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TEMPERATURE HISTORIES OF PLYWOOD ROOF SHEATHING AND ROOF RAFTERS AS USED IN NORTH AMERICAN LIGHT-FRAMED CONSTRUTIION

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ABSTRACT

Temperature histories for plywood roof sheathing and nominal 2- by 6-in. (standard 38- by 140 mm) roof rafters in nonventilated attics were monitored in outdoor attic structuresw using simulated North American light-framed construction. These temperatures have been recorded for 8 years in Madison, Wisconsin, USA (43°N latitude) and for 4 years in Starkville, Mississippi, USA (33°N latitude). In this paper, we present and discuss details of the influences on temperature of black versus white fiberglass shingles, dry versus humidigfied attic spaces, and nothern United States versus southern United States geographic locations. We will also discuss current work that includes recording roof sheathing and nominal 2 by 6 roof rafter temperature histories under wood shake and wood-plastic composite roofing materials and comparing their differences from the temperatures recorded under more common fiberglass shingles. When the data from this work is combined with the FPL roof temperature model, an integrated approach to predicting roof temperatures across North America is possible.

Keywords: Plywood, Sheathing, Trusses, Roof temperature, Temperature

INTRODUCTION

In the late 1980s, the degradation of wood treated with some fiere retardant (FR) chemicals in roof systems became a problem of major national significance. Thousands of cases were reported throughout the Eastern United States [1]. Our understanding of this deterioration in serviceability caused by thermal degrade has been limited because we have been unable to specifically correlate laboratory experiments using steady€and cyclic temperature exposures with actual diurnal field temperature histories of FR-treated roof sheathing plywood. This lack of correlation has inhibited our ability to predcict thermal-induced degradationh of FR-treated plywood in the field based on thermal degradation rates derived in the laboratory.

Between 1985 and 1995, approximately 750,000 multifamily housing units experienced problems with thermal degrade induced by solar radiation of FR-treated (FRT) plywood roof sheathing IFig. 1). The problem was first reviewed by researchers at the USDA Forest Service, Forest Products Laboratory (FP:L) [2]. Between 1991 and 1997, Winandy and coworkders defined the thermal and chemical mechanisms and presented solutions [3].

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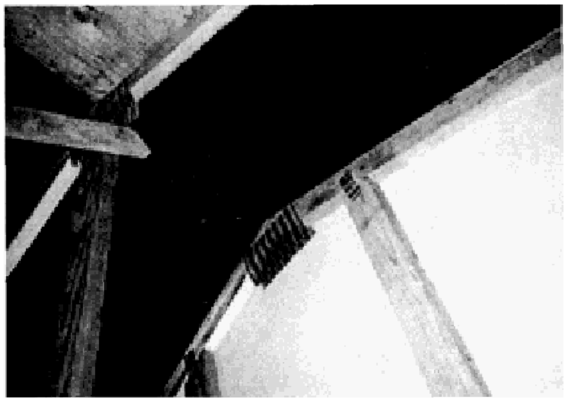

Figure 1. Inside view of failed FRT plywood roof sheathing.

Research conducted at FPL from 1988 through 1999 resulted in more than twenty published technical papers and three new National standards [4] released by the American Society for Testing and Materials (ASTM) and American National Standards Institute (ANSI). These standards form the scientific–technical basis for new performance-based qualification requirements for commercial FRT plywood roof sheathing.

- ASTM/ANSI D5516—Standard test method for thermal degrade of FRT plywood.
- ASTM/ANSI D5664—Standard test method for thermal degrade of FRT lumber.
- ASTM/ANSI D6305—Standard practice for developing engineering design adjustments for allowable properties of FRT plywood.

We developed kinetic degradation models [5]. Later, field serviceability issues were quantified [3,6,7], and the first service life models for thermal degrade of roof sheathing (Fig. 2) were developed to predict residual serviceability of FRT plywood. Research work on the development of residual serviceability model is continuing.

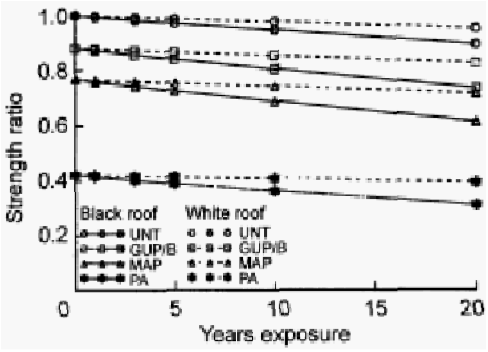

Figure 2. Example of residual serviceability model developed at FPL for FRT plywood roof sheathing exposed in Wisconsin (UNT = untreated, GUP/B = guanylureaphosphate/boric acid, MAP = Monoammonium phosphate, PA = phosphoric acid).

