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Effect of Water Content on Compressive Strength and Impact Properties of New Softwood Pallets

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Abstract The effect of water content on compressive strength and impact properties of new softwood pallets was determined through four experiments. A static compression test was performed on pallet specimens with various water contents. The compressive strength drop rate was 3.4 pounds per square inch (23442 Pascal) per 1% increase of water content. A drop test was performed on pallet specimens with various water contents and cushioning materials at 12-inch (0.3048-meter) drop height. Impact acceleration increased at the rate of 0.14g per 1% increase in water content. A drop test was also performed on pallet specimens with various water contents at 18-inch (0.4572-meter) drop height. Energy absorption reduced at the rate of 0.16% per 1% increase of water content. Thus, softwood pallets, which are often left outdoors and subjected to rain water, have two potential problems with the increase in water content, i.e., reduction in compressive strength under static loading and increase in impact acceleration felt by boxes on these pallets.
Keywords *Mechanical Properties; Distribution Packaging; Wooden Pallets*

1. Introduction

Most products found in retail stores, warehouses, and distribution centers were at some point on a pallet. At a given time there are nearly two billion pallets on the move across the United States and the majority is made from wood [1]. Thus, pallets are the backbone of the packaging industry. The Healthcare Packaging Consortium at Christian Brothers University launched a pallet study in early 2012. Finished work includes effect of high temperature on wooden pallets [2] and water absorption of wooden pallets [3].

Wooden pallets are often left outdoors for days. They are subjected to rain and sometimes accumulation of water on the ground. According to a timber design practice [4], when moisture content during service condition exceeds 19% for an extended period of time, the allowable compressive stress for sawn lumber under static loading needs to be adjusted by C_M or Wet Service Factor, which is less than 1. Thus, wooden pallets would become weaker under static loading when they contain more water. However, the effect of water content on impact properties of wooden pallets is not known. The impact shock felt by contents on these pallets, such as drop, could cause damages. The objectives of this study are twofold: (1) to verify that wooden pallets are weaker when they contain more water under static compression loading, and (2) to determine the effect of water content on impact properties of wooden pallets, specifically, impact acceleration and energy absorption.

2. Materials and Methods

Softwood pallets, made from Yellow Pine, were used throughout this study. Samples were taken from different stringers of different pallets to ensure the diversity of specimens. The following experiments were designed to fulfill the two objectives as shown in Table 1.

Table 1: *Experiments to Fulfill Study Objectives*

Study Objective	Experiment
Objective 1: To verify that wooden pallets are weaker when they contain more water under static loading	**Experiment 1:** Static compression test
Objective 2: To determine the effect of water content on impact properties of wooden pallets	**Experiment 2:** Drop test with a saver cushioned by layers of bubble wrap to determine impact acceleration
	Experiment 3: Drop test with a saver cushioned by a thick layer of foam to determine impact acceleration
	Experiment 4: Drop test with an accelerometer to determine the energy absorbed

Tap water was used to simulate rain water in all four experiments. Specimens were soaked overnight (approximately 18 hours) at the beginning of each experiment. They were then left in the lab so water could evaporate naturally. Specimens were tested on different days to vary the percentage of water content. Water content is determined by:

$$Water\ Content(\%) = \frac{(Wet\ Weight) - (Dry\ Weight)}{(Dry\ Weight)} \times 100$$

2.1. Experiment 1: Static Compression Test

Ten specimens were soaked in water overnight. They were compressed in a compression machine on different days. Thus, water contents varied. The last specimen was placed in oven to obtain 0%

water content and then compressed. Figure 1 shows specimens soaked in a shallow bath tub and a compression test, respectively. The data collected and computed on compressive strength of each specimen are shown in Table 2. Compressive strength of each specimen was calculated using

$$\sigma = \frac{P}{A}$$

Where σ = Compressive strength (psi)
P = Maximum compressive load (lbf)
A = Cross-sectional area (in^2)

