# ELASTOMERIC ADHESIVE PROPERTIES—SHEAR STRENGTH, SHEAR MODULUS, CREEP, AND RECOVERY

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ABSTRACT

Three commercially available adhesives, approved for use in field glued floor systems, were evaluated for potential structural application in light frame wood buildings. All had adequate static shear strength for common floor and roof sheathing uses. Two were sufficiently rigid to generate useful composite action. One displayed relative creep compatible with wood structural design practice but two had excessive relative creep. The adhesive with good creep properties also had good recovery properties. The other two had poor recovery properties. One adhesive that had good shear strength in a conventional block shear test would not consistently sustain stress as low as 25 psi for more than four days. All tests were conducted on bonded wood specimens at 70 F (21 C) and 12% EMC.

*Additional keywords*: *Pseudotsuga menziesii*, construction adhesives, mobile homes, wood buildings, residential construction.

## INTRODUCTION

In recent years, many adhesives have appeared on the market that are rather loosely classified as elastomerics. Some of these adhesives are potentially useful for bonding plywood and lumber structural components so the pieces will function together as composite systems. However, the adhesives differ considerably in strength and performance. The bond must be strong and durable and possess certain stiffness properties if the adhesives are to be structurally useful. Some adhesives meet one or two of these requirements without being able to meet the third.

To design wood structures with elastomeric construction adhesives, we must know the adhesive properties. In most cases the adhesive manufacturer's technical literature does not contain this information. Furthermore, in the absence of standardized methods of testing, the properties of individual adhesives cannot be compared and evaluated. Previous study (McGee and Hoyle 1974; Hoyle 1973, 1976) of the behavior of elastomeric adhesive bonded flexural members shows how shear modulus and shear strength affect the design of wood structures, and that such systems are promising. Therefore, we decided to examine the strength and shear-slip behavior of three available commercial adhesives that are now used for semi-structural purposes.

## OBJECTIVES

Our objectives were to compare and evaluate the performance of three commercially available elastomeric adhesives to determine their suitability for glued wood building systems. Shear modulus, shear strength, creep behavior, and creep recovery properties were determined and some attention was given to adhesive cure time.

## EXPERIMENTAL DESIGN AND TESTING PROCEDURE

Three elastomeric adhesives were evaluated. One was a moisture-curing polyurethane adhesive (100% solids) designated M. The other two adhesives, designated F and W, were solvent type with less than 100% solids. These adhesives have all met the requirements of American Plywood Association (APA) Specification AFG-01 and are recommended for use with APA Glued Floor Systems. They also conform to Housing and Urban Development-Federal Housing Administration (HUD-FHA) Use of Materials Bulletin UM-60. These APA and

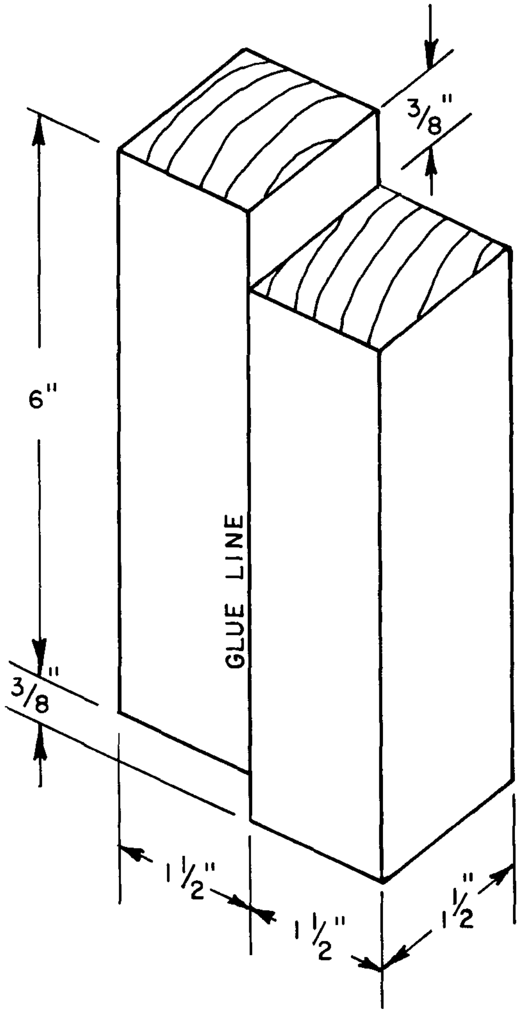


FIG. 1. Compression loaded block-shear specimen for shear strength testing.

