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Date: October 17, 2013

Dear Readers:

It is a great pleasure for me to announce the collaboration between Cloud Publications (Noida, NCR Delhi, India) and the Healthcare Packaging Consortium (Memphis, Tennessee, USA) in designating the *International Journal of Advanced Packaging Technology* as the official journal of the consortium. Our combined effort will result in a valuable resource to packaging researchers, professionals, and students worldwide. The goal of the Healthcare Packaging Consortium is to advance packaging knowledge, which aligns well with Cloud Publications' quest for knowledge. Together we can make packaging knowledge available, free of charge, to all through the open-access concept.

Volume 1 of the journal features research work performed at the consortium since its establishment in 2010. Some articles are previously unpublished original work; some are updated versions of previously published work; and some are reprints of previously published work. I would like to thank Christian Brothers University and the Institute of Packaging Professionals for allowing us to use previously published work from the *Proceedings of the MAESC 2012 Conference*, *Proceedings of the 2012 HPC Fall Meeting*, and *IoPP Journal of Packaging*. The use of previously published work is noted clearly in each article.

I am grateful to the Editorial Board members, who share a common goal with us in creating a valuable resource to the worldwide packaging community. In particular, I would like to thank Dr. Rahul Airan, Managing Editor of Cloud Journals, for entrusting me to serve as Editor-in-Chief of the journal.

On behalf of the journal I would like to invite packaging researchers and professionals to share their knowledge by submitting articles for review. All packaging related topics are welcome.

Sincerely,

S. Malasri

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Research Article **Open Access**

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.

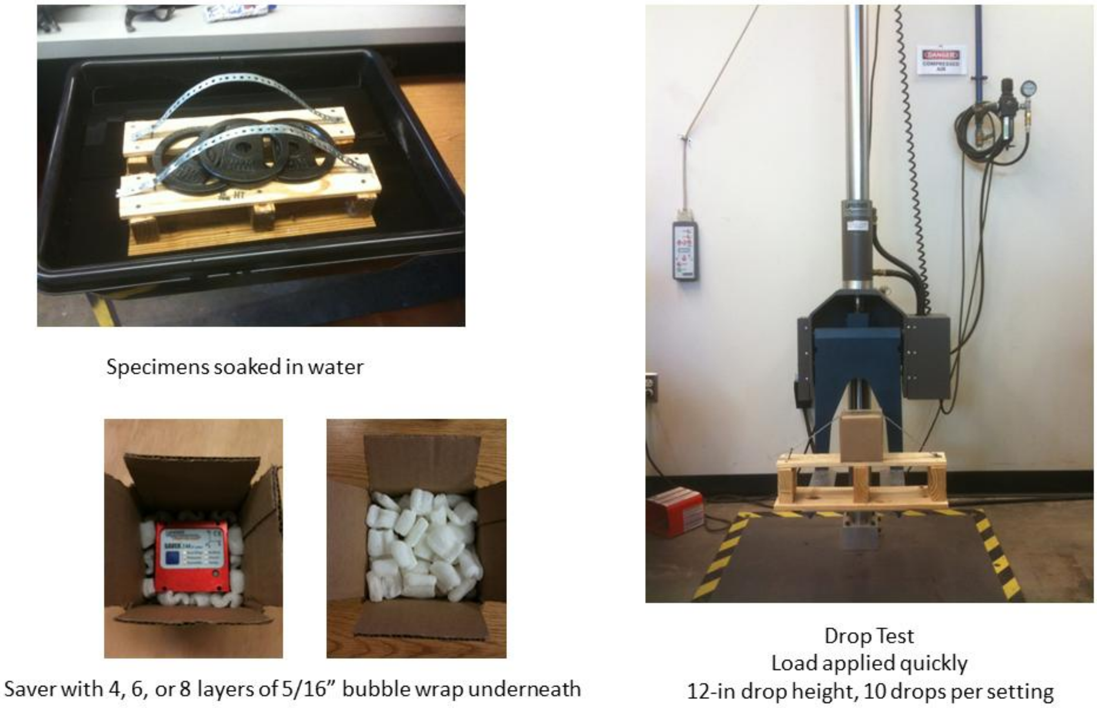

Figure 2: *Drop Test with Saver Cushioned by Bubble Wrap Layers*

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*

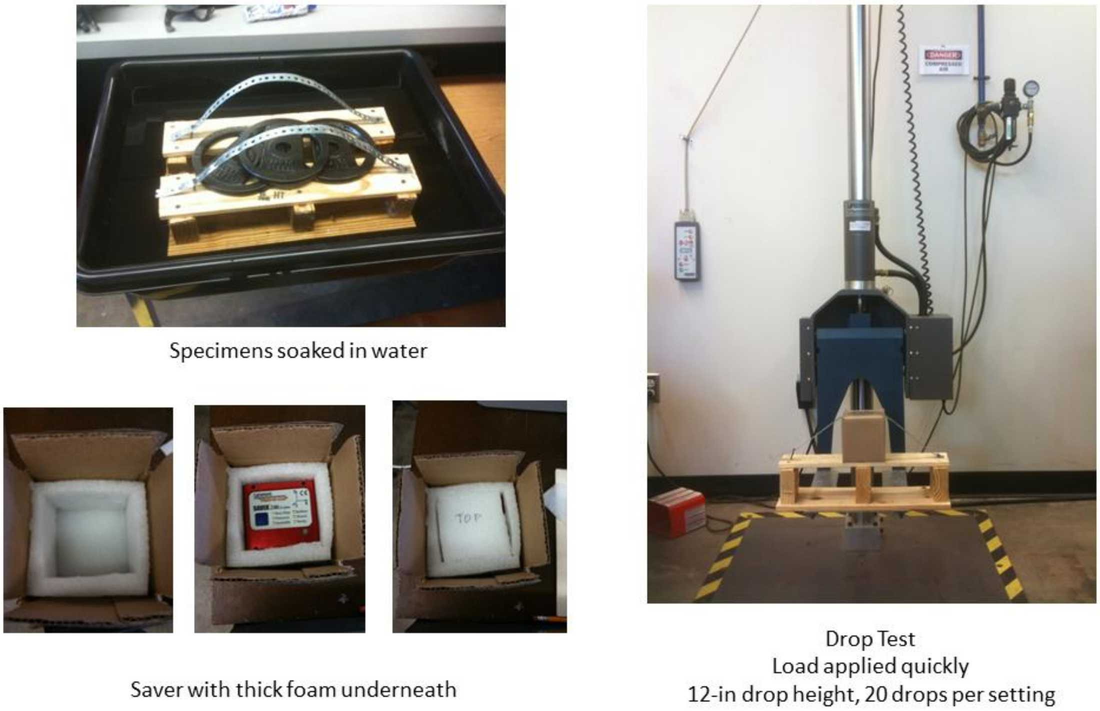

Figure 3: *Drop Test with Saver Cushioned by Thick Foam*

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.

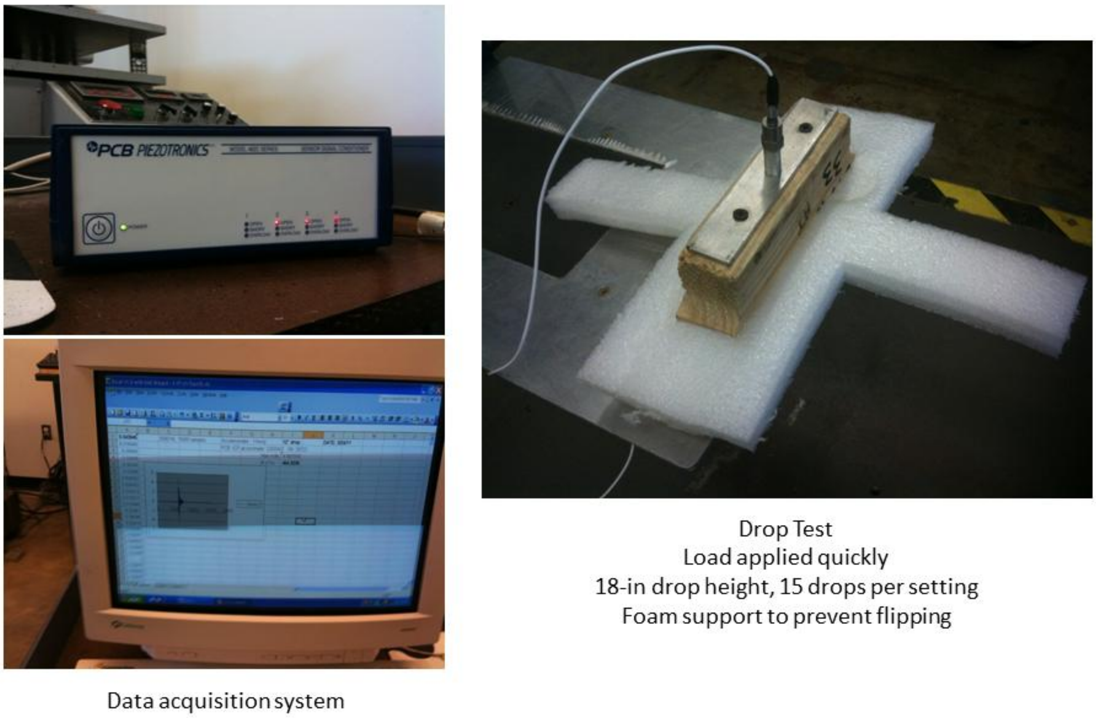

Figure 4: *Drop Test Using Accelerometer (right) and Data Acquisition System (left)*

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.

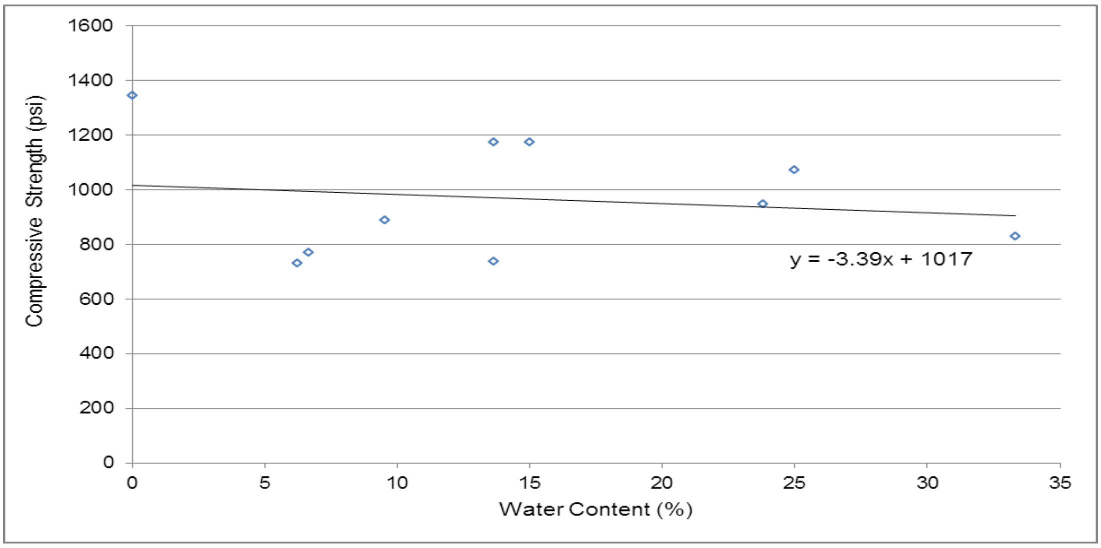

Figure 5: *Result from Experiment 1 – Compressive Strength under Static Loading*

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.

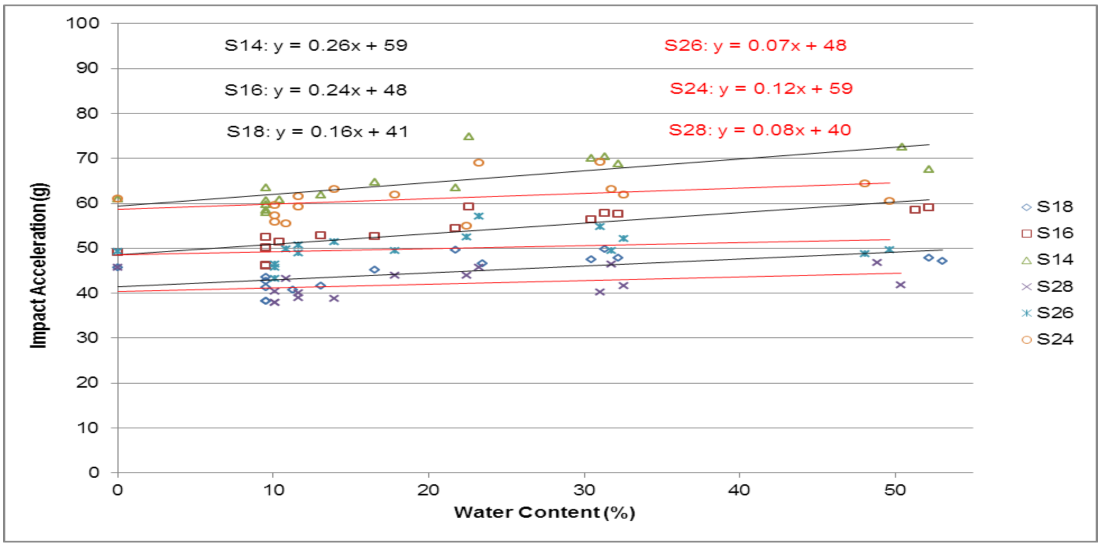

Figure 6: *Result from Experiment 2 – Impact Acceleration Measured from Saver with Bubble Wrap Cushion*

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.

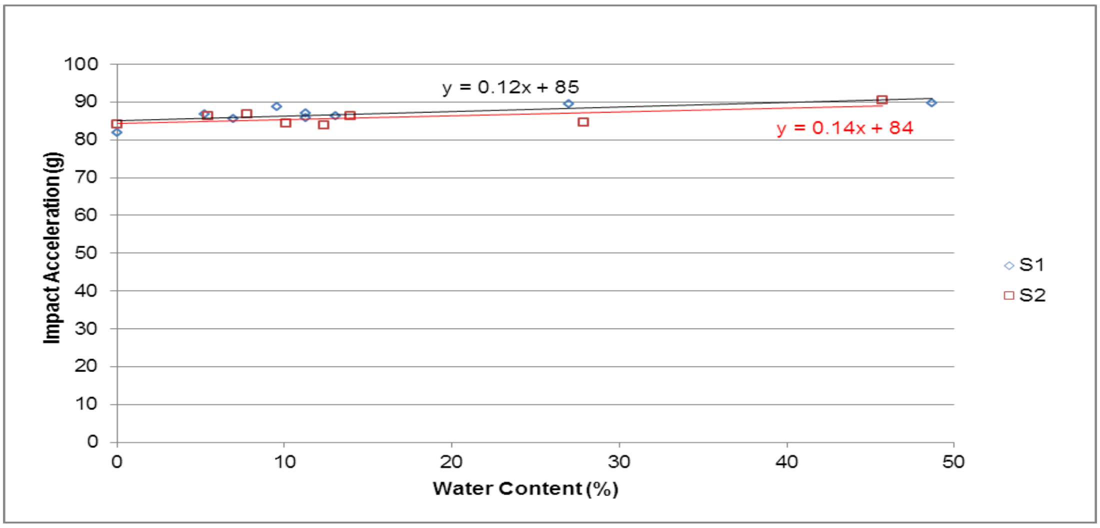

Figure 7: *Result from Experiment 3 – Impact Acceleration Measured from Saver with Foam Cushion*

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.

