Effect of Elevated Temperature Exposures on Shear Properties of Sheathing Panels

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Abstract

Structural wall sheathing such as oriented strand board (OSB) and plywood have been heavily used in residential and commercial timber frame construction. The response of these wood-based composites under elevated temperatures between 100°C and 200°C (herein referred to as elevated temperatures) and exposure time needs to be characterized to assess residual strength of the materials in the existing structures. The main objective of this work is to study the effect of temperature and exposure time on shear strength and shear modulus of plywood and OSB. A total of 110 test specimens was tested in shear after exposure to five different temperatures and two exposure durations, followed by cooling to ambient temperature. The results indicated that the plywood and OSB behaved differently after exposure to elevated temperatures and exposure duration. Plywood showed a consistent degradation of shear strength with elevated temperature and time, while OSB did not exhibit a clear picture of thermal degradation. The results further indicated that the shear modulus of plywood and OSB remained unaffected after exposure to elevated temperatures.

In the United States, a vast majority of residential dwellings are light-frame wood construction, which has performed well historically. In a light-frame structure, the framing consists of dimension lumber, while a plywood or oriented strand board (OSB) is used as sheathing. The sheathing is fastened to the framing using dowel-type fasteners to close the building envelope and resist out-of-plane wind loads. Moreover, sheathing also provides stability to the framing under gravity loads, and for shear walls provides ample shear capacity during events that produce high lateral load demands.

Plywood had been a sheathing material of choice for several decades until OSB was invented and subsequently became the dominant sheathing material. In 2014, 86 percent of structural wall sheathing in single-family homes was comprised of wood structural panels, where OSB and plywood accounted for 73 and 13 percent, respectively (APA 2011). Both plywood and OSB have been well studied and characterized for all the material properties (US Department of Agriculture 2010). Moreover, voluntary product standards exist, such as the US Product Standard 2 (PS2), which provides guidelines for manufacturing and benchmark properties for these panel products.

Some walls in a light-frame construction are designed as shear walls. A shear wall performance is governed by four factors, namely, stiffness of the framing, slip in the dowel-type fasteners that connect the sheathing, shear characteristic of the sheathing, and wall anchorage slip (American Wood Council 2018). Thus, the shear characteristic of the panels plays an important role in the performance of the wall system.

Due to increased use of OSB and plywood in building applications, it is imperative to characterize their properties and performance in all expected loading demands, including elevated temperature (Grundahl 1992, White and Winandy 2006). Postfire concerns include whether the structure has enough residual capacity to withstand the stresses in service during the course of its lifetime and, subsequently, designing a rehabilitation plan for the structure. For both survival time predictions and establishing the residual

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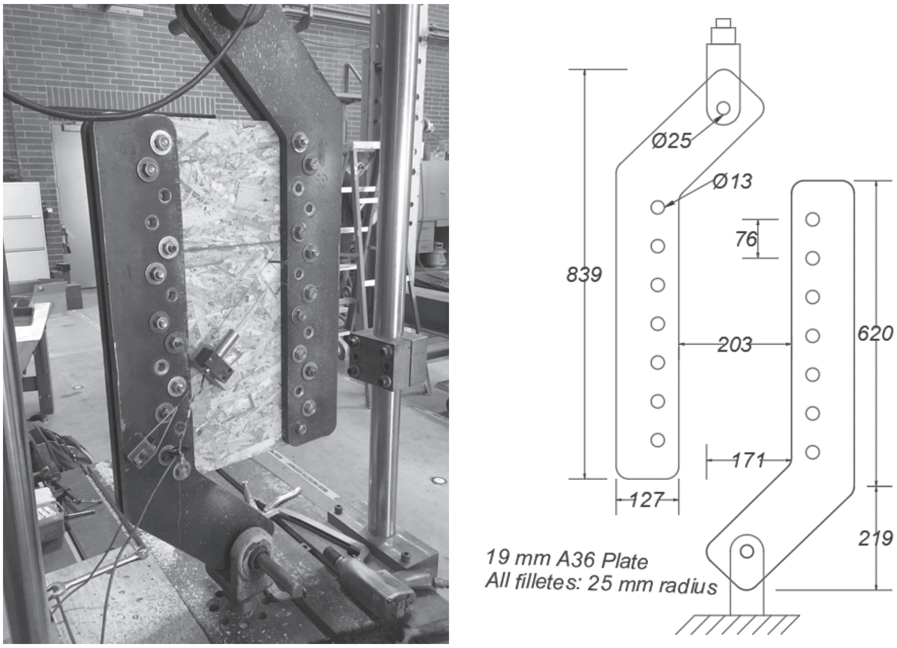