OBJECTIVE

One objective of the program was to collect field data documenting the actual thermal load history of various wood components in traditional light-framed structures. The roof temperature histories presented in this report provide reasonable estimates of actual thermal loads. In addition, the histories provide insight into the effects of shingle color, attic humidity, and climate on thermal loads and a database for modeling the residual serviceablility of roof sheathing for known wood thermal degradation rates [5]. This report summarizes the objective and findings from the roof temperature assessment project [8,9]. The overall program to develop residual serviceability models for roof sheathing involved more than a dozen interrelated studies conducted over 10 years. That research program was summarized by Winandy [3].

BACKGROUND

Heyer [10] reported temperature histories for wall and roof systems for six houses and one office building. The houses were located in Tucson, Arizona; Athens, Georgia; Portland, Oregon; Diboll, Texas; and Madison, Wisconsin. In any one year, maximum roof temperatures were found to reach as high as 75°C, but the cumulative duration of temperatures greater than 70°C did not exceed 21 h, and the cumulative duration of temperatures greater than 65°C did not exceed 64 h.

Roof temperatures attained by structures have been modeled. Ozkan [11] and Wilkes [12] reported on surface and various component temperatures in flat roof systems.

Computer models have been developed that predict the temperature and moisture content of plywood roof sheathing and other lumber roof members based on various constrution details, materials, ventilation factors, and solar gain (radiation load) for the roof [12,13,14,15].

Ten Wolde developed and later verified [16 and 15, respectively] a predictive roof temperature model. In the 1997 report, he described a predictive roof temperature model especially for sloped wood-based roof systems. This model shows that the temperature of the exterior surface of plywood roof sheathing is dominated by solar gain and the heat exchange between the surface and ambient air. Diurnal (daily cyclic) temperature variation and hourly sheathing temperature histories are also influenced by the radiant energy absorptivity of the roofing surface, the roof pitch, and, to a lesser extent, the insulation and attic ventilation.

In 1992, a test facility was constructed at the Building Research Council of the University fo Illinois to measure heat transfer, moisture movement, and airflow in typical residential attic structures under natural conditions [17]. Data from this facility were used to verify the FPL model [15]. The FPL model has been used to predict roof temperature histories for plywood roof sheathing at a dozen locations across the United States. Those predictions were used to determine engineering design adjustments for FRT plywood roof sheathing in ASTM Standard D6305-98 [4].

METHODS

Exposure Structures

In the summer of 1991, five field exposure structures were constructed near Madison, Wisconsin (43° latitude). The Wisconsin exposure structures (WI structures) were constructed to face south in a shadeless area. The construction of the WI structures was descrived by Winandy and Beaumont [8].

In 1994, matched exposure structures were built at the Mississippi State University Forest Products Laboratory in Starkville, Mississippi (33.5° latitude). This research was part of an ongoing effort to relate temperatures in matched roof systems in northern United States and southern United States. The five exposure structures in Mississippi (MS structures) were constructed to face south in a shadeless area. The data from the MS structures provided a direct measure of a more severe (higher solar loading) location than that of Madison, Wisconsin [9].

All ten exposure structures were identical. They were 3.7 m wide by 4.9 m long and constructed to simulate part of a typical multifamily attic-roof system in which U.S. Model Building Codes sometimes allow FRT plywood roof sheathing. Each exposure structure was completely enclosed and unventilated. The four exterior walls were sheathed with 12-mm-thick Southern Pine siding attached to nominal 2- by 4-in. (standard 38- by 89-mm) wall studs. The exterior surfaces were coated with a latex solid-color (light gray, almost white) paint. The walls, floors, and roof system were not insulated. The study variables were exposure loation (Madison, Wisconsin, or Starkville, Mississippi), roof shingle color (black or white), and structure moisture content (heavily humidified or dry).

Recording of Temperatures

To assess the effect of shingle color, the exposure structures were roofed with black or white fiberglass shingles weighing 106 kg/square. The black and white shingles had reflectance values of 3.4% and 26.1%, respectively. Both color shingles had an emissivity rating of 0.91 as reported by their manufacturer.

