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A SIMPLIFIED TEST FOR ADHESIVE BEHAVIOR IN WOOD SECTIONS EXPOSED TO FIRE

Summary

A relatively simple test procedure was developed to evaluate the behavior of various adhesives near fire-exposed surfaces in laminated constructions. A number of sections cut from laminated blocks were exposed to fire on one surface. After this exposure, the sections were transversely cut, and the gluelines were examined for separation depth. In addition, the cool specimens were broken along the glue joints so as to be able to determine the residual bonded area. An equation incorporating both the separation depth and the residual bonded area at the joints was utilized to obtain a “degradation index” on which adhesive behavior near fire-exposed surfaces can be quantitatively based. This index was used to make a preliminary grouping of the behavior under fire of six types of adhesives in laminated sections of Douglas-fir and southern pine.

A SIMPLIFIED TEST FOR ADHESIVE BEHAVIOR

IN WOOD SECTIONS EXPOSED TO FIRE

By

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Introduction

In the selection of adhesives for the bonding of wood constructions, one of the characteristics to be considered is their resistance to fire exposure. The purpose of this study was to develop a simple test for comparing the behavior of adhesive bonds in wood during fire exposure, and to evaluate the performance of several adhesive types using the test procedure. The test is so designed as to utilize the observed behavior of the bond near the fire-exposed surface. In thin members for example, and near fire-exposed surfaces in thicker sections, the adhesive is subjected directly to the severe effect of elevated temperature and a steep thermal gradient. The adhesive bond behavior in this area is therefore a real test of its fire resistance. Interior areas of thick wood sections, however, receive little thermal exposure during fire, so that the thermal resistance of the adhesive used here will have little influence on the overall fire performance of the section.

The intent of this study, then, was to develop a simple test for evaluating the behavior of selected adhesives in laminated constructions near a fire-exposed surface. It can be assumed that the adhesive behavior is unaffected within wood sections at greater depths where temperatures are less than 150° F. It is therefore a test of an adhesive's ability to maintain the wood bond in pyrolyzing and charred wood.

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[1] Appreciation iS expressed to W.Z. Olson of the Laboratory staff for his overall assistance, especially for his experienced and careful estimates of wood faliure.

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

Specimens

To accurately represent adhesive behaivor under fire exposure in actual use conditions, several factors were considered in designing a test specimen. They are:

(1) Gluelines should be perpendicular to the fire-exposed surface,
(2) the specimen should be thick enough to yield the same thermal behavior near the char-wood interface as that of sections 3 inches or thicker for a given exposure, and
(3) the specimen should be cut from a larger laminated section.

The first and third factors were readily accomplished; the second however, required some experimentation to develop adequate thickness. It was found that the behavior of a l-inch-thick plate was the same, for adhesive and laminate, as a 3-inch or thicker section exposed in the same way for short periods.

Southern pine and Douglas-fir were selected for the test material. Six adhesives, one for each of six types, were included for evaluation: Phenol-resorcinol; polyvinyl; urea; melamine; 60 percent melamine-40 percent urea (by weight), mechanically mixed; and casein.

The nominal l-inch-thick laminate material was conditioned to equilibrium in an 80° F., 65 percent relative humidity room, and both bond surfaces were planed before gluing.

Sections 1-1/2 feet long and 7-1/2 inches wide of eight laminations were constructed according to recommended procedures for each adhesive. Following completion of cure, the sections were replaced in the 80° F., 65 percent relative humidity room for 30-day conditioning to equilibrium once more.

Each block was then cut in half with one of the halves saved for control tests. From the other half, a 3-inch end section was discarded, leaving a 6-inch section for fire testing and analysis. Six l-inch-thick plates were cut from this perpendicular to the glue joints and parallel to the grain, and a l/2-inch section was removed from one edge of each plate for determining average specific gravity and average moisture content.

The wood plate prepared for testing was then 1 inch thick, 8 laminates high, and 5-1/2 inches wide with adhesive bond surf aces perpendicular to the plate surface. These plates were maintained at 80° F. and 65 percent relative humidity until testing.

Apparatus

To provide a test that could be simply accomplished with a minimum of time and cost, a fire test procedure similar to that used for plywood described in Products Standard PS-1-66[3] was employed. In the fire test apparatus (fig. 1), the test specimen is supported on a strap iron frame at 30° from the vertical, and the lower face is subjected to the flame from a wing-top Bunsen burner.

The wing-top opening is 2 inches wide for the flame to envelop the width of the specimen surface. Air vents on the burner are adjusted so that the flame is uniformly blue, yet lazy in its burning. The natural gas supply is adjusted so that the flame is 2-1/2 inches high with gas pressure equivalent to 6 inches of water. This type of flame produced flame temperatures between 800° to 900° C. A hooded enclosure surrounds the test apparatus to eliminate drafts.

Test Procedure

A l-inch-thick specimen was taken in its conditioned state and placed on the stand illustrated in figure 1. The surface of the specimen was then subjected to the flame from the Bunsen-type burner, so that the flame center impinged on the test specimen surface at a point 3/4 inch above the lower edge. This exposure continued for 5 minutes. At the end of 5 minutes, the specimen was immediately rotated 180° in the plane of burning and subjected to the same flame for another 5 minutes. At the end of the continuous 10 minutes, the specimen was removed from the flame and the flaming surface “smothered” with an asbestos cloth. No water or other chemical extinguishers were employed.

