- and 90-minute assembly periods. The entire procedure was repeated with casein glue on the two species. The extremely long assembly period (particularly for casein glue) was used to obtain borderline or inferior glue-joint quality. Both types of adhesives were cured at about 80° F. for an overnight period. The laminated boards were allowed to condition for 1 week at 65 percent relative humidity and 80° F. Equal numbers of shear blocks and round plugs were then cut from the glued assemblies in such a way that each plug was cut next to a shear block, both across and along the grain, thus affording both end and side matching.

A universal testing machine (fig. 5) was used for both the block and cylindrical plug shear tests. The rate of loading was 0.015 inch per minute.

The results are shown in tables 2 to 5 inclusive and indicate that the shear strength obtained with the round plug is somewhat lower than that obtained with the standard glue-shear block. The averages for 20 specimens ranged from 0.85 to 1.00 in the plug-to-shear block strength ratios. In slightly more than half of the results, the standard deviation showed greater variations in the data obtained with the plugs than in the data obtained with the shear blocks.

The average estimated wood failures were generally in reasonably good agreement between the two types of specimens, particularly with the resorcinol-glued material.

The causes for the generally lower shear strengths that were obtained using the plugs were not investigated in detail. It is possible, however, that less pure shear develops at the glue line with the cylindrical plug than with the shear block because of the slight tolerance required in order to be able to insert the plug. Because of this tolerance, together with the compression of the wood under the shearing members, the axis of the specimen and the axes of the cylindrical holes into which the specimen is inserted may be at a slight angle with each other at the time of failure. A couple about the glue joint, consequently, will occur that exerts a certain amount of tension perpendicular to the joint. Since wood is weaker in tension perpendicular to the grain than in shear, this couple action could contribute to the lower shear values obtained with the cylindrical specimen.

A couple action develops with the shear block also, but might be less pronounced than that associated with the cylindrical plug specimen. The thickness of the movable shearing member was about 1-5/32 inches and the thickness of the stationary member was about 31/32 inch. The use of thicker shearing members than these would result in less disalinement between the axis of the specimen and the axes of the holes into which the specimen is inserted.

In an attempt to reduce the couple action and to simplify the alinement of the glue line at the interface of the two shearing members, the shear tool was modified as shown in figures 6 and 7. (Figure 8 is a line drawing of the tool.) By means of the locking device shown on the front of the shear tool the specimen can be held securely in position, thus keeping the axis of the specimen more nearly in alinement with the axis of the holes.

A group of plugs were tested in the modified shear tool and a group of shear blocks, end-matched and side-matched to the plugs, were also tested. The diameter of these plugs were about 1.003 inch, slightly shorter than for those used in the previous tests. The results of the shear tests are shown in table 6.

Again, the average shear strength was somewhat higher when the standard block test was used; the difference between the means was significant at the 2.5 percent level, but not at the 1 percent level. The ratio of the average plug strength to average shear block strength was 0.92, which was also the grand average ratio for all tests made before the final modification was made on the shear tool. It is believed, nevertheless, that the locking device is a definite improvement on the shear tool, particularly when the plugs do not fit too snugly (in the final tests, table 6, the diameter of the plugs was about 0.010 less than in the previous tests).

The opening in the top of the fixed shearing member greatly facilitates the positioning of the glue line at the interface of the two shearing members, and appears to be a definite improvement in the ease and speed with which the test can be carried out.

The difference in the height of shearing area between the two types of specimens could cause or contribute to the lower shear strength developed by the cylindrical plug. Johnson and Larson[7] found a reduction in shear strength of about 10 percent in Douglas-fir when the height of the shearing area was reduced from 1.5 to 1 inch.

Lower shear strength values are apparently obtained with a 1-inch-diameter cylindrical specimen than with the standard glue shear block. This does not, however, make the cylindrical specimen unsuitable for evaluation of glue joint quality. For such an evaluation, the amount of wood failure developed is equally important. In general, no consistent differences were found in the amounts of wood failure developed by the two test methods.

Discussion of Test

A larger shearing area would be expected to give less variability between individual test results, but it would also require that heavier tools be used for cutting the plugs than were used in these experiments. In some laminated members or places in laminated members, furthermore, a plug that is larger than 1 inch in diameter would be detrimental. Hence, it was thought, a 1-inch plug was a suitable choice.

The suggestion has been made that shear blocks could be cut from the cylindrical plugs. It is doubtful if this would provide a more accurate evaluation of the glue joints, and it would, of course, reduce the shear area and multiply the work of preparing the test specimens. An outstanding advantage of the cylindrical specimen is the speed with which it can be prepared.

A torsion test on the plugs has also been suggested. This may have possibilities, but experience and data would have to be accumulated before the test would be applicable for assaying glue joints.

Probably many variables or factors might have an effect on the shear strength in a cylindrical plug, such as the angle between grain direction and the glue line. Investigations of the effect of such factors would have been interesting but not necessarily essential to prove the usefulness of this test method. Furthermore, time was not available for an exhaustive study of the various factors that might have affected the results.

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[7] Johnson, R. E., and Larson, W. C. The Effect of Length of Shear Area on the Shear Strength of Wood. Thesis submitted in partial fulfillment of the requirements for the Degree of Bachelor of Science (Civil Engineer), University of Wisconsin, 1950.

The plug cutter that was used was entirely adequate to produce samples for evaluating the test method. To obtain plugs from deep members, a much longer tool than this cutter would be needed. It has been reported that another laboratory is well underway in the development of such a plug cutter, so no work was done along these lines except that the available cutter was extended to about 4 or 5 inches in length.

