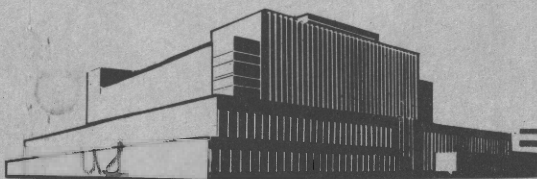
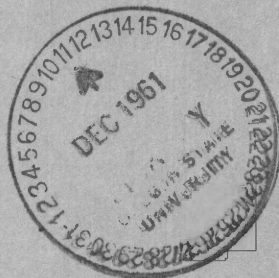


# EFFECTS OF ELEVATED CURING TEMPERATURES ON THE STRENGTH AND DURABILITY OF YELLOW BIRCH PLYWOOD JOINTS MADE WITH ROOM-TEMPERATURE-SETTING UREA GLUES

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UNITED STATES DEPARTMENT OF AGRICULTURE  
FOREST SERVICE

In Cooperation with the University of Wisconsin

EFFECTS OF ELEVATED CURING TEMPERATURES ON THE STRENGTH

AND DURABILITY OF YELLOW BIRCH PLYWOOD JOINTS

MADE WITH ROOM-TEMPERATURE-SETTING UREA GLUES<sup>1</sup>

By

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Introduction

Room-temperature-setting urea-formaldehyde resin glues produced in this country are generally formulated to cure at a minimum temperature of 70° F., at which many hours are required before pressure can be released. The curing of these room-temperature-setting urea glues can be hastened by elevated temperatures and, if the temperature is sufficiently high, the glue can be cured in a few minutes. To save time in the assembly of aircraft parts and other wood-fabrication work, the practice has developed of curing urea glues rapidly by the use of heated presses or jigs. Whether this practice of curing at elevated temperatures affects the quality of the glued joint is not known. Accordingly, this study is being conducted in an attempt to determine whether rapid curing of room-temperature-setting urea-formaldehyde resin glues by elevated temperatures affects the strength and durability of the joints significantly in comparison with joints made with the same glues cured at room temperature.

The general procedure was to make plywood with different urea glues, curing at several temperatures, testing specimens of the plywood so made for initial dry- and wet-joint strength, exposing specimens to various conditions of heat and moisture, and noting whether the rate of deterioration during exposure could be correlated with the original curing temperature.

This report presents the data obtained after the first year of exposure.

Procedures

Preparation of Specimen

This work was done on plywood for ease of preparation and rapid transfer of heat to the glue line. Three-ply panels were made with selected 1/16-inch yellow birch veneer, using five commercial glues, designated in this report by the letters A, B, C, D, and E. The glues were mixed in accordance with the manufacturers' instructions.

The gluing conditions employed were:

Moisture content of veneer when glued: About 12 percent.

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<sup>1</sup>This is one of a series of progress reports prepared by the Forest Products Laboratory relating to the use of wood in aircraft. Results here reported are preliminary and may be revised as additional data become available. Original report dated November 1945.

<sup>2</sup>Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

Spread: 20 to 25 grams of liquid glue per square foot of glue line, applied to the core ply.

Assembly: All assemblies closed; 10 minutes when the curing temperature was 80° F.; 2 minutes when the curing temperature was 160° F.; 2 and 10 minutes when the curing temperature was 180° and 215° F; 2, 10, and 45 minutes when the curing temperature was 250° F.

Pressing: Under 150 pounds per square inch between heavy wood cauls at room temperature, and between canvas cauls at elevated temperatures.

Curing: The panels were under pressure for 8 hours at 80° F.; for 25 minutes at 160° F.; for 9 minutes at 180° F.; for 7 minutes at 215° F.; and for 7 and 35 minutes at 250° F. For the four elevated temperatures, approximately 5 minutes was required to raise the glue line to the temperature indicated. For 80° F. the panels were held in a room at that temperature; for the higher temperatures the panels were pressed between platens heated by steam or hot water.

Conditioning: After removal from the presses, the panels were stored for about 1 week in a room held at 80° F. and 65 percent relative humidity, before being cut into standard shear test specimens.

#### Exposure of Specimens

The plywood specimens were divided into four groups, randomly selected, for exposure to the following conditions:

1. Continuous, 80° F. and 65 percent relative humidity.
2. Continuous, 158° F. and 20 percent relative humidity.
3. Continuous, 80° F. and 97 percent relative humidity.
4. Alternate soaking for 2 days in water at room temperature, followed by drying for 12 days at 80° F. and 30 percent relative humidity.

#### Test Periods

For control values, 14 specimens for each glue and gluing condition were tested dry, and 14 were tested wet after soaking in water at room temperature for 48 hours. The tests were made by pulling the specimens in shear in standard plywood testing grips loading at approximately 750 pounds per minute.