After extinguishing the flame, the test specimen was allowed to cool, and then a sharp circular finish saw was used to cut a cross section through all gluelines along the center of the test specimen (fig. 2). One-half of the specimen was then broken by a carpenter’s hammer as illustrated in figure 3. If fracture occurred along a bond line, wood failure presence was estimated and recorded by an experienced technician.

With the aid of an optical comparator, each glueline in the remaining half specimen was examined. Delamination depth (without any adhesive between laminates) or separation depth of wood surfaces (with adhesive present) was carefully measured from the char zone base (fig. 4) and recorded. Following this examination, this half specimen was also broken as described.

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[3] U.S. Dept. of Commerce. Products Standard PS-I-66, Softwood Plywood, Construction and Industrial . 1966

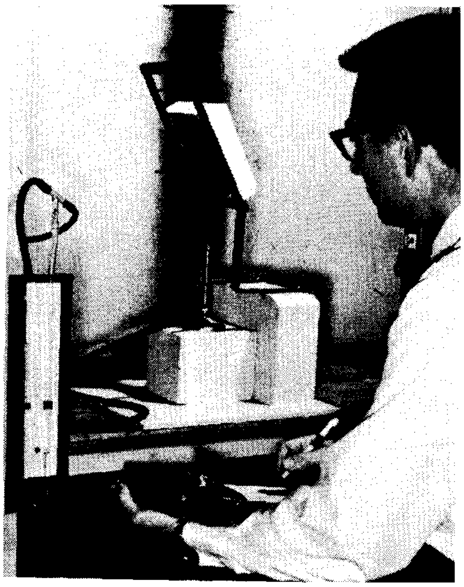

Figure 1 .-- Fire apparatus with test in progress.

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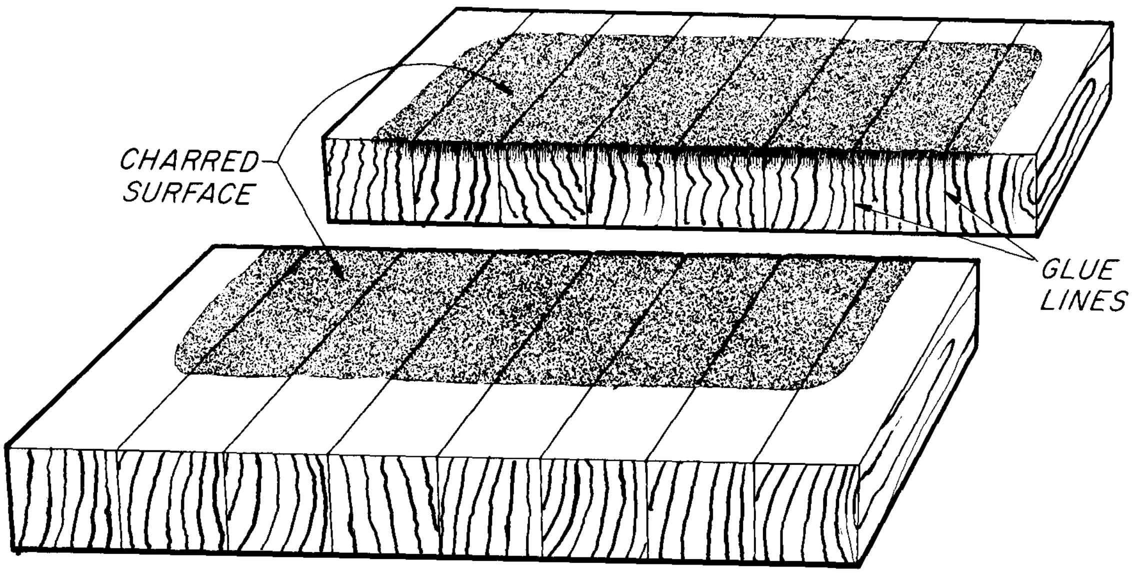

Figure 2. -- Test specimen after flaming, cooling, and sawing showing cross section with gluelines along center. M 133 785

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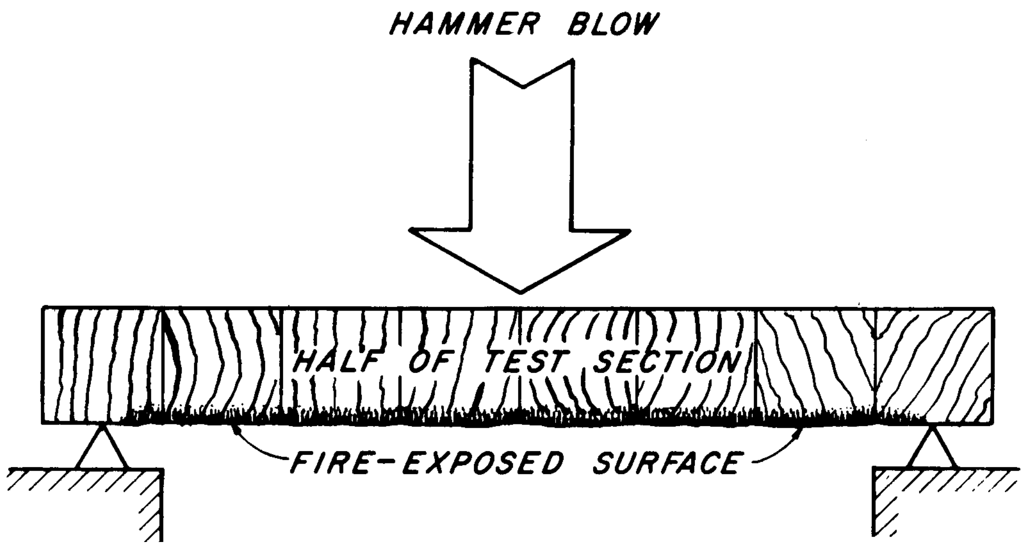