Specimens soaked in water

Compression Test
Load applied slowly

Figure 1: *Static Compression Test*

Table 2: *Static Compression Test Data and Computed Compressive Strength*

Specimen	Water Content (%)	Area (in^2)	Maximum Load (lbf)	Compressive Strength (psi)
1	33.33	6.03	5010	831
2	25.00	6.20	6660	1074
3	23.81	6.06	5740	948
4	15.00	6.09	7150	1174
5	13.64	5.96	7000	1175
6	13.64	6.25	4642	739
7	9.52	6.08	5400	887
8	6.25	5.98	4380	733
9	6.67	6.00	4620	770
10	0.00	5.87	7900	1345

2.2. Experiment 2: Drop Test with a Saver Cushioned by Layers of Bubble Wrap to Determine Impact Acceleration

Two specimens were made from components taken from various softwood pallets in a configuration similar to an actual pallet, i.e., three stringers with top and bottom boards. They were soaked in water overnight. A saver (also known as transport recorder) was used to measure impact acceleration associated with each drop test. In order to prevent the saver from exceeding its 100g capacity, it was cushioned with layers of 5/16-inch bubble wrap sheets underneath. Specimens were dropped at 12-inch height at various water contents. Ten drops were made per water content setting and average impact acceleration was used for that setting. At the beginning of each setting, bubble wrap sheets were inspected for burst bubbles and replaced as needed. It was found that only a few bubbles burst during the test. Figure 2 shows specimens in a bath tub, saver setting, and drop test. Drop test data of the two specimens are summarized in Table 3.

2.3. Experiment 3: Drop Test with a Saver Cushioned by a Layer of Thick Foam to Determine Impact Acceleration

The same two specimens used in Experiment 2 above were used for the same procedure. However, the saver was cushioned by a thick foam layer to ensure uniformity and prevent slippage that could occur between bubble wrap layers. Figure 3 shows specimens in a bath tub, saver setting, and drop test. Drop test data of the two specimens are summarized in Table 4.