It has also been reported that accelerated soaking-drying tests on increment cores from laminated members have been carried out by another laboratory, hence it was decided to limit this investigation to evaluation of the joints by shear tests.

Conclusions

The test that was developed--shearing of glue joints in cylindrical plugs--appears sufficiently promising to be used, where it becomes necessary, to make tests on glue joints of laminated members in service. It also appears to have possibilities as a rapid test method for use in quality control.

When the test is properly carried out and high wood failures and shear strength are obtained, there should be reasonable assurance that the joints are of good quality.

A portable drill could probably be modified to operate a plug cutter under field conditions, but no work was done to explore this phase of sample cutting.

Table 1.--Measurements of diameter parallel to and across the grain of Douglas-fir and southern pine plugs cut with 1-inch plug cutter at two different moisture content levels

12 percent moisture content			6 percent moisture content		
Plug No.	Diameter perpendicular to grain	Diameter parallel to grain	Plug No.	Diameter perpendicular to grain	Diameter parallel to grain
	In.	In.		In.	In.
1P[1]	1.014	1.015	1P	1.014	1.014
2P	1.014	1.014	2P	1.013	1.015
3P	1.014	1.014	3P	1.014	1.015
4P	1.014	1.014	4P	1.015	1.015
5P	1.014	1.014	5P	1.013	1.014
Average:	1.014	1.014		1.014	1.015
1F[1]	1.012	1.013	1F	1.014	1.014
2F	1.013	1.013	2F	1.013	1.014
3F	1.014	1.013	3F	1.014	1.014
4F	1.013	1.013	4F	1.014	1.014
5F	1.013	1.014	5F	1.014	1.014
Average:	1.013	1.013		1.014	1.014

[1]P indicates southern pine and F indicates Douglas-fir

Table 2.--Comparisons of results of shear tests on standard glue-shear blocks[1] and about 1-inch round plugs cut from laminated Douglas-fir boards that were glued and cured at 80° F. with casein glue at three different closed assembly periods

2-minute assembly				45-minute assembly				90-minute assembly			
Shear block		Plug		Shear block		Plug		Shear block		Plug	
Shear strength	Estimated wood failure	Shear strength	Estimated wood failure	Shear strength	Estimated wood failure	Shear strength	Estimated wood failure	Wood strength	Estimated wood failure	Wood strength	Estimated wood failure
P.s.i.	Percent	P.s.i.	Percent	P.s.i.	Percent	P.s.i.	Percent	P.s.i.	Percent	P.s.i.	Percent
[1]1,220	95	793	75	1,093	95	1,091	75	1,567	80	967	50
1,127	90	921	80	1,067	95	942	90	1,047	75	967	15
1,247	95	1,041	90	1,207	95	1,017	95	1,140	25	967	70
1,087	95	1,189	90	1,140	90	921	100	1,127	65	818	50
1,487	100	991	80	1,087	95	1,041	75	1,360	40	893	85
1,207	95	1,189	85	907	95	1,091	100	1,167	65	1,017	5
1,227	90	921	60	1,267	95	1,041	75	1,167	15	893	65
720	100	1,115	65	967	100	1,140	85	860	40	595	0
1,420	85	867	95	1,273	95	818	100	887	10	1,017	85
840	100	1,264	95	927	95	1,238	95	833	55	967	0
1,273	95	1,189	65	1,073	100	921	100	1,233	15	992	95
1,113	90	1,189	95	1,093	95	1,140	100	1,073	60	1,041	5
1,267	100	867	95	1,113	100	1,140	95	1,000	10	1,065	30
1,153	95	1,065	95	1,120	100	992	90	1,033	30	942	0
1,167	95	793	80	1,200	100	1,065	100	1,260	5	1,115	95
973	90	818	80	1,047	95	1,140	90	1,020	40	1,065	0
1,140	85	921	90	1,120	95	921	95	1,153	15	1,189	65
1,040	90	1,065	90	1,027	95	992	95	1,127	35	768	5
1,113	95	942	95	1,020	100	942	95	867	10	743	20
1,247	80	1,091	65	793	90	867	95	1,307	45	921	5
Average:											
1,153	93	1,012	83	1,077	96	1,023	92	1,111	37	947	37
STANDARD DEVIATION											
175		148		119		109		183		137	
AVERAGE RATIO--PLUGS:SHEAR BLOCKS											
		0.88				0.95				0.85	

[1]In accordance with ASTM D805-52.

Table 3.--Comparisons of results of shear tests on standard glue-shear blocks[1] and about 1-inch round plugs cut from laminated southern pine boards that were glued and cured at 80° F. with a casein glue at three different closed assembly periods

