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Effect of Wet-Dry Cycles on Compressive Strength and Impact Properties of New Softwood Pallets

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Abstract Wood pallets are often put in circulation for several years. In a pallet's lifetime it goes through several wet-dry cycles. In this study, softwood pallet specimens were compressed statically and impacted at different water contents through an accelerated drying process for three repeated wet-dry cycles. A static compressive strength test was performed along the grain of pallet stringers to avoid the effect of loadings in different grain directions. Instead of using the standard drop test from a drop tester, an incline impact test was performed to obtain more consistent impact accelerations. Impact data was recorded by a shock recorder to simplify the set up for the experiment. This study has found that there is no significant effect of the wet-dry cycles on static compressive strength and impact acceleration.
Keywords *Mechanical Properties; Softwood Wooden Pallets; Wet-dry Cycles; Static Compressive Strength; Impact Accelerations*

1. Introduction

Most products found in retail stores, warehouses, and distribution centers were at some point on a pallet [1]. The Healthcare Packaging Consortium at Christian Brothers University has been conducting wooden pallet research since 2012. Fungi, and to a lesser extent bacteria, cause decay in wood as a result of wet conditions [2]. Thus, moisture or water content in wooden pallets has been a focus of several parts of CBU's consortium pallet research [1, 3, 4].

Wooden pallets are often left outdoors and exposed to rain water. The wet-dry process repeats several cycles during a pallet's lifetime. This research investigates if repeated wet-dry cycles have any effect on static compressive strength and impact acceleration. The static compression test simulates the application of load from packages on a pallet, while the impact test simulates effects from the impact on a pallet cause by a forklift.

There are several factors that can affect the research data. No two pieces of wood are identical. Even if they are taken from the same stringer of a pallet, which means they are from the same tree; their properties vary. The direction of load with respect to grain direction also makes a difference. Thus, wood is a heterogeneous (location dependency) and anisotropic (direction dependency) material. Moisture in wood specimens is not evenly distributed naturally or artificially. Wood specimens are found to be with less moisture on the exterior surface due to the drying process. Data collection on wood research can be time consuming. A static compression test is destructive by nature, i.e., the specimen cannot be reused after being crushed. This adds more inconsistency into the data.

2. Static Compression Test

Initially, wood samples taken from pallet stringers were compressed in direction “A” shown in Figure 1, to simulate the real orientation of pallets under loading. However, grain patterns on a stringer’s cross section vary significantly as also shown in Figure 1. This anisotropic property affects the results significantly. Figure 2 shows different failures in various specimens due to different grain patterns. In addition, the distance between annual rings and knots contribute to wood mechanical properties. Thus, the loading direction was changed to direction “B” where the load is parallel to the grain. Figure 3 shows specimens placed in a compression tester in directions “A” and “B” accordingly. The standard deviation as percentage of average maximum compressive stress improved from 16% in direction “A” to 13% in direction “B,” which represents about 19% improvement.

The maximum compressive stress (σ_{max} in psi) or compressive stress at failure can be calculated from:

$$\sigma_{max} = \frac{P_{max}}{A}$$

Where, P_{max} is the maximum applied load or load at failure (lbs) and A is the loading area (in^2).