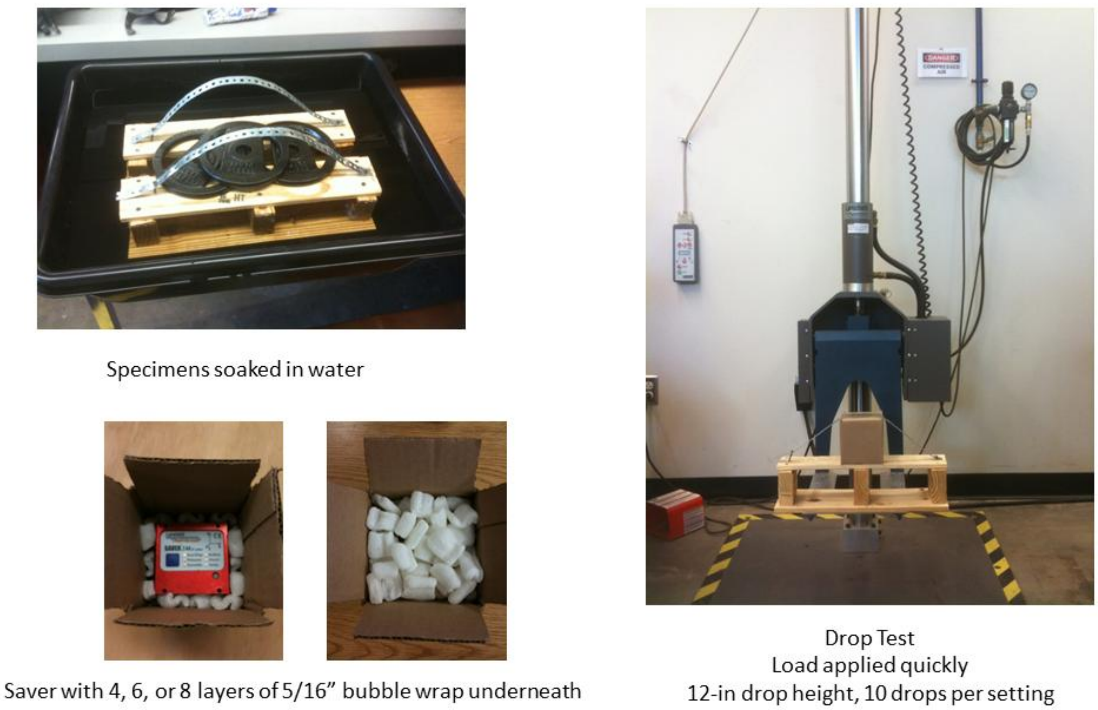

Figure 2: *Drop Test with Saver Cushioned by Bubble Wrap Layers*

2.4. Experiment 4: Drop Test with Accelerometer to Determine the Energy Absorbed

This experiment was designed to measure the effects of moisture level on elasticity of the model material. A single-axis accelerometer connected to a data acquisition system was mounted on the specimen, and then the specimen was dropped from 18-in height vertically. The data acquisition system shown in Figure 4 recorded the time during each drop test. The accelerometer’s response time between the first impact and the second impact resulting from the model re-bouncing off the floor and falling onto the floor again during the same test, Δt, was used to calculate the velocity immediately after the impact. The following equations were used to estimate the percent of energy absorption and the coefficient of restitution for each group of tests.

Table 3: *Drop Test Data for Specimens Using Saver with Bubble Wrap Cushion*

8 Bubble Wrap Layers		6 Bubble Wrap Layers		4 Bubble Wrap Layers	
Water Content (%)	Avg. Impact Acceleration (g)	Water Content (%)	Avg. Impact Acceleration (g)	Water Content (%)	Avg. Impact Acceleration (g)
		Specimen 1			
53.04	47.12	52.17	58.99	52.17	67.59
52.17	47.84	51.30	58.45	50.43	72.60
32.17	47.92	32.17	57.55	32.17	68.80
31.30	49.84	31.30	57.72	31.30	70.34
30.43	47.46	30.43	56.29	30.43	70.12
23.48	46.57	22.61	59.22	22.61	74.88
21.74	49.70	21.71	54.48	21.74	63.45
16.52	45.18	16.52	52.62	16.52	64.78
13.04	41.61	13.04	52.83	13.04	61.87
11.30	40.78	10.43	51.42	10.43	60.73
9.57	42.72	9.57	50.11	9.57	58.05
9.57	43.65	9.57	52.53	9.57	59.82
9.57	38.19	9.57	45.99	9.57	58.49
9.57	38.23	9.57	50.04	9.57	60.68
9.57	41.31	9.57	46.34	9.57	63.44
0.00	45.68	0.00	49.07	0.00	61.07
		Specimen 2			
50.39	41.85	49.61	49.65	49.61	60.47
48.84	46.85	48.06	48.81	48.06	64.31
32.56	41.62	32.56	52.03	32.56	61.91
31.78	46.44	31.78	49.41	31.78	63.15
31.01	40.20	31.01	54.79	31.01	69.22
23.26	45.67	23.26	57.02	23.26	68.97
22.48	43.92	22.48	52.50	22.48	54.89
17.83	43.86	17.83	49.46	17.83	61.90
13.95	38.73	13.95	51.42	13.95	63.20
11.63	38.89	11.63	49.00	11.63	61.59
11.63	40.06	10.85	49.80	10.85	55.52
10.85	43.25	11.63	50.68	11.63	59.29
10.08	37.96	10.08	43.22	10.08	55.91
10.08	37.92	10.08	46.51	10.08	57.25
10.08	40.33	10.08	45.71	10.08	59.64
0.00	45.75	0.00	49.26	0.00	61.08