(a) (b)

Figure 1.—Test specimen: (a) specimen in modified ASTM D2719 shear test apparatus and (b) dimensioned schematic of test apparatus. All dimensions are in millimeters.

capacity of the structure, data on elevated temperature performance are needed for all components and materials of the building system. Essentially, this is the crux of this work.

Survival time models involving wood and wooden structures are lacking due to a lack in understanding of the effect of elevated temperature on several structural properties of common wood-based composite materials. One such property is shear. Several studies and concurrent projects have looked into flexural properties of wood (White and Tran 1992; Bukowski and Babrauskas 1994; Young and Clancy 2001a, 2001b; Bekhta and Niemz 2003; Branca and Blasi 2003; Stamm 2005; Zhong et al. 2015), OSB, and plywood (Winandy et al. 1991, Wang and Rao 1999, Paul et al. 2006, Sinha et al. 2011a, Sinha and Akgul 2016). However, no studies exist that quantify the loss of shear stiffness and strength of these panels after exposure to elevated temperature. Therefore, the objective of this study was to characterize the change in shear properties of structural sheathing as a function of elevated temperature and respective exposure times.

Materials and Methods

Commercial OSB and plywood were procured from local vendors in sizes of 1,220 by 2,400 mm (4 by 8 feet). Both OSB and plywood were 15 mm thick with a span rating of 40/20. OSB was manufactured using mixed hardwood strands using a polymeric diphenyl methane diisocyanate resin, while plywood was comprised of five Douglas-fir veneers glued together using a phenol-formaldehyde resin. The panels were cut to 406 by 610 mm, with the 406-mm dimension being parallel to the strong axis of the panels (Fig. 1a). Each panel yielded two 406 by 610-mm specimens. The specimens were then randomly divided into 10 groups of five for each material. Table 1 presents the test matrix.

Five exposure temperatures were selected, with two exposure times within each temperature (Table 1). Previous studies (Fuller 1990, Young and Clancy 2001, Frangi et al. 2010) have characterized the temperature distribution for unexposed and protected wall assemblies. These studies concluded that protected wall assemblies under fire often withstand temperatures greater than 100°C for 60 to 90 minutes. In some cases, the temperature may rise up to 200°C. Therefore, this characterized the temperature regime in 20°C increments above 100°C until it reached 200°C. Sinha et al. (2011b) further showed that degradation below 100°C is within the statistical scatter even for a robust experimental design; therefore, this study characterized exposure only above 100°C. The experimental program was not designed to characterize in-fire conditions, nor was it designed to characterize postcharring and postcombustion residual strengths. The test evaluated conditions in which protected assemblies are exposed to elevated temperature due to fires adjacent to them. The test specifically measures ambient temperature properties after exposure to elevated temperatures, hence characterizing residual irreversible degradation at room temperature. The experimental design did not attempt to characterize performance postcharring or postpyrolysis; rather, the efforts were directed to characterize performance after exposure to elevated temperatures between 100°C and 200°C. This approach is justified in previous studies, such as Sinha et al. (2011a) and Sinha and Akgul (2016). The degradation in mechanical properties of wood is governed by degradation of hemicelluloses. Hemicellulose and its acetyl group are hydrolyzed, forming acetic acid. The acetic acid is autocatalytic in nature and leads to formation of more acetic acid, leading to further degradation of hemicelluloses. The acetic acid also attacks

Table 1.—Text matrix.