2-minute assembly				45-minute assembly				90-minute assembly			
Shear block		Plug		Shear block		Plug		Shear block		Plug	
Shear strength	Estimated wood failure	Shear strength	Estimated wood failure	Shear strength	Estimated wood failure	Shear strength	Estimated wood failure	Wood strength	Estimated wood failure	Wood strength	Estimated wood failure
P.s.i.	Percent	P.s.i.	Percent	P.s.i.	Percent	P.s.i.	Percent	P.s.i.	Percent	P.s.i.	Percent
[1]2,027	20	1,618	100	1,900	40	1,742	100	1,780	70	1,642	95
1,880	95	1,671	100	1,907	75	1,866	90	1,947	100	1,792	60
1,760	95	1,692	95	1,760	75	1,792	50	1,760	60	1,493	100
1,973	85	1,468	95	1,780	90	1,940	90	1,787	95	1,866	55
1,787	100	1,692	95	1,940	85	1,518	40	2,007	65	1,044	75
1,800	95	1,742	100	1,633	80	1,742	75	1,807	80	2,063	80
1,833	100	1,742	80	1,860	55	1,493	75	1,740	65	1,193	30
2,153	95	1,567	100	1,420	70	1,990	80	1,900	65	1,940	40
2,000	85	1,742	90	1,853	75	2,012	80	2,033	25	1,393	100
2,167	50	2,190	95	1,747	75	1,742	65	1,887	100	1,965	100
1,913	95	1,891	95	1,760	70	1,542	65	1,820	55	1,168	30
2,093	50	1,468	95	1,533	70	1,618	45	1,640	95	2,012	60
1,867	75	1,965	90	1,927	60	1,742	90	2,007	60	1,418	40
2,040	70	1,542	100	1,720	80	2,012	80	1,593	90	1,542	80
1,973	75	1,816	80	1,967	65	1,443	75	1,933	55	1,518	55
2,100	90	1,244	100	1,680	80	1,866	65	1,627	90	1,742	60
1,907	65	1,716	85	1,893	40	1,293	100	1,953	20	1,493	70
1,913	95	1,318	95	1,120	30	1,816	80	1,533	75	1,343	50
1,773	100	1,816	65	1,993	80	1,468	85	1,820	90	1,368	30
2,027	100	1,518	100	1,880	15	1,642	85	1,567	75	1,692	15
Average: 1,949	82	1,671	93	1,764	66	1,714	76	1,807	72	1,584	61
STANDARD DEVIATION											
126		218		212		207		154		295	
AVERAGE RATIO--PLUGS:SHEAR BLOCKS											
		0.86				0.97				0.88	

[1]In accordance with ASTM D805-52.

Table 4.--Comparisons of results of shear tests on standard glue-shear blocks[1] and about 1-inch round plugs cut from laminated Douglas-fir boards that were glued and cured at 80° F. with a phenol-resorcinol adhesive at three different closed assembly periods

2-minute assembly				45-minute assembly				90-minute assembly			
Shear block		Plug		Shear block		Plug		Shear block		Plug	
Shear strength	Estimated wood failure	Shear strength	Estimated wood failure	Shear strength	Estimated wood failure	Shear strength	Estimated wood failure	Wood strength	Estimated wood failure	Wood strength	Estimated wood failure
P.s.i.	Percent	P.s.i.	Percent	P.s.i.	Percent	P.s.i.	Percent	P.s.i.	Percent	P.s.i.	Percent
[1]1,040	95	1,240	100	1,287	95	1,251	95	1,413	85	1,710	90
1,333	90	1,065	100	1,580	95	1,289	100	1,693	90	1,684	95
1,347	100	1,462	95	1,353	100	1,486	100	1,273	90	1,213	95
1,460	95	921	100	1,620	95	1,377	100	1,700	95	1,660	100
1,293	95			1,307	100	1,412	100	1,720	95	1,338	100
1,660	75	1,238	100	1,633	100	1,264	100	1,467	90	1,537	100
1,207	100	1,437	95	1,507	95	1,438	100	1,413	100	1,635	100
1,413	95	942	100	1,687	95	1,510	95	1,513	95	1,785	100
1,247	90			1,747	100	1,710	90	1,693	95	1,510	100
1,507	100	1,189	95	1,747	95	1,735	95	1,647	90	1,312	95
1,060	90	1,685	95	1,833	100	1,537	100	1,493	85	1,585	95
1,547	95	1,041	100	1,633	90	1,833	100	1,887	95	1,338	95
1,067	90	1,537	100	1,867	95	1,734	95	1,640	95	1,684	90
1,380	85	1,115	90	1,893	95	1,783	95	1,873	100	1,510	90
1,027	95	1,238	100	1,693	100	1,560	100	1,747	90	1,859	95
1,473	95	1,213	95	1,247	95	1,883	90	2,047	95	1,135	100
1,313	95	1,189	100	1,587	95	1,213	100	1,640	80	2,017	100
1,367	100	1,213	95	1,620	90	1,486	100	1,753	100	1,759	100
1,180	100	1,486	100	1,760	90	1,510	95	1,700	80	1,958	100
1,500	100	1,213	95	1,600	100	1,289	95	1,900	95	1,635	100
Average: 1,321	94	1,246	98	1,610	96	1,515	97	1,661	92	1,593	97
STANDARD DEVIATION											
182		206		189		206		190		237	
AVERAGE RATIO--PLUGS: SHEAR BLOCKS											
		0.94				0.94				0.96	

[1]In accordance with ASTM D805-52.

Table 5.--Comparisons of results of shear tests on standard glue-shear blocks[1] and about 1-inch round plugs cut from laminated southern pine boards that were glued and cured at 80° F. with a phenol-resorcinol adhesive at three different closed assembly periods