Three of the five WI exposure structures were each instrumented with nine type-T thermocouples placed at varoius locations within the structure. These structures were (1) a black-shingled structure that was not ventilated or humidified, (2) a black-shingled structure that was unventilated and artifically humidified from April through October to mantain >85% relative humidity for most of the diurnal cycle, and (3) a white-shingled structure that was not ventilated or humidified. Indoor temperature was not controlled. Two MS structures were humidified using a cold steam atomizing humidifier system such that the relative humidity was maintained at >85% for most of the diurnal cycle. The interiors of the other three MS structures were kept dry.

Temperature data at each location (Wisconsin and Mississippi) was collected every 5 min, and an hourly average was recorded from each thermocouple location. Two Campbell-Scientific (Logan, UT) model CR10 data loggers and two model AM416, 32-channel multiplexers were used; one set (data logger plus multiplexer) was used in Wisconsin and the other in Mississippi. The data loggers had a reported accuracy of 0.2% more than the service temperature range of 55°C to 85°C. Both the Mississippi and the Wisconsin installations were nearly identical, and their mechanics were previously described in detail by Winandy and Beaumont [8].

RESULTS AND DISCUSSION

For the WI structures, we compiled the number of hours recorded for each thermocouple into 5°C temperature bins. These 5°C bins (0°C to <5°C, 5°C to <10°C, ..., 70°C to 75°C) are heaqre after defined as "exceedance temperatures." The value reported as the exceedance temperature for 70°C is thus the number of hours the temperature at that thermocouple location equalled or exceeded 70°C but was less than 75°C. The exceedance temperature data were averaged across their 8- or 4-year history to produce an annualized roof temperature history for each configuration.

Maximum Temperatures

For the Mississippi exposure site, maximum "1-hour average" temperatures recorded for black-shingled roofs in dry structures were 78°C and 63°C for the top and bottom plies of the plywood roof sheathing, respectively, and 58°C for the rafter. The maximum temperatures recorded for the matched WI structures were 75°C, 59°C, and 54°C, respectively. The MS and WI black-shingled structured showed only small differences (3°C to 4°C) in maximum record temperatures.

Annual Temperature Trends

The average 8- or 4-year temperature histories for each thermocouple in each exposure structure were discussed by Winandy and others [9] and are replotted for the roof sheathing and rafters Mississippi and Wisconsin structures in Figures 3 and 4. The relative form of the exceedance temperature distributions was generally similar between each exposure site, roof color, and attic humidity configuration. As expected, the MS structures experienced many more hours of exposure to high air temperatures than did the WI structures. However, although air temperatures were often warmer in Mississippi than in Wisconsin, the differences in annual maximum temperatures of the top and bottom of the plywood roof sheathing were very similar. Winandy and others [9] observed that the higher portions of the roof sheathing temperature histories were clearly controlled by solar radiation and not the outside air temperature (Fig. 3), which reaffirms the earlier observations of

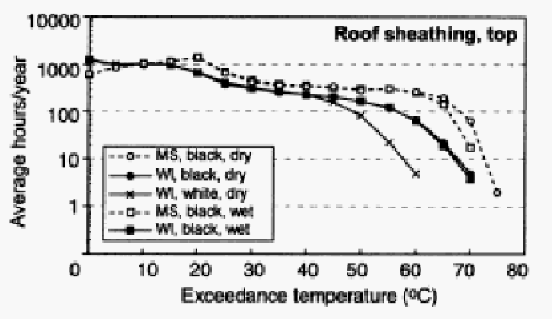

Figure 3. Average annual roof sheathing temperature histories in black- and white-shingled structures in Wisconsin and black-shingled humidified structures in Mississippi. In both Wisconsin and Mississippi, one black-shingled structure was unhumidified (dry) and another was heavily humidified (wet) [9, Figure 9].