	Time	Temperature (°C)					
Material	(min)	25	120	140	160	180	200
Oriented strand board	0	5[a]					
($N = 55$)	60		5	5	5	5	5
	120		5	5	5	5	5
Plywood ($N = 55$)	0	5[a]					
	60		5	5	5	5	5
	120		5	5	5	5	5

[a] Controlled specimens.

the glycosidic bonds and reduces the degree of polymerization of the glucose and hence, in turn, the strength of wood. Elevated temperature (140°C to 160°C) conditions start this degradation process, but this degradation can also occur at room temperature in the presence of chemicals and moisture, with an increase in temperature accelerating the entire process (Sinha 2010).

The average specific gravity of plywood was 0.48, while for OSB it was 0.57. The as-received average measured moisture content was 7.0 percent for plywood and 5.2 percent for OSB. All specimens were conditioned to equilibrium moisture content (EMC) prior to exposure to temperature. The EMC for OSB and plywood were 10.5 and 12 percent, respectively. After exposure to elevated temperature, the specimens were cooled to room temperature for 24 hours in a room permanently maintained at 20°C and 65 percent relative humidity (continually monitored) but were not re-equilibrated with moisture. As a result, the strength changes of this study may represent the combined effects of strength changes due to moisture change and due to the prior high-temperature exposure. This step was necessary to characterize only the irreversible degradation since, with cooling down, the reversible effects of elevated temperature exposure would be negated. The panels were first exposed to elevated temperature in a convection oven. The oven was preheated to the desired temperature, and then the samples were placed in the oven. After desired exposure, the samples were allowed to cool down for 24 hours before testing.

The panels were tested for in-plane shear using a modified version ASTM D2719 Method C in the strong axis perpendicular to the direction of applied load as recommended by ASTM D2719 (ASTM International 2013). The tests were conducted on an MTS 170 kN Hydraulic Actuator (model no. 244.23)–enabled universal testing machine. The size of the specimen was 610 mm in height by 406 mm in width. The ASTM D2719 Method C procedure requires bonding heavy lumber rails to the long edges of the shear specimen with adhesive. Steel brackets were bolted to the specimen instead of the adhesive-attached lumber rails, as shown in Figure 1 (similar to the testing bracket used in Shrestha et al. 1995). The brackets are made from a 19-mm-thick steel plate with seven holes in each drilled for 12.7-mm-diameter bolts to clamp the brackets to the specimen. Holes were drilled through the specimen for the bolts to clamp the steel brackets together. The space between the brackets was 203 mm. The brackets were then pulled in tension by the crosshead at a displacement rate of 1.5 mm/min to create a shearing force on the specimen. Two linear variable differential transformers (LVDTs) were used to measure the deflection caused by shear strain and measured a distance of 200 mm across the sample's center point at 45° angles (Fig. 2). One LVDT was attached on each side of the panel, one for capturing the deflection in the compression angle and the other for the tension angle; then the average of the two was taken to calculate shear strain.

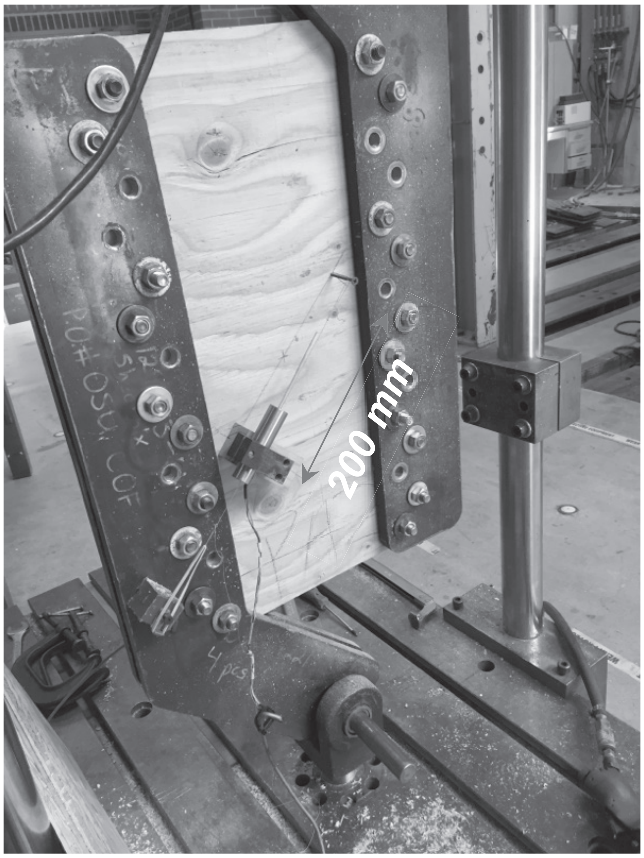


Figure 2.—Linear variable differential transformers installed on plywood.