2-minute assembly				45-minute assembly				90-minute assembly			
Shear block		Plug		Shear block		Plug		Shear block		Plug	
Shear strength	Estimated wood failure	Shear strength	Estimated wood failure	Shear strength	Estimated wood failure	Shear strength	Estimated wood failure	Wood strength	Estimated wood failure	Wood strength	Estimated wood failure
P.s.i.	Percent	P.s.i.	Percent	P.s.i.	Percent	P.s.i.	Percent	P.s.i.	Percent	P.s.i.	Percent
[1]2,193	100	1,841	85	1,653	95	1,293	90	1,647	80	1,518	90
1,973	90	1,891	75	1,660	90	1,293	100	1,533	95	1,518	75
2,133	80	1,642	85	1,700	95	1,642	85	1,427	85	1,518	95
1,933	100	2,015	95	1,667	90	1,618	95	1,533	90	1,443	85
2,027	90	1,518	90	1,727	100	1,567	85	1,320	95	1,542	90
2,000	85	2,114	85	1,687	95	1,518	95	1,767	80	1,418	95
2,020	85	1,841	80	1,667	95	1,965	80	1,220	90	1,493	85
2,127	95	2,139	80	2,040	80	1,542	100	1,300	75	1,193	90
1,847	95	1,717	65	1,587	95	1,217	95	1,500	95	1,518	95
1,940	95	2,164	100	1,727	70	1,567	90	1,400	95	1,692	100
2,027	90	1,716	95	1,767	90	1,891	90	1,380	95	1,642	95
1,980	95	1,915	95	1,793	85	1,592	90	1,767	95	1,217	95
2,133	95	1,891	100	1,673	95	1,368	95	1,587	95	1,542	95
1,920	95	1,439	80	1,953	90	1,716	70	1,853	90	1,816	70
2,360	90	2,139	90	1,533	85	1,493	95	1,587	85	1,642	90
2,147	90	1,990	95	2,000	50	1,468	90	1,800	90	1,518	70
2,327	80	2,090	95	1,347	85	1,493	85	1,620	95	1,792	90
2,173	90	1,915	95	1,960	70	1,592	90	1,760	95	1,692	100
1,700	90	1,792	85	1,833	70	1,368	95	1,480	95	1,642	85
2,000	80	2,388	90	2,120	45	1,443	95	1,713	85	1,816	35
Average:											
2,048	91	1,908	88	1,755	84	1,532	91	1,560	90	1,559	86
STANDARD DEVIATION											
156		233		186		187		183		169	
AVERAGE RATIO--PLUGS:SHEAR BLOCKS											
		0.93				0.87				1.00	

[1]In accordance with ASTM D805-52.

Table 6.--Results of shear tests on standard glue shear blocks and on cylindrical plugs using modified shear tool

Shear block		Cylindrical plug	
Shear strength	Estimated wood failure	Shear strength	Estimated wood failure
P.s.i.	Percent	P.s.i.	Percent
1,527	95	1,316	95
1,640	95	1,595	100
1,700	80	1,532	95
1,513	95	1,639	95
1,414	100	1,101	100
1,607	95	1,620	90
1,460	100	1,323	100
1,467	100	1,715	95
1,660	100	1,487	100
1,367	95	1,633	100
1,740	75	1,335	95
1,280	90	1,539	100
1,860	100	1,722	95
1,860	90	1,835	95
1,813	95	1,785	100
1,727	100	1,532	95
1,853	100	1,614	100
1,840	90	1,861	85
1,793	95	1,601	95
1,787	90	1,633	60
1,820	80	1,658	85
1,853	100	1,690	95
1,780	90	1,677	95
1,600	80	1,759	80
1,820	90	1,734	85
1,800	70	1,462	80
1,793	100	1,608	95
1,660	95	1,405	100
1,593	95	1,171	95
1,370	90	1,297	100
1,100	95	1,070	100
1,327	100	962	75
1,473	95	1,000	95
1,113	100	1,120	95
1,733	90	1,772	95
1,513	90	1,272	95
1,380	85	1,082	95
1,800	95	1,411	90
1,947	95	1,810	95
Average: 1,625	93	1,497	93
STANDARD DEVIATION			
216.5		253.1	
AVERAGE RATIO--PLUGS:SHEAR BLOCKS 0.92			