Figure 3. -- Schematic of specimen subjected to impact blow for fracture test.
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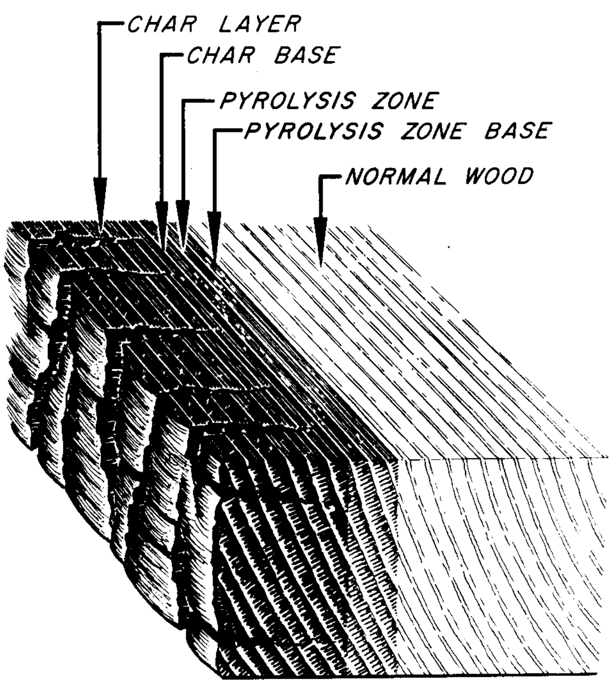

Figure 4. -- Zones of degradation near surface in wood undergoing combustion.

M 130 020

Half specimens from nonfire-exposed sections were likewise broken with a carpenter's hammer and wood failure presence estimated and recorded.

Results and Analysis

Transverse sections and photomicrographs of specimens typical of each adhesive are shown in figures 5 and 6. In examining these sections, several types of adhesive behavior were noted. The phenol-resorcinol and melamine--and 60 percent melamine-40 percent urea in Douglas-fir--did not delaminate or separate in the wood and even maintained the bond in the char. The urea, casein, and polyvinyl-type adhesives, however, allowed separation or delamination to occur for various depths into the pyrolyzed zone and the normal wood section as well as allowed char fissures to occur at bond lines. No separation or delamination was observed for the full thickness of the specimen for any adhesive tested. These adhesive specimens represented an adhesive of each type under a typical gluing condition. The results of evaluating the fire resistance of the adhesives must be considered preliminary and primarily for the purpose of proving the test method. This is particularly true for the casein-glued specimens where the wood failure in the control specimen glued joints averaged only 65 percent. A more extensive investigation involving several adhesives of each type under a range of gluing conditions would be necessary to confirm the relative fire resistance obtained for the various types of adhesives.

Data recorded after examination of the fire-exposed sections are given as part of table 1. The number of separations and delamination is given as a proportion of the total number of bond lines tested. The maximum depth of separation-delamination (as measured from the char zone base) is expressed both in actual dimension and as a proportion of the pyrolysis zone thickness (δ_p). The pyrolysis zone (fig. 4) is characterized by a color change in the normal wood structure from charcoal black through brown shades to yellow and finally to the initial color of the nongraded wood. The thickness of the pyrolysis zone increases with duration of fire exposure and in these tests was found to lie between 0.095 and 0.125 inch (2.4 - 3.2 mm.). The wood failure estimates, based on the total bonded area, are given in percent.

From the data given in the tabular results, some differences occur in behavior of a given adhesive depending on the species used for the laminate material. For the 60 percent melamine-40 percent urea, for example, no separations are recorded in Douglas-fir, but shallow separations are seen in southern pine (fig. 6). Also, the wood failures in southern pine appear to be consistently lower for urea, polyvinyl, and casein.