At the end of 2, 4, 6, and 12 months of exposure, from each of exposure conditions 1, 2, and 3, five specimens were tested dry after conditioning in a room at 80° F. and 65 percent relative humidity, and five were tested wet after soaking for 48 hours in water at room temperature. At these same times, five specimens from exposure condition 4 were tested wet.

Enough specimens were prepared and exposed to continue the experiment for 3 years with testing periods at 18, 24, 30, and 36 months.

#### Results

The average values of the shear strength and wood failure data obtained from the plywood shear tests are presented in tables 1 through 7.

From the data for glues B, C, and D, there appears to be no significant difference in the quality of the joints cured at the different temperatures and tested as controls. For these three glues, there is little or no evidence in the data of tables 1 and 2 that the plywood joints, made at any of the several curing temperatures, fell off in joint quality during the 12-month exposure to 80° F. and 65 percent relative humidity. These urea glues deteriorated in joint quality when exposed to 158° F. and 20 percent relative humidity according to the data of tables 3 and 4, and there is some difference in the rates of deterioration in the joints set at different temperatures, but the differences are not pronounced. What evidence there is indicates no ill effect by curing these glues at elevated temperatures and perhaps even some slight benefit. Also, from the effects of the continuous exposure to 97 percent relative humidity (tables 5 and 6) and alternate soaking and drying (table 7), the differences in the durability of these three glues due to differences in curing temperature are not pronounced and may not be significant.

The joints made at 250° F. with glue A exhibited poorer performance, generally, under the exposures than those made at 80° and 180° F., but the control specimens made at 250° F. with this glue were poorer in quality than those made at 80° F. or 180° F.

The joints made with glue E and cured at 215° F. and at 250° F. for 2 minutes after 2 minutes assembly time were, in general, of poorer durability than those made at lower temperatures or at 250° F. with longer assembly time or longer curing time. The comparative quality of the joints in the control specimens, however, was in this same order.

In the case of glues A and E, therefore, there was a difference in durability in the plywood specimens cured at different temperatures, but there was a parallel difference in the quality of the control joints. To ascertain more conclusively whether the curing temperature was responsible for the mediocre quality of certain of the control joints, two to five additional sets of panels were prepared with these two glues under the same conditions at different times, cut into shear specimens, and tested for joint strength. The data from these experiments are given in table 8, in which each value represents the averaged results for one set of panels. From these data it is apparent that low or high wood failure was not consistently associated with any particular curing temperature or combination of curing time, temperature, and assembly period, but that panels that gave relatively low wood failure occasionally occurred at the different temperatures. From the available evidence, it would be expected that the occasional panels showing low original wood failure would exhibit relatively poor joint durability under exposure, and this might happen with glues A and E with any of the curing temperatures.

As a broad conclusion from the data thus far obtained in this study, it appears that, for the five glues tested and the particular exposure conditions employed, there was no important effect on the original joint strength or joint durability by the temperature of curing within the range 80° F. to 250° F.



Table 1.--Results of dry<sup>1/</sup> shear tests of three-ply, 3/16-inch yellow birch plywood bonded with room-temperature-setting urea glues at various temperatures, before and after exposure to 80° F. and 65 percent relative humidity

| Glue | Period of exposure | Curing conditions |  |            |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |   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|      |                    | 80° F.            |  |            |  |           |  | 160° F.   |  |           |  |           |  | 180° F.   |  |           |  |           |  | 215° F.   |  |           |  |           |  | 250° F.   |  |           |  |           |  | 250° F.   |  |           |  |           |  | 250° F.   |  |           |  |           |  | 250° F.   |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |           |  |   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| 2 minutes |  |

<sup>1/</sup>Tested dry after removal from exposure.

<sup>2/</sup>The first value is the average shear strength in pounds per square inch; the second value is the average wood failure in percent.

Table 2.---Results of wet<sup>1/</sup> shear tests of three-ply, 3/16-inch yellow birch plywood, bonded with room-temperature-setting urea glues at various temperatures, before and after exposure to 80° F. and 65 percent relative humidity