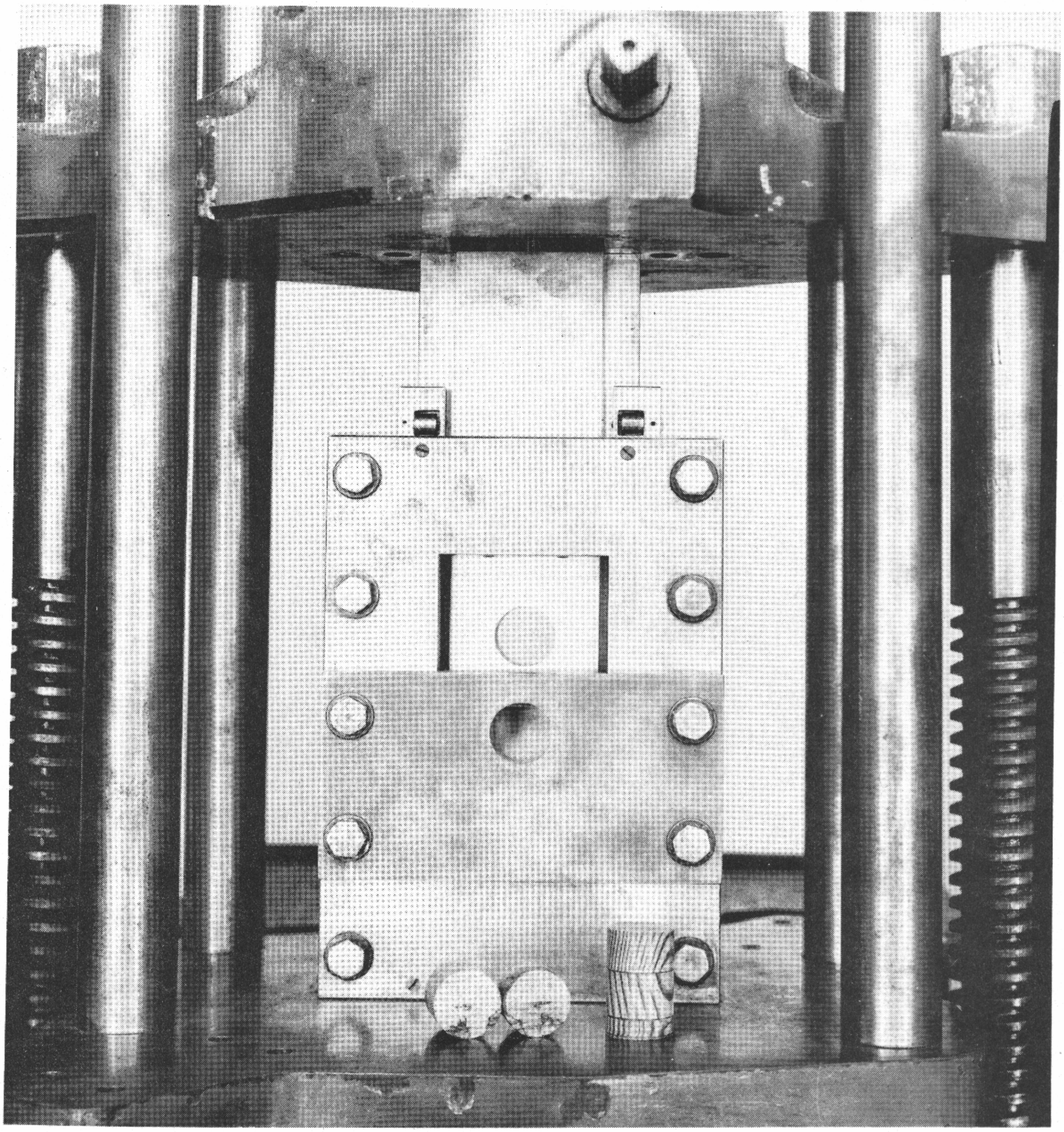

Figure 1.--Front view of shear tool for testing cylindrical specimens. The two cylindrical holes must coincide before specimen can be inserted.

Z M 116 355

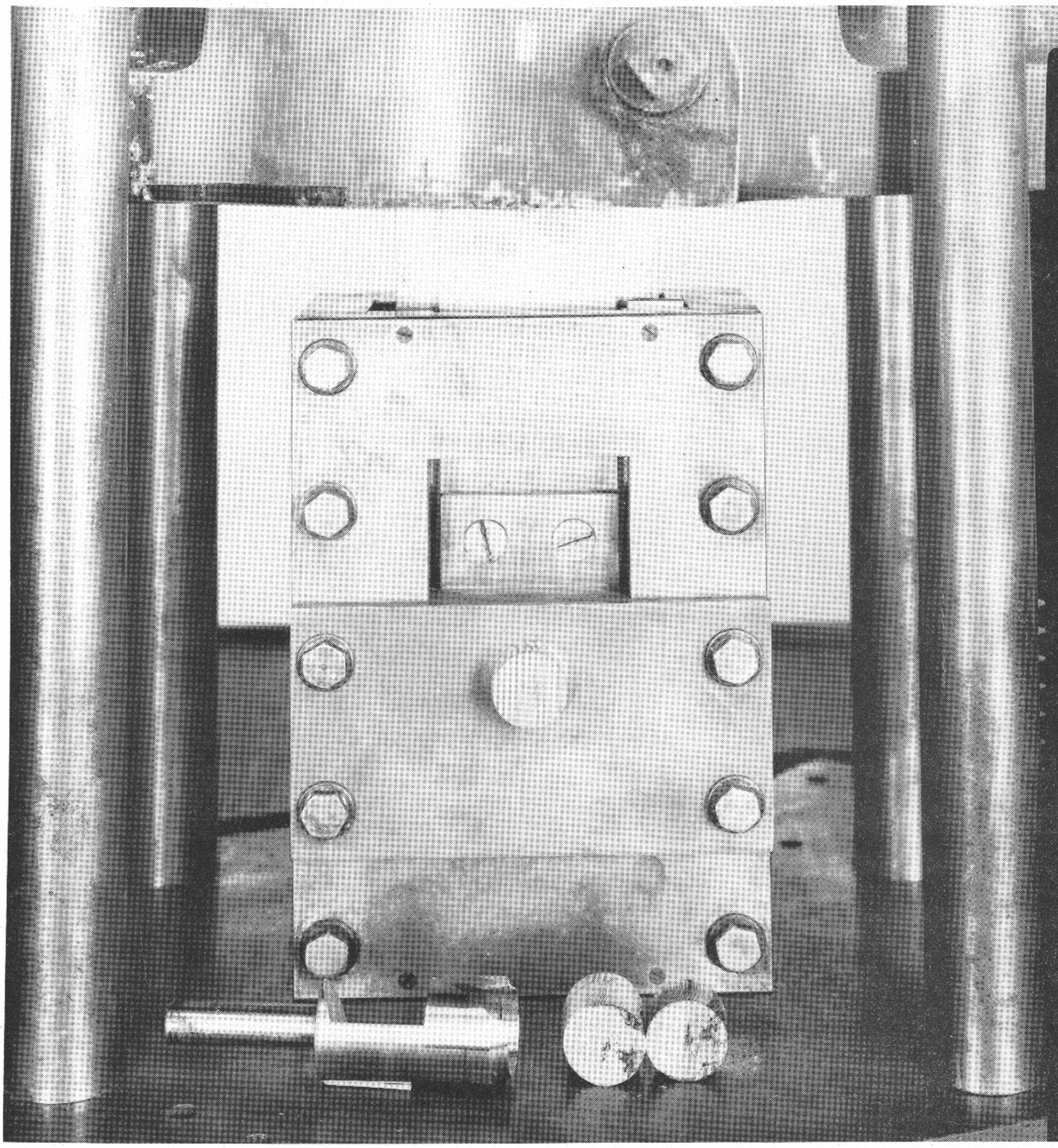

Figure 2. --Shear tool with cylindrical specimen inserted for testing. A broken specimen and a plug cutter are shown at the base of the tool.