Table 1. -- Results of fire-exposure and impact bending

Douglas-fir: Proportion of separations	Douglas-fir: Maximum separation depth: Actual	Douglas-fir: Maximum separation depth: Proportion of δ_p[1]	Douglas-fir: Wood failure[2]	Douglas-fir: Degradation index D	Southern pine: Proportion of separations	Southern pine: Maximum separation depth: Actual	Southern pine: Maximum separation depth: Proportion of δ_p[1]	Southern pine: Wood failure[2]	Southern pine: Degradation index D
	In.		Pct.			In.		Pct.	
PHENOL-RESORCINOL									
0/7	0	0	100	0	0/7	0	0	95	0.05
0/7	0	0	100	0	0/7	0	0	95	.05
0/7	0	0	100	0	0/7	0	0	100	0
0/7	0	0	95	.05	0/7	0	0	90	.11
0/7	0	0	75	.33	0/7	0	0	90	.11
0/7	0	0	75	.33	0/7	0	0	75	.33
			Average	.12				Average	.11
MELAMINE									
0/7	0	0	95	.05	0/7	0	0	95	.05
0/7	0	0	100	0	0/7	0	0	100	0
0/7	0	0	100	0	0/7	0	0	100	0
0/7	0	0	95	.05	0/7	0	0	100	0
0/7	0	0	95	.05	0/7	0	0	80	.25
0/7	0	0	100	0	0/7	0	0	85	.18
			Average	.03				Average	.08
60 PERCENT MELAMINE-40 PERCENT UREA									
0/7	0	0	80	.25	0/7	0	0	100	0
0/7	0	0	70	.43	1/7	.06	.50	80	.75
0/7	0	0	95	.05	1/7	.06	.50	90	.61
0/7	0	0	100	0	1/7	.06	.50	90	.61
0/7	0	0	100	0	0/7	0	0	100	0
0/7	0	0	95	.05	1/7	.06	.50	90	.61
			Average	.13				Average	.43
CASEIN									
7/7	.062	0.62	50	0.92	7/7	.110	.91	30	2.08
7/7	.094	.94	50	1.24	7/7	.094	.78	35	1.64
7/7	.078	.78	55	.96	7/7	.310	2.58	40	3.21
7/7	.125	1.25	65	1.25	7/7	.062	.51	40	1.14
7/7	.125	1.25	60	1.33	7/7	.094	.78	15	4.11
7/7	.094	.94	25	2.54	7/7	.093	.77	60	.85
			Average	1.37				Average	2.17
UREA									
7/7	.125	1.0	80	1.25	6/7	.125	1.0	45	2.22
7/7	.125	1.0	75	1.33	7/7	.125	1.0	30	3.33
7/7	.125	1.0	65	1.54	7/7	.125	1.0	75	1.25
7/7	.125	1.0	80	1.25	7/7	.125	1.0	100	1.00
7/7	.125	1.0	75	1.33	7/7	.155	1.24	50	2.24
7/7	.155	1.24	75	1.57	6/7	.157	1.26	90	1.37
			Average	1.38				Average	1.42
POLYVINYL									
2/7	.13	1.0	95	1.05	4/7	.30	2.14	80	2.39
3/7	.25	1.92	95	1.97	4/7	.30	2.14	40	3.64
2/7	.30	2.31	80	2.56	5/7	.27	1.93	35	3.79
3/7	.10	.77	80	1.02	6/7	.32	2.29	35	4.15
2/7	.28	2.15	70	2.58	3/7	.37	2.65	40	4.15
3/7	.28	2.15	90	2.26	3/7	.13	.93	90	1.04
			Average	1.91				Average	3.19

[1] δ_p, thickness of pyrolysis zone (Fig. 4).

[2] Control wood failures are all 100 percent except casein which was 65 percent in both Douglas-fir and southern pine.