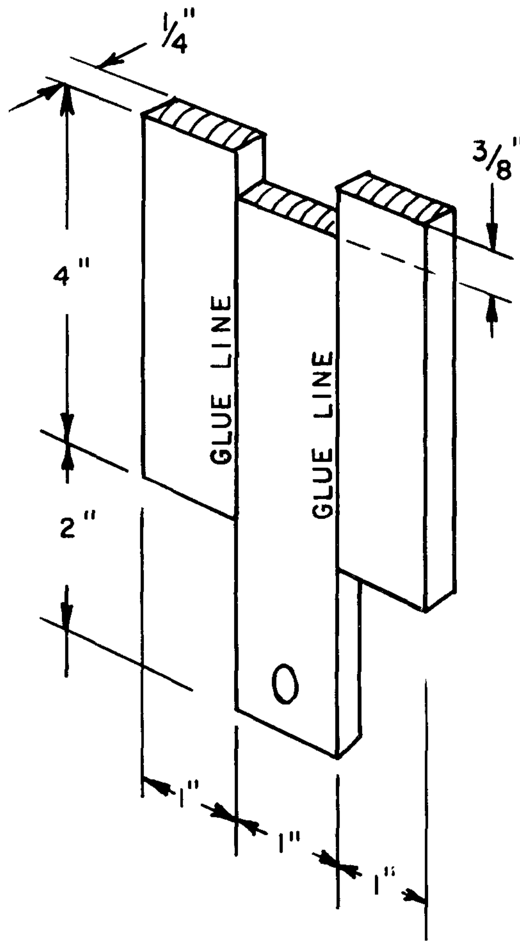


FIG. 2. Double shear specimen for shear modulus and creep measurement.

HUD-FHA tests do not evaluate shear modulus or creep properties.

The *shear strength* of adhesive M had been determined previously by Hsu (1974) and Hoyle (1970). The shear strength of adhesives F and W was determined using Douglas-fir (*Pseudotsuga menziesii* (Mirb) Franco) specimens of the type shown in Fig. 1. The wood was preconditioned to 12% moisture content. The glue lines were 1/32-inch (0.8-mm) thick, controlled by clamping the specimens with 1/32-inch metal shims between the two halves. The blocks were 8 inches (203 mm) long when glued, with shims at the extreme ends at clamp pressure points. After the adhesive had cured from 24 to 48 h, the clamps were removed and the blocks were cut to final size and stored in a 12% EMC humidity chamber at 70 F (21 C). Specimens for ten replications of these adhesive F and W tests were made. The specimens were loaded at a rate of 0.02 inches (0.5 mm) per minute cross-head speed.

*Shear modulus* and *creep behavior* were determined using specimens of the type shown in Fig. 2. This specimen was designed to utilize a multispecimen loading bench available in our laboratory. The test