Shear stiffness G_{xy} was calculated using the following equation:

$$G_{xy} = \left(\frac{P}{\Delta l}\right) \times \left(\frac{D}{L \times t \times 2}\right)$$

where ($P/\Delta l$) is the slope of the plotted load versus the deflection curve in the linear region, which was at a load between 18 and 27 kN; L is the length of the specimen; D is the gauge length (diagonal); and t is the thickness of the specimen. Shear strength was found using the following equation:

$$\tau_{xy} = \left(\frac{P_{\max}}{L \times t}\right)$$

where $P_{\max}$ is the measured peak load during the shear test.

Results and Discussion

The shear tests were carried out on plywood and OSB to study the effect of elevated temperatures and their extended period of exposures. The test results for each exposure were compared across five different elevated temperatures. A

Table 2.—Shear stress (MPa) of oriented strand board and plywood.[a]

Time (min)	0	60					120				
Temperature (°C)	25	120	140	160	180	200	120	140	160	180	200
Oriented strand board	4.84	7.51	7.61	6.93	6.39	7.12	7.29	7.36	5.79	6.96	7.71
	6.90	7.01	5.93	5.28	7.20	7.11	6.78	8.06	7.16	6.55	7.63
	5.86	6.67	6.60	6.50	5.72	7.70	7.64	7.66	6.12	6.80	5.23
	7.61	6.72	6.30	5.43	6.69	7.11	7.56	7.84	6.68	4.75	7.75
	6.72	6.53	6.96	6.59	6.81	7.45	7.76	6.89	6.43	5.24	6.94
Average	6.38	6.89	6.68	6.15	6.56	7.30	7.41	7.56*	6.44	6.06	7.05
Coefficient of Variation (%)	17	6	10	12	8	4	5	6	8	16	15
Plywood	3.74	2.56	3.22	3.08	2.56	3.09	3.37	2.63	2.97	2.55	2.25
	3.79	3.12	3.22	3.16	2.80	2.89	3.42	2.88	2.81	2.78	2.90
	3.59	3.23	3.63	2.90	3.06	3.14	3.01	2.81	2.18	2.71	2.90
	3.48	3.25	3.68	3.20	3.23	2.89	2.41	3.00	3.07	3.56	2.67
	3.37	2.95	3.23	3.11	2.85	2.94	3.41	2.92	3.11	3.48	2.57
Average	3.59	3.02*	3.40	3.09*	2.90*	2.99*	3.12*	2.85*	2.83*	3.01*	2.66*
Coefficient of Variation (%)	9	9	7	4	9	4	14	5	13	16	10

[a] Asterisks denote that the value is significantly different from the control.

summary of test results for shear stress and shear modulus are presented in Tables 2 and 3, respectively.

As is evident from Table 3, there is no observable degradation pattern of shear modulus with an increase in temperature and time of exposure. This observation is consistent with Mitsuhashi-Gonzalez (2010) and Sinha et al. (2011a), where the authors observed that modulus is the least affected property when exposed to elevated temperatures.