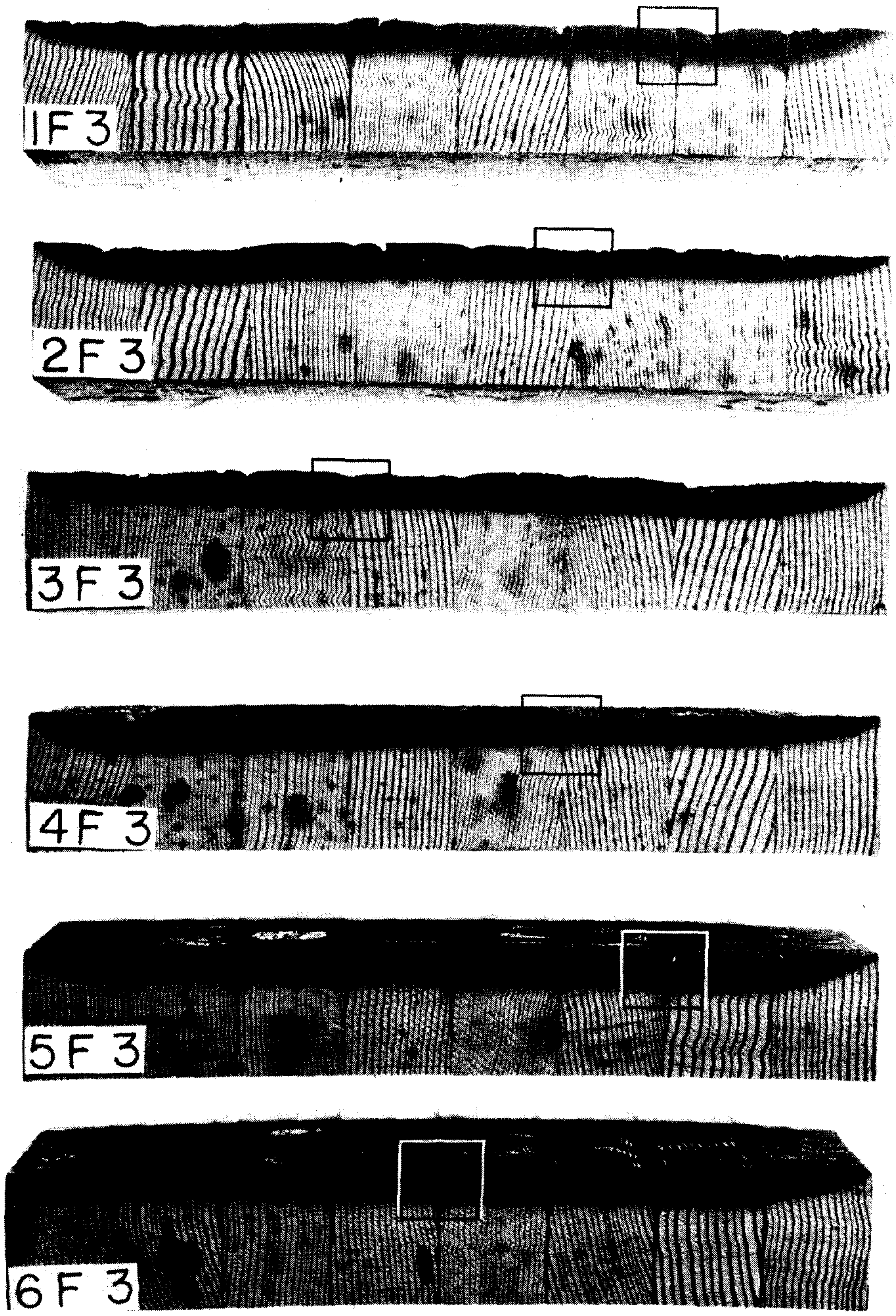

Figure 5. -- Cross sections of laminated Douglas-fir specimens after exposure to fire. Adhesives are phenol-resorcinol, IF3; melamine, 2F3; 60 percent melamine-40 percent urea, 3F3; urea, 4F3; polyvinyl, 5F3; and casein, 6F3.

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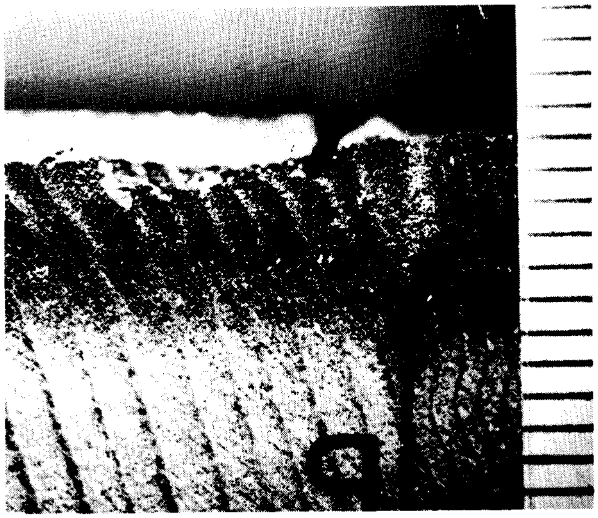
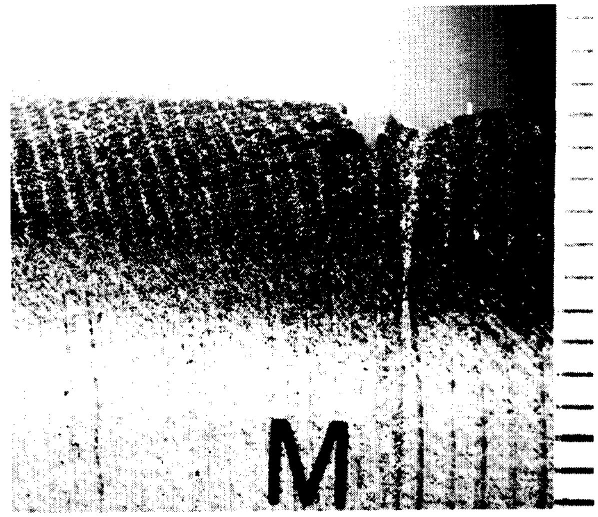
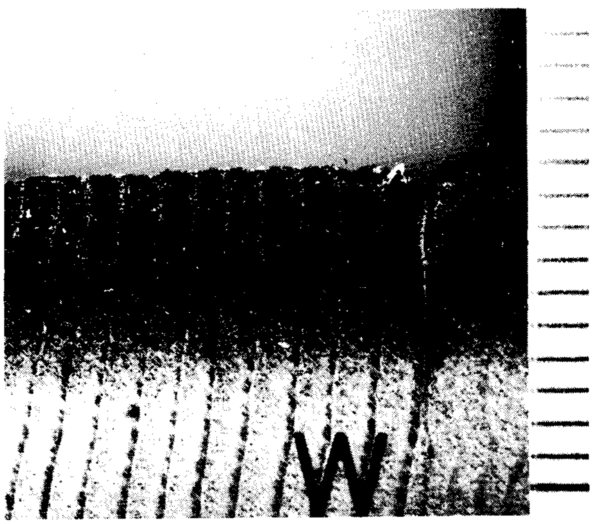


