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COMPRESSION TESTING OF HONEYCOMB PAPER  
PALLETS

presented by

Ravi Verma

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**COMPRESSION TESTING OF HONEYCOMB PAPER PALLETS**

**By**

**Ravi Verma**

**A THESIS**

**Submitted to  
Michigan State University  
In partial fulfillment of the requirements  
for the degree of**

**MASTER OF SCIENCE  
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## **ABSTRACT**

### **COMPRESSION TESTING OF HONEYCOMB PAPER PALLETS**

**By**

**Ravi Verma**

106 Honeycomb paper pallets, nonreversible type, manufactured by *EcoDuro* Inc. and L & F Inc. were compression tested in Distribution Dynamics Lab of School of Packaging. 98 Pallets had footprint of 48" X 40". Deck variable were: Material (Basis weight 42 lbs, 69 lbs and 90 lbs). Cell sizes variation was 7/16", 3/8", and 1/2". Deck thickness tested was 7/8", 1", 1 & 3/16", and 1 & 1/4". Stringer variables included—Material (Brown colored form-board, white colored chip-board, and tubes made from recycled Kraft paper that are spirally wound). Thickness of stringer varied from 0.08", 0.1", 0.12", 0.16" and 0.2". Stringer stuffing's varied from fully stuffed to 3 blocks stuffing, tubes, wrapped blocks and tube blocks. Some of the pallets were conditioned at 90 % relative humidity and 90 degrees F for 24 hours. The testing followed a modified ASTM D-1185, "Standard Test Methods for Pallets and related structures employed in Materials handling and shipping", test protocol for paper pallets. The pallets were evaluated with flexible and rigid load on Lansmont Model 1S2-30TTC at room temperature. For half an inch deflection the values for decks range from 1400 to 1800 lbs and for stringers between 14000 to 23000 lbs at 72 F and 50 % RH. Loss in strength of decks and stringers is about 20 % and 24% respectively after conditioning at 90 F and 90 % RH for 24 hours period.

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# 1. The Test Protocol

Table 1-1: Testing protocol, School of Packaging.

**Table 1-1:** Paper Honeycomb Pallets Testing Protocol, School of Packaging, Michigan State University.

No	Manufacturer	Pallet foot print	Approximate Deck Thickness	Cell size	Liner weight	Structure	Description of the rails	Quantity
1	EcoDuro Inc.	48 X 40	1"	1/2"	69	Single	0.12" rails - 4 way	6
2	EcoDuro Inc.	48 X 40	1"	3/8"	69	Single	0.16" rails - 4 way	6
3	EcoDuro Inc.	48 X 40	1"	1/2"	69	Single	0.2" rails - 4 way	6
4	EcoDuro Inc.	48 X 40	1 1/4"	3/8"	90	Single	0.12" rails - 4 way	6
5	EcoDuro Inc.	48 X 40	1"	3/8"	69	Single	0.12" rails with Tube blocks - 4 way	5
6	EcoDuro Inc.	48 X 40	7/8"	1/2"	69	Single	0.1" rails - 4 way	6
7	EcoDuro Inc.	48 X 40	1"	1/2"	69	Single	0.12 rails fully stuffed - 2 way	6
8	EcoDuro Inc.	48 X 40	1 1/4"	3/8"	90	Single	0.16" tubes with stuffed ends - 2 way	6
9	EcoDuro Inc.	48 X 40	1 1/4"	1/2"	69	Single	0.16" rails - 4 way	6
10	EcoDuro Inc.	48 X 40	1 1/4"	1/2"	90	Single	0.16" rails - 4 way	6
11	EcoDuro Inc.	48 X 40	1	1/2"	69	Single	6" X 8" wrapped blocks - 4 way	6
12	EcoDuro Inc.	48 X 40	1 1/4"	3/8"	90	Single	5.5" X 8" Tube blocks - 4 way	6
14	EcoDuro Inc.	48 X 40	1"	3/8"	69	Single	0.1" rails - 4 way	6
15	EcoDuro Inc.	48 X 40	1"	3/8"	69	Single	0.08" rails - 4 way	6
16	EcoDuro Inc.	48 X 40	1 1/4"	3/8"	90	Single	0.12" rails - 4 way	6
17	L & F Inc.	48 X 40	1 1/4"	7/16"	69	Single	0.2" rails - 4 way	6
18	EcoDuro Inc.	48 X 40	1 3/16	3/8"	69	Single	0.16" rails - 4 way - unexpanded	3
19	EcoDuro Inc.	40 X35	1/2" X 2	1/2"	42	Double	0.12" rails - 2 way - cross laminated	4
20	EcoDuro Inc.	42 X 42	1/2" X 2	1/2"	42	Double	0.12" rails - 2 way - cross laminated	4
TOTAL PALLETS								106