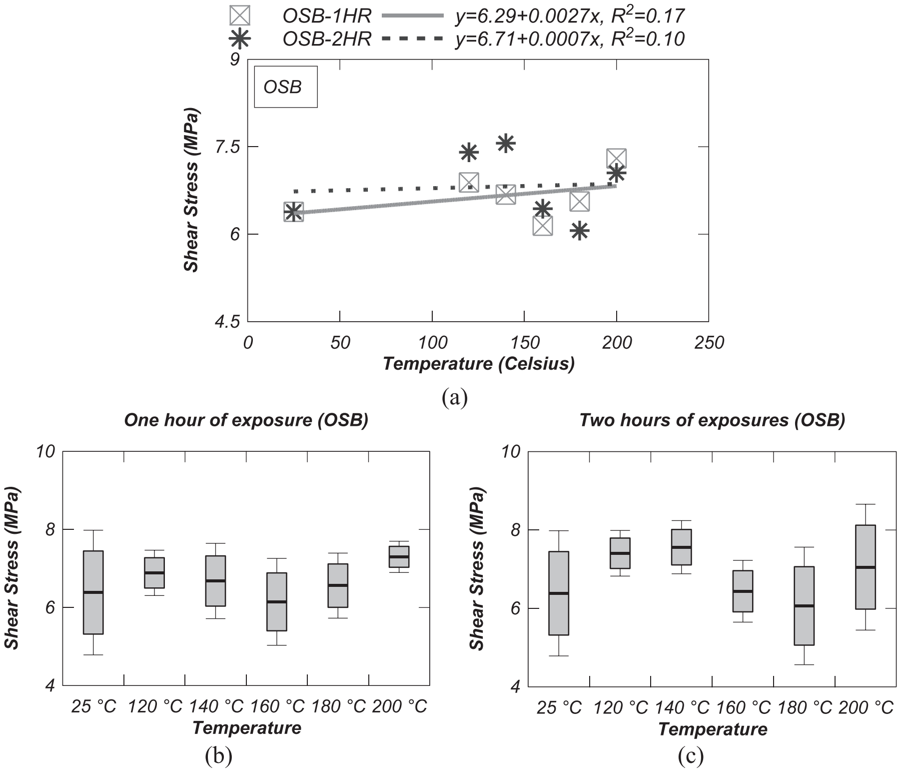
Changes in maximum shear stress for both OSB and plywood are reported in Table 2. OSB and plywood behaved very differently when exposed to elevated temperatures. The shear stress capacity of OSB appeared to increase after exposure to elevated temperature (Fig. 3a). However, low correlation values indicate that the results are not conclusive, and the average maximum shear stresses before and after exposure to elevated temperatures are within the experimental scatter. Although statistical conclusions cannot be drawn, the data provide valuable qualitative insights for OSB. On further inspection of the OSB control specimen, it seems that one of the panels performed poorly. An explanation for this trend is possibly the variability in the composite. Moreover, OSB manufacturing relies on a heated press, which is needed for the resin to cure. The increase in shear strength of the exposed sample might be due to additional curing of the resin with exposure to heat, therefore increasing the shear transfer capacity across the interphase. From Figures 3b and 3c, it is observed that the variability for the measurement of shear stress increased with the exposure durations. Furthermore, the skewness of the data suggests a nonnormal distribution of shear stress at 1 hour of exposure. In contrast, the shear stress data for the 2 hours of exposure showed a symmetric distribution, confirming the normal distribution of shear stress for the given elevated temperatures.

The maximum shear stress data for the plywood are summarized in Table 2. Unlike OSB, plywood showed a clear trend of degradation of shear capacity after exposure to elevated temperature (Fig. 4a). The higher values of R^2 for each trend line suggested that there was a strong correlation between strength degradation and exposure duration. Both exposures showed the symmetric spread of data, suggesting a normal distribution of shear stress at each elevated temperature (Figs. 4b and 4c). As expected, the higher exposure showed a higher variability of the shear stress.

Mean shear stress after exposure to an elevated temperature for plywood was significantly different from the control values ($\alpha = 0.05$) as indicated by the P values

Table 3.—Shear modulus (MPa) of oriented strand board and plywood.