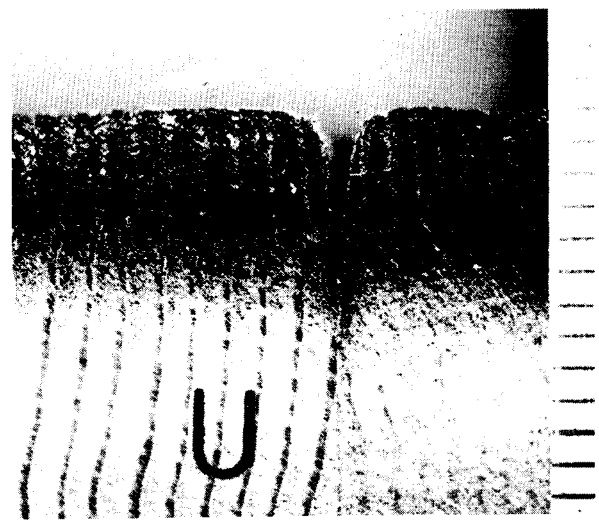
1F3 M 131 797



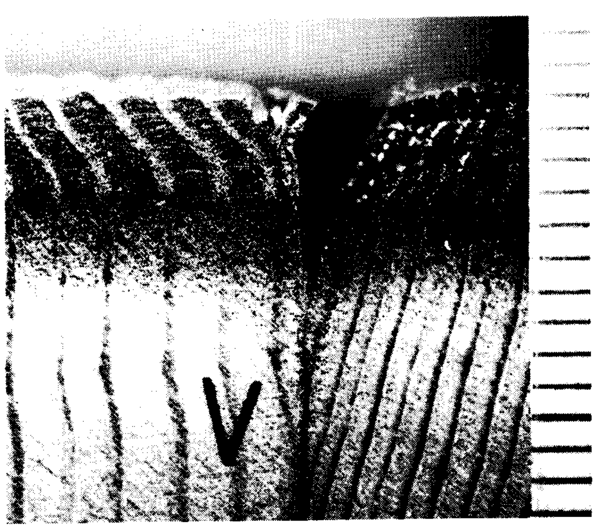
2F3 M 131 794



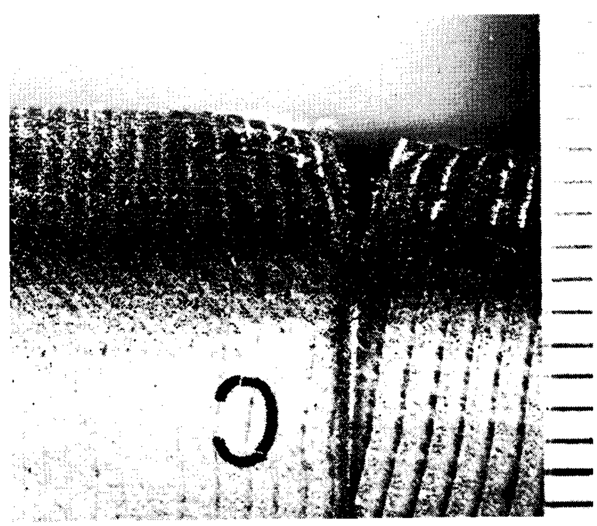
3F3 M 131 803



4F3 M 131 800



5F3 M 131 802



6F3 M 131 793

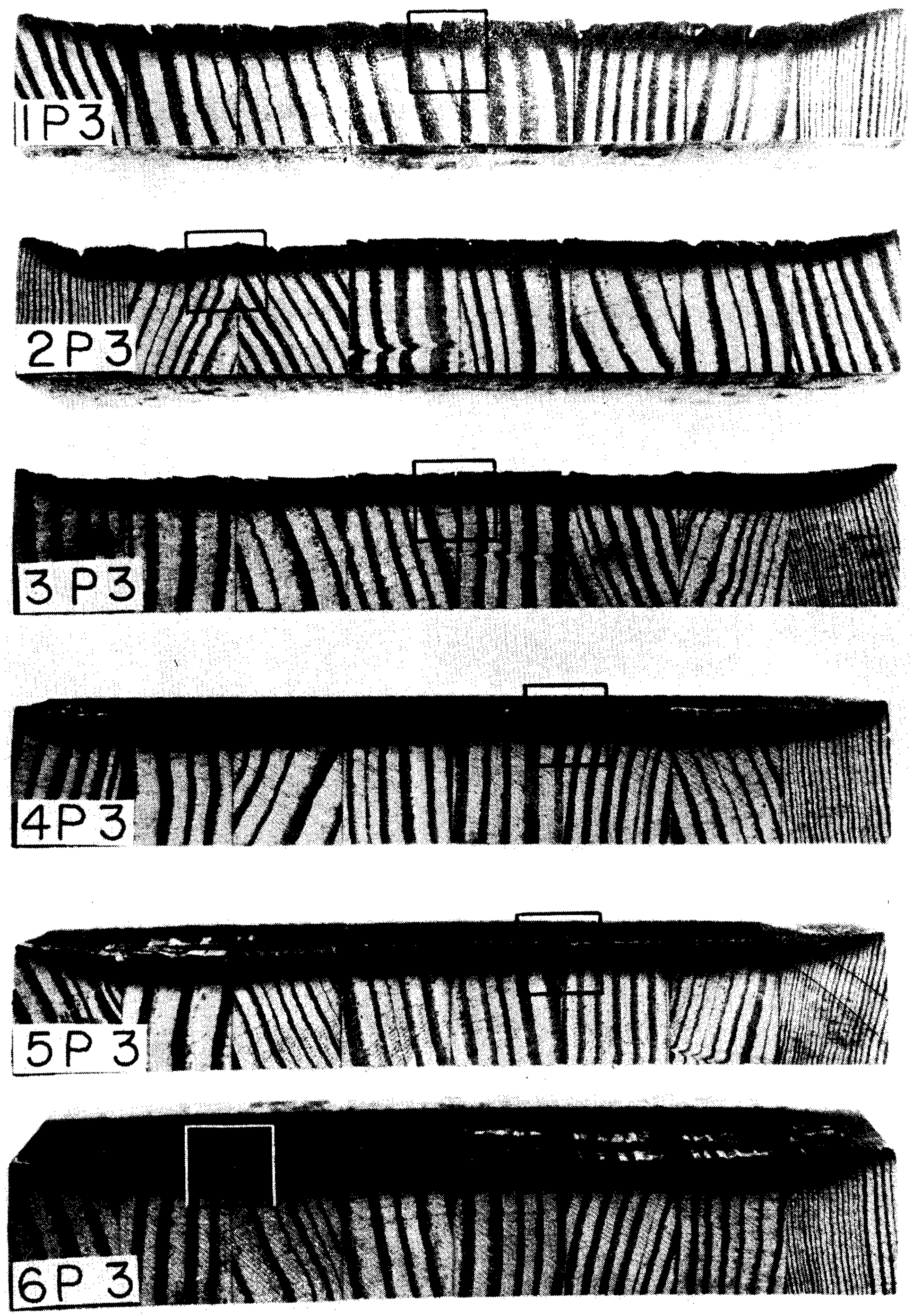


Figure 6. -- Cross sections of laminated southern pine specimens after exposure to fire. Adhesives are phenol-resorcinol, 