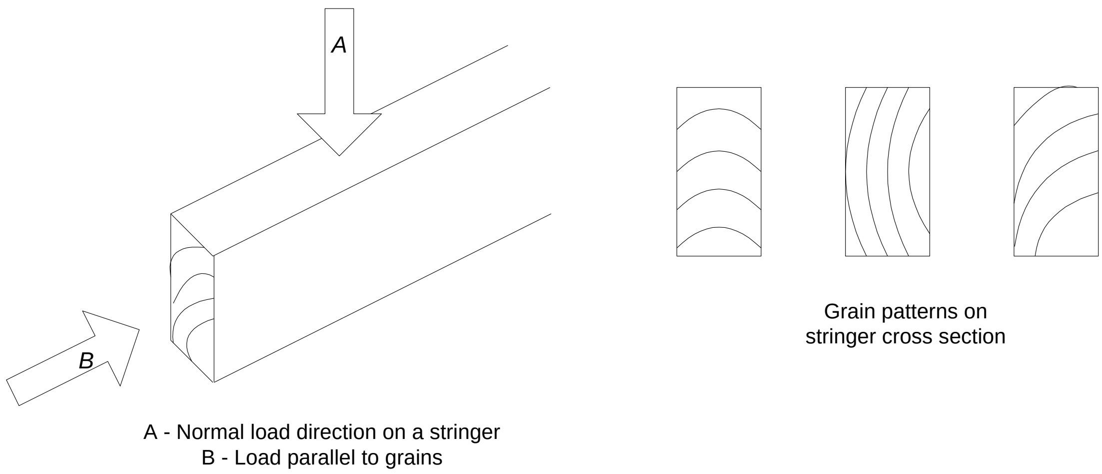

Figure 1: *Loading Orientations for Static Compression Test*

Figure 2: *Failures of Specimens with Different Grain Orientations*

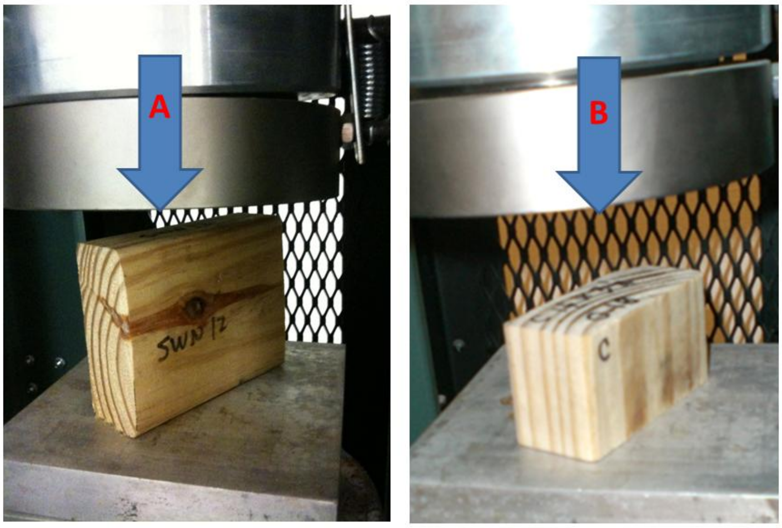

Figure 3: *Loading Directions "A" and "B"*

For this test several specimens were first dried completely to obtain dry weights. Then they were soaked in water over a weekend to start the first wet-dry cycle. All specimens were dried in room environment, which was about 70$^\circ F$ and 50% RH. Each day from Monday to Friday, a specimen was weighed to determine its wet weight and then compressed to failure. The remaining specimens were soaked again over the weekend to start the second cycle. This process was repeated for the third cycle. Data and results are summarized in Table 1.

Table 1: *Static Compression Test*

Cycle	Specimen No	Area (in^2)	Dry Weight (lb)	Test Date	Test Time	Wet Weight (lb)	Water (lb)	Water Content (%)	P_{max} (lb)	σ_{max} (psi)
1	1	4.58	0.18	M 4/8/13	1:42 PM	0.32	0.14	**77.78**	18450	**4030**
	2	4.41	0.18	T 4/9/13	4:12 PM	0.30	0.12	**66.67**	18900	**4289**
	3	4.88	0.18	W 4/10/13	2:15 PM	0.28	0.10	**55.56**	19110	**3920**
	4	5.06	0.18	R 4/11/13	3:58 PM	0.24	0.06	**33.33**	19230	**3799**
	5	3.25	0.12	F 4/12/13	1:13 PM	0.16	0.04	**33.33**	17690	**5443**
2	6	3.66	0.14	M 4/15/13	1:32 PM	0.22	0.08	**57.14**	15210	**4160**
	7	4.41	0.18	T 4/16/13	3:10 PM	0.30	0.12	**66.67**	21220	**4816**
	8	4.81	0.18	W 4/17/13	1:45 PM	0.26	0.08	**44.44**	20540	**4268**
	9	4.41	0.18	R 4/18/13	1:48 PM	0.22	0.04	**22.22**	23380	**5306**
	10	3.19	0.12	F 4/19/13	4:40 PM	0.16	0.04	**33.33**	16460	**5164**
3	11	4.81	0.18	M 4/22/13	2:32 PM	0.30	0.12	**66.67**	18780	**3902**
	12	3.25	0.12	T 4/23/13	11:01 AM	0.18	0.06	**50.00**	14430	**4440**
	13	3.25	0.12	W 4/24/13	2:11 PM	0.16	0.04	**33.33**	14000	**4308**
	14	4.22	0.16	R 4/25/13	10:44 AM	0.22	0.06	**37.50**	21540	**5106**
	15	4.81	0.18	F 4/26/13	12:56 PM	0.24	0.06	**33.33**	18310	**3805**
									AVG =	4450
									SD =	570
									SD as % of AVG =	13

3. Impact Test

Instead of using a standard drop tester to drop a pallet specimen, an in-house custom-built incline impact tester (Figure 4) was used. A specimen cut from a pallet stringer was clamped into the lower left end of the tester. A short top board was attached to the specimen to simulate a real pallet. A metal bent was used to cover the end of the specimen to prevent damage from multiple impacts of the sliding part along the incline. The metal bent would not affect the results of this study since only relative values were needed. The actual impact force from a forklift would vary in the real world. Thus, an impact force on the specimen is arbitrary. A tri-axial shock recorder, mounted on the top board, was used to measure impact acceleration. Impacts from this incline test are more consistent than regular free-fall drops from a drop tester.