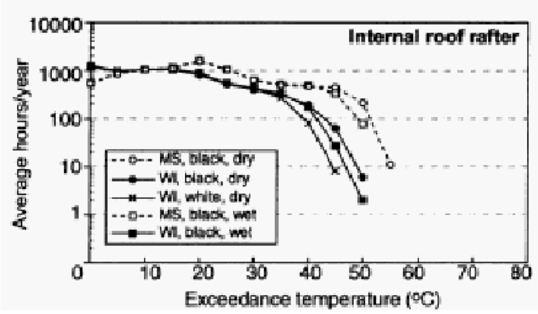

Figure 4. Average annual roof rafter temperature histories in black- and white-shingled structures in Wisconsin and black-shingled humidified structures in Mississippi. In both Wisconsin and Mississippi, one black-shingled structure was unhumidified (dry) and another was heavily humidified (wet) [9, Figure 11].

Winandy and Beaumont [8] and the predictions of the Ten Wolde [15] model. They also found that internal rafter temperature was mearly coincident with inside attic air temperature and both attic air and rafter temperatures appeared to be controlled by solar radiation and outside air temperature. Thus, although solar radiation may control sheathing temperature, attic air space or rafter temperature was also strongly influenced by outside air temperatures during most of the year.

Ongoing Research on Roof Temperatures

New wood–thermoplastic composite roofing materials (Figs. 5 and 6) are currently being evaluated to assess their UV durability and their influence on the solar-induced thermal loads they impart to

Figure 5. Experimental house at FPL roofed with wood–thermoplastic roofing shingles and currently under long-term field monitoring for durability, color stability, and UV weathering.

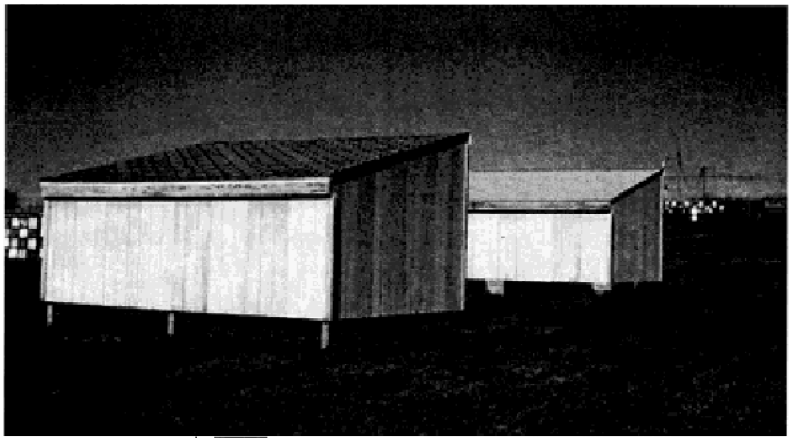

Figure 6. Wood–thermoplastic roofing (foreground) and matched white fiberglass shingle roofing (background) on test structures near Madison, Wisconsin. Black fiberglass shingles and wood shake roof material were also monitored for long-term temperature histories.

wood roof truss lumber plywood roof sheathing in traditional North American light-framed constructions. Such a roof system was recently developed and installed on a demonstration structure (Fig. 5) [18]. The system can use wood fiber and thermoplastics from virgin and recycled sources. Preliminary results indicate it may be a viable roof-cladding product.

SUMMARY

The results of this research study are summarized as follows:

- The annual 1-h maximum temperatures of various wood components were similar in Mississippi and Wisconsin roof systems; these temperatures were only 3°C to 4°C higher in the MS structures.
- Although the annual maximum and the form of the recorsded exceedance temperatures were similar in the MS and WI exposure structures, the MS structures experienced higher temperatures for many more hours per year compared with matched WI structures. Temperatures of wood components in the MS structures were generally 5°C to 10°C warmer than those of matched WI structures.
- Black-shingled roof systems tended to be 5° to 10°C warmer on sunny afternoons than did white-shingled systems.
- Temperatures at the top of the roof sheathing were controlled by solar gain, not outside air or attic air temperatures.
- Temperatures at the bottom of the roof sheathing were usually congtrolled by solar gain, except on a few of the hotetest days, when sheathing temperatures were also influenced by outside air or attic air temperatures.
- Rafter temperatures were usually controlled by attic air temperatures, except on a few of the hottest days, when they were also influenced by solar radiation.
- The major difference in the temperature of wood components used in attics in the northern exposure (Wisconsin) compared with those used in the southern exposure (Mississippi) was in minimum temperatures, which were as much as 20°C lower in the WI structures.
- New wood-thermoplastic composite roofing materials are currently being evaluated to assess their UV durability and the solar-induced thermal loads they imparted to wood roof truss lumber plywood roof sheathing in traditional North American light-framed constructions.

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