| Glue | Period of exposure | Curing conditions      |            |           |            |           |            |           |            |           |            |           |          |
|------|--------------------|------------------------|------------|-----------|------------|-----------|------------|-----------|------------|-----------|------------|-----------|----------|
|      |                    | 80° F.                 |            |           |            |           |            | 180° F.   |            |           |            |           |          |
|      |                    | 20 minutes             |            | 4 minutes |            | 2 minutes |            | 4 minutes |            | 2 minutes |            | 2 minutes |          |
|      |                    | 2 minutes              |            | 2 minutes |            | 2 minutes |            | 2 minutes |            | 2 minutes |            | 2 minutes |          |
|      |                    | 2 minutes              |            | 2 minutes |            | 2 minutes |            | 2 minutes |            | 2 minutes |            | 2 minutes |          |
|      |                    | Assembly time (closed) |            |           |            |           |            |           |            |           |            |           |          |
| A    | Months             | 0 (Controls)           | 10 minutes | 2 minutes | 10 minutes | 2 minutes | 10 minutes | 2 minutes | 10 minutes | 2 minutes | 10 minutes | 2 minutes |          |
|      |                    |                        | 2/457-93   | 2/460-83  | 2/460-83   | 2/460-83  | 2/460-83   | 2/460-83  | 2/460-83   | 2/460-83  | 2/460-83   | 2/460-83  | 2/460-83 |
|      |                    |                        | 476-100    | 451-40    | 394-76     | 385-44    | 395-28     | 552-91    | 465-91     | 572-97    | 572-97     | 572-97    | 572-97   |
|      |                    |                        | 443-93     | 394-76    | 385-44     | 395-28    | 552-91     | 465-91    | 572-97     | 572-97    | 572-97     | 572-97    | 572-97   |
|      |                    |                        | 447-62     | 394-76    | 385-44     | 395-28    | 552-91     | 465-91    | 572-97     | 572-97    | 572-97     | 572-97    | 572-97   |
|      |                    |                        | 453-92     | 394-76    | 385-44     | 395-28    | 552-91     | 465-91    | 572-97     | 572-97    | 572-97     | 572-97    | 572-97   |
| B    | 0 (Controls)       | 468-88                 | 572-97     | 550-92    | 552-91     | 552-91    | 552-91     | 552-91    | 552-91     | 552-91    | 552-91     | 552-91    |          |
|      |                    | 458-99                 | 550-92     | 552-91    | 552-91     | 552-91    | 552-91     | 552-91    | 552-91     | 552-91    | 552-91     | 552-91    |          |
|      |                    | 439-100                | 552-91     | 552-91    | 552-91     | 552-91    | 552-91     | 552-91    | 552-91     | 552-91    | 552-91     | 552-91    |          |
|      |                    | 469-99                 | 552-91     | 552-91    | 552-91     | 552-91    | 552-91     | 552-91    | 552-91     | 552-91    | 552-91     | 552-91    |          |
|      |                    | 488-87                 | 552-91     | 552-91    | 552-91     | 552-91    | 552-91     | 552-91    | 552-91     | 552-91    | 552-91     | 552-91    |          |
|      |                    | 488-87                 | 552-91     | 552-91    | 552-91     | 552-91    | 552-91     | 552-91    | 552-91     | 552-91    | 552-91     | 552-91    |          |
| C    | 0 (Controls)       | 391-88                 | 464-100    | 502-100   | 510-99     | 510-99    | 510-99     | 510-99    | 510-99     | 510-99    | 510-99     | 510-99    |          |
|      |                    | 427-100                | 502-100    | 510-99    | 510-99     | 510-99    | 510-99     | 510-99    | 510-99     | 510-99    | 510-99     | 510-99    |          |
|      |                    | 406-100                | 462-100    | 424-100   | 448-100    | 448-100   | 448-100    | 448-100   | 448-100    | 448-100   | 448-100    | 448-100   |          |
|      |                    | 414-80                 | 450-97     | 427-92    | 430-97     | 430-97    | 430-97     | 430-97    | 430-97     | 430-97    | 430-97     | 430-97    |          |
|      |                    | 437-100                | 460-100    | 473-98    | 435-96     | 435-96    | 435-96     | 435-96    | 435-96     | 435-96    | 435-96     | 435-96    |          |
|      |                    | 437-100                | 460-100    | 473-98    | 435-96     | 435-96    | 435-96     | 435-96    | 435-96     | 435-96    | 435-96     | 435-96    |          |
| D    | 0 (Controls)       | 490-93                 | 501-100    | 516-95    | 521-99     | 521-99    | 521-99     | 521-99    | 521-99     | 521-99    | 521-99     | 521-99    |          |
|      |                    | 472-100                | 516-95     | 521-99    | 521-99     | 521-99    | 521-99     | 521-99    | 521-99     | 521-99    | 521-99     | 521-99    |          |
|      |                    | 433-100                | 511-100    | 514-95    | 504-91     | 504-91    | 504-91     | 504-91    | 504-91     | 504-91    | 504-91     | 504-91    |          |
|      |                    | 452-98                 | 486-99     | 475-98    | 465-68     | 465-68    | 465-68     | 465-68    | 465-68     | 465-68    | 465-68     | 465-68    |          |
|      |                    | 433-98                 | 479-91     | 483-95    | 457-74     | 457-74    | 457-74     | 457-74    | 457-74     | 457-74    | 457-74     | 457-74    |          |
|      |                    | 433-98                 | 479-91     | 483-95    | 457-74     | 457-74    | 457-74     | 457-74    | 457-74     | 457-74    | 457-74     | 457-74    |          |
| E    | 0 (Controls)       | 440-100                | 507-90     | 499-74    | 447-31     | 447-31    | 447-31     | 447-31    | 447-31     | 447-31    | 447-31     | 447-31    |          |
|      |                    | 458-81                 | 469-69     | 442-25    | 422-25     | 422-25    | 422-25     | 422-25    | 422-25     | 422-25    | 422-25     | 422-25    |          |
|      |                    | 440-98                 | 443-39     | 415-40    | 415-40     | 415-40    | 415-40     | 415-40    | 415-40     | 415-40    | 415-40     | 415-40    |          |
|      |                    | 386-100                | 473-53     | 411-21    | 438-28     | 438-28    | 438-28     | 438-28    | 438-28     | 438-28    | 438-28     | 438-28    |          |
|      |                    | 413-94                 |            |           |            |           |            |           |            |           |            |           |          |
|      |                    | 413-94                 |            |           |            |           |            |           |            |           |            |           |          |