Z M 116 356

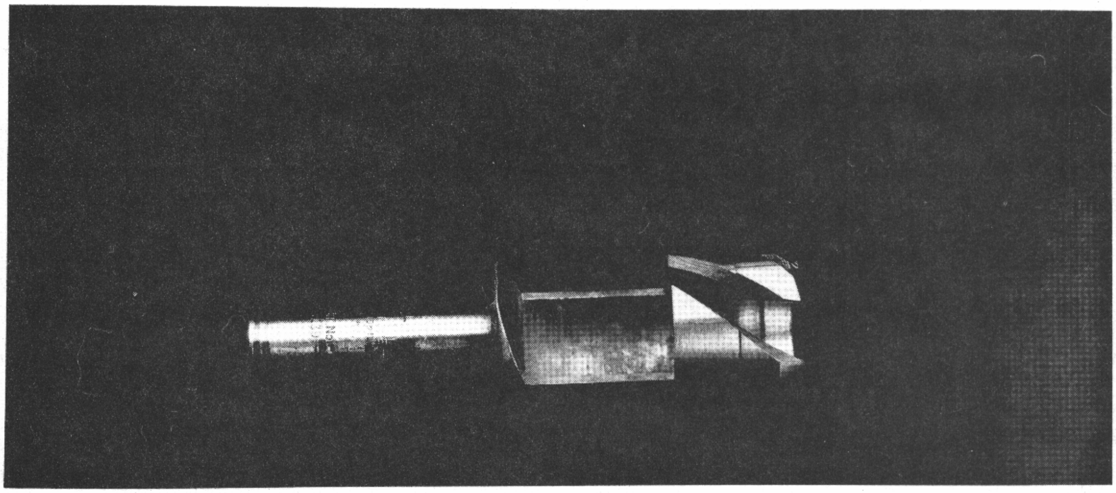

Figure 3.--Cutter for making 1-inch cylindrical plugs about 2 inches long.

Z M 116 036

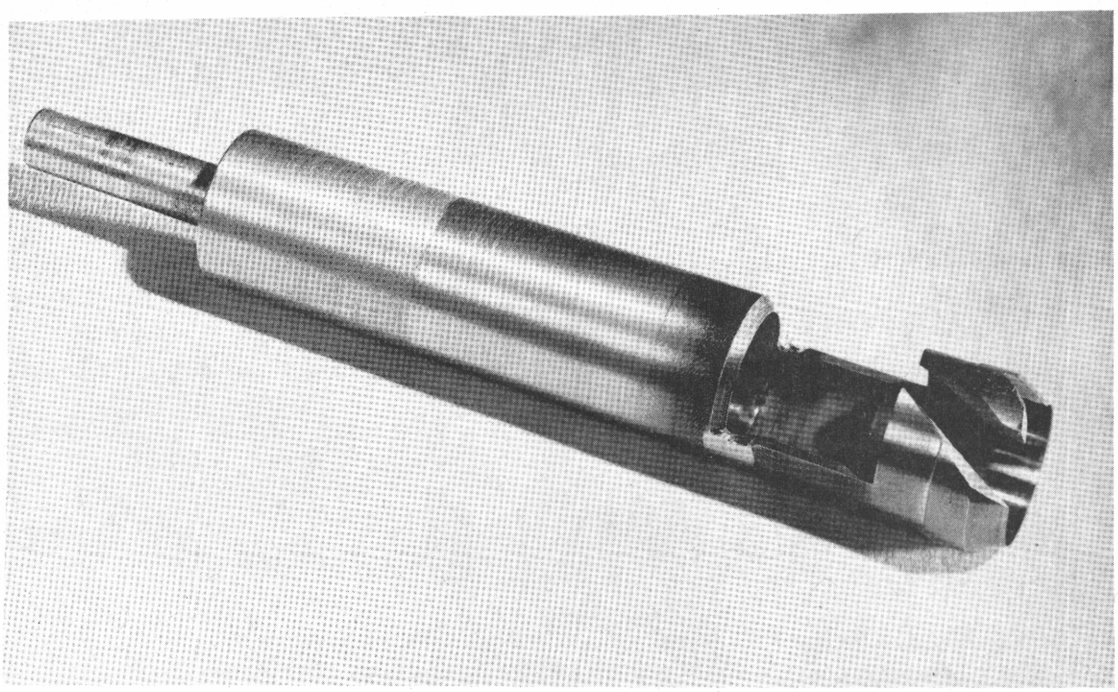

Figure 4.--Cutter after extension was added so plugs 4 to 5 inches in length could be cut.