Note: *Impact acceleration values are based on 10-drop averages*

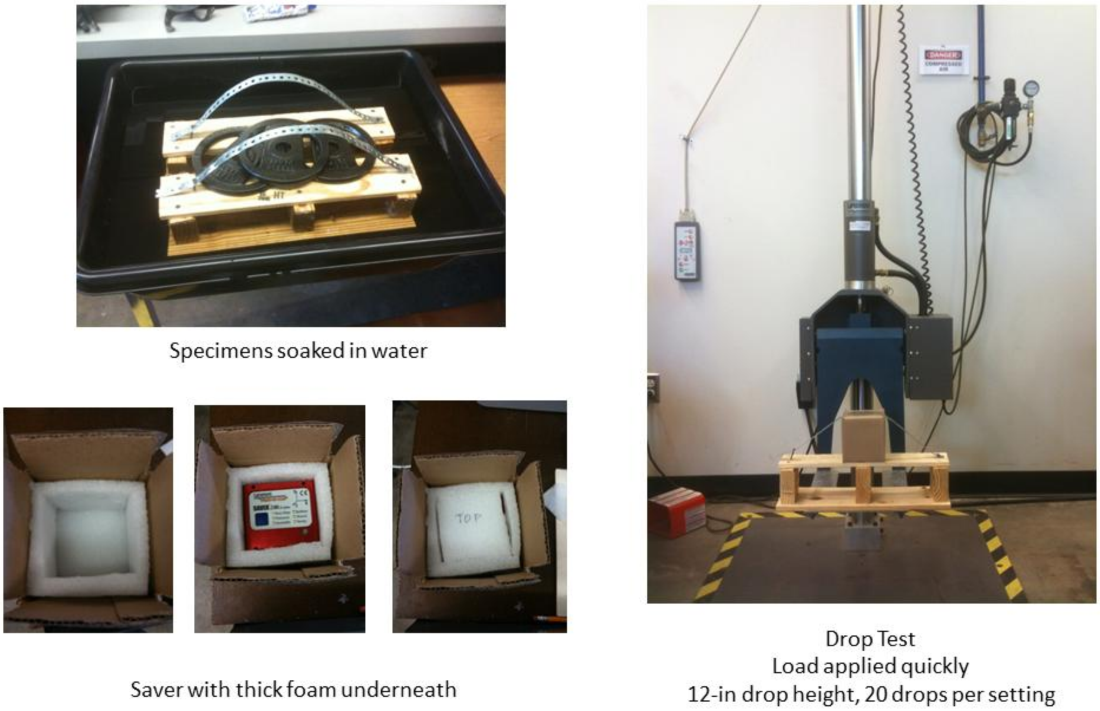

Figure 3: *Drop Test with Saver Cushioned by Thick Foam*

Table 4: *Drop Test Data for Specimens Using Saver with Thick Foam Cushion*

Specimen 1		Specimen 2	
Water Content (%)	**Average Impact Acceleration (g)**	**Water Content (%)**	**Average Impact Acceleration (g)**
0.00	82.01	0.00	84.09
48.70	89.78	45.74	90.35
26.96	89.51	27.91	84.69
13.04	86.31	13.95	86.42
11.30	85.91	12.40	83.91
11.30	86.96	10.08	84.37
9.57	88.69	7.75	86.79
5.22	86.67	5.43	86.25
6.96	85.68		

Note: *Impact acceleration values are based on 20-drop averages*

$$v_1 = \sqrt{2gh}$$

$$v_2 = \frac{g\Delta t}{2}$$

$$\%\ Energy\ absorbed\ during\ impact = \left(\frac{v_1^2 - v_2^2}{v_1^2}\right) * 100$$

$$e = \frac{v_2}{v_1}$$

Where:

v_1 = The velocity of the model right before impact

v_2 = The velocity of the model right after the impact

Δt = The time interval between the first and second impacts

g = The gravitational acceleration

h = The drop height

e = The coefficient of restitution

The data obtained from these tests are shown in Table 5.