Figure 1-1: Pallet. Reference: <http://www.ecoduro.com/>

The above figure has been redrawn from the website.

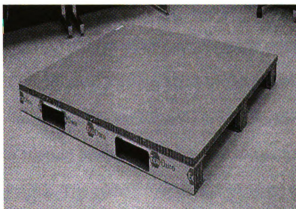


Figure 1-2: Pallet. Reference: <http://www.ecoduro.com/>

## **2. The Test**

### **2.1 Type of testing:**

The pallets manufactured by *EcoDuro* inc. and L&F inc. were tested for basis strength performance in constant deflection rate compression testing.

### **2.2 Pallet size tested:**

- 48X40, nonreversible, 4 way *EcoDuro* pallets.
- 48X40, nonreversible, 4 way L&F pallets.
- 48X40, nonreversible, 2 way *EcoDuro* pallets.
- 40X35, nonreversible, 4 way *EcoDuro* pallets.
- 40X42, nonreversible, 4 way *EcoDuro* pallets.

### **2.3 Test Methods:**

The testing followed a modified ASTM D-1185, Standard Test Methods for Pallets and Related Structures employed in Materials handling and shipping, test protocol for paper pallets. Computer assisted, calibrated compression testing machine, Lansmont Compression Testing Machine, Model 1S2-30TTC, was used. This machine has sufficient load capacity to structurally fail the pallet and a sufficient large bed to support the pallet. This machine has a floating head to apply rigid or flexible loads. The pallets (deck and stringers) were evaluated with flexible and rigid load. For the flexible load test and for full coverage, the load was applied by placing an airbag between the floating head and the pallet on the fixed bed. For the rigid load test, the load was applied without a rigid plate (wooden plank) between the floating head and the pallet on the bed of the

machine. The load and deflection was measured by the computer and graphs for every test were plotted by the computer. Machine set up was as follows: yield point: 30%; Maximum deflection: 2"; Stop force: 30000 lbs; Preload: 500 lbs; Test mode: constant rate; Test speed: 0.5" per minute.

Depending upon the type of deck and configuration of the stringers, the liner (top and bottom facings) of *EcoDuro* Inc. Pallets were of basis weight 42, 69 or 90. The core was of basis weight 32. The stringers, fabricated by cutting the paper tubes of various thicknesses, had punched holes for 4 way entry configuration. The stuffing's in stringers were of basis weight 69 and having core of basis weight 32. Patented adhesive was used for manufacturing and assembly of pallets. The liners for L & F pallets decks were of basis weight 69 and core of basis weight 32. 18 different types of pallets manufactured *EcoDuro* were tested. Only one type of pallet made by L & F with 6 replicates was tested. Total number of pallets tested was 106. Refer to protocol for details. Some replicates were conditioned for 24 hours at 90 F and 90% RH. All tests were carried out in room temperature conditions.