Time (min)	0	60					120				
Temperature (°C)	25	120	140	160	180	200	120	140	160	180	200
Oriented strand board	1,800	1,552	1,336	1,580	1,756	1,935	3,871	1,935	1,498	1,191	1,352
	1,403	1,661	1,838	1,610	1,500	1,935	1,072	1,105	1,935	1,265	1,725
	1,244	1,176	1,426	1,935	1,656	1,186	1,438	1,935	1,517	1,438	1,336
	1,935	1,083	1,935	1,068	1,318	1,601	1,401	804	1,115	889	1,298
	1,434	1,362	1,616	1,189	1,922	1,746	1,935	626	1,261	940	1,384
Average	1,563	1,367	1,631	1,477	1,630	1,681	1,943	1,281	1,465	1,145	1,419
Coefficient of Variation (%)	19	18	16	24	14	18	58	48	21	20	12
Plywood	691	453	741	598	603	794	780	617	588	797	587
	532	505	798	469	776	812	672	752	573	597	813
	812	522	631	749	1,551	618	635	815	1,008	1,140	662
	746	492	662	878	816	692	439	660	505	651	1,105
	534	485	508	713	938	728	534	665	432	669	650
Average	663	491	668	681	937	729	612	702	621	771	764
Coefficient of Variation (%)	19	5	17	23	39	11	21	11	36	28	27

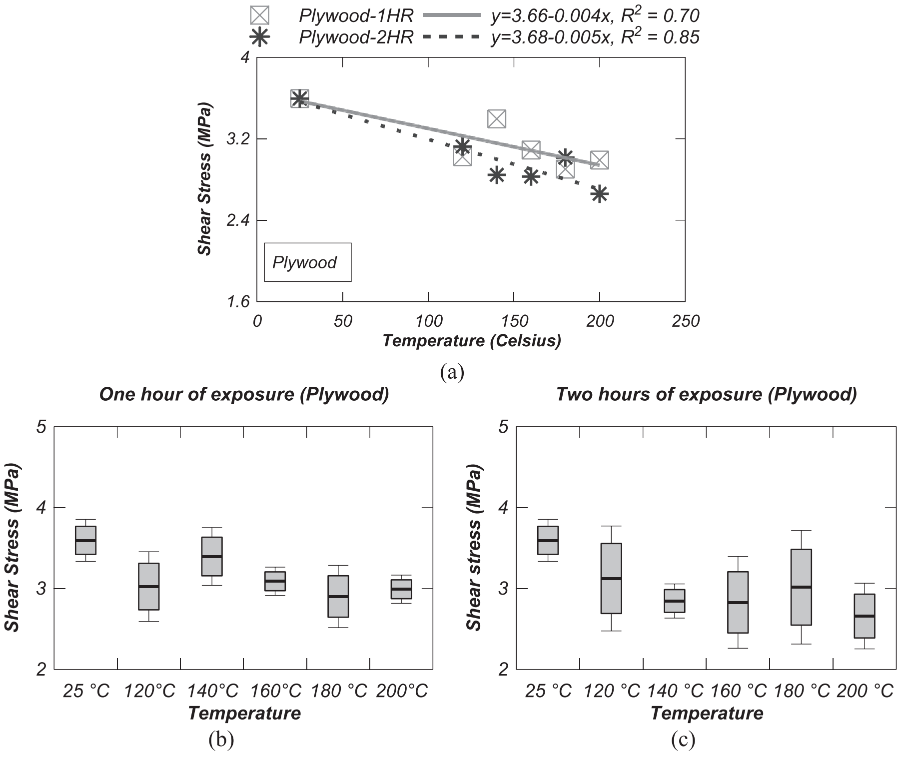


(a)

(b)

(c)

Figure 3.—Thermal effect on shear stress of oriented strand board (OSB): (a) scatter plot with fitted lines, (b) median-based box-and-whisker plot after 1 hour of exposure, and (c) median-based box-and-whisker plot after 2 hours of exposure.