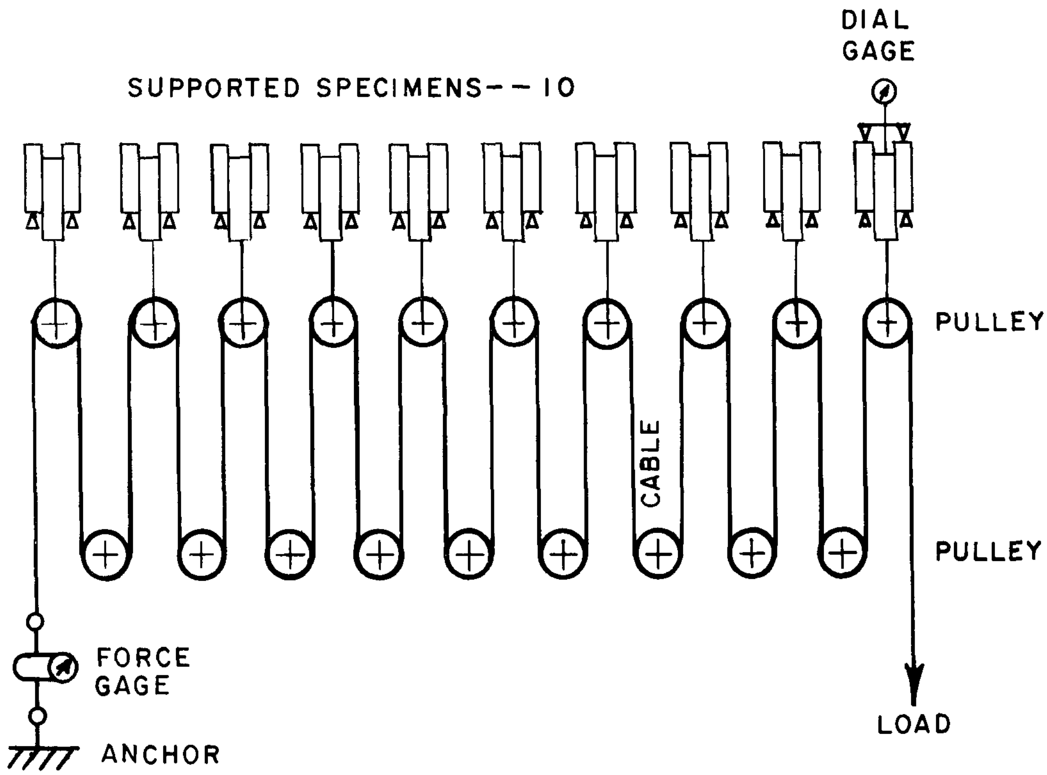


FIG. 3. Schematic diagram of test bench for measuring shear modulus, creep, and recovery.

specimens were fabricated from clear wood preconditioned to 12% moisture content. Blocks one inch (25.4 mm) thick by 5.5 inches (140 mm) wide by 8 inches long were glued to form a three-layer block with 1/32-inch glue lines controlled by metal shims. After 48 h of positive clamping, these blocks were placed in a 12% EMC humidity chamber at 70 F. After two weeks the three-layer blocks were sawed to the desired ¼-inch (6.35 mm) thickness and trimmed to the shape shown in Fig. 2. The actual glueline thickness of each specimen was measured with a graduated eyepiece at the time of testing, since changes in thickness sometimes occurred upon removal of the shims and initial aging of the specimens, as indicated in Table 1.

Figures 3 and 4 describe the loading bench used for the shear modulus and creep measurements. The bench accommodates ten specimens. The loading cable ran over aircraft pulleys with negligible bearing friction, from a force dynamometer on one end to a loading pallet on the other. The load was applied very slowly to preclude any impact overloads. Shear deflection was measured with a dial gauge mounted on the U-notch of each specimen.

The first shear deflection was measured two minutes after loading, to obtain an "initial elastic deflection." The shear deflections under load were measured every half hour for the first two hours, then every hour for the next six hours, then daily until the creep had stopped or was proceeding at a much reduced rate. The time under stress in Table 1 is the elapsed time from load application to load removal. At this time the load was completely released and measurements of shear deflection were continued on a daily basis until recovery had apparently ceased. All tests were conducted in a humidity room at 12% EMC at 70 F.