Z M 117 945

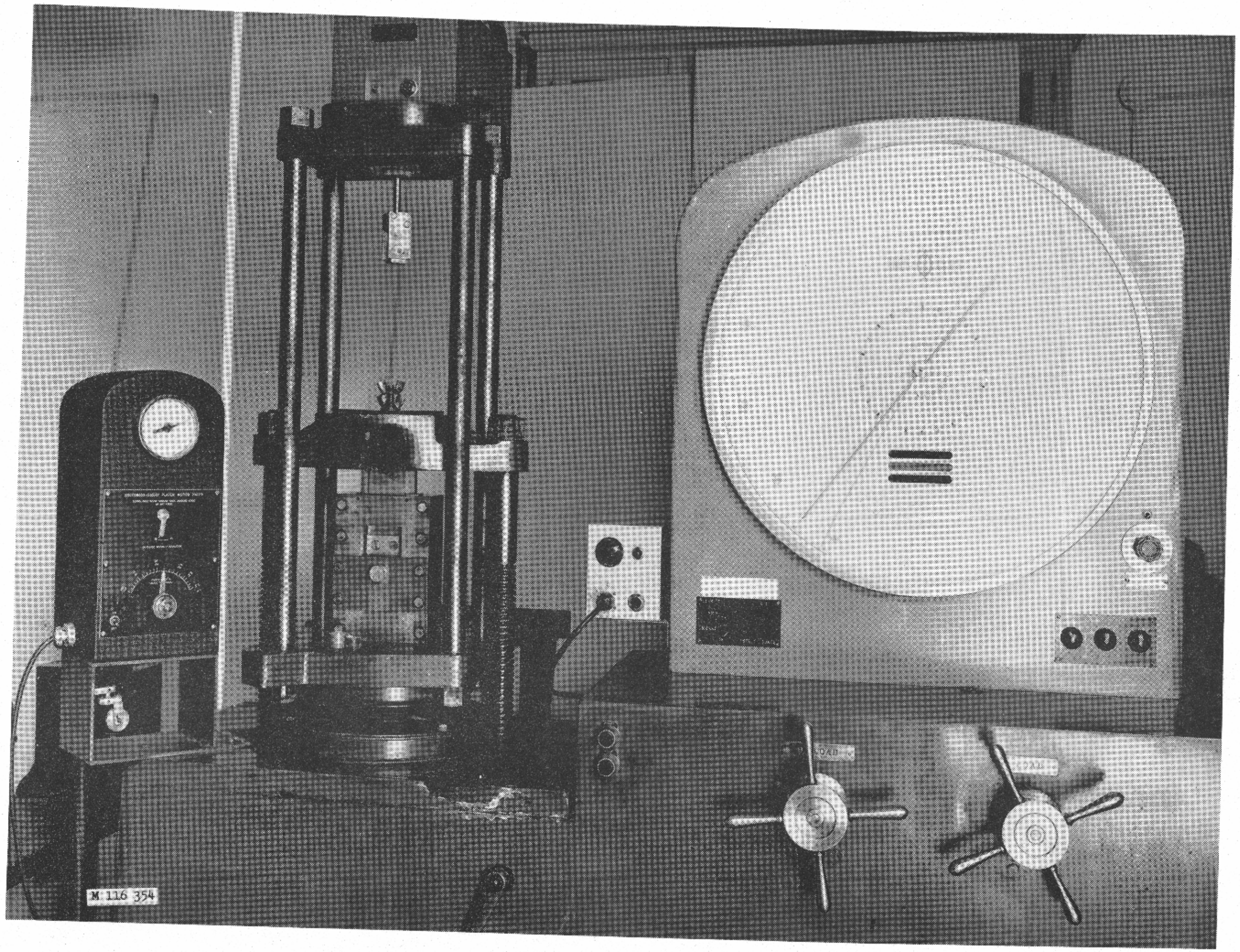

Figure 5. --Testing glue joints in cylindrical specimens in universal testing machine.

Z M 116 354

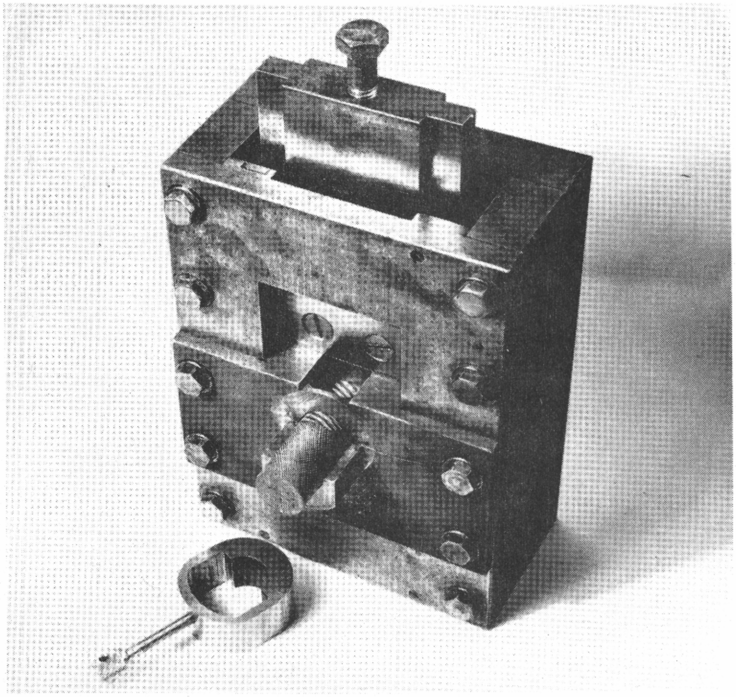

Figure 6.--Modified shear tool for testing glue joints in cylindrical plugs. A device for holding the specimen securely in place during test is shown in front of the tool.