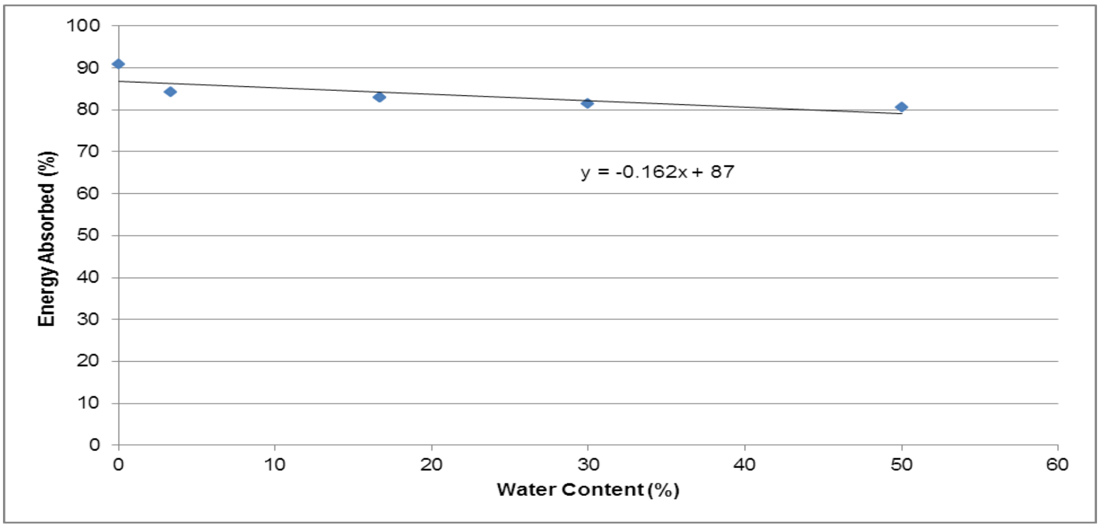

Figure 8: *Result From Experiment 4 – Energy Absorption*

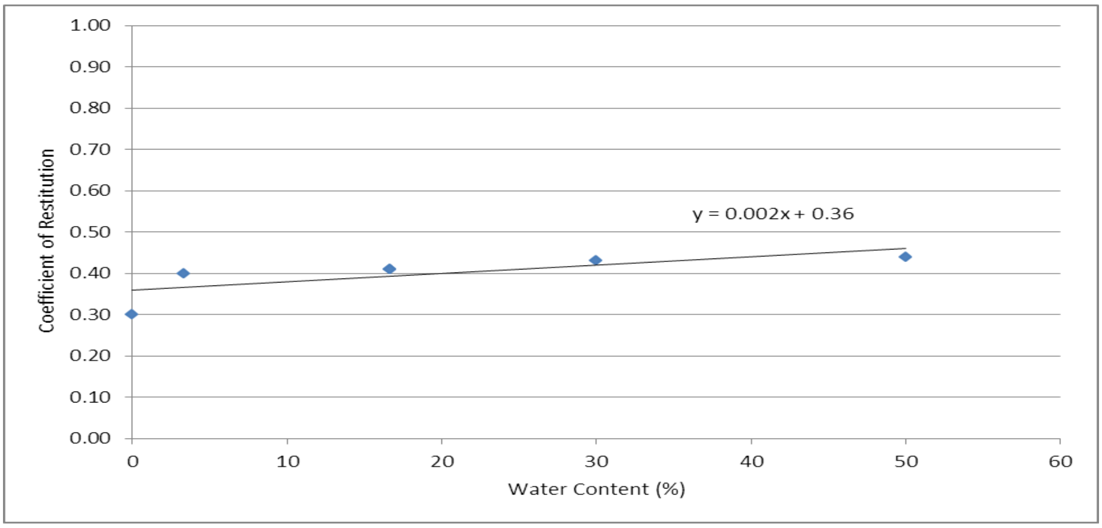

Figure 9: *Result From Experiment 4 – Coefficient of Restitution*

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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Methodology Article

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Peel Test Comparison

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(This article belongs to the previously presented work at Healthcare Packaging Consortium at CBU, USA)

Abstract Three standardized peel test variations; unrestrained, 90^o restrained and 180^o restrained, for testing the integrity of edge sealed flexible pouches are compared in this article. A total of 30 samples of identically sealed pouches were tested for each method using standards set forth in ASTM F88/F88M-09. The three methods yielded consistent differences ranging from 40% between the 90^o restrained and unrestrained methods to 190% between the 90^o restrained and 180^o unrestrained methods.

Keywords *Peel Tests; Flexible Sealed Pouches; Medical Device*

1. Introduction

The use of flexible sealed pouches for protective product containers has gained wide acceptance in the medical device industry where atmospheric contamination of the product must be kept to a minimum if not eliminated entirely. Such containers typically consist of two flat impermeable or semi-permeable membranes “sandwiched” together and sealed on three sides as supplied by their manufacturer. This permits the medical device manufacturer to insert a product under appropriate sanitary conditions and then seal the remaining open side to form an air-tight protective capsule for shipping the product. The integrity of the seal is quantified by the force necessary to peel the two membranes apart– “The Peel Test”. There are three variations in the method to determine this force, however most companies choose only one for testing their product. The current experiment was conducted to investigate possible differences in results from the three variations and to provide a means for comparing results from future tests.

Industry standards for the testing of the integrity of the sealed edges of the pouch are set forth by ASTM (American Society for Testing and Material) specifically, ASTM F88/F88M-09 [1]. In this standard, restrictions are set for the three different methods of peel testing a fin seal as shown in

Figure 1. In the document, the appropriate apparatus and procedure is given with its specific uncertainty for each process. Potential interferences and bias are also discussed in this document. The ASTM standard is set in order for multiple companies to be able to compare and correlate peel test results.

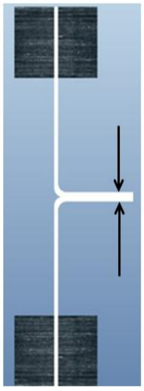
A search for previous work was conducted so that the results of the current research could be compared with others in order to validate the results. No previous work was found in relation to the experiment.

UNRESTRAINED

Each tail of the specimen is secured in opposing grips and the seal remains unsupported while the test is being conducted.

90^o RESTRAINED

Each tail of the specimen is secured in opposing grips and the seal remains hand-supported at a perpendicular angle to the tails while the test is being conducted.



180^o RESTRAINED

The least flexible tail is supported flat against a rigid alignment plate held in one grip. The more flexible tail is folded 180^o and is held in the opposing grip while the test is being conducted.

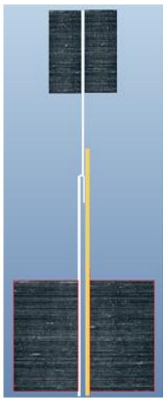


Figure 1: *Three Different Methods of Peel Testing a Fin Seal*

2. Materials and Methods

Peel tests were done in the CBU Packaging lab using a Tinius Olsen H5KS tensile tester (Figure 2) specially adapted for peel testing. In all, ninety test runs were done on samples prepared from sterile high density polyethylene. The pouch samples were all cut into one inch by three and half inch strips with one inch adhesive on each strip. All of the pouches were sealed using the same adhesive and sealing process. All tests were run at room temperature using either unrestrained, 90^o restrained, or 180^o restrained tail configuration at a jaw separation speed of 1 inch/min. The maximum peel force reached during each test run was recorded.

Figure 2: *H5KS Tensile Tester*

3. Results and Discussion

For the three testing methods, the results are shown in Table 1 and Figure 3 below.

Table 1: *Peel Force Data*

Sample	Test 1- Unrestrained Force (lbf)	Test 2- 90^0 Restrained Force (lbf)	Test 3- 180^0 Restrained Force (lbf)
1	1.87	1.24	3.93
2	1.65	1.31	3.9
3	1.76	1.09	3.75
4	2.29	1.01	3.82
5	1.54	1.39	4.05
6	1.76	1.31	3.97
7	1.87	1.2	3.93
8	1.84	1.16	4.08
9	1.72	1.2	3.93
10	1.69	1.35	3.86
11	1.91	1.57	3.97
12	1.76	1.35	3.63
13	1.95	1.65	3.67
14	1.84	1.27	3.71
15	2.25	1.54	4.05
16	1.91	0.97	3.63
17	1.84	1.5	3.9
18	1.91	1.54	3.86
19	2.02	1.39	4.01
20	1.80	1.46	3.48
21	1.46	1.61	3.93
22	2.02	1.27	3.75
23	2.25	1.24	3.67
24	2.10	1.05	4.01
25	1.87	1.39	3.52
26	1.65	1.27	3.75
27	2.32	1.2	4.2
28	1.72	1.76	4.16
29	1.31	1.31	4.01
30	1.99	1.46	3.97
Average (lbf)	*1.86*	*1.34*	*3.87*
STD Deviation (lbf)	*0.235*	*0.191*	*0.181*
STD Deviation (%)	*12.6%*	*14.3%*	*4.67%*

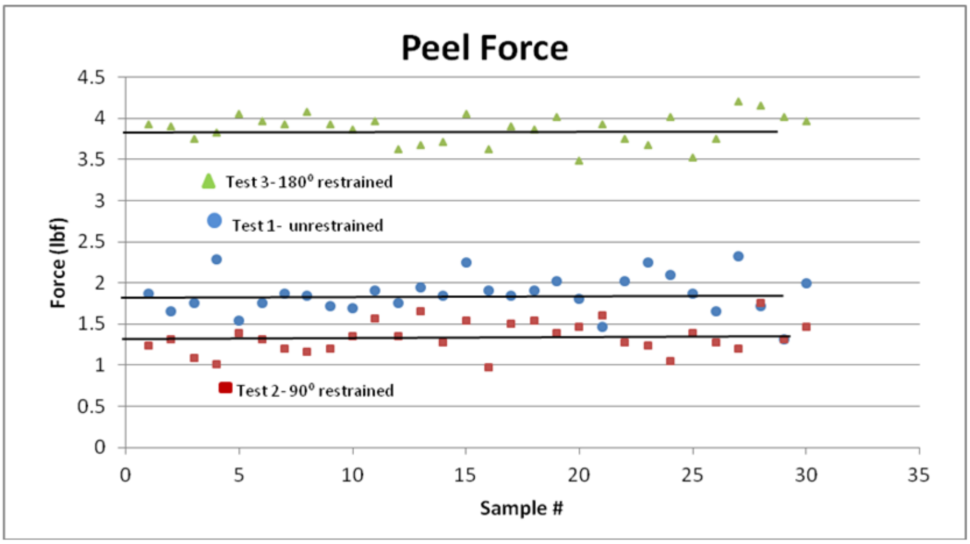


Figure 3: *Peel Force Results*

4. Conclusion

The unrestrained results had an average value of 1.86 lbf and a standard deviation of 12.6% of the average value as shown in Table 1. The 90° restrained results had an average value of 1.34 lbf and a standard deviation of 14.3% of the average value as shown in Table 1. The 180° restrained results had an average value of 3.87 lbf and a standard deviation of 4.67% of the average value as shown in Table 1. A comparison of the three tests is shown in Figure 3. The 90° restrained and unrestrained results are similar with averages of 1.34 & 1.86 lbf but the 180° restrained results are significantly higher with an average of 3.87 lbf. The 180° restrained results were the most consistent of the three tests, possibly because it had a more stable constraint applied to the sample. The three methods yield consistent differences ranging from 40% between the 90° restrained and unrestrained methods to 190% between the 90° restrained and 180° unrestrained methods. In view of these significant differences, it is recommended that any reporting of peel test data must include the testing method used.

Acknowledgement

This paper was previously published in the Proceedings of the MAESC 2012 Conference (May 2012) as part of the paper entitled “Packaging Analysis.” Use with permission from Christian Brothers University.

Reference

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Research Article **Open Access**

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 ($\sigma_{\max}$ 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).

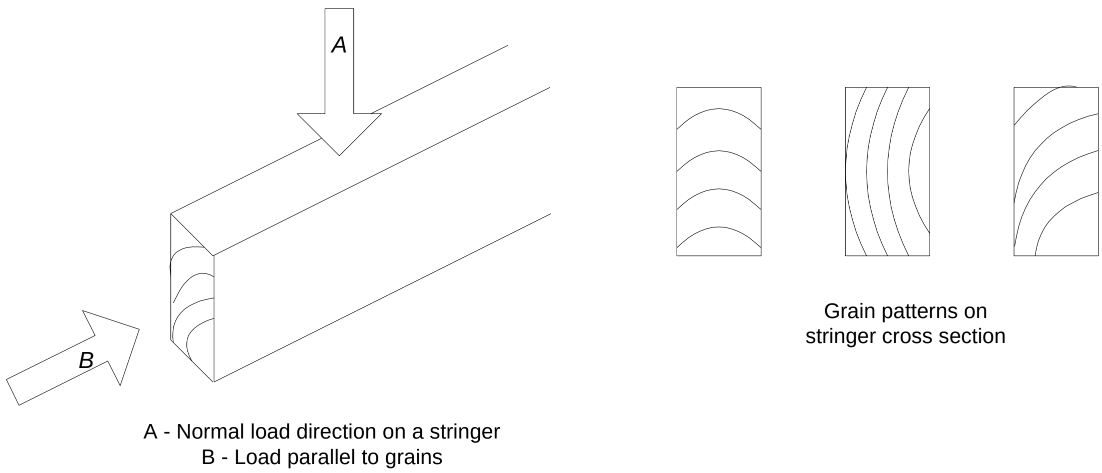

Figure 1: *Loading Orientations for Static Compression Test*

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

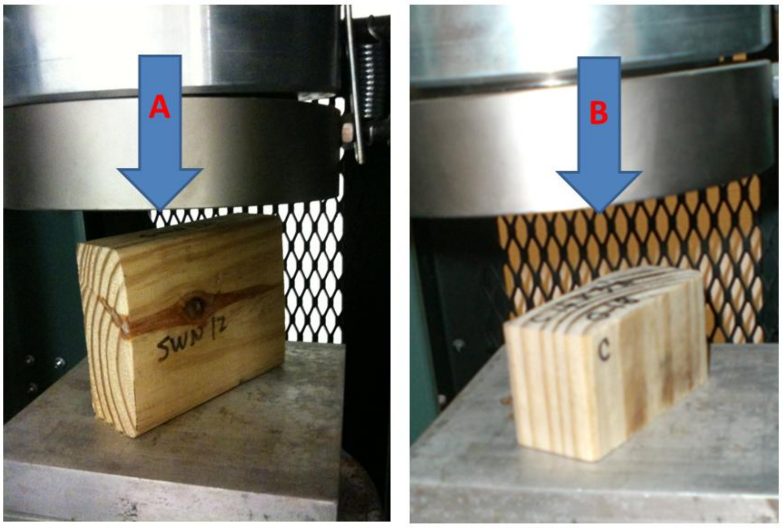

Figure 3: *Loading Directions "A" and "B"*

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)	$\sigma_{\max}$ (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.

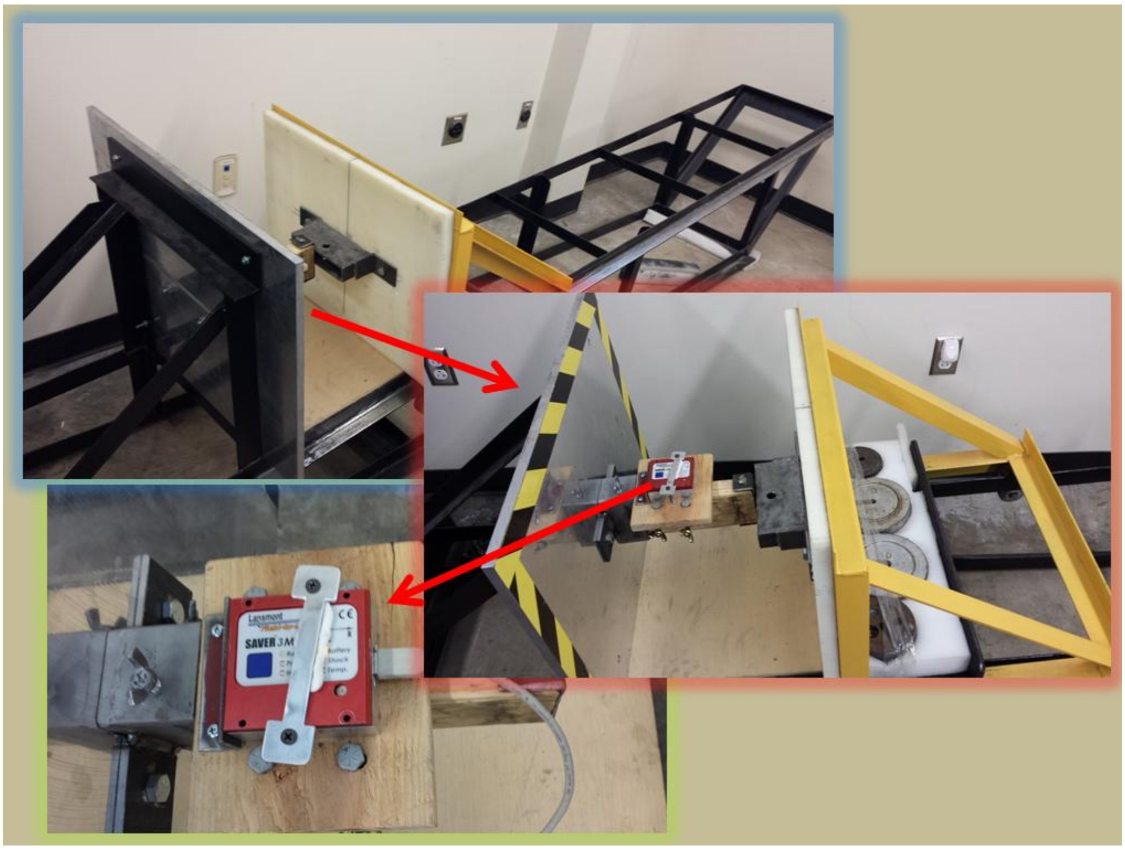

Figure 4: *Custom Incline Impact Tester*

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.