1P3; melamine), 2P3; 60 percent melamine-40 percent urea, 3P3; urea, 4P3; polyvinyl, 5P3; and casein, 6P3.

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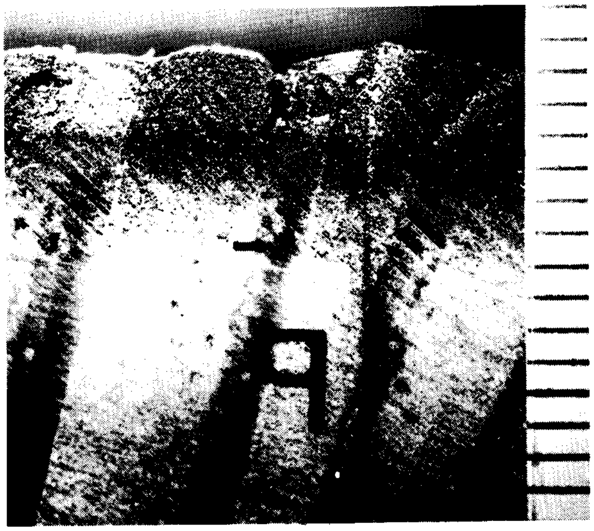

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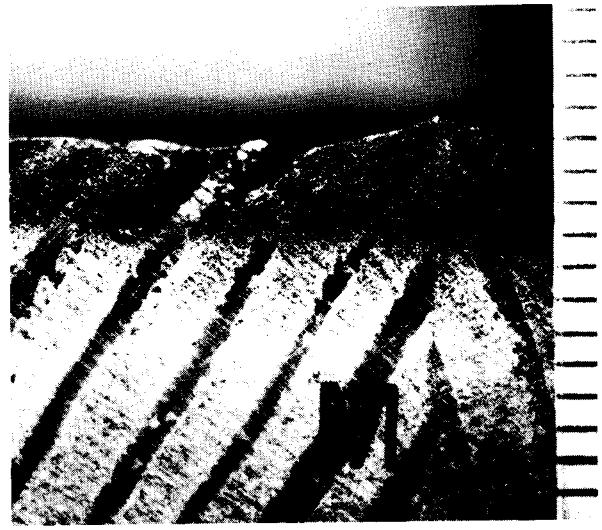
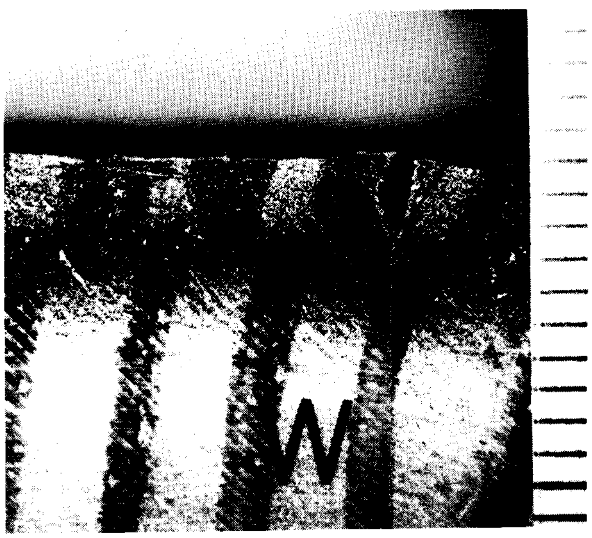
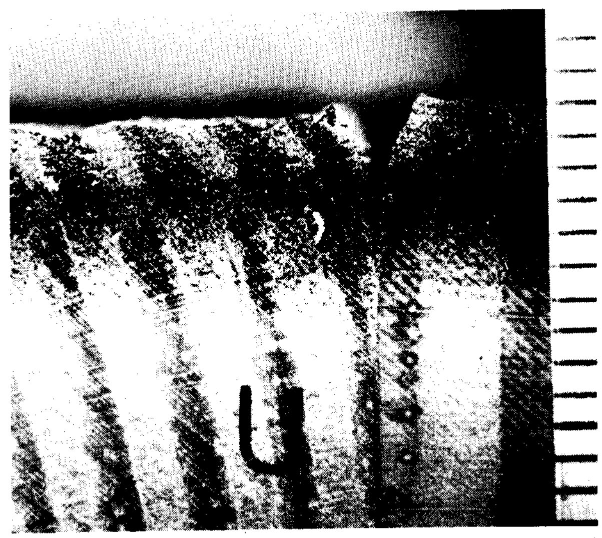