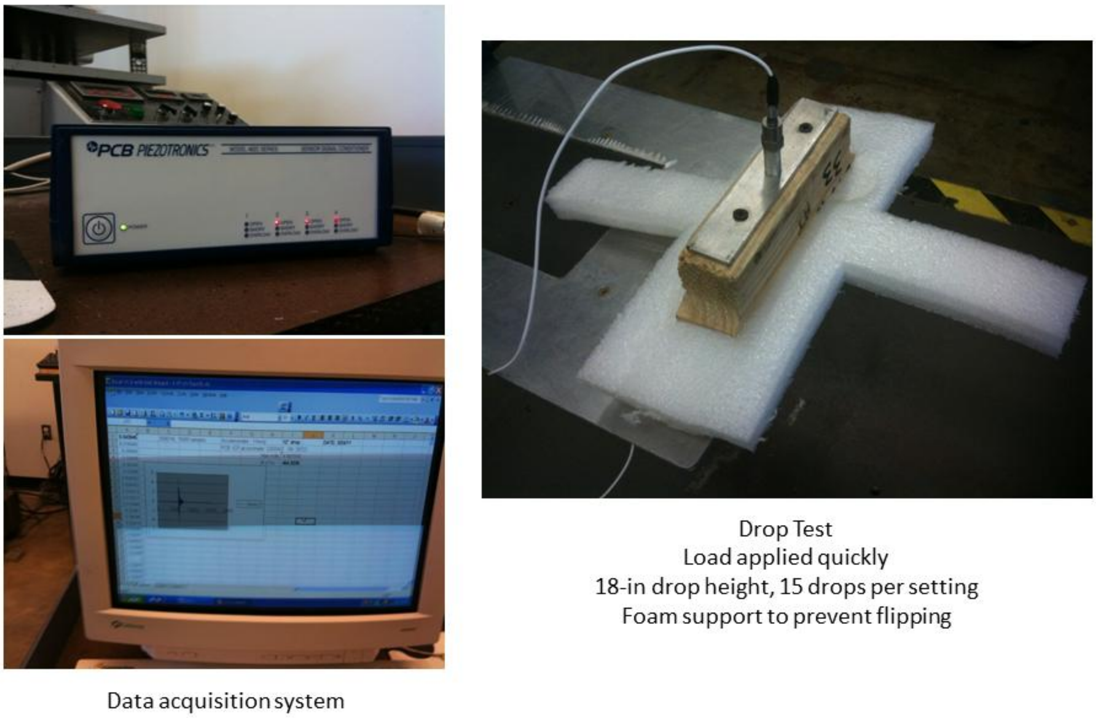

Figure 4: *Drop Test Using Accelerometer (right) and Data Acquisition System (left)*

Table 5: *Drop Test Data for Specimen Using Accelerometer*

Water Content (%)	Average Energy Absorbed (%)	Coefficient of Restitution	No. of Drops Used
0.00	90.90	0.30	8
3.33	84.34	0.40	5
16.67	82.91	0.41	8
16.67	82.94	0.41	6
30.00	81.53	0.43	8
50.00	80.60	0.44	9

3. Results and Discussion

Data from Experiment 1 as shown in Table 2 is plotted in Figure 5. The graph shows that wooden pallets become weaker with larger water content, which verifies current timber design practice [4]. Compressive strength of softwood pallets drops at the rate of 3.4 psi per 1% water content increase.

Within the study range from 0% to 35% water contents, the compressive strength drops at about 12%.

This could be more significant when the water contents are higher.