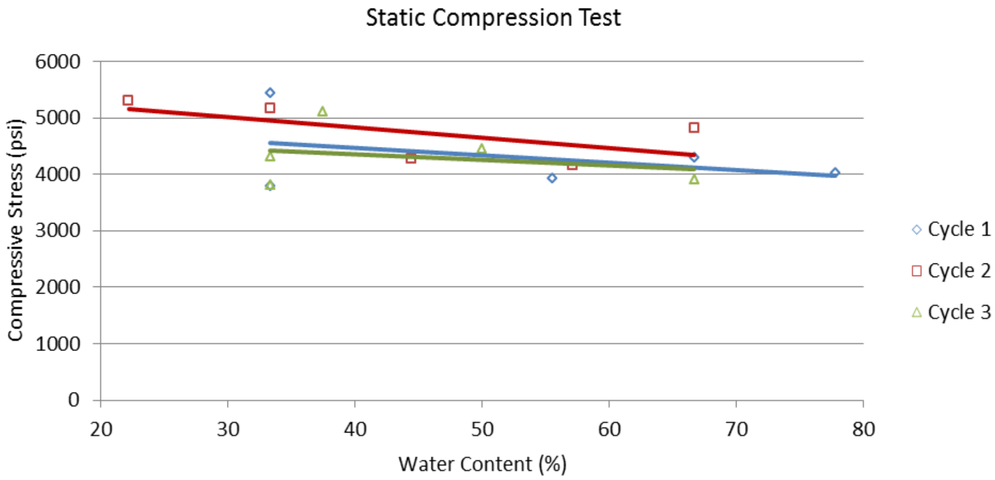

Figure 5: *Static Compression Test Results*

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.

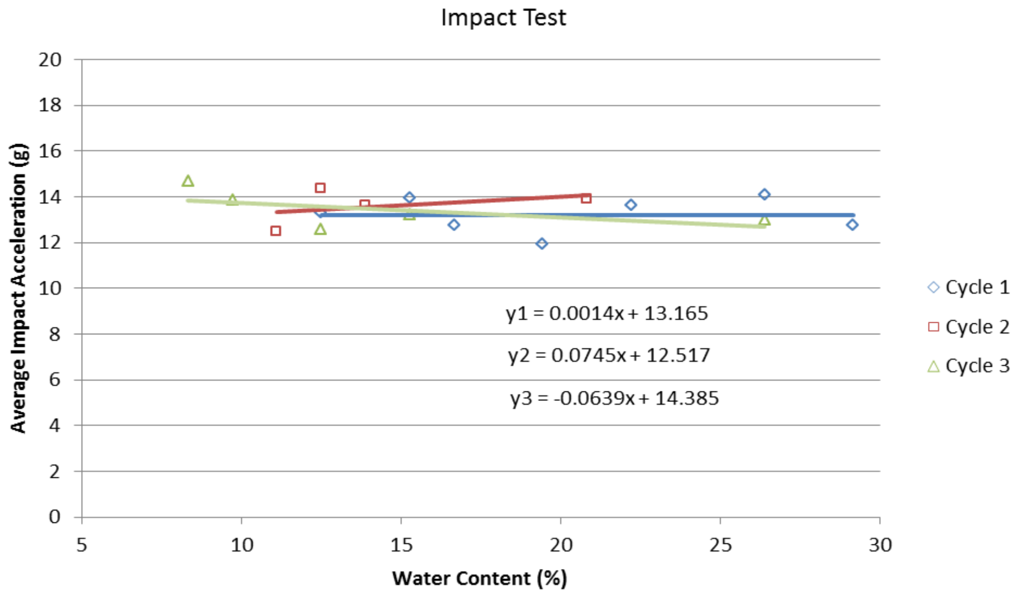

Figure 6: *Impact Test Results*

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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Research Article **Open Access**

Recycled Cardboard Comparison

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Abstract Three tests were conducted to determine the relative strengths of virgin and recycled cardboard. Edge crush tests were performed to measure the maximum force per inch to crush the walls of a cardboard box. Burst tests were performed to determine the pressure required to rupture the side of a cardboard box. Compression tests were used to determine the behavior of cardboard under a crushing load. All tests were performed according to TAPPI protocols at standard and extreme environmental conditions. Results showed that both recycled and virgin materials exceeded industry specifications at standard conditions but that the performance of both were severely degraded at extreme conditions with the recycled material showing the greatest degradation.
Keywords *Recycled Material; Virgin Material; Environment*

1. Introduction

The use of recycled cardboard has gained wide acceptance in the packaging industry where sustainability has become a priority of consumers. However, recycling cardboard can have a negative impact on the strength properties of the material. The purpose of this experiment is to determine the effect of recycling cardboard at varying environmental conditions.

For this experiment, three tests were conducted to determine the strength of virgin and recycled cardboard. Edge crush tests (ECT) were performed to measure the maximum force per inch to crush the walls of a cardboard box. Burst tests were performed to determine the pressure required to rupture the side of a cardboard box. Compression tests were used to determine the behavior of cardboard under a crushing load. All tests were performed according to TAPPI standards at standard and extreme environmental conditions.

Industry standards for the testing of the edge crush test, burst test, and compression test of corrugated boxes are set forth by TAPPI (Technical Association of the Pulp and Paper Industry), specifically TAPPI T839 om-08 [1], TAPPIT T807 om-11 [2], and TAPPI T804 om-06 [3], respectively. In these standards, restrictions are set for each testing procedure. In the documents, the appropriate apparatus and procedure is given with its specific uncertainty for the process for each test. The TAPPI standard is set in order for multiple companies to be able to provide and compare universal results. The testing standards are set forth for standard conditions and make no reference to testing at extreme conditions.

A literature search for similar comparisons of recycled and virgin materials was unsuccessful. No previous work was found.

2. Materials and Methods

2.1. Samples

In all, 14 different box sizes were tested. The 14 boxes were split into 7 different categories according to size and material. Each category consisted of two materials, Virgin and 100% Recycled. The nomenclature used in testing and results is the size of the box varying 1 through 7 followed by either “V” for virgin or “R” for recycled.

2.2. Conditioning

Each test was performed at two separate conditions. The first condition was at 73° F and 50% relative humidity. This will be referred to as Standard Condition henceforth. The second condition was at 90° F and 90% relative humidity. This condition will henceforth be referred to as Extreme Condition. All conditioning was performed in a Cincinnati Sub-Zero 32 Environmental Chamber located in the Christian Brothers University Certified Packaging Laboratory.

To condition the samples, the samples were subjected to an initial drying period at 90° F and 10% relative humidity for 24 hours. Immediately following the drying period, the samples were exposed to Standard Conditions for 48 hours. Once the standard samples were tested, the remaining samples were exposed to Extreme Condition for 48 hours and were immediately tested.

2.3. Edge Crush Test

The edge crush test was done in the CBU Certified Packaging Lab using a Crush Tester V5.0 Buchel BV (Figure 1) with jig (Figure 2) specially adapted for edge crush testing. In all, 140 samples were tested, 5 for each box per condition.

The cardboard samples were all cut into two inch by two inch squares. The samples were then conditioned. All tests were loaded into the jig with flutes parallel to the force applied. The sample was then tested until failure, and the maximum force was recorded.

Figure 1: *Crush Tester*

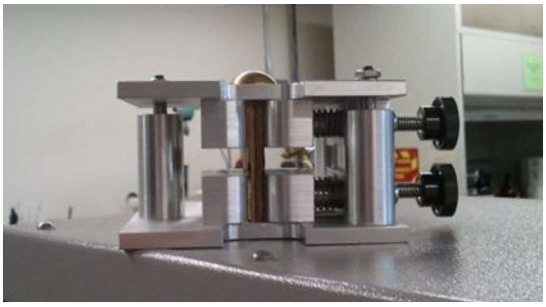

Figure 2: *Jig*

2.4. Burst Test

The burst test was done in the CBU Certified Packaging Lab using a Mullen Burst Tester (Figure 3) specially adapted for burst testing. In all, 140 samples were tested, 5 for each box per condition. The cardboard samples were all cut into six inch by six inch squares. The samples were then conditioned. All tests were loaded under the jaws of the Burst Tester. The jaws were clamped to 100 psi. The sample was then tested until failure, and the maximum pressure was recorded.

Figure 3: *Burst Tester*

2.5. Compression Test

The compression test was done in the CBU Certified Packaging Lab using a modified Gaynes Engineering Compression with a DigiWeigh Model TI-5000E floor scale (Figure 4) specially adapted for compression testing. In all, 2 or 3 box samples per condition. Only categories 1 to 5 were tested due to conditioning constraints. The cardboard samples were assembled using the force of the compression table. All tests were loaded into the compression table. The box was preloaded to a specified force. For single corrugated boxes, category 1, the preload was 50 pounds. For double corrugated boxes, categories 2 through 5, the preload was 100 pounds. The sample was then tested until failure, and the maximum force and deflection was recorded.

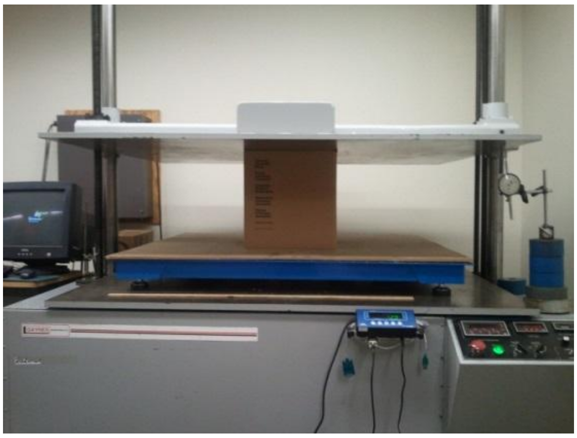

Figure 4: *Compression Tester*

3. Results and Discussion

3.1. Edge Crush Test

Table 1 shows the average results for the samples at each condition. It also shows the industrial strength (determined) ECT listing for each box. The percentage listing is the experimental ECT for each condition related to the industrial listing. Figure 5 shows a comparison of the determined ECT, virgin, and recycled results at extreme conditions.

Table 1: *Results for ECT*

Sample	Determined ECT (lbs/in)	Standard (lbs/in)	Percentage	Extreme (lbs/in)	Percentage
1V	32	42.727	134%	21.564	67%
1R	32	25.782	81%	14.572	46%
2V	48	63.09	131%	30.323	63%
2R	48	55.74	116%	26.155	54%
3V	48	65.09	136%	35.49	74%
3R	48	52.63	110%	24.052	50%
4V	51	65.45	128%	36.714	72%
4R	51	46.745	92%	24.205	47%
5V	48	67.17	140%	30.824	64%
5R	48	48.373	101%	18.354	38%
6V	48	66.78	139%	30.949	64%
6R	48	44.654	93%	18.493	39%
7V	51	73	143%	29.698	58%
7R	51	49.086	96%	15.338	30%

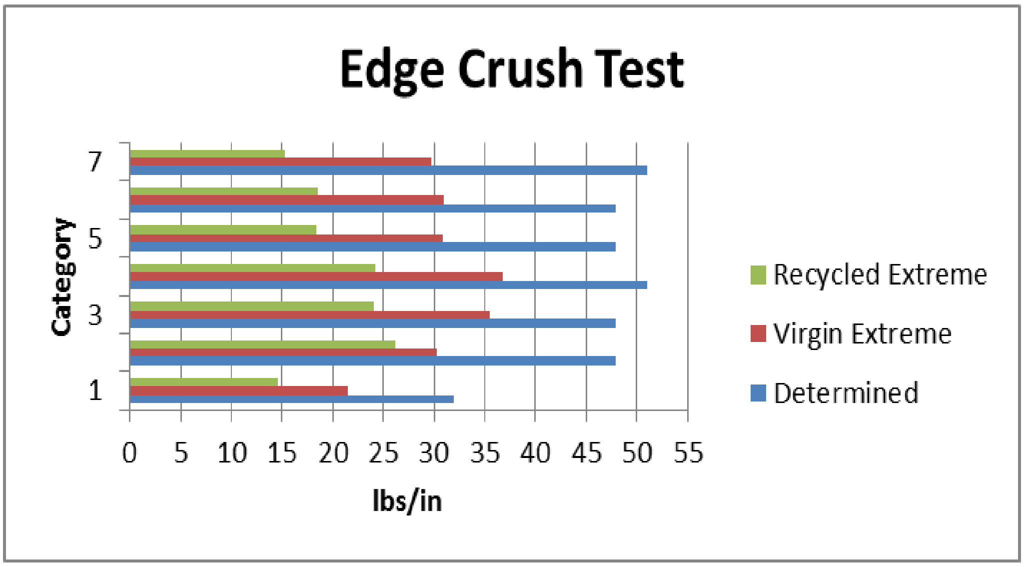

Figure 5: *Results for ECT*

At standard conditions, both virgin and recycled Cardboard matched or exceeded the determined ECT. At extreme conditions, both are reduced below the industrial listings; however, the recycled samples were much more significantly reduced. As seen in Figure 5, the percentages for recycled cardboard are consistently below 50% of the determined ECT while the virgin samples were closer to 65%.

3.2. Burst Test

Table 2 shows the average results for the samples at each condition. The percent change shows the drop in strength between standard and extreme conditions. Figure 6 shows a comparison of the virgin and recycled results at standard and extreme conditions.

Table 2: *Results for Burst Test*

Sample	Standard (psi)	Extreme (psi)	% Change
1V	303.2	205	32.388%
1R	158.4	112	29.293%
2V	439.2	264	39.891%
2R	188.4	150	20.382%
3V	445	238	46.517%
3R	190	148	22.105%
4V	388	330	14.948%
4R	211.8	162	23.513%
5V	443.4	298	32.792%
5R	196.6	140	28.789%
6V	373	278	25.469%
6R	191.2	146	23.640%
7V	458.4	342	25.393%
7R	165	140	15.152%

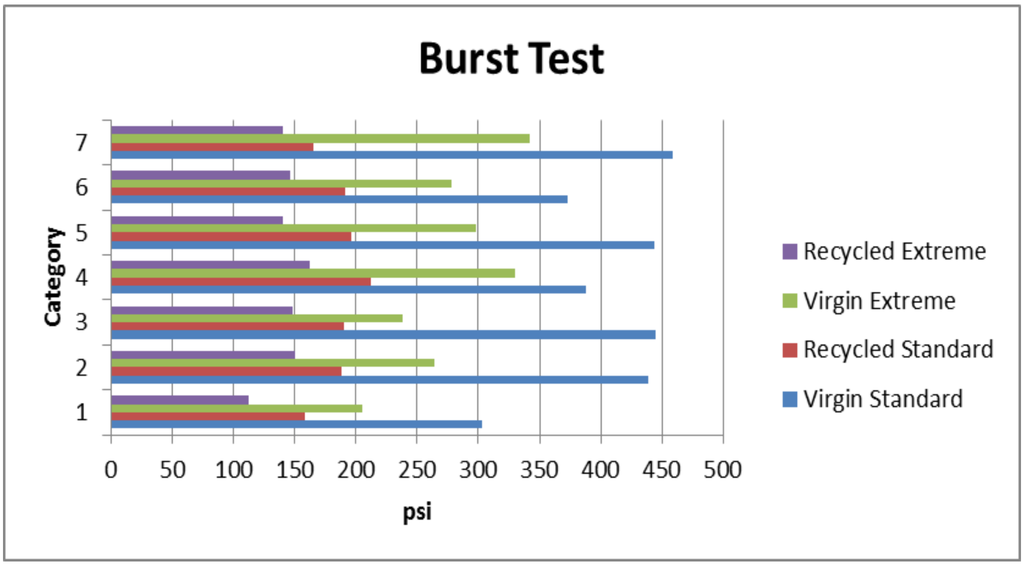

Figure 6: *Results for Burst Test*

At both conditions, virgin material is considerably stronger than its recycled counterpart. Due to its high rupture points as seen in Table 2, virgin cardboard showed a larger percent drop than recycled cardboard. Even with the higher percentage drop, the virgin cardboard at extreme conditions is stronger than recycled cardboard at standard conditions as seen in Figure 6.