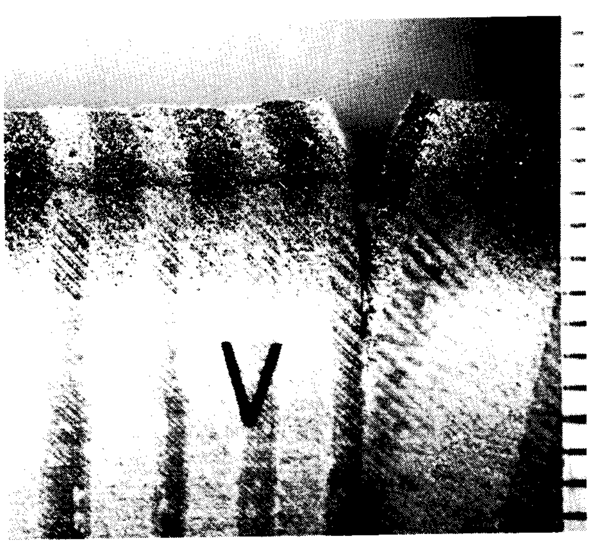
2P3 M 131 795



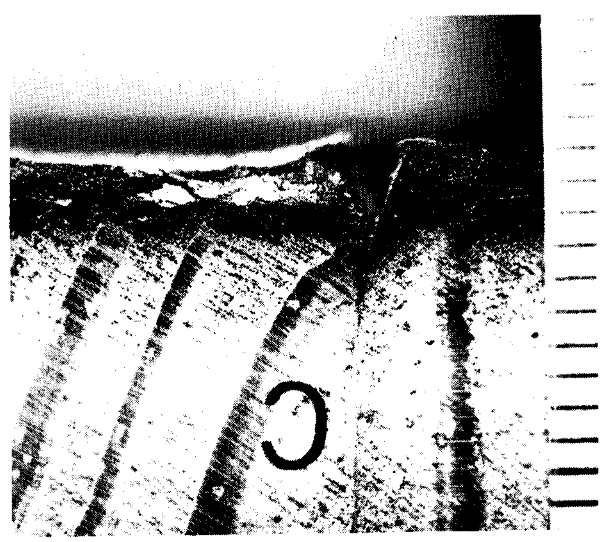
3P3 M 131 804



4P3 M 131 799



5P3 M 131 801



6P3 M 131 792

To provide a quantitative basis for ranking the performance of the adhesives evaluated by this test method, the following equation was employed to obtain a degradation index D:

$$D = \left[\frac{\delta}{\delta_p} \right] + \left[\frac{W_{f_o}}{W_f} - 1.0 \right]$$

where

δ = maximum depth of separation-delamination (measured from the char zone base).

δ_p = pyrolysis zone thickness.

W_{f_o} = wood failure in control specimen.

W_f = wood failure in fire-exposed specimen.

The degradation indices calculated for each specimen are included in table 1. Note that the higher the degradation index D becomes, the poorer the adhesive behavior near the char-wood interface as a result of this test. This adhesive behavior during fire can be better classified into groups that reflect their effectiveness in maintaining bond in the three wood zones indicated in figure 4:

Group I--Those adhesives that maintain bond throughout the pyrolysis and normal wood zones.

Group II--Those adhesives that maintain bond throughout the normal wood zone.

Group III--Those adhesives that have bond separation occurring in the normal wood.

Within each group, the degradation index provides a finer preliminary assessment of behavior for adhesives in this group. Performing this grouping of adhesives tested, recognizing that the results of this reflect only the behavior of a given adhesive in a single wood block and a statistical experiment is required for conclusive analysis, yields the following for each species:

	Douglas-fir	Southern pine
I	Melamine	Melamine
	Phenol-resorcinol	Phenol-resorcinol

	Douglas-fir	Southern pine
II	60 percent Melamine-40 percent urea	60 percent Melamine-40 percent urea
	Urea, Casein	**Urea**
		Casein
III	Polyvinyl	Polyvinyl

Urea and case in are reanked the same in Douglas-fir due to the small difference between their degradational indices in the species.

Conclusions

(1) The test method used can adequately differentiate between adhesive bond performance near the char-wood interface in wood laminates subjected to fire in a simple and rapid manner. It is especially suited to investigating their delamination or separation response to fire. Remaining bond strength is more difficult to assess by the method, as a technician experienced in wood failure estimating is required.

(2) Of six adhesives preliminarily tested, only polyinyl failed to effectively limit separation-delamination at gluelines to the thickness of the pyrolysis zone.

(3) Preliminary results also show that melamine and phenol-resorcinol adhesives will not allow separation to occur in either the char or the wood during fire exposure.

(4) The adhesives' performance in this fire exposure can be grouped into: I, those maintaining apparent bond strength even in char; II those confining delamination separation to pyrolysis zone; and III, those which allow delamination separation to extend into normal wood area.