**Table 2-1: Lansmont Test Machine set up details**

Machine Set Up for tests	
Yield Point	30%
Maximum Deflection	2"
Stop Force	30000 lbs
Preload	500 lbs
Test Mode	Constant rate
Test Speed	0.5" per minute

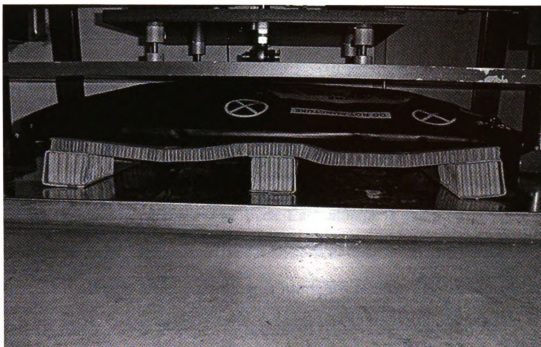


Figure 2-1: Compression Test in progress

### **3. The Pallets**

#### **Pallet 1**

This pallet manufactured by EcoDuro Inc. is single layer, 4-way with 3 stringers and has a foot print of 48" X 40". The top deck is 1" thick with cell size ½" (core – 33 lbs basis) and liner of 69 lbs basis weight. The brown colored stringers are made of "Formboard", and are 0.12" thick. Each stringer is stuffed with 3 numbers of honeycomb blocks. The dimensions of each block are: Length - 8.5", Width: 3.25", Height: 3.25". Each stringer has two punched holes of dimensions 8" X 2.75" along its wall and is at 9" from each end of the stringer. Figures 3-1 and 3-2 give two views of the pallet.

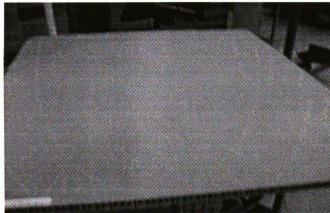


Figure 3-1: Top deck of the Pallet 1.

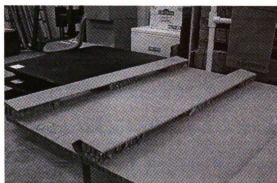


Figure 3-2: Stringers of the Pallet 1.

Table 3-1 gives the maximum compressive strength of the stringers for the pallet and Table 3-2 gives the performance data for the deck respectively.

Table 3-1: Compressive strength of the stringers for Pallet 1.

Pallet Number, footprint	Conditioning	Sample	Force at Yield point, Pounds	Deflection at Yield point, inches
1, 48" X 40"	72 F, 50% RH	1	8775.1	0.3
	72 F, 50% RH	2	9157.6	0.27
		Average	8966.35	0.285
	90F, 90% RH	1	6700.9	0.32

Table 3-2: Performance of the deck for the Pallet 1.

Pallet Number, footprint	Conditioning	Sample	Force at Yield point, Pounds	Deflection at Yield point, inches
1, 48" X 40"	72 F, 50% RH	1	1600	0.56
	72 F, 50% RH	2	1700	0.58
		Average	1650	0.57
	90F, 90% RH	1	1400	0.5

## **Pallet 2**

This pallet has a footprint of 48" by 40" and is 4-way with 3 stringers. It is single layer and the deck is 1" thick. The cell size is 3/8" (core –26 lbs basis) and the top liner is 69 lbs basis weight. The stringers are 0.16" thick and made of "Chipboard" with "EcoDuro" printed on it. EcuDuro Inc manufactures the pallet. The stringers have two holes (8" by 2.75") punched at 9" from each end. The stringers are stuffed with honeycomb blocks, each of dimensions: 8.5" X 3.25" X 3.25", cell size 1/2" and 69 lbs liner.

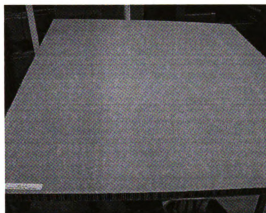


Figure 3-3: Top view of the Pallet 2.