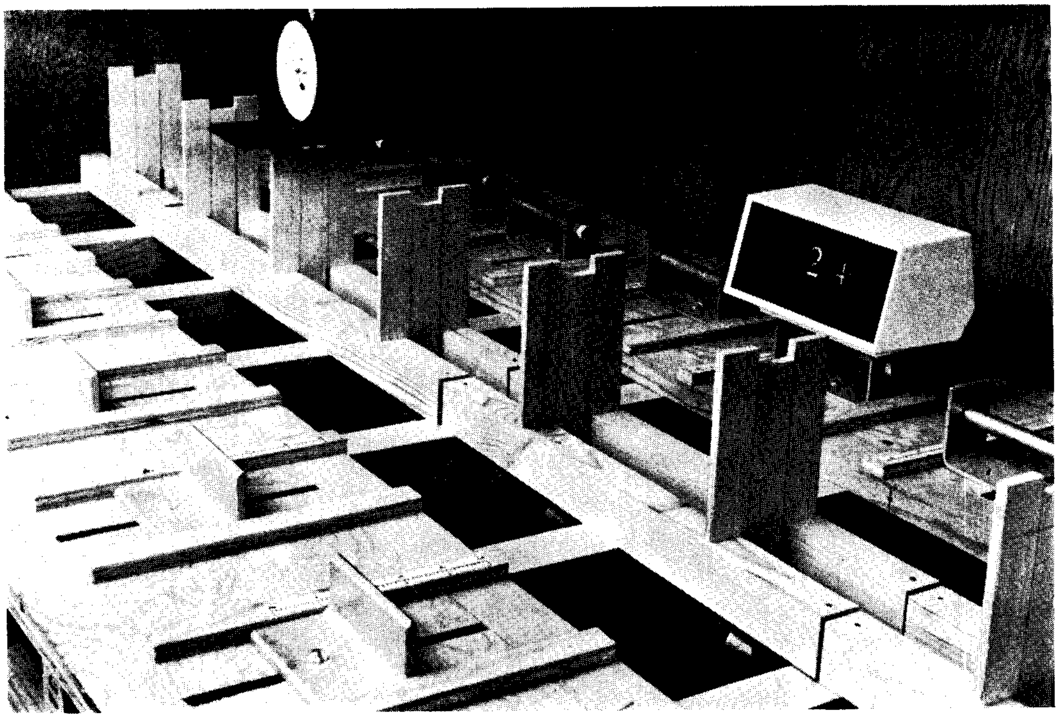

FIG. 4. Test bench for measuring shear modulus, creep, and recovery.

Considerable previous experience with adhesive M had shown that cure could be achieved in two months. Two sets of ten adhesive M specimens, cured for two months, were loaded at stress levels of 25 psi (172 kPa) and 50 psi (345 kPa).

Initial testing of adhesive F specimens at 25 psi and a 30-day cure indicated they

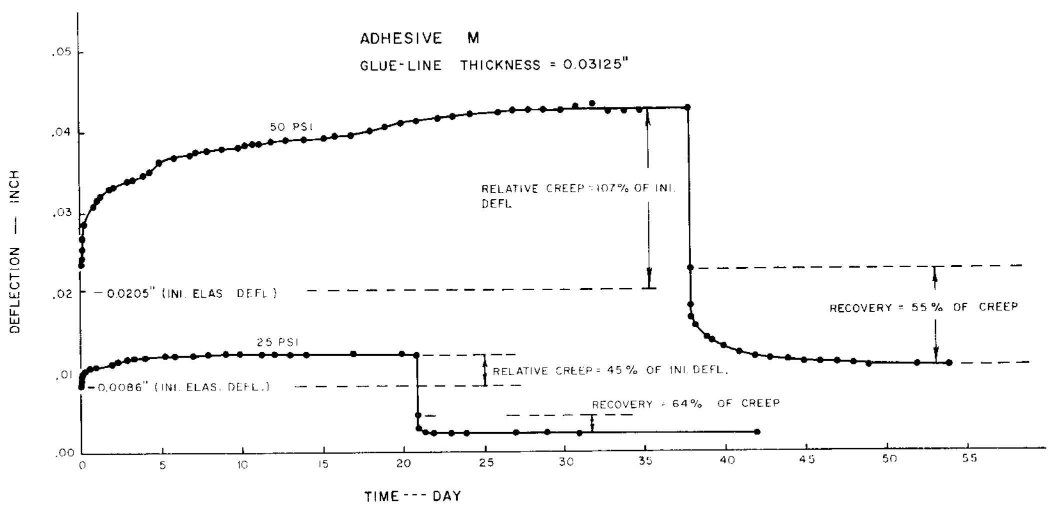


FIG. 5. Glue-line creep and recovery for adhesive M.