<sup>1/</sup> Specimen soaked for 48 hours in water at room temperature after removal from exposure.

<sup>2/</sup> The first value is the average shear strength in pounds per square inch; the second value is the average wood failure in percent.

Table 3.---Results of dry<sup>1/</sup> shear tests of three-ply, 3/16-inch yellow birch plywood, bonded with room-temperature-setting urea glues at various temperatures, before and after exposure to 15° F. and 20 percent relative humidity

| Glue   | Period of exposure | Curing conditions      |                      |                     |                     |                     |                     |                     |                     |                      |                      |                      |                      |
|--------|--------------------|------------------------|----------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|----------------------|----------------------|----------------------|----------------------|
|        |                    | Assembly time (closed) |                      |                     |                     |                     |                     |                     |                     |                      |                      |                      |                      |
|        |                    | 80° F. : 8 hours       | 160° F. : 20 minutes | 180° F. : 4 minutes | 180° F. : 2 minutes | 215° F. : 2 minutes | 215° F. : 2 minutes | 250° F. : 2 minutes | 250° F. : 2 minutes | 250° F. : 30 minutes | 250° F. : 30 minutes | 250° F. : 45 minutes | 250° F. : 45 minutes |
| Months |                    |                        |                      |                     |                     |                     |                     |                     |                     |                      |                      |                      |                      |
| A      | 0 (Controls)       | 2/453-79               | 2/.....              | 2/.....             | 2/.....             | 2/.....             | 2/.....             | 2/.....             | 2/.....             | 2/.....              | 2/.....              | 2/.....              | 2/.....              |
|        | 2                  | 282-19                 | .....                | 250-42              | .....               | .....               | .....               | .....               | .....               | .....                | .....                | .....                | .....                |
|        | 4                  | 252-7                  | .....                | 270-50              | .....               | .....               | .....               | .....               | .....               | .....                | .....                | .....                | .....                |
|        | 6                  | 263-4                  | .....                | 329-23              | .....               | .....               | .....               | .....               | .....               | .....                | .....                | .....                | .....                |
|        | 12                 | 216-2                  | .....                | 233-2               | .....               | .....               | .....               | .....               | .....               | .....                | .....                | .....                | .....                |
|        | 18                 | .....                  | .....                | .....               | .....               | .....               | .....               | .....               | .....               | .....                | .....                | .....                | .....                |
| B      | 0 (Controls)       | 473-81                 | 519-96               | 479-88              | 484-12              | 494-87              | 487-87              | 440-85              | 515-94              | 471-86               | 554-92               | 423-100              | 483-100              |
|        | 2                  | 385-39                 | 457-48               | 484-12              | 378-4               | 494-87              | 382-72              | 393-78              | 397-65              | 366-68               | 456-64               | 396-89               | 435-89               |
|        | 4                  | 363-37                 | 399-14               | 378-4               | 401-25              | 362-24              | 401-25              | 406-42              | 381-50              | 350-24               | 405-45               | 369-21               | 394-83               |
|        | 6                  | 364-34                 | 415-29               | 386-2               | 396-6               | 434-10              | 396-6               | 420-39              | 393-26              | 336-10               | 443-30               | 393-11               | 363-57               |
|        | 12                 | 242-4                  | 298-2                | 286-1               | 311-0               | 275-1               | 311-0               | 312-9               | 274-1               | 257-1                | 407-8                | 294-0                | 310-9                |
|        | 18                 | .....                  | .....                | .....               | .....               | .....               | .....               | .....               | .....               | .....                | .....                | .....                | .....                |
| C      | 0 (Controls)       | 403-79                 | 468-100              | 451-96              | 416-7               | 463-97              | 451-84              | 481-80              | 458-87              | 439-100              | 416-83               | 413-100              | 370-99               |
|        | 2                  | 325-64                 | 347-66               | 349-16              | 416-7               | 344-90              | 347-47              | 338-33              | 342-43              | 353-64               | 275-14               | 375-58               | 292-49               |
|        | 4                  | 376-36                 | 377-49               | 392-4               | 387-26              | 429-55              | 387-26              | 362-4               | 391-10              | 370-18               | 345-13               | 390-18               | 381-47               |