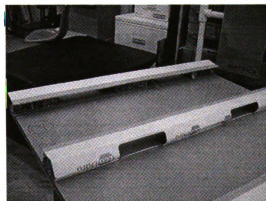


Figure 3-4: 3 Stringers, each with 2 holes of Pallet 2.

Table 3-3 and Table 3-4 give the compressive strength of the stringers and performance of decks respectively.

**Table 3-3: Compressive strength of the stringers for Pallet 2.**

Pallet Number, footprint	Conditioning	Sample	Force at Yield point, Pounds	Deflection at Yield point, inches
2, 48" X 40"	72 F, 50% RH	1	9520.6	0.32
	72 F, 50% RH	2	9234.1	0.31
		Average	9377.35	0.315
	90F, 90% RH	1	6818	0.38

**Table 3-4: Performance of the deck at first yield point of Pallet 2.**

Pallet Number, footprint	Conditioning	Sample	Force at Yield point, Pounds	Deflection at Yield point, inches
2, 48" X 40"	72 F, 50% RH	1	1450	0.42
	72 F, 50% RH	2	1800	0.61
		Average	1625	0.515
	90F, 90% RH	1	1400	0.5

### **Pallet 3**

The pallet has 1" thick deck and is single layered. *EcoDuro* manufactures this type of 4-way pallet. The footprint is 48" X 40" and the cell size is  $\frac{1}{2}$ " (core –33 lbs basis). The top liner has a basis weight of 69 lbs. It has 3 stringers, each 0.2" thick. They are white in color, 0.2" thick, and made from "Chipboard" with "EcoDuro" printed on it. The stringers have holes (8.5" X 2.75") punched at 9" from each end. Each stringer is stuffed with 3 honeycomb blocks of dimensions 8.5" X 3.25" X 3.25"; cell size  $\frac{1}{2}$ " with 69 lbs liner. Figures 3-5 and 3-6 give two views of the pallet.

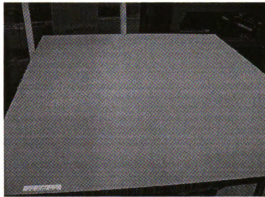


Figure 3-5: Top view of the Pallet 3.

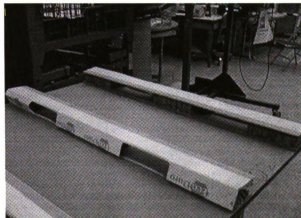


Figure 3-6: The 3 stringer construction of Pallet 3.

Table 3-5 and Table 3-6 give the compressive strength of the stringers and performance of deck respectively.

**Table 3-5: Compressive strength of the stringers for Pallet 3.**

Pallet Number, footprint	Conditioning	Sample	Force at Yield point, Pounds	Deflection at Yield point, inches
3, 48" X 40"	72 F, 50% RH	1	13181.8	0.3
	72 F, 50% RH	2	10910.3	0.32
		Average	12046.05	0.31
	90F, 90% RH	1	7848.8	0.3

**Table 3-6: Measure of the load at first yield point for the deck for Pallet 3.**

Pallet Number, footprint	Conditioning	Sample	Force at Yield point, Pounds	Deflection at Yield point, inches
3, 48" X 40"	72 F, 50% RH	1	1800	0.63
	72 F, 50% RH	2	1600	0.55
		Average	1700	0.59
	90F, 90% RH	1	1200	0.37

#### **Pallet 4**

EcoDuro Inc. manufactures this type of 4-way pallet with deck of thickness 1.25". It has a single layer and 3 stringers of 0.12" thickness. The deck cell size is 3/8" (core –26 lbs basis) and the liner is 90 lbs basis weight. The stringers have holes (8" X 2.75") at 9" from each end. Stringers are stuffed with honeycomb blocks each of dimensions 8.5" X 3.25" X 3.25" with cell size 1/2" and 69 lbs liner. Stringers are made from "Chipboard" with "EcoDuro" printed on it. Figures 3-7 and 3-8 give the two views of the pallet.