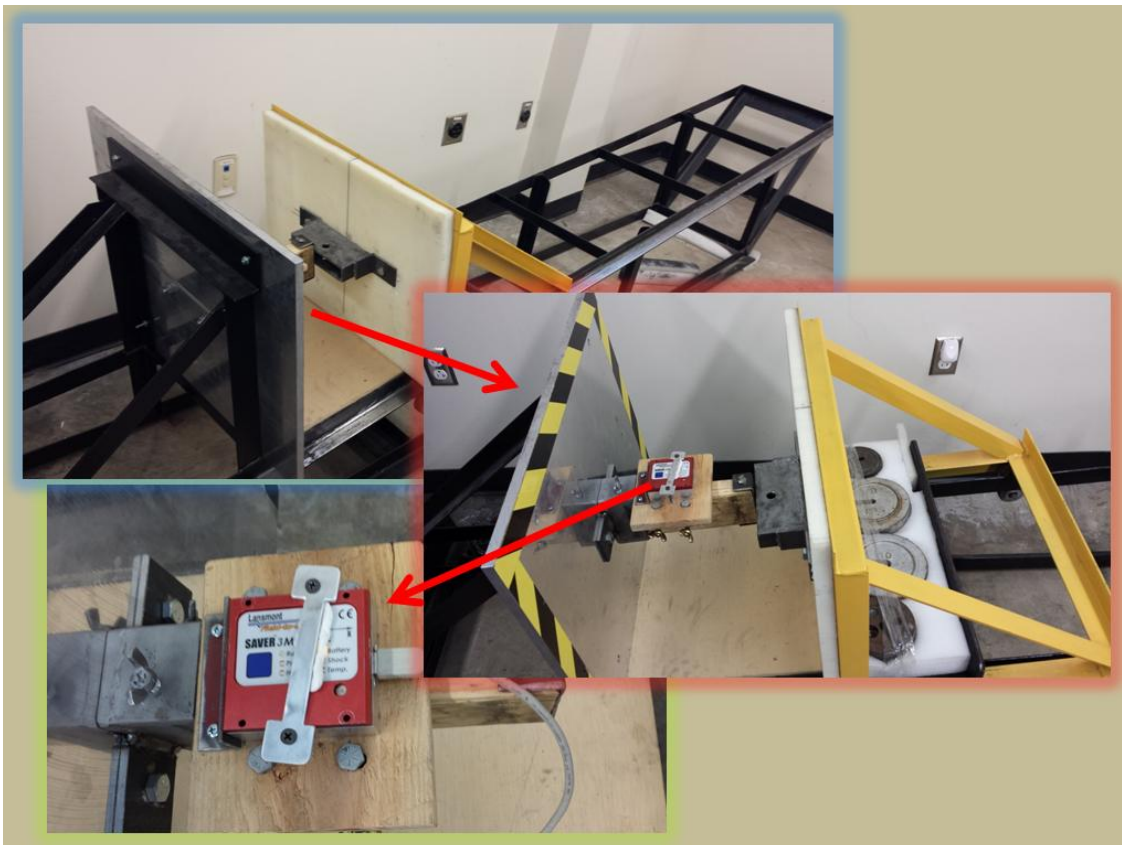

Figure 4: *Custom Incline Impact Tester*

The specimen was soaked in water over night. The specimen was then tested seven times in a day during the first cycle with an approximated one hour interval. During these intervals the specimen was placed in an oven to accelerate the drying process. Fifteen to twenty impacts were made per test and an average acceleration was used, as summarized in Table 2. The specimen was then dried in an oven. It was then soaked again over night and the process was repeat for the second cycle and then the third cycle.

Table 2: *Impact Test*

Cycle 1 (Monday, August 5, 2013)		Cycle 2 (Wednesday, August 7, 2013)		Cycle 3 (Friday, August 9, 2013)	
Water Content (%)	Average* Impact Acceleration (g)	Water Content (%)	Average* Impact Acceleration (g)	Water Content (%)	Average* Impact Acceleration (g)
29.17	12.74	27.78**	46.26**	26.39	13.01
26.39	14.07	26.39**	34.52**	15.28	13.20
22.22	13.63	20.83	13.92	12.50	12.56
19.44	11.92	13.89	13.63	9.72	13.84
16.67	12.74	12.50	14.36	8.33	14.70
15.28	13.93	11.11	12.51		
12.50	13.31				

* *15 – 20 average*

** *Ignored, out of norm, due to the loosen plate on the incline.*

4. Results, Discussion and Conclusion

Results from the static compression test were plotted in Figure 5. The following observations can be made:

- As water content increases, the static compressive stress decreases. This trend is consistent with the previous study [1].
- Data from this study is more consistent than data from the previous study [1] since loading direction along grains was used as mentioned earlier.
- There is no significant difference among the three wet-dry cycles.