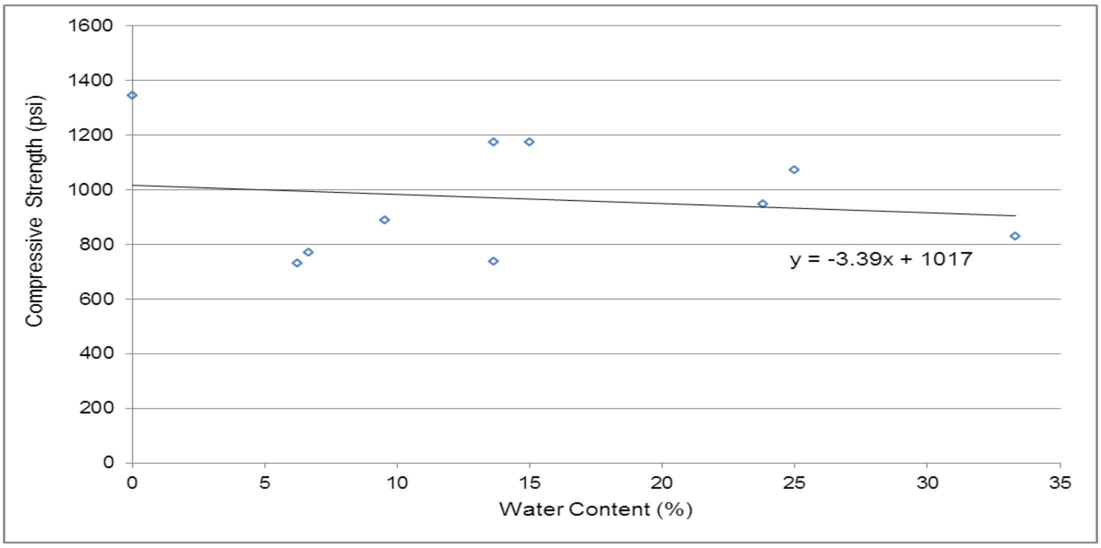

Figure 5: *Result from Experiment 1 – Compressive Strength under Static Loading*

Data from Experiment 2 as shown in Table 3 is plotted in Figure 6. S_{ij} refers to the i^{th} specimen with j layers of 5/16-inch bubble wrap. Both trend lines indicate that softwood pallets become stronger with higher water contents. The average slopes of specimens 1 and 2 are 0.22g and 0.09g per 1% water content increase, respectively. Overall average considering both specimens is 0.15g per 1% water content increase. This is opposite to the trend line of the static compression test in Experiment 1. Static loading gives water sufficient time to be squeezed out of the specimen, while the impact loading does not. Trapped water under fast impact loading provides additional resistance to the applied load, which makes pallets stronger. This additional resistance results in increased impact felt by contents placed on pallets. Thus, there is higher potential of damages to the pallet contents when impact occurs under high water content.

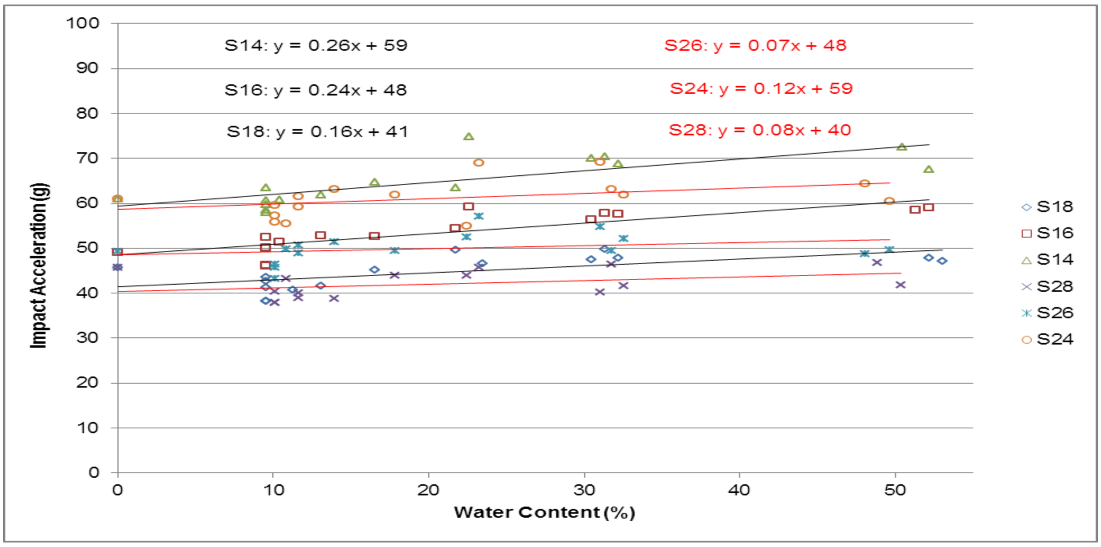

Figure 6: *Result from Experiment 2 – Impact Acceleration Measured from Saver with Bubble Wrap Cushion*