Figure 3-7: Top view of the Pallet 4.

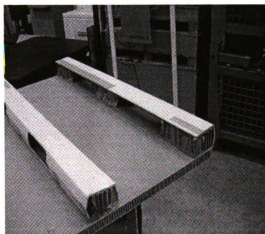


Figure 3-8: The 4-way stringer construction of Pallet 4.

Table 3-7 and Table 3-8 give the compressive strength of the stringers and performance of deck respectively.

**Table 3-7: Compressive strength of the stringers of Pallet 4.**

Pallet Number, footprint	Conditioning	Sample	Force at Yield point, Pounds	Deflection at Yield point, inches
4, 48" X 40"	72 F, 50% RH	1	6508.8	0.25
	72 F, 50% RH	2	6814.8	0.23
		Average	6661.8	0.24
	90F, 90% RH	1	5026.8	0.24

**Table 3-8: Measure of the load for the deck of Pallet 4.**

Pallet Number, footprint	Conditioning	Sample	Force at Yield point, Pounds	Deflection at Yield point, inches
4, 48" X 40"	72 F, 50% RH	1	3000	1.2
	72 F, 50% RH	2	3000	1.2
		Average	3000	1.2
	90F, 90% RH	1	2300	0.95

### **Pallet 5**

This pallet, footprint 48" X 40", is a 4-way, with 3 stringers and has a single layer deck of thickness 1". The cell size of the deck is 3/8" (core –26 lbs basis) and liner thickness is 69 lbs basis weight. The stringers are made of "Formboard" a type of recycled Kraft paper. The thickness of stringers is 0.12". Each stringer is stuffed with 3 tube blocks. Each tube block is about 7" X 3.25" X 3.25" and 0.12" thick. The stringers have 2 holes punched at 9" from the ends, and are of dimensions 8" X 2.75". Pallet is manufactured by EcoDuro Inc. Figure 3-9 gives the tube in stringer view of the pallet.

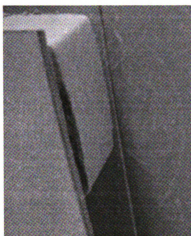


Figure 3-9: The tube in stringer view of the Pallet 5.

Table 3-9 and 3-10 give the compression strength of the stringers and the measure of the load for the deck of Pallet 5.

**Table 3-9: Performance of the stringers of Pallet 5.**

Pallet Number, footprint	Conditioning	Sample	Force at Yield point, Pounds	Deflection at Yield point, inches
5, 48" X 40"	72 F, 50% RH	1	12097	0.46
	72 F, 50% RH	2	12023.8	0.43
		Average	12060.4	0.445
	90F, 90% RH	1	9034.2	0.42

**Table 3-10: Measure of the load for the deck of Pallet 5.**

Pallet Number, footprint	Conditioning	Sample	Force at Yield point, Pounds	Deflection at Yield point, inches
5, 48" X 40"	72 F, 50% RH	1	1600	0.5
	90F, 90% RH	1	1250	0.21

### **Pallet 6**

This type of pallet is manufactured by EcoDuro Inc. and is 4-way with single layer deck of thickness 7/8". The cell size of the deck is 1/2" (core –33 lbs basis) and the liner is 69 lbs basis weight. The stringers are 0.1" thick, and made from white colored "Chipboard", with "EcoDuro" printed on it. Stringers are stuffed with honeycomb blocks of dimensions 8.5" X 3.25" X 3.25" with 1/2" cell and 69 lbs liner. Stringers have holes of dimensions 8" X 2.75" and are punched at 9" from each end. Figure 6 shows the stringer with a honeycomb stuffing.

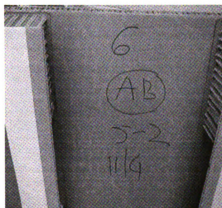


Figure 3-10: Stringers with honeycomb stuffing of the Pallet 6.