3.3. Compression Test

Table 3 shows the average results for the samples at each condition. The percent change shows the drop in strength between standard and extreme conditions. Figure 7 shows a comparison of the virgin and recycled results at standard and extreme conditions.

Table 3: *Results for Compression Test*

Sample	Force (lbs)			Deflection (in)		
	Standard	Extreme	% Change	Standard	Extreme	% Change
1V	906.5	347	61.721%	0.6785	0.375	44.805%
1R	499.5	142	71.572%	0.5005	0.136	72.927%
2V	1622	789	51.356%	1.089	0.843	22.590%
2R	1038	303.5	70.761%	0.2365	0.197	16.913%
3V	1463.5	610.33	58.296%	0.7685	0.622	19.020%
3R	1088.5	358	67.111%	0.297	0.187	37.149%
4V	1521	556.5	63.412%	0.889	0.497	44.151%
4R	798	278.5	65.100%	0.8215	0.615	25.137%
5V	1773	760.5	57.107%	0.707	0.382	46.040%
5R	1208.5	381.5	68.432%	0.382	0.200	47.775%

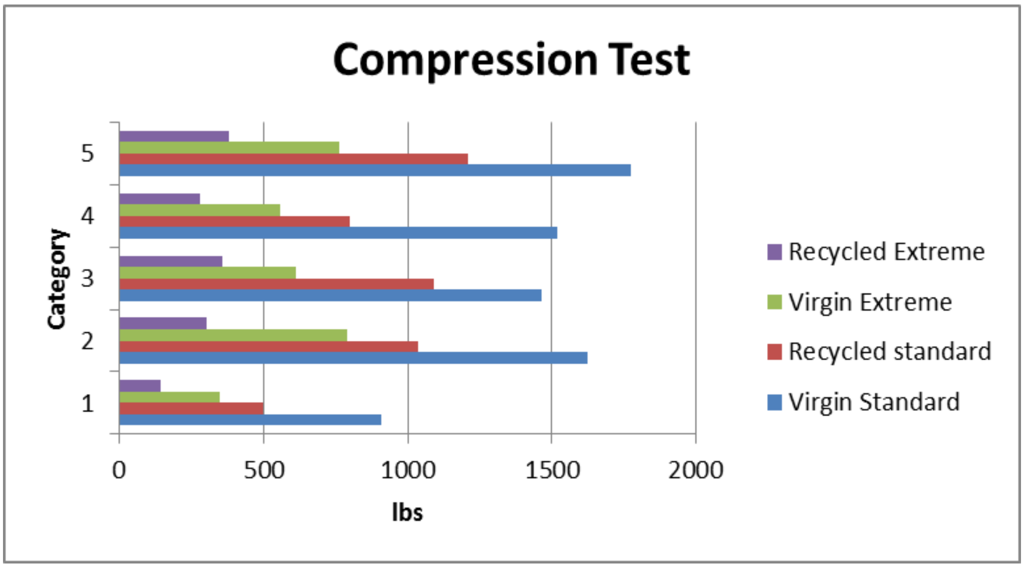

Figure 7: *Results for Compression Test*

In Figure 7, the virgin boxes are stronger at both conditions. Additionally, the virgin boxes show a lower percentage change as seen in Table 3 for each category. This shows the humidity had more of an effect on the recycled boxes.

4. Conclusion

Virgin cardboard tested stronger than recycled cardboard in every test, despite identical industrial strength listings. In extreme conditions, the difference between recycled and virgin cardboard increases. If a company is striving towards sustainability, one option would be to use higher rated recycled cardboard material in place of virgin material.

Acknowledgement

This paper was previously published in the *Proceedings of the MAESC 2012 Conference* (May 2012) as part of the paper entitled “Packaging Analysis.” Use with permission from Christian Brothers University.

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Research Article **Open Access**

Effect of Temperature on Static and Impact Properties of New Softwood Pallets

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(A part of this article belongs to the previously presented work at Healthcare Packaging Consortium at CBU, USA)

Abstract The first part of this study verifies that static compressive strength of new wooden pallets decreases as temperature increases. The drop of compressive strength is at a small rate of 0.61 psi per 1°F of temperature increase within the temperature range of 80°F to 160°F. This is consistent with the current timber structural design practice. The strength reduction is small and has little effect on pallet static compression performance. The second part of this study investigates impact acceleration from free-fall drop tests performed at temperatures ranging from 80°F to 160°F. As temperature rises, specimens become weaker thus they absorb more impact energy, which results in lower impact acceleration. The drop of impact acceleration is also at a small rate of 0.034g per 1°F of temperature increase. When temperature rises from normal temperature of around 80°F to a high temperature of 160°F, the impact acceleration reduces about 2.72g. This rise results in less potential damages on products on the pallet. The third part of this study looks at the impact acceleration due to horizontal impact due to a forklift at a lower range of temperature of 33°F to 72°F. The drop of impact acceleration is at a faster rate of 0.674g per 1°F of temperature increase. When temperature drops from 59°F to 48°F, the impact acceleration increases about 7.41g. This increases the damage potential of products on pallets.
Keywords *High Temperature; Low Temperature; Compressive Strength; Impact Acceleration; Softwood Pallets; Free-Fall Drop Test; Forklift Impact Simulation*

1. Introduction

Pallets are handled under different temperature environments. On a hot summer day in Arizona, a pallet in a tractor-trailer could be subjected to over 150 °F temperature. On the other hand, during a cold night in Michigan a pallet left outdoor could be under freezing temperature. It has been well established in timber structural design, such as for buildings, that a timber member under high temperature for a substantial period of time becomes weaker under static loading. The National Design Standard [1] reduces the allowable stress by a factor of C_t when a timber member is in such a situation. In this research, wood specimens were prepared from new softwood pallets. Static compression tests were performed to validate the timber design practice above. Drop test, a simulation of vertical dropping of a pallet by a forklift, was performed to gain insight of how high temperature affects pallet impact property. Finally, incline impact test, a simulation of horizontal impact on a pallet by a forklift, was performed at lower temperature to see the effect of low temperature on pallet impact property. A normal temperature used in the study is around 70°F, which is the typical temperature in the CBU certified packaging laboratory and is comparable to the normal controlled condition used by test procedures, such as ISTA Procedure 3A [2], set by the International Safe Transit Association, i.e., 73°F and 50%RH.

2. Materials and Methods

2.1. Temperature Range & Monitoring

The first phase of this study is the determination of the range of temperature to be used. The normal temperature used for the high temperature study part was 80°F, representing approximate lab temperature during the summer when the study was conducted. This is slightly higher than the ISTA normal temperature of 73°F. The normal temperature used for the low temperature study part was 73°F, representing approximate lab temperature during the fall when this part of study was conducted.

The upper limit for the high temperature study was selected as 160°F based on several considerations:

- The heat treatment process that is used to eliminate pests from pallets requires wood packaging materials to be heated with a minimum temperature of 132.8°F for a minimum duration of 30 continuous minutes to heat the wood thoroughly [3].
- On a hot summer day in Memphis, TN, with an exterior temperature of 92°F, the interior temperature of an enclosed outdoor storage, measured by an infrared thermometer gun, was 155°F. The interior of a tractor-trailer would be around the same figure.
- The following model, Eq. 1, was developed from heat transfer principles [4] for a parked tractor trailer:

$$T_i - T_\infty = \left(\frac{q_s \alpha}{1.91/W^{1/4} + 2.84 H^{3/4} \left(\frac{1}{W} + \frac{1}{L} \right)} \right)^{0.8} \quad \text{……….. Eq. 1}$$

Where T_i = interior temperature of tractor trailer (°C), T_∞ = exterior temperature (°C), q_s = sun load (1000 W/m^2), α = absorptivity of solar radiation, L = length of tractor trailer (m), H = height (m), and W = width (m). Figure 1 shows the relationship between interior and exterior temperatures, which were converted from °C to °F, at different absorptivity.

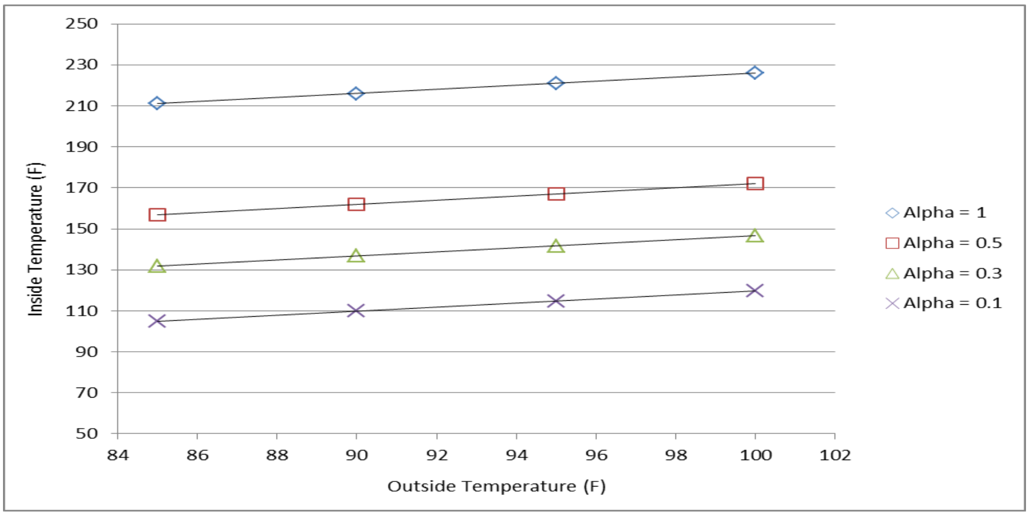

Figure 1: *Interior and Exterior Temperatures of a Parked Tractor-Trailer*

This equation demonstrates that the truck container would absorb all the sun heat when Alpha = 1 and reflect most of the sun's heat when Alpha = 0.1. A more realistic absorptivity of solar radiation is around 0.5, thus an interior temperature of around 150°F to 170°F would be reasonable.

The lower limit of the low temperature study was 33°F, just slightly above the freezing point to avoid the change in wood's internal structure due to freezing.

For the high temperature study, samples of softwood pallet stringers were placed over night in a temperature/humidity chamber which was set at 180°F temperature and 40% relative humidity as shown in the left photo of Figure 2. Each sample was then placed at room temperature with thermocouples placed at mid-depth, quarter-depth, and on the surface as shown in the middle photo of Figure 2. The end of each thermocouple wire exiting from each specimen was also sealed to prevent heat loss through the hole made for thermocouple insertion. However, these seals are not shown in the figure. A PC-based data acquisition system was used to record and plot temperature values from thermocouples at a 2-minute time interval (with the first reading at 160°F) until the temperatures dropped to room temperature as shown in the right photo of Figure 2. Only mid-depth temperature values were used to represent the temperature state of a specimen at a given time for simplicity. Figure 3 shows cool-down curves for three softwood stringers. An average temperature equation was used in estimating temperature of a specimen during compression test and impact test.

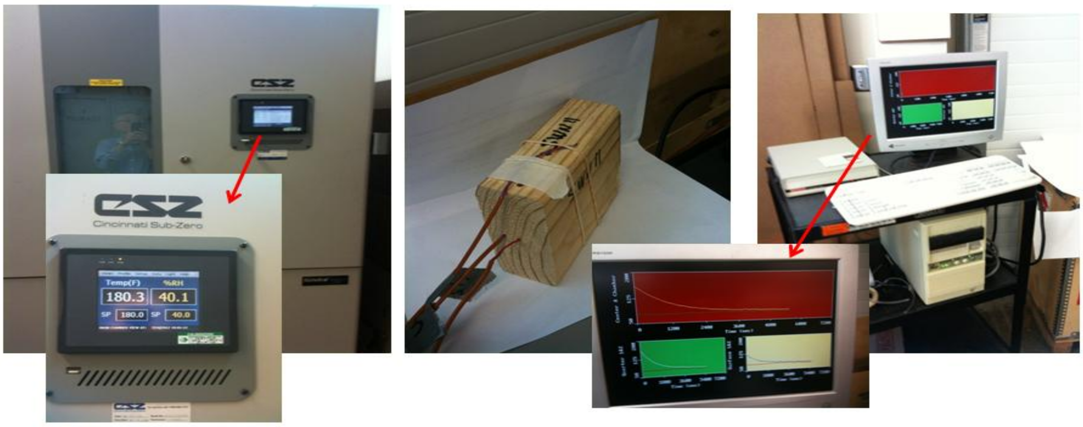

Figure 2: *Temperature Monitoring for High Temperature Study*

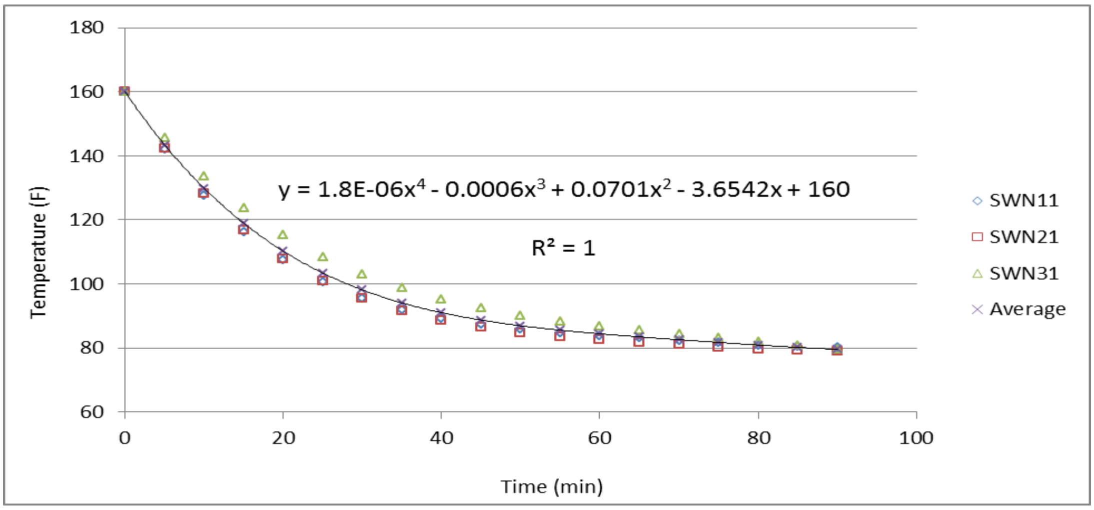

Figure 3: *Cool-down Curve for High Temperature Study*

For the low temperature study, a specimen was placed in a chamber at 33°F with thermocouples inserted into the specimen at mid-depth, quarter-depth, and on the surface to monitor the temerature. Once the temperature at mid-depth of specimen reached 33°F, the specimen was allowed to warm up outside the chamber. A temperature profile was developed in Figure 4.