|        | 6                  | 369-1                  | 378-52               | 392-4               | 403-24              | 376-26              | 403-24              | 377-7               | 370-28              | 390-10               | 350-7                | 382-10               | 378-8                |
|        | 12                 | 263-0                  | 291-27               | 287-0               | 305-4               | 265-9               | 305-4               | 295-6               | 304-5               | 283-3                | 216-11               | 300-7                | 247-0                |
|        | 18                 | .....                  | .....                | .....               | .....               | .....               | .....               | .....               | .....               | .....                | .....                | .....                | .....                |
| D      | 0 (Controls)       | 498-98                 | 529-67               | 496-88              | 367-35              | 519-90              | 536-91              | 469-99              | 464-95              | 498-93               | 495-95               | 449-98               | 505-93               |
|        | 2                  | 317-64                 | 345-75               | 367-35              | 330-26              | 306-13              | 312-34              | 317-20              | 291-20              | 318-23               | 305-46               | 343-62               | 298-19               |
|        | 4                  | 295-40                 | 348-11               | 330-26              | 327-13              | 324-16              | 327-13              | 345-43              | 315-9               | 281-10               | 294-22               | 336-41               | 288-6                |
|        | 6                  | 342-34                 | 345-3                | 315-11              | 342-4               | 333-3               | 342-4               | 357-32              | 384-4               | 285-3                | 306-29               | 344-11               | 308-7                |
|        | 12                 | 253-4                  | 291-3                | 267-2               | 284-2               | 242-0               | 284-2               | 305-3               | 303-4               | 253-2                | 251-10               | 272-1                | 273-0                |
|        | 18                 | .....                  | .....                | .....               | .....               | .....               | .....               | .....               | .....               | .....                | .....                | .....                | .....                |
| E      | 0 (Controls)       | 483-94                 | 438-73               | 456-47              | 279-0               | 439-59              | 416-20              | 417-46              | 374-33              | 400-77               | 441-37               | 402-89               | 458-87               |
|        | 2                  | 277-2                  | 271-0                | 279-0               | 236-0               | 296-1               | 314-0               | 333-0               | 242-1               | 272-3                | 315-5                | 321-3                | 336-27               |
|        | 4                  | 261-7                  | 241-0                | 236-0               | 229-0               | 239-0               | 229-0               | 229-0               | 202-0               | 222-3                | 300-15               | 253-1                | 300-9                |
|        | 6                  | 270-5                  | 229-2                | 244-0               | 227-0               | 252-3               | 227-0               | 271-0               | 212-0               | 241-3                | 304-3                | 256-2                | 318-4                |
|        | 12                 | 213-0                  | 188-0                | 166-0               | 134-0               | 68-0                | 134-0               | 213-0               | 113-0               | 204-3                | 253-6                | 227-1                | 242-0                |
|        | 18                 | .....                  | .....                | .....               | .....               | .....               | .....               | .....               | .....               | .....                | .....                | .....                | .....                |

<sup>1/</sup>Tested after 2 days at 80° F. and 65 percent relative humidity.

<sup>2/</sup>The first value is the average shear strength in pounds per square inch; the second value is the average wood failure in percent.

Table 4.---Results of wet<sup>1/</sup> shear tests of three-ply, 3/16-inch yellow birch plywood, bonded with room-temperature-setting urea glues at various temperatures, before and after exposure to 15°F. and 20 percent relative humidity

| Curing conditions |                    |                        |            |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |         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| Glue              | Period of exposure | Assembly time (closed) |            |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |         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|                   |                    | 80° F.                 |            |           | 160° F.   |           |           | 180° F.   |           |           | 215° F.   |           |           | 250° F.   |           |           | 250° F.   |           |           | 250° F.   |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |         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|                   |                    | 8 hours                | 20 minutes | 4 minutes | 4 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 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minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 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minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes | 2 minutes |

<sup>1/</sup> Specimen soaked for 48 hours in water at room temperature after removal from exposure.

<sup>2/</sup> The first value is the average shear strength in pounds per square inch; the second value is the average wood failure in percent.