Z M 121 064

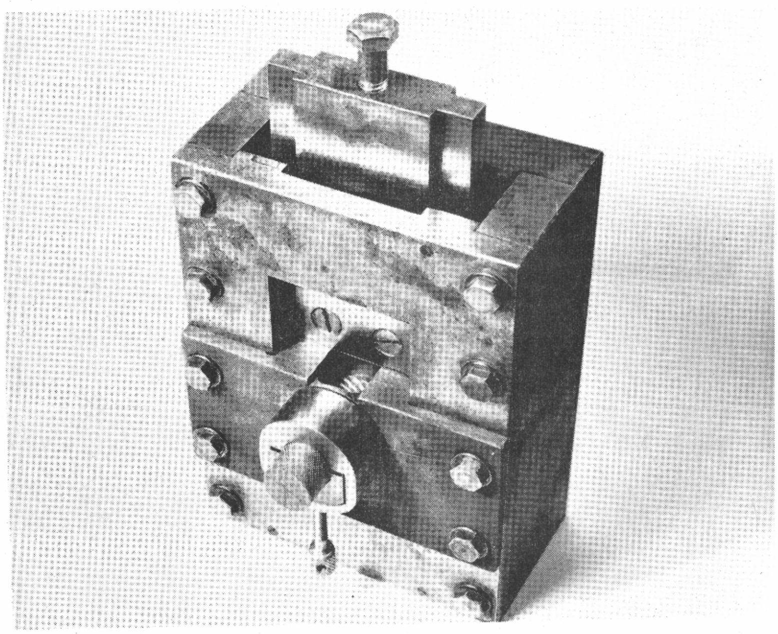

Figure 7.--Modified shear tool with plug-holding device in place and specimen ready for testing.

Z M 121 065

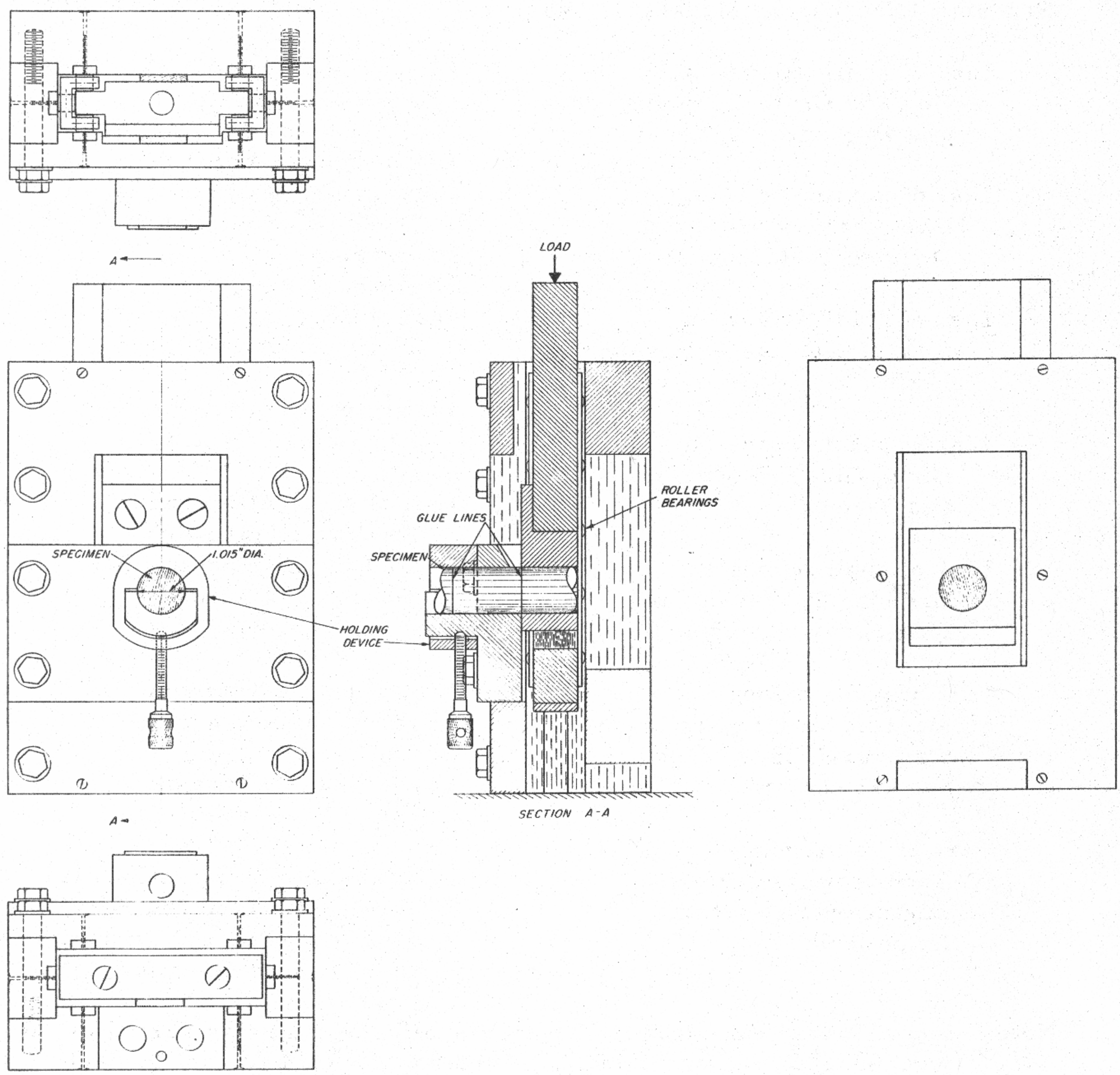

Figure 8. --Modified glue-block shear tool for shear testing glue joints in cylindrical specimens.

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