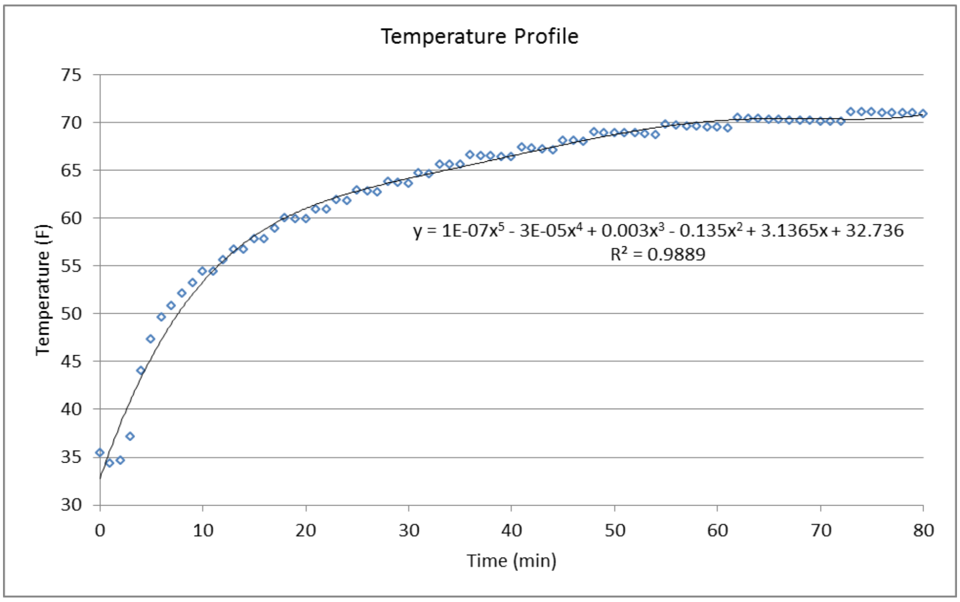

Figure 4: *Warm-up Curve for Low Temperature Study*

2.2. Compression Test

Stringers are the main part of a pallet that resists vertical load. Thus, stringer specimens were used in static compression test in this study. Fourteen specimens were placed overnight in an altitude chamber (photo on the left in Figure 5) with the temperature set to 82.2°C (180°F). The time a specimen was removed from the chamber to the first compression test is about the same as the time when it was removed from the chamber to the time the thermocouples made their first readings of the temperature as mentioned earlier. Knowing the time from the compression of the first specimen, the temperature of a subsequent specimen was determined by the average cooling equation shown in Figure 3. Each specimen was compressed in a compression machine (photo on the right in Figure 5). Compressive stress was calculated for each specimen using the following equation:

$$Compressive\ Stress = \frac{Maximum\ Load}{Area} \qquad \text{……….. Eq. 2}$$

Figure 5: *Equipment Used in Static Compression Test*

2.3. Free-Fall Drop Test

Due to the limited size of the temperature/humidity chamber, two smaller specimens (as shown in the lower left photo in Figure 6) were made to replicate a real pallet. Each specimen consists of three stringers taken from three different pallets. A data logger (also known as "saver" or "transportation recorder") was placed on layers of 5/16" bubble wrap sheets and housed in a single-wall corrugated box (as shown in the upper left photo in Figure 6). Four to eight layers of bubble wrap were used to see what the effect of cushion has on the impact acceleration. The instrument's box was then secured to each specimen with a plumber strap. Drop tests were then performed at a 12-inch drop height (as shown in the right photo in Figure 6).

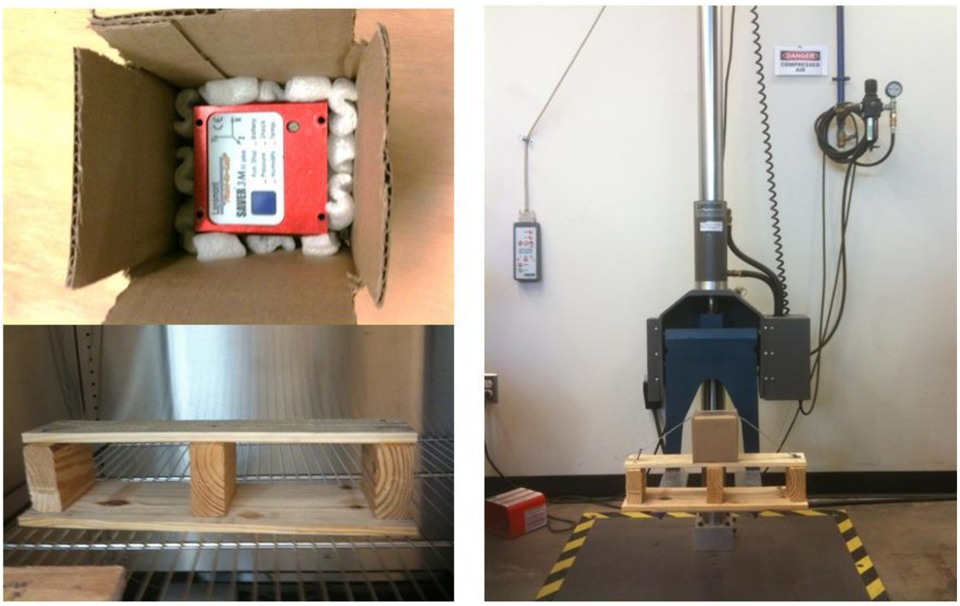

Figure 6: *Drop Test of Pallet Specimens*

2.4. Incline Impact Test

An incline impact test was used to simulate horizontal impact from a forklift at low temperatures. The setup was similar to that of a previous study [5], as shown in Figure 7. The specimen was impacted at about 5-minute intervals for about one hour. The shock recorder had the time stamped for impact acceleration recorded. Knowing the time of impact from the time the specimen was taken out of the *temperature* chamber led to the determination of temperature at impact as produced from the temperature profile shown in Figure 4.

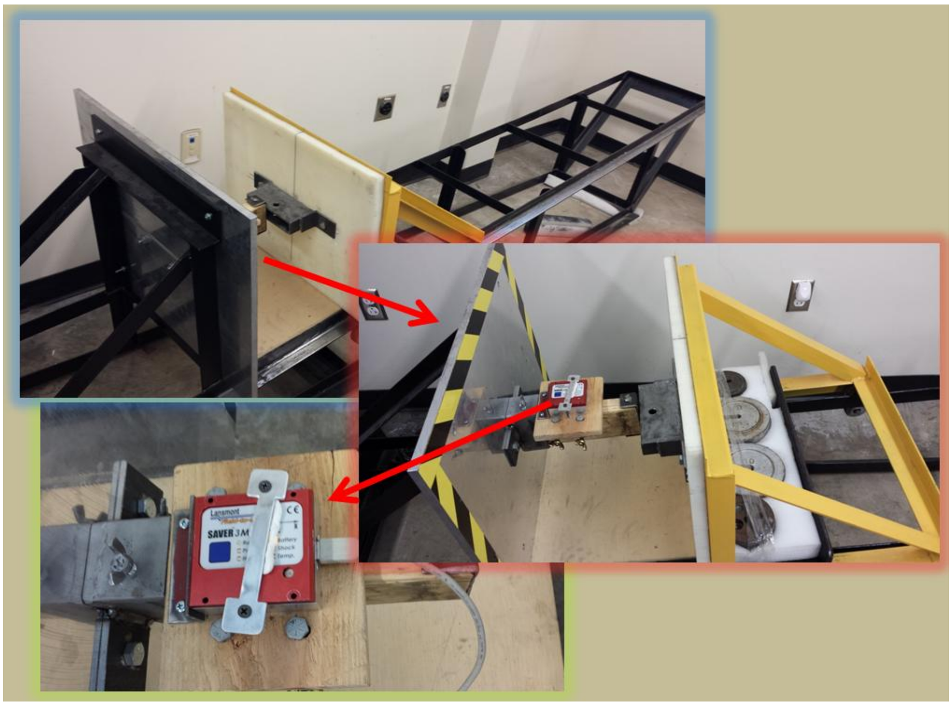

Figure 7: *Incline Impact Test Setup*

3. Results and Discussion

3.1. Compression Test

Compressive stress, calculated from Eq. 2, was plotted against estimated specimen temperature as shown in Figure 8. The trend of the curve indicates that the pallet stringer is weaker at higher temperature, thus indicating lower compressive stress. This validates the current practice in timber design. Data points are not quite consistent since each specimen is different. A specimen is crushed to failure; thus, a new specimen must be used where temperatures may fluctuate. It is a well-known fact that wood properties vary significantly. In addition, the direction of wood grains affects the compressive strength as pointed out in a previous article [5].

3.2. Free-Fall Drop Test

Results from the drop test were plotted in Figure 9. The black equations are from specimen No. 1 while the red equations are from specimen No. 2. Specimen No. 1 was made from new softwood pallets while specimen No. 2 was from heat treated softwood pallets. Since both specimens were heated to 180°F overnight, which was greater than the temperature and duration requirements specified in ISPM 15 [3], both specimens are essentially heat treated. In Figure 9, S_{ij} means the i^{th}

specimen with j layers of bubble wrap; e.g., S24 means specimen No. 2 with four layers of 5/16” bubble wrap.

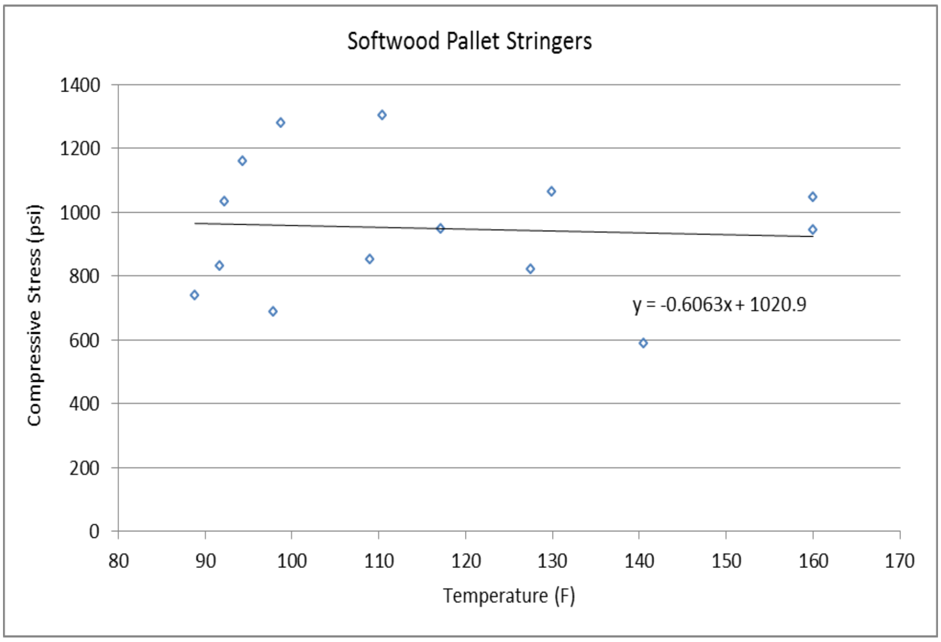

Figure 8: *Compressive Strength versus Temperature Graph*

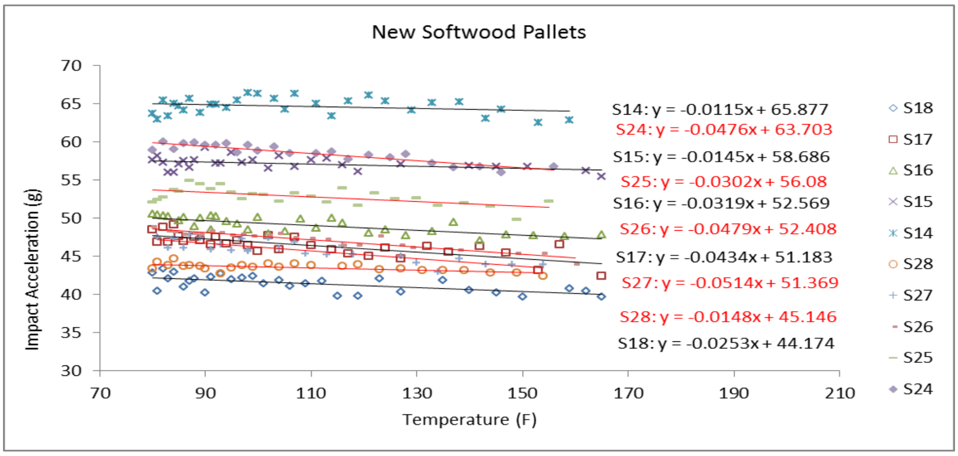

Figure 9: *Drop Test Results*

The following observations can be made from Figure 9:

- All lines shown have negative slopes. Thus, the temperature affects the impact property the same way it does for static compressive loading. As temperature rises, the wood becomes weaker, thus it deforms more. With more deformation, the pallet absorbs more impact energy, thus results in lower impact acceleration.
- The five black equations for specimen No. 1, i.e., S14, S15, S16, S17, and S18, are relatively parallel.
- The four red equations for specimen No. 2, i.e., S24, S25, S26, and S27, are also relatively parallel. S28 line seems to be skewed from the group.

- The average slope for specimen No. 1 and No. 2 are -0.025g/°F and -0.038 g/°F, respectively. The average slope of all ten specimens is -0.034g/°F with a range from -0.051g/°F to -0.012g/°F.

3.3. Incline Impact Test

Impact accelerations were plotted against temperature as shown in Figure 10. The acceleration became constant between 58°F to 72°F. Thus, only data between 48°F to 58°F was plotted in Figure 11.

The following observations can be made from Figure 11:

- The trend follows the same pattern as the static compression test and vertical drop test results. As temperature increases, the wood becomes weaker resulting in more deformation which allows more energy to be absorbed.
- On the opposite direction as temperature drops from normal temperature to near freezing, the wood becomes harder with less deformation, thus higher impact acceleration. This has potential in creating more damage to contents on the pallet.
- The rate of change as temperature increases is -0.674g/°F. Thus, dropping temperature from a temperature of 59°F to 48°F results in an increase of 7.41g of impact acceleration.

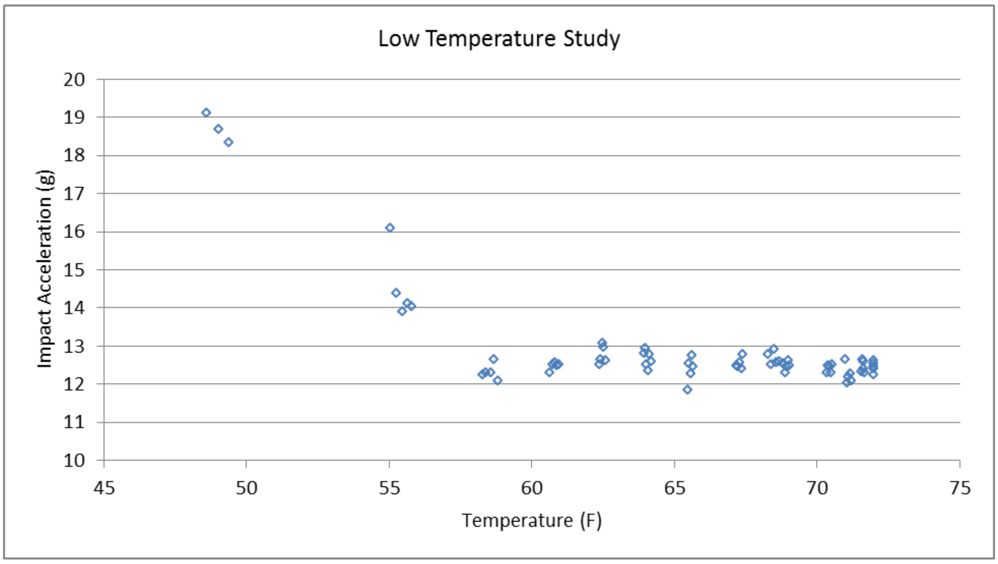

Figure 10: *Impact Acceleration vs Temperature (48°F to 72°F)*

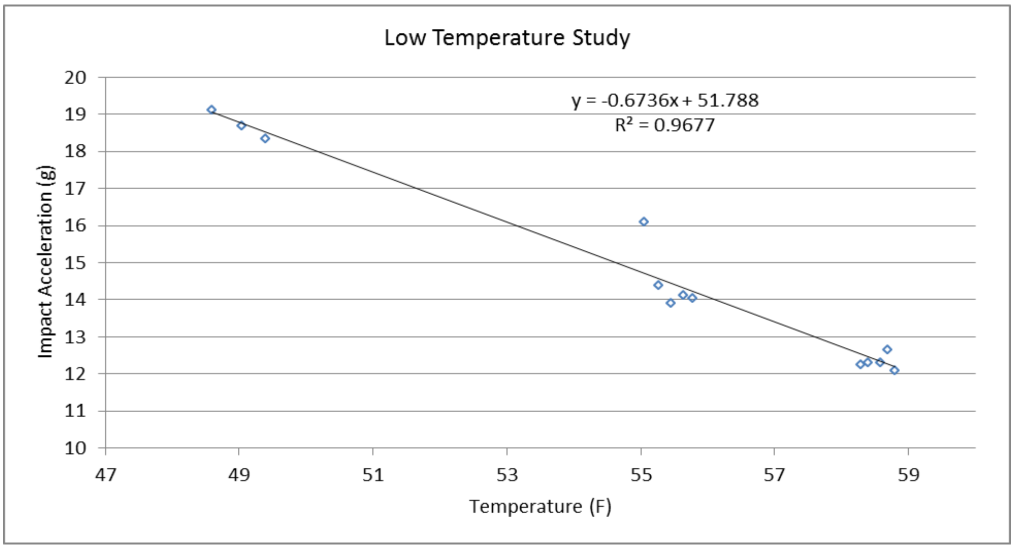

Figure 11: *Impact Acceleration vs Temperature (48°F to 59°F)*

3.4. Effect of Temperature Range

Range of temperature used in developing a temperature profile has an effect on the prediction of temperature. As an example, Figure 12 shows three cool-down temperature profiles starting from different temperatures and merging to the same room temperature. For a given test time, t_1 , three different temperatures, T_1 , T_2 , and T_3, can be predicted. However, in this study the same temperature range was used in the temperature profile development and an actual test. Thus, temperature prediction was accurate.