Table 3-11 gives the performance of the stringers under compression load and

Table 3-12 gives the performance of the deck for the Pallet 6.

Table 3-11: Performance of the stringers of Pallet 6.

Pallet Number, footprint	Conditioning	Sample	Force at Yield point, Pounds	Deflection at Yield point, inches
6, 48" X 40"	72 F, 50% RH	1	10402.8	0.29
	72 F, 50% RH	2	11698.3	0.32
		Average	11050.55	0.305
	90F, 90% RH	1	7071.8	0.32

**Table 3-12: Performance of the deck of Pallet 6.**

<b>Pallet Number, footprint</b>	<b>Conditioning</b>	<b>Sample</b>	<b>Force at Yield point, Pounds</b>	<b>Deflection at Yield point, inches</b>
<b>6, 48" X 40"</b>	72 F, 50% RH	1	1800	0.6
	72 F, 50% RH	2	1800	0.6
		<b>Average</b>	1800	0.6
	90F, 90% RH	1	1300	0.45

### **Pallet 7**

This type of pallet has a footprint of 48" X 40" and is 2-way with single layer of 1" thick deck. The cell size of the deck is ½" (core –33 lbs basis) and liner is 69 lbs basis weight. The 3 stringers are made from brown colored "Formboard" having some recycled Kraft content. Stringers are fully stuffed with honey comb material of dimension 48" X 3.25" X 3.25" with cell size ½" and 69 lbs liner. The thickness of the liner is 0.12". Figure 3-11 gives the fully stuffed view of the stringer.

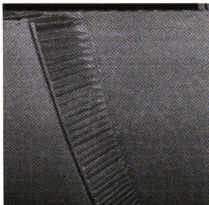


Figure 3-11: Fully stuffed stringer of the Pallet 7.

Table 3-13 gives the compression strength of the stringers and Table 3-14 gives the performance of the decks for Pallet 7.

Table 3-13: Compression strength of the stringers for Pallet 7.

Pallet Number, footprint	Conditioning	Sample	Force at Yield point, Pounds	Deflection at Yield point, inches
7, 48" X 40"	72 F, 50% RH	1	17318.5	0.28
	72 F, 50% RH	2	18523.5	0.32
		Average	17921	0.3
	90F, 90% RH	1	14330.1	0.29

**Table 3-14: Performance of the deck of Pallet 7.**

<b>Pallet Number, footprint</b>	<b>Conditioning</b>	<b>Sample</b>	<b>Force at Yield point, Pounds</b>	<b>Deflection at Yield point, inches</b>
<b>7, 48" X 40"</b>	72 F, 50% RH	1	2350	0.7
	72 F, 50% RH	2	2250	0.65
		<b>Average</b>	<b>2300</b>	<b>0.675</b>
	90F, 90% RH	1	1700	0.5

### **Pallet 8**

This type of pallet is single layer, of footprint 48" X 40", with deck thickness 1.25" having a liner of 90 lbs basis weight. The cell size is 3/8" (core –26 lbs basis). The three stringers are tubes of dimensions 48" X 5.5" X 0.16". They are stuffed in the ends with honeycomb blocks of dimensions: 8" X 5.25" X 3.125" of cell size 1/2" with liner weight 69 lbs. The pallet is 2-way. The tubes are made of Kraft paper with some recycle content and spirally wound. Figures 3-12 and 3-13 give the two views of the pallet.



Figure 3-12: Stringer of the Pallet 8.

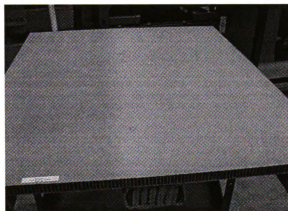


Figure 3-13: Pallet 8.

Table 3-15 gives the performance of the stringer under compressive load. Table 3-16 gives the performance of the deck under loading conditions up till first yield point.