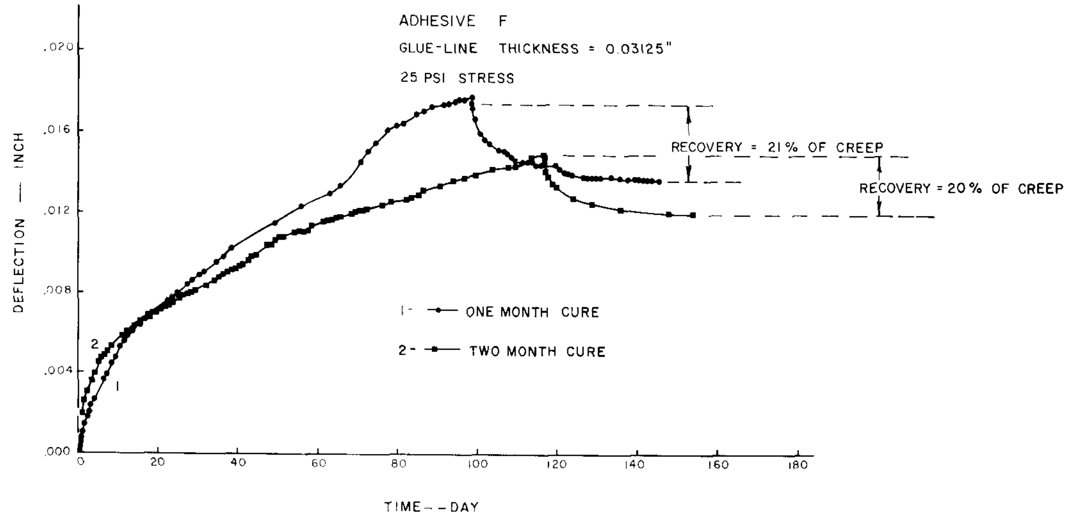


FIG. 6. Glue-line creep and recovery for adhesive F.

might not survive 50 psi stresses. Therefore, two sets of ten specimens were used, one cured for one month and the other for two months, both tested at 25 psi.

A set of ten adhesive W specimens was cured for one month prior to testing at a stress of 25 psi. They did not withstand 25 psi under continuous loading, so a second set of 9 specimens in which the glue line cured for 2 months was loaded at the same stress level for 144 h, then the load was removed and measurement of shear deflection was continued on a daily basis for 20 days. Note that the 1/32-inch glue-line thickness in Figs. 5, 6, 7, and 8 are thicknesses as applied. Table 1 indicates the glue-line thicknesses after cure due to adhesive shrinkage.

## RESULTS AND DISCUSSION

### *Adhesive M*

Table 1 shows results obtained for this adhesive. The 100 psi shear modulus confirmed other tests previously obtained using test specimens of larger glue-line area and other glue-line thicknesses.

Relative creep is creep expressed as a percentage of the initial elastic response to the applied load. An interesting and perhaps significant feature of the relative creep of this adhesive is that it was proportional to stress level. The absolute creep of this elastomeric adhesive was more than proportionally increased by stress level increases. Absolute creep in wood has been observed proportional to stress level, and so has elastic deflection, but relative creep has been the same at several stress levels.

The period of time required for creep to reach a maximum was much longer at higher stress level as illustrated in Fig. 5. It was essentially complete in 10 days at 25 psi stress, but required about 30 days at 50 psi.