Table 5.--Results of dry<sup>1/</sup> shear tests of three-ply, 3/16-inch yellow birch plywood, bonded with room-temperature-setting urea glues at various temperatures, before and after exposure to 80° F. and 97 percent relative humidity

| Glue | Period of exposure | Curing conditions      |                       |                      |                      |                      |                      |                      |                      |                       |                       |                       |                       |
|------|--------------------|------------------------|-----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
|      |                    | Assembly time (closed) |                       |                      |                      |                      |                      |                      |                      |                       |                       |                       |                       |
|      |                    | 80° F.<br>8 hours      | 160° F.<br>20 minutes | 180° F.<br>4 minutes | 180° F.<br>4 minutes | 215° F.<br>2 minutes | 215° F.<br>2 minutes | 250° F.<br>2 minutes | 250° F.<br>2 minutes | 250° F.<br>30 minutes | 250° F.<br>30 minutes | 250° F.<br>30 minutes | 250° F.<br>45 minutes |
|      | 10 minutes         | 2 minutes              | 2 minutes             | 10 minutes           | 2 minutes            | 2 minutes            | 10 minutes           | 45 minutes           | 2 minutes            | 10 minutes            | 10 minutes            | 45 minutes            |                       |
| A    | 0 (Controls)       | 2/453-79               | 2/.....               | 2/.....              | 2/453-83             | 2/.....              | 2/.....              | 2/.....              | 2/410-48             | 2/.....               | 2/.....               | 2/.....               | 2/.....               |
|      | 2                  | 348-19                 | .....                 | .....                | 403-29               | .....                | .....                | .....                | 339-5                | .....                 | .....                 | .....                 | .....                 |
|      | 4                  | 321-98                 | .....                 | .....                | 392-59               | .....                | .....                | .....                | 358-34               | .....                 | .....                 | .....                 | .....                 |
|      | 6                  | 264-100                | .....                 | .....                | 308-100              | .....                | .....                | .....                | 280-60               | .....                 | .....                 | .....                 | .....                 |
|      | 12                 | 141-100                | .....                 | .....                | 142-100              | .....                | .....                | .....                | 110-100              | .....                 | .....                 | .....                 | .....                 |
|      | 18                 | .....                  | .....                 | .....                | .....                | .....                | .....                | .....                | .....                | .....                 | .....                 | .....                 | .....                 |
| B    | 0 (Controls)       | 473-81                 | 519-96                | 479-88               | 551-100              | 487-87               | 440-85               | 515-94               | 471-86               | 423-100               | 478-85                | 483-100               | .....                 |
|      | 2                  | 475-90                 | 553-91                | 503-46               | 538-80               | 547-97               | 529-89               | 510-63               | 495-98               | 468-100               | 520-65                | 500-93                | .....                 |
|      | 4                  | 357-97                 | 506-93                | 499-55               | 445-83               | 475-99               | 432-100              | 434-82               | 413-100              | 451-100               | 448-60                | 465-94                | .....                 |
|      | 6                  | 317-100                | 309-100               | 357-99               | 342-100              | 306-100              | 361-100              | 424-80               | 358-99               | 347-100               | 384-82                | 402-99                | .....                 |
|      | 12                 | 154-100                | 185-100               | 208-100              | 222-100              | 180-100              | 208-100              | 201-100              | 197-100              | 163-100               | 197-100               | 236-100               | .....                 |
|      | 18                 | .....                  | .....                 | .....                | .....                | .....                | .....                | .....                | .....                | .....                 | .....                 | .....                 | .....                 |
| C    | 0 (Controls)       | 403-79                 | 468-100               | 451-96               | 463-97               | 451-84               | 481-80               | 458-87               | 439-100              | 413-100               | 402-78                | 370-99                | .....                 |
|      | 2                  | 498-83                 | 505-100               | 547-100              | 509-96               | 564-93               | 559-92               | 595-100              | 582-99               | 491-100               | 564-91                | 495-95                | .....                 |