**Table 3-15: Performance of the stringer of Pallet 8.**

Pallet Number, footprint	Conditioning	Sample	Force at Yield point, Pounds	Deflection at Yield point, inches
8, 48" X 40"	72 F, 50% RH	1	17209.2	0.56
	72 F, 50% RH	2	18482.1	0.57
		Average	17845.65	0.565
	90F, 90% RH	1	12553.5	0.59

**Table 3-16: Performance of the deck of Pallet 8.**

Pallet Number, footprint	Conditioning	Sample	Force at Yield point, Pounds	Deflection at Yield point, inches
8, 48" X 40"	72 F, 50% RH	1	6000	1.75
	72 F, 50% RH	2	6750	1.8
		Average	6375	1.775
	90F, 90% RH	1	5300	1.65

### **Pallet 9**

This pallet is made by *EcoDuro* Inc. and is single layer, 4-way, having a deck thickness 1.25" with cell size  $\frac{1}{2}$ " (core –33 lbs basis) and liner weight 69 lbs on basis weight. There are 3 stringers each 0.16" thick and are made from white color "Chipboard", with "*EcoDuro*" printed on it. They are stuffed with honeycomb blocks of dimension 8.5" X 3.25" X 3.25" with cell size  $\frac{1}{2}$ " and liner 69 lbs. Stringers have a hole of dimension 8" X 2.75" punched in their wall at a distance of 9" from each end. Figures 3-14 and 3-15 give the two views of the pallet.



Figure 3-14: Pallet 9.

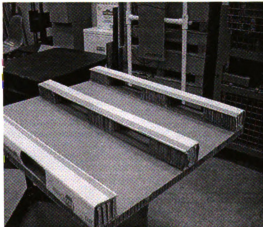


Figure 3-15: Three stringers of the Pallet 9.

Table 3-17 gives the performance of the stringers under compressive load. Table 3-18 gives the deck performance under loading conditions up till first yield point.

**Table 3-17: Performance of the stringers of Pallet 9.**

Pallet Number, footprint	Conditioning	Sample	Force at Yield point, Pounds	Deflection at Yield point, inches
9, 48" X 40"	72 F, 50% RH	1	11050.1	0.23
	72 F, 50% RH	2	10072.7	0.23
		Average	10561.4	0.23
	90F, 90% RH	1	7040.3	0.3

**Table 3-18: Performance of deck up till first yield point of Pallet 9.**

Pallet Number, footprint	Conditioning	Sample	Force at Yield point, Pounds	Deflection at Yield point, inches
9, 48" X 40"	72 F, 50% RH	1	2400	0.75
	72 F, 50% RH	2	2500	0.85
		Average	2450	0.8
	90F, 90% RH	1	2050	0.72

### **Pallet 10**

This pallet has a liner of 90 lbs on basis weight and a single layer deck of thickness 1.25". The cell size is  $\frac{1}{2}$ " (core –33 lbs basis) and the footprint is 48" X 40". It is a 4-way pallet manufactured by EcoDuro Inc. The stringer is 0.16" thick made of white color "Chipboard", with "EcoDuro" printed on it. It is stuffed with honeycomb blocks of dimension 8.5" X 3.25" X 3.25" of cell size  $\frac{1}{2}$ " and liner weight 69 lbs. The stringers are punched with two holes of dimension 8" X 2.75", at a distance of 9" from the ends. Figures 3-16 and 3-17 give the two views of the pallet.

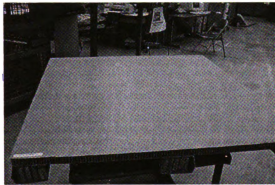


Figure 3-16: Pallet 10.

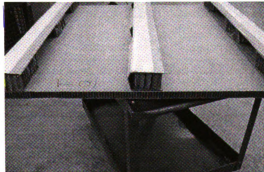


Figure 3-17: Stringers of Pallet 10.

Table 3-19 gives the performance of the stringers under the compressive load.

Table 3-20 gives the measure of load for deck up till first yield point.