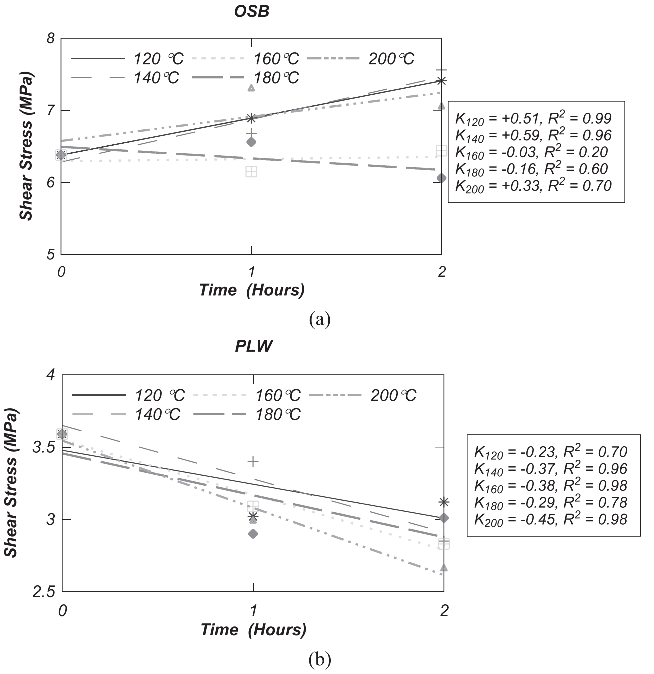


(a)

(b)

(c)

Figure 4.—Thermal effect on shear stress of plywood: (a) scatter plot with fitted lines, (b) mean-based box-and-whisker plot after 1 hour of exposure, and (c) mean-based box-and-whisker plot after 2 hours of exposure.



(a)

(b)

Figure 5.—(a) Shear stress of oriented strand board (OSB) over time, (b) shear stress of plywood (PLW) over time, and (c) plot of the slope of shear stress degradation (K) against temperature.

less than 0.05 in a two-sample *t* test. This indicates that plywood had a pronounced effect on maximum shear stress capacity even after exposure to a lower range of elevated temperatures. On the other hand, OSB shear stress values were not statistically different from the control means observed ($\alpha = 0.05$). However, if the statistical power is lowered from $\alpha = 0.05$ to $\alpha = 0.10$, then OSB after 200°C exposure for 1 hour is significantly lower than that of the control specimen. Similarly, when comparing the degradation in shear stress capacity with time after exposure to the same elevated temperature, it was observed that OSB and plywood behaved differently.

The rates of degradation for OSB and plywood are shown in Figures 5a and 5b, respectively. For all exposure temperatures, the shear stress capacity after 1 hour of exposure and after 2 hours of exposure was significantly lower than that of the control specimen for plywood. On the other hand, no marked degradation with time was observed for OSB within one temperature exposure. The rate of degradation for plywood was fairly consistent across all temperature studies. These observations are consistent with Sinha et al. (2011b), where OSB had a lower initial bending strength than plywood but plywood had a severe degradation profile as a function of time and exposure temperature. The inherent difference in material structure between OSB and plywood is perhaps the cause of this difference in performance. Plywood, unlike OSB, relies on few adhesive layers to transfer the stress from one ply to another, and hence degradation in either the wood, the adhesive system, or the interface after exposure to elevated temperature causes marked degradation in the properties of plywood. That is the reason for OSB being more resilient to elevated temperature exposures. OSB has a higher redundancy for stress transfer across the surface as well as through the thickness. If the materials had been exposed for a longer period at elevated temperatures, a significant difference in shear stress capacity of OSB could have been observed, as was observed in Sinha et al. (2011b), where exposure time was a maximum of 8 hours.

Conclusions

The thermal effect on the shear strength of plywood and OSB was investigated by performing shear tests under five different elevated temperatures (120°C, 140°C, 160°C, 180°C, and 200°C) and two different periods of exposures (after 1 and 2 hours). A total of 110 specimens was tested to understand the thermal performance of plywood and OSB. From the test results, the following conclusions can be drawn:

1. When exposed to elevated temperatures, the plywood is more susceptible to strength degradation in shear than that of the OSB. The plywood showed a consistent decrease in shear strength with respect to exposure temperature and time. Unlike the plywood, the OSB did not show a manifest train of strength degradation.
2. The shear modulus of plywood and OSB appeared to be less sensitive to exposure time and duration, which is consistent with findings from previous studies.
3. Both plywood and OSB showed higher variability in their shear stress when they were exposed to a higher extended period of exposure.
4. Although the test results appeared to be insufficient to provide a complete picture of thermal degradation on OSB when exposed to elevated temperatures for 2 hours, a strength degradation of OSB can be expected in the higher extended period of exposure, as reported in previous studies.

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