|      | 4                  | 372-100                | 528-100               | 536-100              | 513-100              | 418-100              | 510-100              | 550-100              | 513-100              | 546-100               | 469-54                | 509-96                | .....                 |
|      | 6                  | 313-100                | 300-100               | 378-100              | 385-100              | 390-100              | 390-100              | 422-100              | 377-100              | 419-100               | 497-85                | 394-100               | .....                 |
|      | 12                 | 188-100                | 196-100               | 200-100              | 180-100              | 195-100              | 186-100              | 245-100              | 204-100              | 216-100               | 253-100               | 215-100               | .....                 |
|      | 18                 | .....                  | .....                 | .....                | .....                | .....                | .....                | .....                | .....                | .....                 | .....                 | .....                 | .....                 |
| D    | 0 (Controls)       | 498-98                 | 529-67                | 496-88               | 519-90               | 536-91               | 469-99               | 464-95               | 498-93               | 449-98                | 499-93                | 505-93                | .....                 |
|      | 2                  | 478-98                 | 515-70                | 522-86               | 568-88               | 484-91               | 526-98               | 527-98               | 513-79               | 496-96                | 524-89                | 489-88                | .....                 |
|      | 4                  | 561-94                 | 548-70                | 569-91               | 577-65               | 512-44               | 583-92               | 562-98               | 540-94               | 478-97                | 544-62                | 532-41                | .....                 |
|      | 6                  | 473-69                 | 481-44                | 511-61               | 494-75               | 501-27               | 535-78               | 522-98               | 442-5                | 453-69                | 516-27                | 502-40                | .....                 |
|      | 12                 | 244-100                | 278-100               | 304-100              | 302-100              | 188-100              | 257-84               | 350-100              | 346-100              | 381-80                | 406-49                | 333-61                | .....                 |
|      | 18                 | .....                  | .....                 | .....                | .....                | .....                | .....                | .....                | .....                | .....                 | .....                 | .....                 | .....                 |
| E    | 0 (Controls)       | 483-94                 | 438-73                | 456-47               | 439-59               | 416-20               | 417-46               | 374-33               | 400-77               | 402-89                | 415-93                | 458-87                | .....                 |
|      | 2                  | 463-90                 | 376-4                 | 426-1                | 411-15               | 368-3                | 447-0                | 403-2                | 436-29               | 465-13                | 462-25                | 440-91                | .....                 |
|      | 4                  | 456-43                 | 422-1                 | 391-0                | 448-8                | 392-2                | 390-2                | 362-8                | 385-10               | 418-37                | 423-29                | 463-85                | .....                 |
|      | 6                  | 405-80                 | 348-0                 | 326-0                | 365-4                | 286-4                | 359-2                | 300-3                | 389-15               | 414-13                | 415-13                | 388-15                | .....                 |
|      | 12                 | 286-100                | 278-90                | 271-52               | 279-85               | 184-22               | 233-41               | 224-54               | 257-68               | 308-45                | 289-47                | 287-70                | .....                 |
|      | 18                 | .....                  | .....                 | .....                | .....                | .....                | .....                | .....                | .....                | .....                 | .....                 | .....                 | .....                 |
| 24   | .....              | .....                  | .....                 | .....                | .....                | .....                | .....                | .....                | .....                | .....                 | .....                 | .....                 |                       |
| 30   | .....              | .....                  | .....                 | .....                | .....                | .....                | .....                | .....                | .....                | .....                 | .....                 | .....                 |                       |
| 36   | .....              | .....                  | .....                 | .....                | .....                | .....                | .....                | .....                | .....                | .....                 | .....                 | .....                 |                       |