Since the results from Experiment 2 gave different results from those obtained in Experiment 1, Experiment 3 was performed. The bubble wrap cushion in Experiment 2 was replaced by a thick layer of foam. This eliminated some factors that could contribute to errors, including slippage of bubble wrap layers and bursting of some bubbles. Data from Experiment 3 as shown in Table 4 was plotted in Figure 7. The slopes obtained from the two specimens are 0.12g and 0.14g per 1% increase in water content. The average slope of the two specimens is 0.13g, which is consistent with 0.15g obtained from Experiment 2. The average slope from Experiments 2 and 3 is 0.14g. Thus, softwood pallets become stronger under impact when they have higher water content.

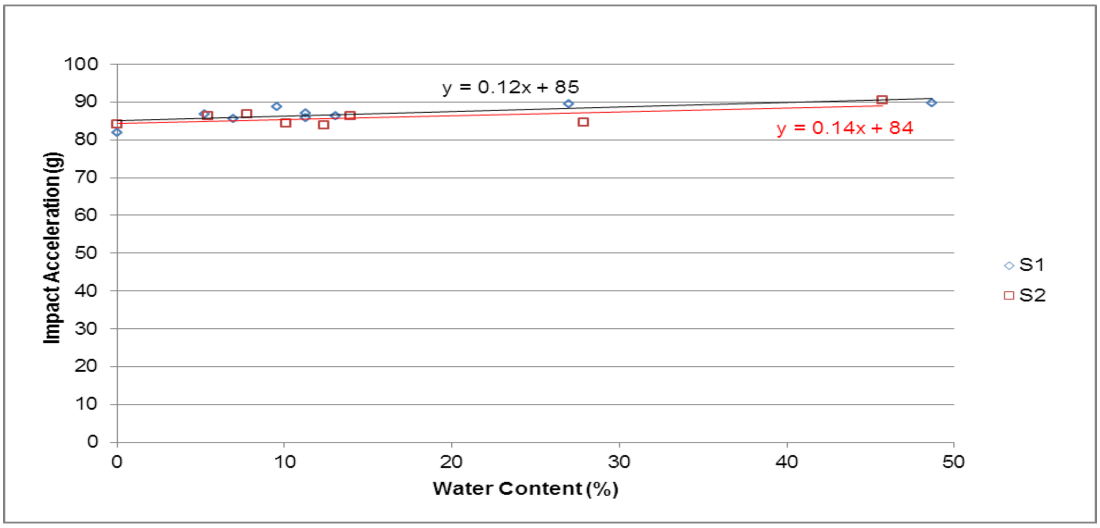

Figure 7: *Result from Experiment 3 – Impact Acceleration Measured from Saver with Foam Cushion*

To confirm that wetter softwood pallets become stronger under impact, Experiment 4 was performed. In this experiment, the energy absorbed was calculated. Data shown in Table 5 was plotted in Figures 8 and 9. The data in Table 5 indicates that increasing the water level contained in the model results in higher coefficient of restitution and higher level of elasticity (Figure 9). Figure 8 shows that less energy is absorbed when water content increases. Less energy absorbed implies a stronger specimen. These results are consistent with the results shown in Figures 6 and 7. A stronger specimen produces higher impact acceleration felt by pallet contents.