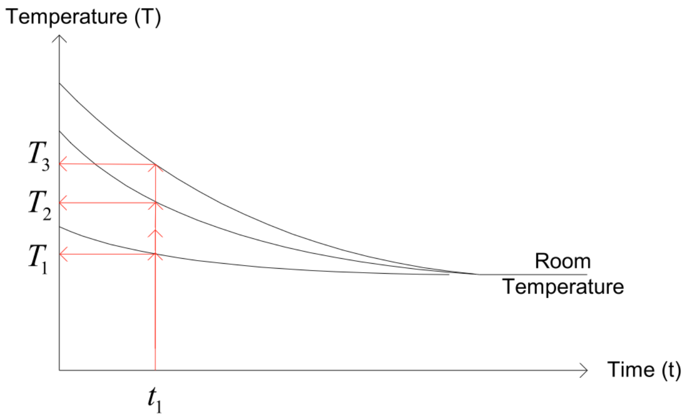

Figure 12: *Effect of Temperature Range Used in Developing Temperature Profile*

4. Conclusions

The following conclusions can be made from this study:

- As the temperature rises, wooden pallets become weaker in compression resistance. However, the drop is not significant. Within the 80°F to 160°F range used in this study, the compressive strength drops from 972 psi at 80°F to 923 psi at 160°F, which is about a 5% drop in strength.

- As the temperature rises, wooden pallets absorb more impact energy therefore the impact acceleration felt at the top of pallet is reduced. Thus, it is better off in terms of damage potential from impact for a pallet to be under high temperature, such as 160°F, than at a more normal temperature, such as 80°F.
- As temperature drops, wooden pallets absorb less impact energy. This increases the potential damage to products on pallets.
- Since wood properties vary significantly from one piece to another, the rates of change calculated in this article could vary somewhat. However, the trends should remain consistent.

Acknowledgement

The static compression test and vertical drop test of this article were previously published in the Proceedings of the 2012 HPC Fall Meeting (November 2012) in a paper entitled "*Effect of High Temperature to Compressive Strength and Impact Acceleration of New Softwood Pallets*". Use with permission from Christian Brothers University.

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Review Article **Open Access**

Plastic Tote Distribution

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Abstract Plastic totes have been commonly used to transport healthcare products from a distribution center to a retail store. Damages often occur in partially-filled totes. This article reviews the research performed at the Healthcare Packaging Consortium, including problem validation, the use of a bubble wrap sheet at the bottom of a plastic tote to cut down potential damages, the use of air pillows at the top of the a tote to reduce immediate and subsequent impact accelerations, and equations developed to predict drop height and impact acceleration at the interior tote bottom based on peak accelerations logged from a shock recorder.
Keywords *Plastic Totes; Cushion; Impact Acceleration; Drop Height*

1. Introduction

Plastic totes are commonly used to distribute products from distribution centers (DC) to retail stores. Typically the distribution cycle is daily and within a few hundred mile radius from a DC. Partially-filled totes with an unorganized arrangement of contents are usually found to be the case (Figure 1). Damages (Figure 2) of contents occur to the product packaged in loosely packed totes. These damages include abrasion, dent, corner crushing, bending, scratch, and etc., which can negatively influence customers' decision when buying the products.

Figure 1: *Unorganized Partially-Filled Plastic Tote*

Figure 2: *Samples of Damages*

The Healthcare Packaging Consortium at Christian Brothers University studied this problem during 2010 to 2012 and published findings in the Proceedings of the 2011 International Transport Packaging Forum [1], the IoPP Journal of Packaging [2, 3], and the MAESC 2012 Conference Proceedings [4, 5], which was hosted by the consortium. This article provides a review of these findings so they can be archived in one article.

2. Materials and Methods

2.1. Problem Validation

The first part of the CBU tote study was to validate the problem [1]. Two partially-filled totes were shipped to a site about 150 miles away and returned via a commercial carrier. The first tote contained randomly placed healthcare products, similar to Figure 1. The second tote contained the same products. Its contents, however, were organized to reduce voids, as shown in Figure 3. The objective of this part of the study was to see the differences, if any, between the two tote content arrangements.

Figure 3: *Tote Contents Organized to Reduce Voids*

2.2. Weight Study

Thirty free-fall, flat-bottom drops were made for totes weighing at 7.36 lb, 9.36 lb, 12.36 lb, and 16.20 lb at different drop heights of 12”, 15”, 18”, 21”, and 24” [4]. Impact accelerations were recorded using a shock recorder (red instrument on the left side of Figure 4 labeled “A”). Due to the 100-g maximum limit of the recorder, it was placed on a thick layer of bubble wrap. A single-axis accelerometer was also used to measure the impact acceleration at the tote bottom in parallel to the shock recorder. However, data from the accelerometer was not used in this study due to its inconsistency. Part “B” of Figure 4 shows the tote placement on a free-fall drop tester. The objective of this part of the study was to see the effect that different weights had on impact acceleration.

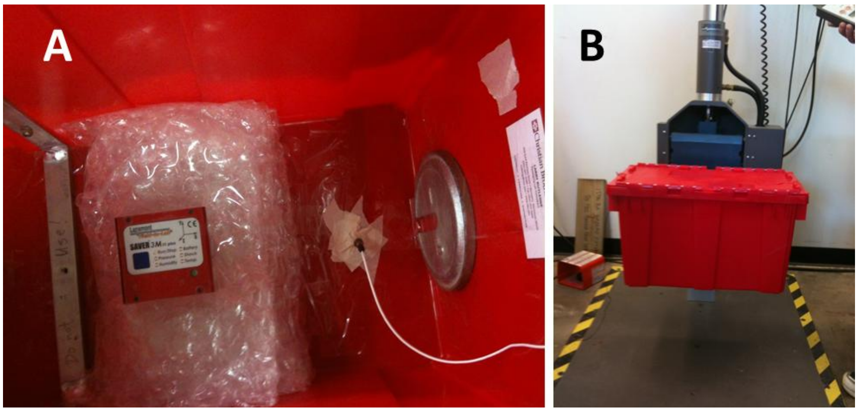


Figure 4: *Setup for Weight Study*

2.3. Cushioning at Tote Bottom and Top

An over-the-counter medication box was placed at the tote bottom with three different cushioning materials underneath: $^{3}/_{16}$” bubble wrap, $^{5}/_{16}$” bubble wrap, and ½” 1.3 lb/ft^3 viscoelastic foam [2]. A single-axis accelerometer was attached to the top of the product package (“A” in Figure 5). Impact accelerations from the accelerometer were recorded through a data acquisition system as shown in "B," "D," and "E" of Figure 5. Drop heights were 12" to 24" with a 3" increment. The purpose of this part of the study was to see the effectiveness of shock absorption of the three different cushioning materials.

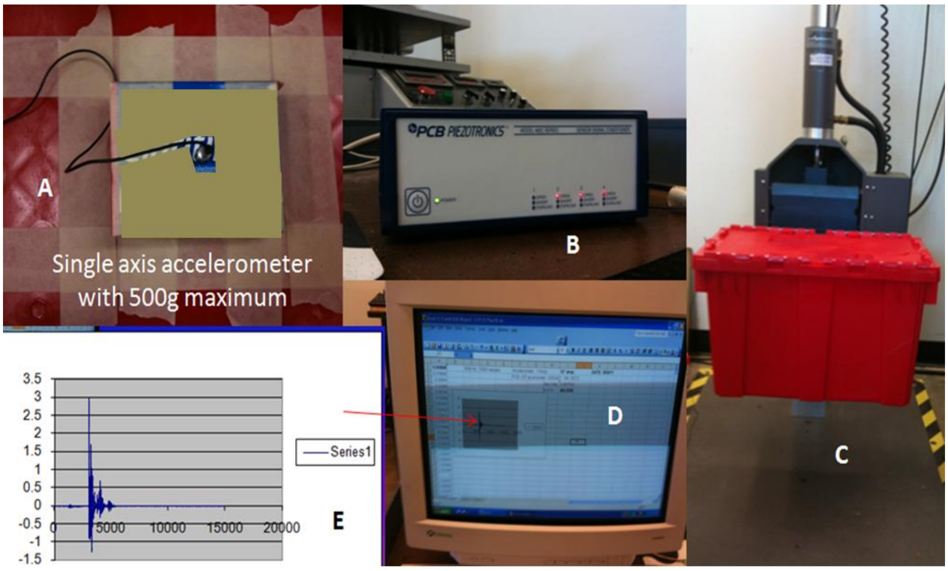


Figure 5: *Setup for Cushioning at the Tote Bottom*

Air pillows have been used to tighten up the empty space above products in a tote/box. A fixture was developed to simulate how a product moves in flexible air pillows as shown in Figure 6. The ball-bearing sleeve, labeled "B", moved in the vertical direction along the guide rod, labeled "A", then, into the air pillows or into the air when no air pillow was used. A single-axis accelerometer was mounted to the sleeve at position labeled "C." A flexible disc, shown as "D", was used as the platform to support the sleeve. A PVC pipe ("E") prevented the disc and sleeve from sliding downward. The purpose of this part of the study was to investigate the effect the air pillows had on impact acceleration.

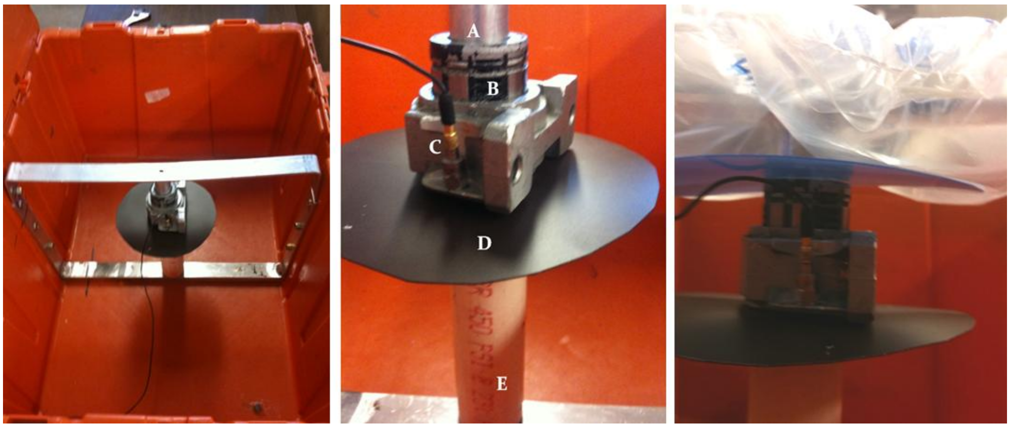


Figure 6: *Simulating Product Movement with Air Pillows on the Tote Top*

2.4. Drop Height and Impact Acceleration at Tote Bottom

A shock recorder or an accelerometer records impact acceleration. Often, it is desirable to know drop heights. Correlation of drop heights and impact acceleration was made using a shock recorder [3]. The shock recorder used in this work had a limit of 100g, thus, it was housed in a corrugated box with eight layers of $^{5}/_{16}$" bubble wrap underneath as shown in Figure 7. The box was secured in a plastic tote, which was dropped at 12" to 24" with a 3" increment. Later the experiment was extended to a 48" drop height.

Figure 7: *Shock Recorder Setup*

An attempt was made to measure impact acceleration at the tote bottom. However, due to the vibration of the thin plastic bottom of the tote, the data varied significantly. An indirect approach was used to determine the impact acceleration at tote bottom with one layer of $^{5}/_{16}$" bubble wrap from the data obtained from an experiment with multi-layers of the wrap [3].

3. Results and Discussion

3.1. Problem Validation

Damages to products, such as printed-carton abrasion and scuffing, folding-carton crushing, shrink wrap-film tares as shown in Figure 2, are numerous [1] in the randomly-placed, partially-filled tote. Organizing the products in a partially-filled plastic tote would prevent some damages. However, productivity would be reduced and training would be required. In addition, it would be hard to develop a rigid "how-to" manual/training on filling a tote appropriately due to the many product sizes, shapes, weights, as well as quantity of each product type in the tote. Only general rules based on common sense can be established.

3.2. Weight Study

Data from drop tests of different tote weights at different drop heights was compiled in Table 1 [4]. For each drop height, impact accelerations of different tote weights were comparable. Thus, the tote weight has no effect on impact acceleration. However, a heavier tote has more mass, thus, more impact force is created as determined from **F** = **ma**, where "**F**" is the impact force, "**m**" is the tote mass, and "**a**" is the impact acceleration.

Table 1: *Thirty-Drop Average of Impact Accelerations Obtained from Saver/Recorder*

Tote Weight (lbs)	12-inch Drop Height	15-inch Drop Height	18-inch Drop Height	21-inch Drop Height	24-inch Drop Height
7.36	37.90g	43.32g	49.08g	53.75g	59.32g
9.36	37.92g	43.35g	49.30g	54.56g	58.65g
12.36	37.38g	42.86g	49.12g	50.20g	54.26g
16.20	36.76g	41.76g	46.84g	52.41g	58.13g
Average =	37.49g	42.82g	48.59g	52.73g	57.59g

3.3. Cushioning at Tote Bottom and Top

Thirty-drop averages of tote with cushioning at tote bottom were summarized in Table 2 [2]. Bubble wrap placed at the tote bottom is very effective. The $^{3}/_{16}$" and $^{5}/_{16}$" wraps reduced the impact acceleration by 23% and 34%, respectively. The more expensive viscoelastic foam only reduced the impact acceleration by 9%.

Table 2: *Summary of Tote Bottom Cushioning Drop Tests*

Drop Height (in)	No Cushion	3/16" Bubble Wrap		5/16" Bubble Wrap		1/2" 1.3 lb/ft^3 Viscoelastic Foam	
	Impact Acceleration	Impact Acceleration	% Change from No Cushion	Impact Acceleration	% Change from No Cushion	Impact Acceleration	% Change from No Cushion
12	146.93g	120.09g	-18	110.03g	-25	134.45g	-8
15	200.09g	154.33g	-23	136.14g	-32	180.65g	-10
18	229.76g	179.94g	-22	151.38g	-34	209.75g	-9
21	264.25g	194.23g	-26	159.24g	-40	246.63g	-7
24	293.68g	219.18g	-25	183.65g	-37	257.99g	-12
			Avg = -23		Avg = -34		Avg = -9

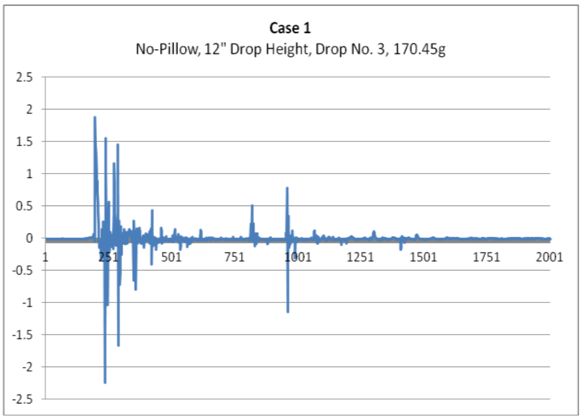
Thirty-drop averages of tote with air pillows at tote top were summarized in Table 3 [2]. On average, the impact acceleration was reduced by 15.33% by tightening up the tote contents using air pillows. In addition, air pillows reduced the subsequent impact accelerations [5] as shown in Table 4 and Figure 8, where impact acceleration versus time graphs of comparable peak impact accelerations were compared.