Other reported research (Hoyle 1973) shows that the glue-line shear stress due to permanent load will be in the range of 10 to 20 psi (69–138 kPa) for typical "I" and "T" sections. Since creep requires time, the permanent load is the principal basis for creep in ordinary residential and light frame buildings. This elastomeric adhesive will apparently creep less than 45% (Fig. 5) at stress below 25 psi, which is consistent with design allowable creep for wood buildings in general. Adhesive M has adequate shear strength (Table 1) for the total or maximum load stresses in "I" and "T" section glue lines, i.e., 50 psi as described by McGee and Hoyle (1974). Long-time durability was not assessed in this study.

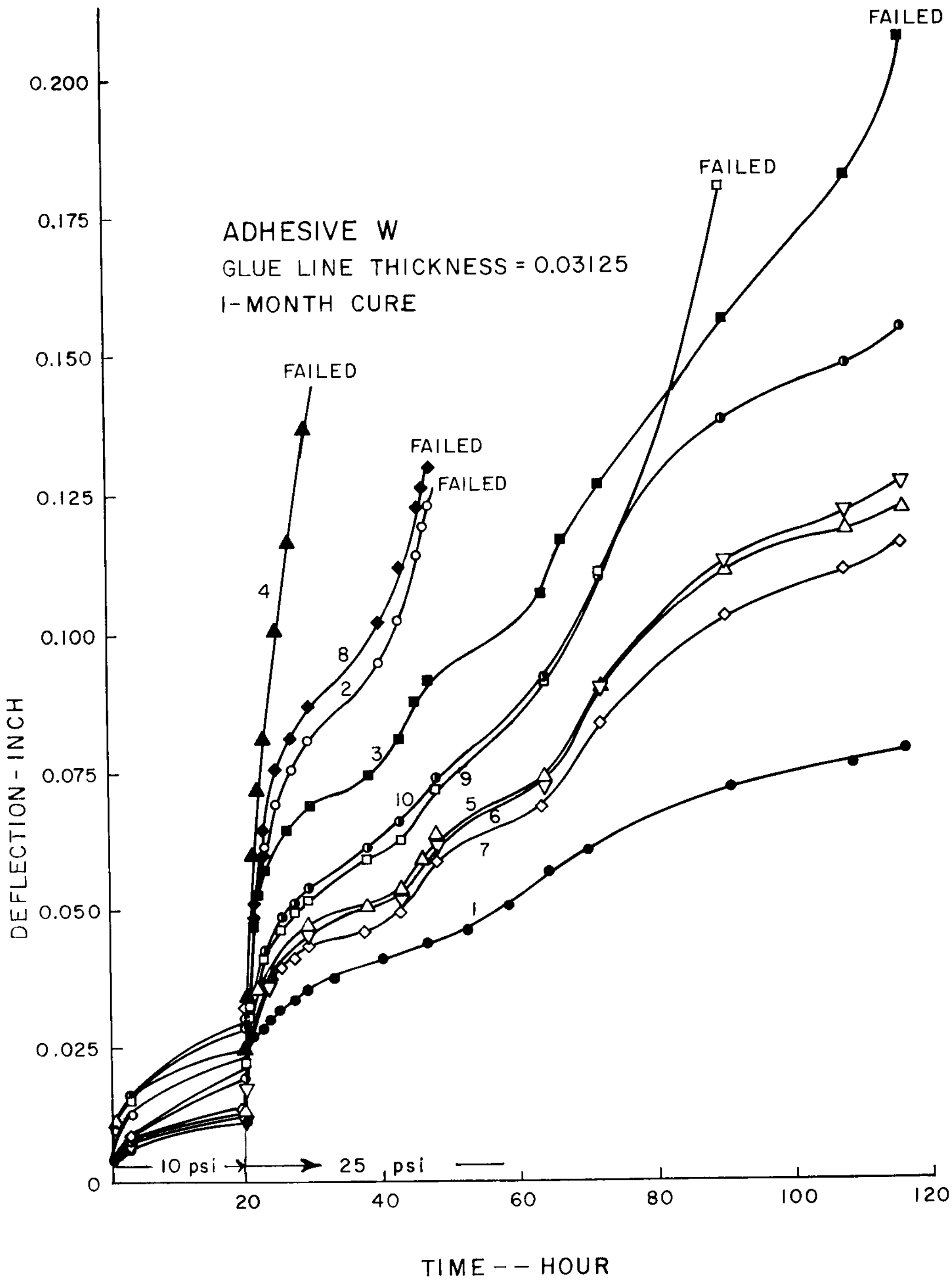


FIG. 7. Glue-line creep study of adhesive W, cured for 30 days.

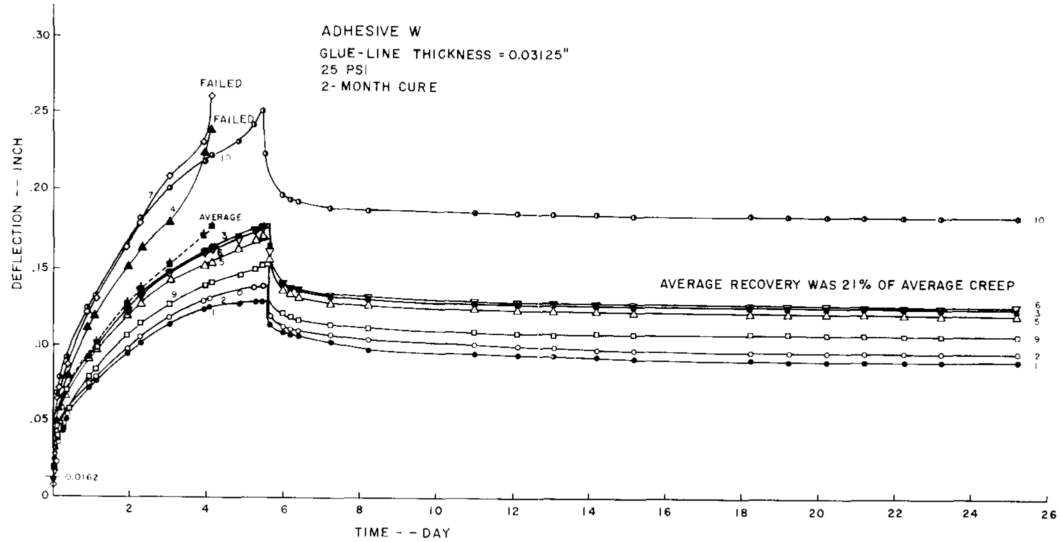


FIG. 8. Glue-line creep and recovery of adhesive W, cured for 60 days.

Recovery is expressed as a percentage of relative creep. Table 1 shows recoveries of 55 to 64% at the two stress levels, suggesting that the adhesive will not develop substantial permanent set from short-term live loads. Live loads are those service loads additional to permanent loads, such as snow, wind, occupancy, or traffic.

### *Adhesive F*

We found that this adhesive would not continuously sustain moderate stress and its creep properties were quite poor despite its very high shear modulus of rigidity. Its measured shear modulus of 1960 psi (13514 kPa), Table 1, is an excellent value that would provide virtually as much composite action as a rigid phenol-resorcinal adhesive in "I" and "T" sections (Hoyle 1976). At 25 psi stress level, it survived a 100-day test when cured for 30 days or more. Creep was 88 times its initial elastic deflection and showed evidence of a diminishing rate of increase. However, there would have been some additional creep, if the test period had been continued, possibly into the tertiary stage beyond an inflection point with growth in deflection to ultimate failure at 25 psi. Therefore no test series at 50 psi was conducted.

A second series of ten specimens cured for 60 days prior to test showed slightly better performance in a 120-day test, but the difference was not dramatic.

As indicated in Table 1 and Fig. 6, this adhesive did not recover well (21%) upon release of stress. It would probably develop more permanent set under short-term live load than would be tolerable in some structures.