<sup>1/</sup> Tested dry after removal from exposure.

<sup>2/</sup> The first value is the average shear strength in pounds per square inch; the second value is the average wood failure in percent.





Table 6.---Results of shear tests on specimens of three-ply 3/16-inch birch plywood glued with room-temperature-setting urea glues at various curing temperatures and assembly times.

| Glue | Curing temperature | 80° F.      |               | 160° F.     |               | 180° F.     |               | 180° F.     |               | 215° F.     |               | 250° F.     |               | 250° F.     |               | 250° F.     |               | 250° F.     |               |
|------|--------------------|-------------|---------------|-------------|---------------|-------------|---------------|-------------|---------------|-------------|---------------|-------------|---------------|-------------|---------------|-------------|---------------|-------------|---------------|
|      |                    | 8 hours     |               | 20 minutes  |               | 4 minutes   |               | 4 minutes   |               | 2 minutes   |               | 2 minutes   |               | 2 minutes   |               | 2 minutes   |               | 2 minutes   |               |
|      |                    | Curing time | Assembly time | Curing time | Assembly time | Curing time | Assembly time | Curing time | Assembly time | Curing time | Assembly time | Curing time | Assembly time | Curing time | Assembly time | Curing time | Assembly time | Curing time | Assembly time |
| A    | Dry <sup>1</sup>   | 453-79      | 10 minutes    | 422-64      | 2 minutes     | 453-83      | 10 minutes    | 459-100     | 2 minutes     | 482-97      | 2 minutes     | 410-48      | 10 minutes    | 440-96      | 2 minutes     | 420-78      | 2 minutes     | 449-79      | 30 minutes    |
|      |                    | 475-43      | 10 minutes    | 452-82      | 2 minutes     | 396-11      | 10 minutes    | 468-40      | 2 minutes     | 476-99      | 2 minutes     | 467-72      | 10 minutes    | 490-94      | 2 minutes     | 444-93      | 2 minutes     | 424-88      | 30 minutes    |
|      |                    | 411-50      | 10 minutes    | 468-72      | 2 minutes     | 420-81      | 10 minutes    | 481-70      | 2 minutes     | 458-94      | 2 minutes     | 438-80      | 10 minutes    | 461-68      | 2 minutes     | 472-82      | 2 minutes     | 424-88      | 30 minutes    |
|      |                    | 316-2       | 10 minutes    | 473-91      | 2 minutes     | 448-61      | 10 minutes    | 504-100     | 2 minutes     | 478-73      | 2 minutes     | 456-60      | 10 minutes    | 454-99      | 2 minutes     | 479-54      | 2 minutes     | 440-85      | 30 minutes    |
| A    | Wet <sup>2</sup>   | 488-98      | 10 minutes    |             |               | 465-100     | 10 minutes    |             |               | 476-87      | 2 minutes     | 460-98      | 10 minutes    |             |               | 442-96      | 2 minutes     | 460-80      | 30 minutes    |
|      |                    | 457-93      | 10 minutes    |             |               | 460-83      | 10 minutes    |             |               |             |               |             |               |             |               |             |               |             |               |
|      |                    | 504-65      | 10 minutes    |             |               | 451-9       | 10 minutes    |             |               |             |               |             |               |             |               |             |               |             |               |
|      |                    | 422-50      | 10 minutes    |             |               | 500-81      | 10 minutes    |             |               |             |               |             |               |             |               |             |               |             |               |
| E    | Dry <sup>1</sup>   | 470-38      | 10 minutes    | 488-97      | 2 minutes     | 480-98      | 10 minutes    | 497-100     | 2 minutes     | 484-100     | 2 minutes     | 432-26      | 10 minutes    | 490-100     | 2 minutes     | 456-100     | 2 minutes     | 472-91      | 30 minutes    |
|      |                    | 457-93      | 10 minutes    |             |               | 460-83      | 10 minutes    |             |               |             |               |             |               |             |               |             |               |             |               |
|      |                    | 504-65      | 10 minutes    |             |               | 451-9       | 10 minutes    |             |               |             |               |             |               |             |               |             |               |             |               |
|      |                    | 422-50      | 10 minutes    |             |               | 500-81      | 10 minutes    |             |               |             |               |             |               |             |               |             |               |             |               |
| E    | Wet <sup>2</sup>   | 483-94      | 10 minutes    | 438-73      | 2 minutes     | 439-59      | 10 minutes    | 456-47      | 2 minutes     | 416-20      | 2 minutes     | 400-77      | 10 minutes    | 441-37      | 2 minutes     | 402-89      | 2 minutes     | 415-93      | 30 minutes    |
|      |                    | 457-93      | 10 minutes    |             |               | 428-50      | 10 minutes    | 483-83      | 2 minutes     | 421-81      | 2 minutes     | 454-97      | 10 minutes    | 425-95      | 2 minutes     | 407-81      | 2 minutes     | 400-73      | 30 minutes    |
|      |                    | 452-77      | 10 minutes    | 397-39      | 2 minutes     | 428-77      | 10 minutes    | 421-56      | 2 minutes     | 376-10      | 2 minutes     | 436-86      | 10 minutes    | 426-88      | 2 minutes     | 398-90      | 2 minutes     | 388-86      | 30 minutes    |
|      |                    | 424-69      | 10 minutes    | 428-18      | 2 minutes     | 382-22      | 10 minutes    | 418-34      | 2 minutes     | 494-86      | 2 minutes     | 449-56      | 10 minutes    | 463-76      | 2 minutes     | 422-52      | 2 minutes     | 403-44      | 30 minutes    |
| E    | Wet <sup>3</sup>   | 440-100     | 10 minutes    | 507-90      | 2 minutes     | 495-75      | 10 minutes    | 495-75      | 2 minutes     | 446-19      | 2 minutes     | 486-86      | 10 minutes    | 501-65      | 2 minutes     | 498-100     | 2 minutes     | 453-99      | 30 minutes    |
|      |                    | 528-77      | 10 minutes    | 554-90      | 2 minutes     | 500-83      | 10 minutes    | 500-83      | 2 minutes     | 460-87      | 2 minutes     |             |               | 481-96      | 2 minutes     | 419-81      | 2 minutes     | 444-70      | 30 minutes    |
|      |                    | 540-99      | 10 minutes    | 437-44      | 2 minutes     | 473-57      | 10 minutes    | 473-57      | 2 minutes     | 490-15      | 2 minutes     | 594-94      | 10 minutes    | 563-95      | 2 minutes     | 476-97      | 2 minutes     | 458-89      | 30 minutes    |
|      |                    |             | 10 minutes    |             |               |             |               |             |               |             |               |             |               |             |               |             |               |             |               |

<sup>1</sup>Tested dry after at least one week at 80° F. and 65 percent relative humidity.

<sup>2</sup>The first value is the average shear strength in pounds per square inch; the second value is the average wood failure in percent. Each value is the average of 20 tests.

<sup>3</sup>Tested wet after soaking in water at room temperature for 48 hours.



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