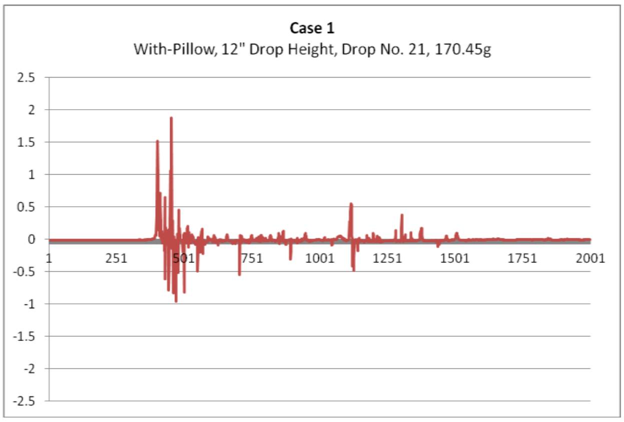
Table 3: *Summary of Tote Top Cushioning Drop Tests*

Drop Height	No Air Pillows	With Air Pillows	% Change by Adding Air Pillows
12 inches	220g	203g	-8
15 inches	252g	242g	-4
18 inches	326g	248g	-24
21 inches	347g	252g	-27
24 inches	315g	272g	-14
			Average = -15

Table 4: *Twelve Comparison Cases*

Case	Max Impact Acceleration (g)			Subsequent Impact Accelerations Reduced by Pillow?
	Drop Height (in)	No Air Pillow	With Air Pillow	
1	12	Drop No. 3 170.45	Drop No. 21 170.45	Yes
2	12	Drop No. 13 221.5	Drop No. 12 221.95	Yes
3	15	Drop No. 3 245.47	Drop No. 11 242.37	Yes
4	15	Drop No. 2 323.6	Drop No. 13 324.04	No
5	18	Drop No. 2 227.27	Drop No. 25 226.38	Yes
6	18	Drop No. 5 196.2	Drop No. 21 198.42	Yes
7	21	Drop No. 8 378.2	Drop No. 9 375.98	Yes
8	21	Drop No. 22 270.33	Drop No. 19 273.88	Yes
9	24	Drop No. 25 289.42	Drop No. 8 288.97	Yes
10	24	Drop No. 13 239.26	Drop No. 1 242.81	Yes
11	12/18	Drop No. 9 (12-in) 299.18	Drop No. 16 (18-in) 299.63	Yes
12	21/15	Drop No. 14 (21-in) 282.76	Drop No.16 (15-in) 280.54	No





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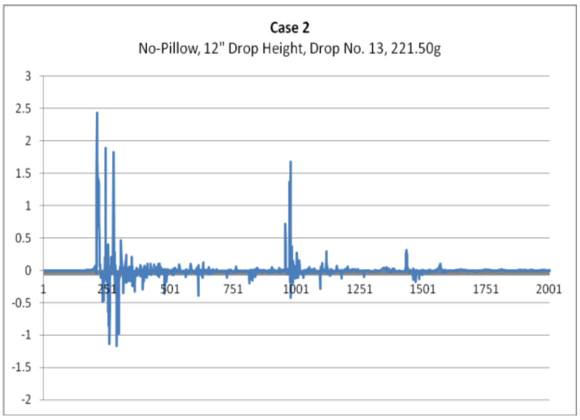

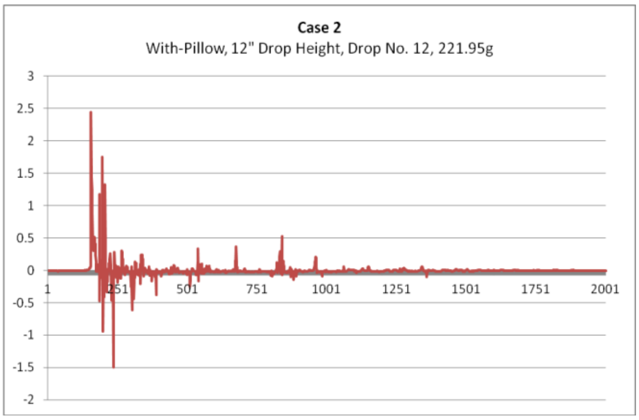

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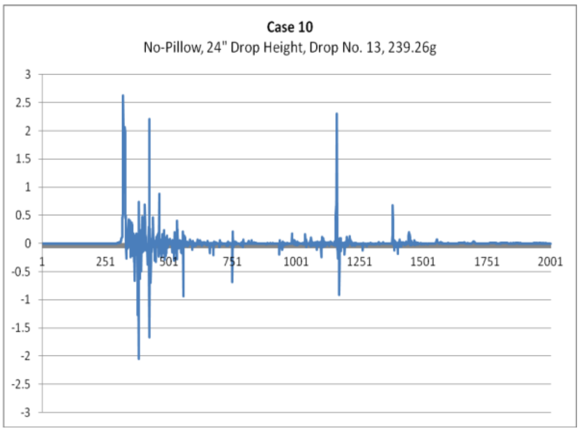

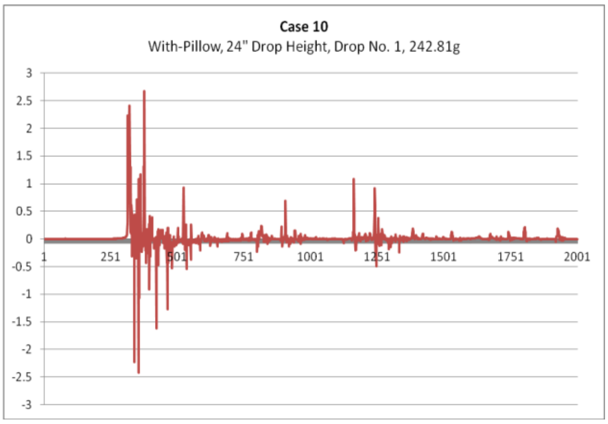

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Figure 8: *Effect of Air Pillows on Subsequence Impact Accelerations – Comparison Samples*

Validation of the effectiveness of using bubble wrap at tote bottom and/or air pillows at tote top was performed using vibration and drop tests. For each test, the four totes contained the same products randomly placed. However, the randomness was kept consistent among the four totes. The first tote used had no cushion, while the 2nd, 3rd, and 4th used $^{5}/_{16}$" bubble wrap at tote bottom, air pillows at tote top, and bubble wrap at tote bottom together with air pillows at tote top, respectively. Figure 9 shows a $^{5}/_{16}$" bubble wrap sheet and air pillows placed at tote bottom and top.

Figure 9: *Bubble Wrap Sheet (left) and Air Pillows (right)*

A one-hour vibration sequence was used per ISTA Procedures 1C, 1D, 1E, 1F, 1G, 1H, 2A, 2B, and 4G [6]. Flat-bottom, free-fall drops at a 24-inch drop height was used in the validation. Validation results are shown in Tables 5 and 6. Using both bubble wrap at tote bottom and air pillows at tote top were found to be most effective.

Table 5: *Vibration Validation Test Results*

Case	Damaged Items	Damage Type
No cushion	5 out of 18 items	Abrasion (1 item) Dent (1 item) Corner crushing (2 items) Bending (1 item)
Bubble wrap sheet at bottom	4 out of 18 items	Edge crushing (1 item) Bending (1 item) Scratch (1 item) Corner crushing (1 item)
Air pillows at top	2 out of 18 items	Abrasion (2 items)
Bubble wrap sheet at top and air pillows at bottom	0 out of 18 items	None

Table 6: *Drop Validation Test Results*

Case	Damaged Items	Damage Type
No cushion	6 out of 18 items	Edge crushing (3 items) Bending (2 items) Dent (1 tiem)
Bubble wrap sheet at bottom	3 out of 18 items	Edge crushing (3 items)
Air pillows at top	2 out of 18 items	Edge crushing (2 items)
Bubble wrap sheet at top and air pillows at bottom	1 out of 18 items	Edge crushing (1 item)

3.4. Drop Height and Impact Acceleration at Tote Bottom

Thirty-drop impact acceleration averages per drop height were summarized in Table 7 [3]. Initially, data from 12" to 24" drop heights was used to develop an equation to estimate a drop height for a given impact acceleration. Later the range was expanded from 12" to 48" drop heights. Thus, the following two equations were obtained, where y = estimated drop height (inches) and x = saver's impact acceleration (g):

$y = 0.5243x - 3.4853$ (R^2=0.969) for drop heights from 12" to 24" … Eqn. (1)
$y = 0.5082x - 2.7711$ (R^2=0.9989) for drop heights from 12" to 48" … Eqn. (2)

Validation was made using 85 independent drop data (Figure 10). Both equations yield comparable results. Equation 1, though, yields slightly better results at higher drop heights. However, realistic drop heights are in the range of 12" to 24".

Table 7: *Average Recorder's Impact Acceleration from 30 Drops per Drop Height with 8 Layers of 5/16" Bubble Wrap underneath the Recorder*

Drop Height (in)	Average Recorder's Impact Acceleration (g)
12	30.67
15	35.33
18	39.76
21	45.52
24	52.37
27	58.15
30	64.73
33	70.63
36	76.72
39	82.27
42	88.40
45	94.38
48	99.32

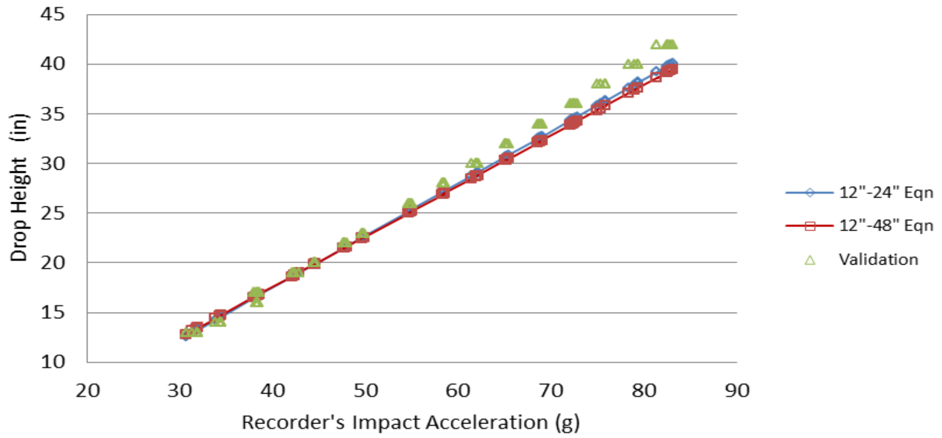

Figure 10: *Validation of Drop Heights Using 85 Drops*

To develop an equation to estimate the impact acceleration at the interior tote bottom, initially, direct measurement using an accelerometer was used. However, it was shown [3] that data collected was inconsistent with standard deviations in the range of 25% to 37% of average values. An indirect approach was then developed using 3 to 8 layers of $^5/_{16}$" bubble wrap. One and two layers of bubble wrap yielded unacceptable standard deviations. Data from 3 to 8 layer cases was used to predict the impact acceleration with one layer of $^5/_{16}$" bubble wrap. It should be noted that one layer of $^5/_{16}$" bubble wrap at tote bottom was recommended since it was shown to reduce impact acceleration by 34% in Table 2. These predicted impact accelerations were then correlated with drop heights to yield the following equation:

$$y = 4.1854x + 146.68 \qquad \text{… Eqn. 3}$$

Where x = drop height obtained from Equation 1 (inches) and y = impact acceleration at tote bottom with a layer of $^5/_{16}$" bubble wrap (g).

Validation was made using the 85 data points used earlier in drop height prediction. Three different trend lines were plotted in Figure 11; (1) direct approach (12" to 24" drop height range), (2) indirect approach (12" to 24" drop height range), and (3) indirect approach (12" to 42" drop height range). As can be seen, the two trend lines using indirect approach yielded much better results than that from direct approach. Also, the 12" to 24" range trend line was slightly better since it divided validation data points almost 50-50, i.e., 43 above and 42 below, while the 12" to 42" range trend line had 48 above and 37 below. It should be noted that the 85 data points for validation were obtained using direct measurement which yielded highly inconsistent data.

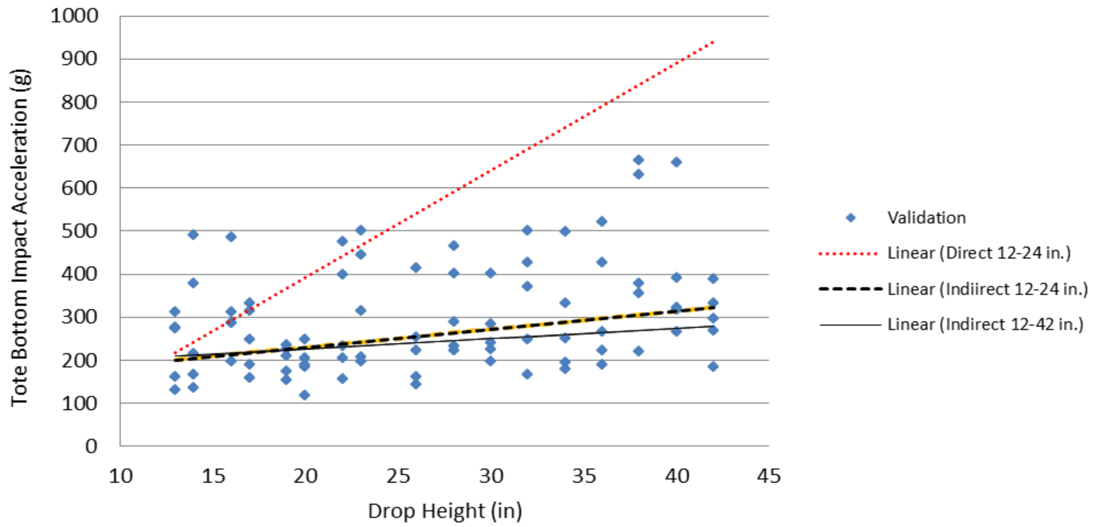

Figure 11: *Validation of Tote Bottom Impact Acceleration*

4. Conclusions

From the tote study at the Healthcare Packaging consortium, the following conclusions/ recommendations can be made:

- Randomly and partially filled plastic totes have high potential of product damages.
- Tote weight does not affect impact acceleration. However, heavier totes result in higher impact force.
- Providing a layer of $^{5}/_{16}$" bubble wrap sheet at the bottom of the tote interior could reduce impact acceleration by 34% while tighten up the space at the top using air pillows could reduce impact acceleration by 15%. Using both a bubble wrap sheet at tote bottom together with air pillows at tote top is the most effective way to reduce product damages.
- A drop height could be estimated accurately from an impact acceleration obtained from a shock recorder using Equation 1 given that the recorder is set the way described in this article.
- Impact acceleration at tote bottom is hard to predict. Equation 3 can provide an estimate, which could be off significantly from an actual single drop.
- All data presented was based on flat-bottom drops. Real-life drops could be on an edge or a corner, which would result in much higher impact accelerations.

Acknowledgement

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Research Article **Open Access**

Effect of Cushion Placed on Wooden Pallets

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Abstract Wooden pallets are commonly dropped vertically and hit horizontally during distribution. To reduce the impact, it seems logical to place cushioning materials on a pallet. In this study an anti-vibration pad was used in free-fall vertical drop tests and horizontal impact tests of softwood pallets. Results indicate that placing cushioning materials on a pallet does in fact increase impact acceleration significantly due to the uneven surface of the top board of the pallet in the free-fall drop case and due to the additional friction force from the cushioning materials in the horizontal impact case. Thus, placing cushioning materials on wooden pallets is not recommended.
Keywords *Wooden Pallets; Free-Fall Drop; Side Impact; Cushion*

1. Introduction

Wooden pallets are used widely in carrying goods during the distribution stage. They are normally handled by forklifts. A pallet could be dropped vertically or hit horizontally by a forklift. Merchandises on the pallet feel the shock from a drop or a hit. Cushioning materials have been used in containers to absorb shock, resulting in the reduction of potential damages to the merchandise. Thus, it would be logical to place cushioning materials on a pallet to absorb the shock, even though this is not common due to the added cost of the cushion. The purpose of this study is to determine if the addition of cushion reduces the shock received from a vertical drop or a horizontal impact.

2. Materials and Methods

2.1. Free-Fall Vertical Drop

A full pallet was dropped vertically from a drop tester (Figure 1a) with a shock recorder mounted at the center of the pallet (Figures 1a and 1b). The pallet was then lifted up 8 inches and dropped to the steel base of the tester. About twenty drops were made for two setups; (1) no cushion and (2) with cushion between the pallet's top board and shock recorder. An anti-vibration pad (Figure 1c), used for reducing vibration from machinery transmitted to the floor, was used as a cushioning material in this study.