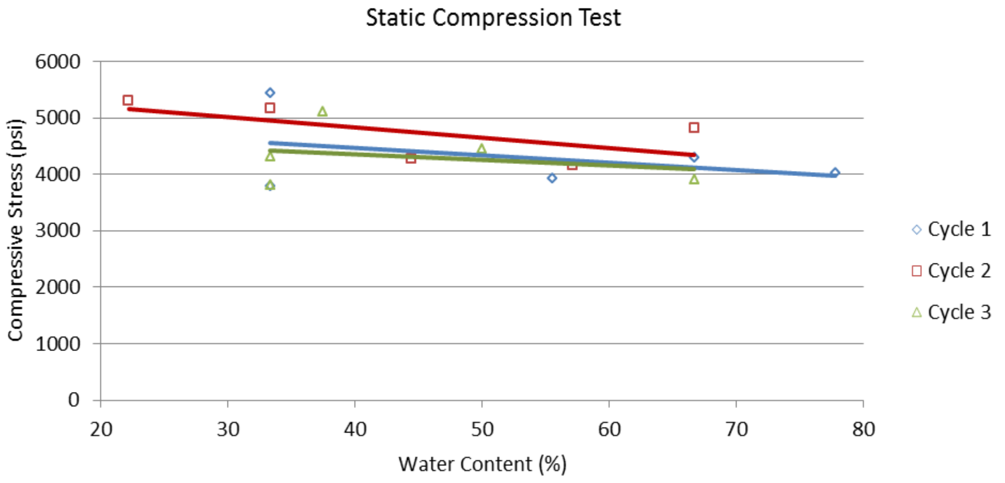

Figure 5: *Static Compression Test Results*

Results from impact test were plotted in Figure 6. The following observations can be made:

- As water content increases, the impact acceleration increases in two out of three cycles. This is consistent with the previous study [1]. However, the trend in Cycle 3 shows an opposite effect. The slopes of the three cycles are so small that a slight error could change a slope from positive to negative.
- Data from this study is more consistent than data from the previous study [1] due to the fixture used with the incline impact tester.
- There is no significant difference among the three wet-dry cycles.

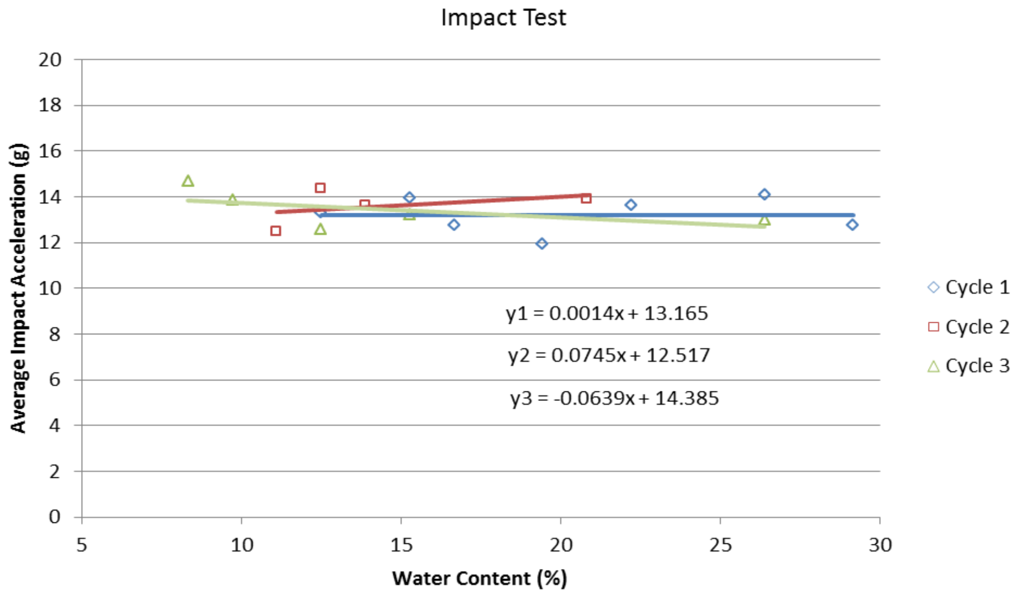

Figure 6: *Impact Test Results*

Both tests indicate that wet-dry cycles do not affect the static and impact properties of softwood pallets. However, if a pallet is wet for a longer duration, decay and mold [4] could follow. Decay would then weaken the pallet.

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