Because short-term strength and shear modulus were good, the adhesive should serve well for the short-term loads imposed on transportable structures. However, as a permanently useful structural adhesive it is somewhat deficient.

### *Adhesive W*

The shear modulus of adhesive W proved to be quite low, 37 psi (255 kPa). The group of specimens cured for 60 days did not resist creep measurably better than the group cured for 30 days, as can be seen by comparing Figs. 7 and 8. Those cured for 60 days exhibit a lower percentage of failures in the first five to six days under stress. (Note that we had only nine 60-day cure specimens.) Although relative creep was only about one-tenth that shown by adhesive F, it was twenty times that measured

TABLE 1. *Properties of three elastomeric adhesives*

| Adhesive | Shear[a] Modulus, G, psi | Relative Creep, % @50psi | Relative Creep, % @25psi | Time Period Under Stress, hr @50psi | Time Period Under Stress, hr @25psi | Relative Creep after 96 hr at 25psi stress, % | Recovery[b], % From stress at 50psi | Recovery[b], % From stress at 25psi | Shear Strength by static test, psi mean | Shear Strength by static test, psi stnd. dev. | Glue Line Thickness at test, inch |
|---|---|---|---|---|---|---|---|---|---|---|---|
| M | 100 (n=20) | 107 | 45 | 910 | 480 | 51 | 55 | 64 | 145[d] (n=15) | 41 | 0.033 avg. (0.026-0.038) |
| F | 1960 (n=10) | - | 8800 | - | 2400 | 8330 | - | 21 | 280 (n=10) | 67 | 0.027 avg. (0.022-0.030) |
| W | 37 (n=9) | - | 994 | - | 144[c] | 988 | - | 21 | 150 (n=10) | 29 | 0.021 avg. (0.018-0.026) |

[a] Calculated from initial elastic deflection two minutes after loading, load and actual glue line thickness.

[b] Recovery is expressed as a percentage of relative creep.

[c] These specimens deflected 300% of glue line thickness in 45 hours.

[d] Determined by Hoyle (1970).

for adhesive M. Adhesive W, like adhesive F, would not sustain a 50 psi stress continuously for any useful period of time. The time required for 300% relative creep was less than two days at 25 psi. Because recovery in 20 days from 25 psi stress for 5.5 days was only 21% of relative creep, this adhesive could be expected to behave plastically under short-term loads without good recovery when load is reduced or renewed.

Adhesive W was moderately strong under short-term load tests and, like adhesive F, might be useful in providing temporary strength and very moderate stiffness advantages during periods of shipping for mobile home units.

### *Variation in creep*

Figures 7 and 8 show the creep curves for the individual adhesive W specimens. Adhesive W was the only one where specimens actually failed during the creep test periods, and we believed the individual curves were needed to show this behavior.

Figures 5 and 6 do not contain individual specimen curves, so the variation in creep may interest some readers. The coefficients of variation of relative creep for adhesive M (Fig. 5) were 0.33 at 50 psi and 0.30 at 25 psi. For adhesive F (Fig. 6) it was 0.55 for the one-month cure and 0.74 for the two-month cured pieces. For adhesive W (Fig. 8) calculated at the minimum specimen life of 4 days, the coefficient of variation of relative creep was 0.41.

## CONCLUSIONS

Of the three adhesives studied, only adhesive M appears to be an adequate structural elastomeric. Its shear modulus, strength, creep, and recovery characteristics at 70 F (21 C) are all compatible with the needs of structural wood building components for roof and floor systems. An evaluation of this adhesive at extreme service temperatures would be desirable.

The other adhesives were very prone to creep and would not sustain useful shear stresses permanently.

Adhesive F might be useful in improving the resistance of structures to wind and seismic loads and possibly other short-term loads.

Adhesive W was inferior to adhesive F in all respects.

This study shows that static tests for shear modulus and strength do not sufficiently evaluate structural elastomeric adhesives. Sustained load studies for creep, recovery, and shear strength are necessary.

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