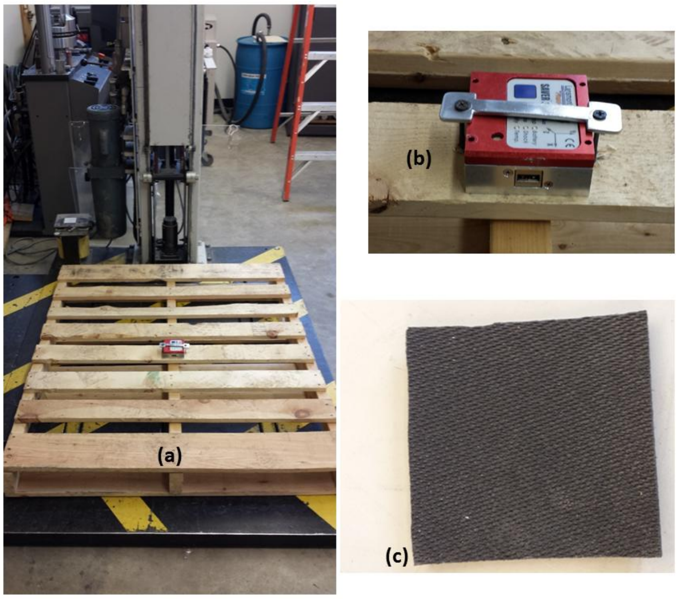

***Figure 1**: (a) Pallet on Drop Tester, (b) Shock Recorder, and (c) Anti-Vibration Pad*

2.2. Incline Impact

A specimen was cut from a softwood pallet stringer and one end clamped to a custom-built incline impact tester's back panel (Figure 2a). The other end of the specimen was hit by the sliding plate to simulate the impact experienced from a forklift. A piece of the pallet's top board was attached to the specimen with a shock recorder mounted to the top (Figure 2b). About twenty hits were made for two setups; (1) no cushion and (2) with cushion between the pallet's top board and shock recorder. An aluminum plate shown in Figure 2b was later added (to be discussed later in this article). A steel bent (shown in Figure 2b but not shown in Figure 2a) was used to cover the end of the specimen to protect damages from repeated hits received by the sliding panel. The same anti-vibration pad (Figure 2c) used in the vertical drop test was utilized. The tri-axial recorder was set to align with the direction of impact so impact acceleration is independent of the incline angle. This setup for impact study yields more consistent results than the free-fall drop test [1] and is a better simulation of horizontal hits obtained from a forklift.

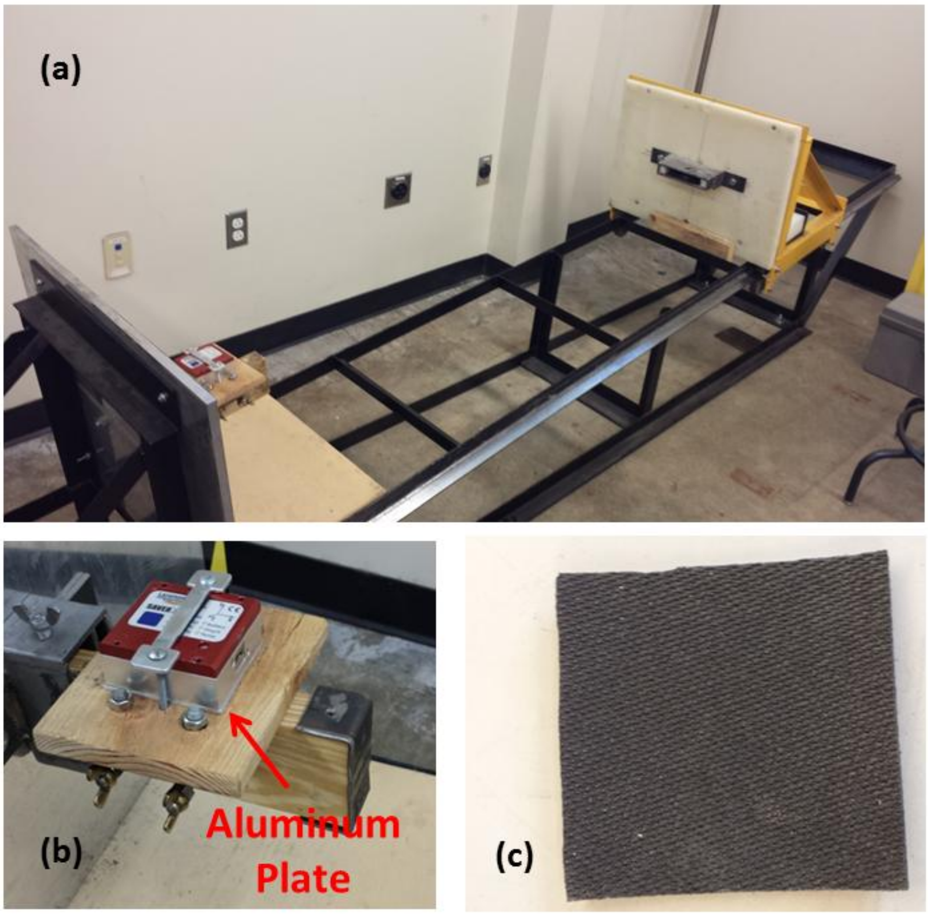

Figure 2: *(a) Specimen Setup for Incline Impact Test, (b) Shock Recorder, and (c) Anti-Vibration Pad*

3. Results and Discussion

3.1. Free-Fall Vertical Drop

Impact accelerations from about twenty drops at an 8-inch drop height were attained by a shock recorder. They are shown in Cases 1 and 2 of Table 1, where the recorder was placed directly on the pallet's top board with and without an anti-vibration pad between the top board and shock recorder. Sketches of the two cases are shown in Figure 3. The shock recorder with the anti-vibration pad underneath felt about 14% more impact than without the pad. Thus, the pad does not help in reducing the shock from a drop, which is counter intuitive.

Table 1: *Drop Test Data & Results*

	Impact Acceleration (g) at 8-inch Drop Height			
	Case 1 Wood + Recorder	**Case 2** Wood + Cushion + Recorder	**Case 3** Wood + Aluminum Plate + Recorder	**Case 4** Wood + Aluminum Plate + Cushion + Recorder
1	25.20	40.60	40.34	32.15
2	33.51	46.30	36.95	33.59
3	26.90	43.18	32.8	20.72
4	31.81	32.83	36.89	36.96
5	27.58	38.95	44.47	27.45
6	25.75	30.65	42.07	31.64
7	21.41	38.51	34.81	40.93
8	31.76	33.15	30.39	37.34
9	35.61	24.11	44.06	19.82
10	31.48	39.46	34.91	31.38
11	27.80	24.61	39.8	34.18
12	25.74	31.10	42.5	36.99
13	28.63	31.90	40.93	29.45
14	34.56	27.91	37.06	32.81
15	30.45	37.50	33.13	38.16
16	37.66	35.53	18.93	19.56
17	33.06	21.97	21.89	19.22
18	34.86	39.40	42.11	41.2
19				27.73
AVG (g) =	**30.21**	**34.31**	**36.34**	**31.12**
SD (g) =	**4.33**	**6.82**	**7.09**	**7.12**
SD (% of AVG) =	**14.35**	**19.86**	**19.51**	**22.89**
Change (%) =		**13.59** (Change from Case 1)		**-14.35** (Change from Case 3)

Typically, the surface of a pallet's top board is not smooth. The contact area between the shock recorder and wood surface when no pad was used (Figure 4a) is less than when a pad was used (Figure 4b). The pad was quite flexible and elastic, thus it was pushed to fill in the uneven wood surface. More contact area allows more shock to transmit from the bottom of the pallet up toward the shock recorder located on the top. To prove this explanation, an aluminum plate was placed above the pallet's top board (Figure 5). Impact accelerations captured by the shock recorder were read for cases with and without the anti-vibration pad between the aluminum plate and shock recorder and summarized in Cases 3 and 4 of Table 1. Sketches of these two new cases are shown in Figure 3. Both cases were based on the same contact area between the aluminum plate and wood surface. It turned out that the pad reduced about 14% of the impact.

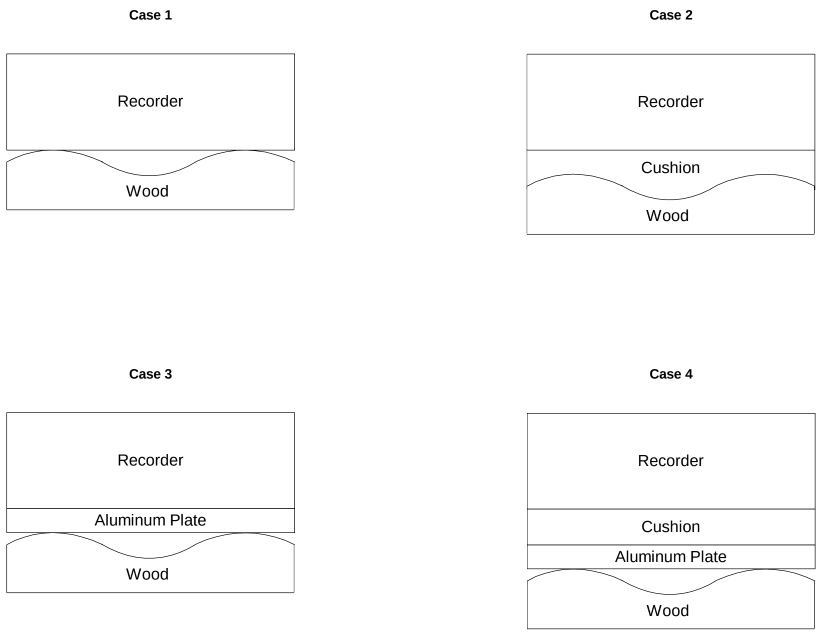

Figure 3: *Four Setup Cases*

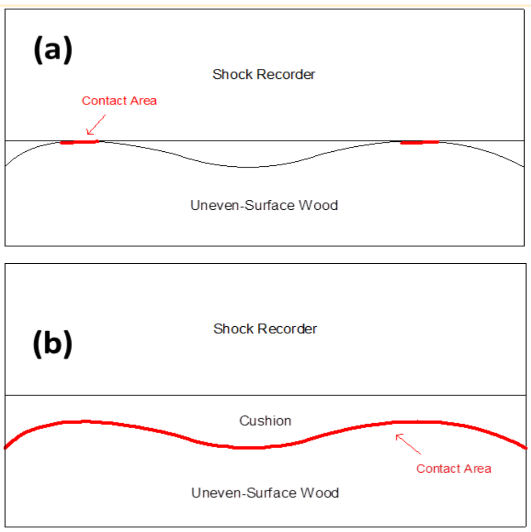

Figure 4: *(a) Shock Recorder Placed on Pallet Top Board without Cushion; (b) Shock Recorder Placed on Pallet Top Board with Cushion*

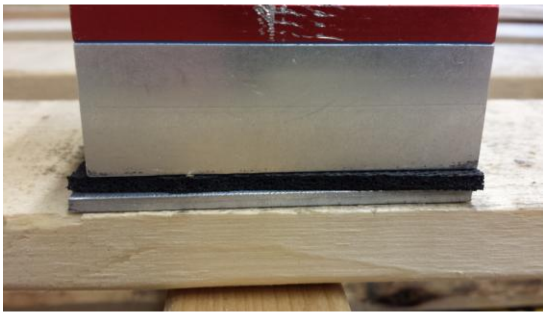

Figure 5: *Aluminum Plate Placed on the Pallet Top Board with Cushion above (Case 4)*

3.2. Incline Impact

Impact accelerations of about twenty side impacts were captured by a shock recorder. They are shown in Cases 1 and 2 of Table 2, where the recorder was placed directly on pallet's top board with and without anti-vibration pad between the top board and shock recorder. These are the same cases used previously in Table 1 and Figure 3. The shock recorder with anti-vibration pad underneath felt about 3% more impact than without the pad. Thus, the pad does not help in reducing the shock from a side impact, which is counter intuitive.

Table 2: *Side Impact Test Data & Results*

	Impact Acceleration (g) From Side Impact				
	Case 1 Wood + Recorder	**Case 2** Wood + Cushion + Recorder	**Case 3** Wood + Aluminum Plate + Recorder	**Case 4** Wood + Aluminum Plate + Cushion + Recorder	**Case 5** Wood + Aluminum Plate + Cushion + Aluminum Plate + Recorder
1	14.43	12.44	13.86	13.66	14.85
2	12.79	14.37	14.62	17.39	16.81
3	13.09	14.49	14.43	18.74	17.39
4	13.1	14.03	14.15	19.68	17.4
5	13.46	13.62	14.7	20.15	16.02
6	13.67	14.09	14.07	20.5	16.41
7	13.78	13.82	14.04	20.37	15.98
8	13.48	15.01	14.64	20.76	14.09
9	13.82	15.22	14.08	21.79	14.57
10	13.73	14.39	14.1	21.02	14.28
11	13.61	14.98	14.62	20.89	14.46
12	13.86	14.18	14.51	22.26	14.39
13	13.64	14.28	14.97	20.98	15.37
14	14.17	14.31	14.27	20.6	15.61
15	14.5	14.24	15.27	20.25	15.98
16	14.42	14.81	15.63	21.08	16.58
17	14.17	14.01	15.2	21.01	18.1
18	14.23	13.75	15.46	20.97	
19	14.73	14.64	14.96	21	
20	14.38	14	15.83	21.69	
AVG (g) =	**13.85**	**14.23**	**14.67**	**20.24**	**15.78**
SD (g) =	**0.52**	**0.60**	**0.58**	**1.88**	**1.23**
SD (% of AVG) =	**3.77**	**4.24**	**3.93**	**9.28**	**7.78**
Change (%) =		**2.75** (Change from Case 1)		**37.96** (Change from Case 3)	**-22.02** (Change from Case 4)

As in the vertical drop experiment above, an aluminum plate was placed on the pallet's top board and the shock recorder was placed with and without the anti-vibration pad underneath. Data was summarized in Cases 3 and 4 of Table 2 (same as those used previously in Table 1 and Figure 3). Instead of reduction in impact acceleration as in the vertical drop situation, the shock recorder with anti-vibration pad underneath felt 38% more impact than without the pad. Since the impact force was applied horizontally to the free end of the stringer, the recorder on the top board tended to slide horizontally which was resisted by a friction force. The anti-vibration pad gave a higher coefficient of friction, thus gave more resistance and resulted in more impact. To prove this friction concept, an additional aluminum plate was placed between the anti-vibration pad and recorder (Figure 6). Data was summarized in Case 5 of Table 2. The additional aluminum plate cut down the coefficient of friction significantly. The recorder in Case 5 felt about 22% less impact than that in Case 4. Clamping force had direct effect on this friction force. In this study, clamping force was not accurately controlled, thus the results could be off somewhat. In a real situation clamping force depends on the weight of packages on the cushion. Heavier packages would create more friction force, thus more impact would be felt by the packages.

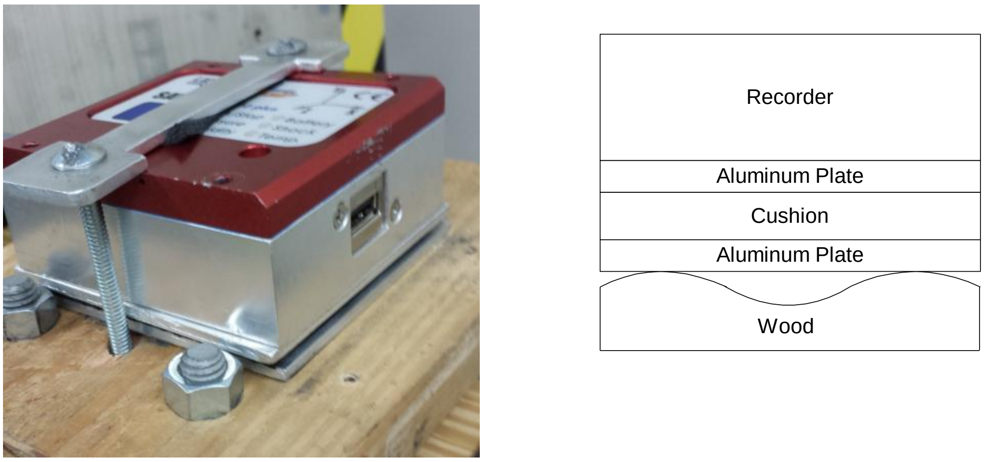

Figure 6: *Anti-vibration Pad Placed Between Two Aluminum Plates (Case 5)*

4. Conclusion

In practice placing a sheet of cushion, such as the anti-vibration pad used in this study, would add cost to the pallet. Manufacturers would be reluctant to add the cost to pallets since most distributions are one way. However, for some expensive merchandise one might attempt to place some cushion to reduce the impact which could reduce product damage potential. This study shows that placing cushion on a wooden pallet would increase damage potential to the product. This is due to the increased contact area in the case of the vertical drop and the increased coefficient of friction in the case of the slide impact.

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Dear Readers:

Volume 1 of the **International Journal of Advanced Packaging Technology** has finally come to the end. As the official journal of the Healthcare Packaging Consortium, it is very fitting to showcase the research work of the consortium in this premiere volume.

On behalf of the journal, I would like to thank the following individuals who were involved with Volume 1 of the journal:

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We look forward to contributions from other organizations for future volumes of the journal. Together we will create a great resource for packaging researchers, professionals, and students.

Happy Holidays!

S. Malasri

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