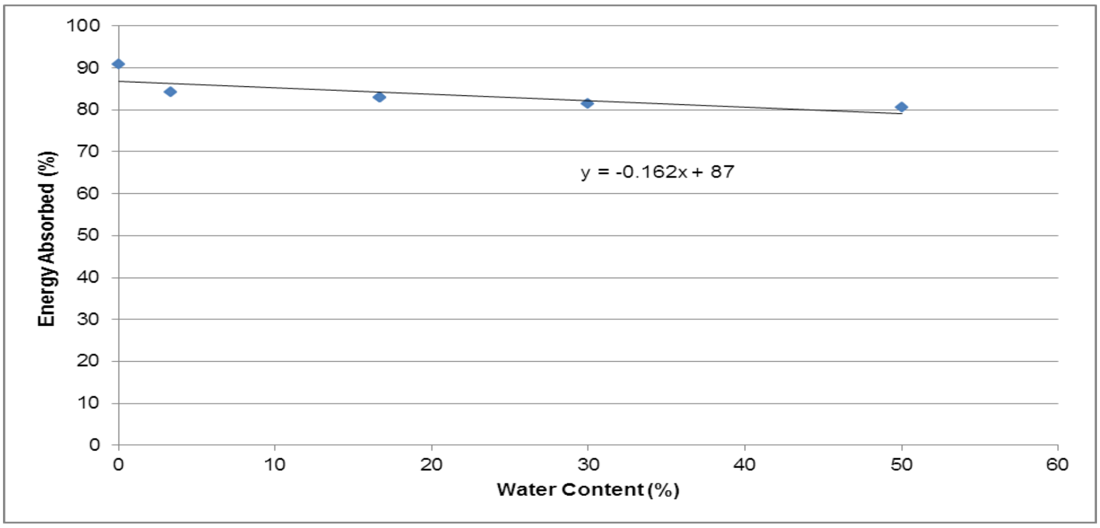

Figure 8: *Result From Experiment 4 – Energy Absorption*

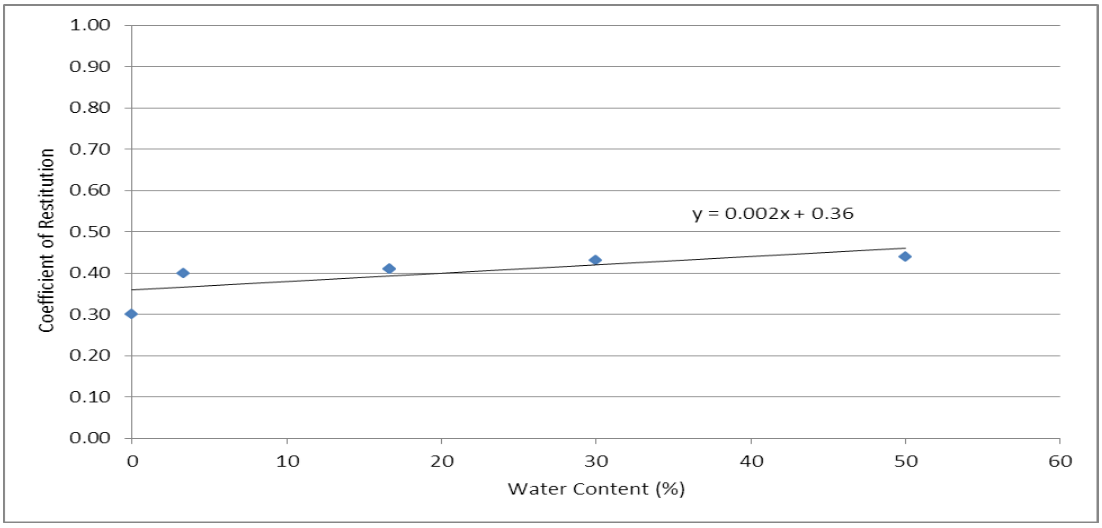

Figure 9: *Result From Experiment 4 – Coefficient of Restitution*

4. Conclusion

This study shows two potential problems that could occur with softwood pallets under higher water contents; reduction in compressive strength under static loading and increase in impact acceleration felt by pallet contents under impact loading. Reduction in compressive strength weakens the pallet while increased impact acceleration intensifies potential damage to products on the pallet. Thus, when pallets are staging outdoors, effective drainage of the staging area is recommended to avoid accumulation of rain water.

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