**Table 3-19: Performance of the stringers of Pallet 10.**

Pallet Number, footprint	Conditioning	Sample	Force at Yield point, Pounds	Deflection at Yield point, inches
10, 48" X 40"	72 F, 50% RH	1	10162	0.29
	72 F, 50% RH	2	10268.9	0.25
		Average	10215.45	0.27
	90F, 90% RH	1	7309.2	0.27

**Table 3-20: Measure of load for deck up till first yield point for Pallet 10.**

Pallet Number, footprint	Conditioning	Sample	Force at Yield point, Pounds	Deflection at Yield point, inches
10, 48" X 40"	72 F, 50% RH	1	2500	0.85
	72 F, 50% RH	2	2300	0.75
		Average	2400	0.8
	90F, 90% RH	1	1700	0.58

### **Pallet 11**

This type of pallet, manufactured by *EcoDuro*, has a footprint of 48" X 40". The single layer top deck is 1" thick with cell size of  $\frac{1}{2}$ " (core –33 lbs basis) and liner weight is 69 lbs basis weight. It is a 4-way pallet and has 9 wrapped blocks instead of stringers. Each wrapped blocks has dimensions of 8" X 8"x 3.25". The wrapping is type "C", corrugated sheet that encloses honeycomb block of dimension 8" X 8" X 3", cell size  $\frac{1}{2}$ " and liner weight 69 lbs. Figure 3-18 shows the view of the wrapped block on the pallet.

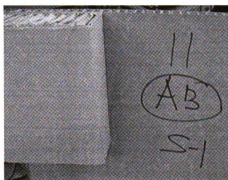


Figure 3-18: Wrapped block on the Pallet 11.

Table 3-21 gives the compressive strength of the wrapped block under fixed platen test. Table 3-22 gives the performance of the deck up till first yield point as per Airbag test.

**Table 3-21: Compressive strength of the wrapped block for Pallet 11.**

Pallet Number, footprint	Conditioning	Sample	Force at Yield point, Pounds	Deflection at Yield point, inches
11, 48" X 40"	72 F, 50% RH	1	17327.1	0.44
	72 F, 50% RH	2	17136.9	0.49
		Average	17232	0.465
	90F, 90% RH	1	12045.2	0.55

**Table 3-22: Performance of the deck for Pallet 11.**

Pallet Number, footprint	Conditioning	Sample	Force at Yield point, Pounds	Deflection at Yield point, inches
11, 48" X 40"	72 F, 50% RH	1	1550	0.4
	72 F, 50% RH	2	1600	0.53
		Average	1575	0.465
	90F, 90% RH	1	1600	0.53

### **Pallet 12**

This pallet has a footprint of 48" X 40" and has a single layer deck of thickness 1.25" having a cell size of 3/8"(core –26 lbs basis) and a liner weight of 90 lbs on basis weight. Instead of stringers there are 9 hollow tubes of dimensions 8" X 5.5"X 0.16" thickness. These tubes are made from Kraft paper with some recycled content and have been spirally wound. The pallet is 4-way and is manufactured by EcoDuro Inc. Figure 3-19 gives a view of the pallet.



Figure 3-19: Tubes cut to sizes, on the Pallet 12.

Table 3-23 gives the performance of the tube under compressive load. Table 3-24 gives the performance of the deck under the Airbag test up till the first yield point.

Table 3-23: Performance of the tube for Pallet 12.

Pallet Number, footprint	Conditioning	Sample	Force at Yield point, Pounds	Deflection at Yield point, inches
12, 48" X 40"	72 F, 50% RH	1	8106	0.67
	72 F, 50% RH	2	6665.5	0.44
		Average	7385.75	0.555
	90F, 90% RH	1	5908.8	0.54

**Table 3-24: Performance of the deck for Pallet 12.**

<b>Pallet Number, footprint</b>	<b>Conditioning</b>	<b>Sample</b>	<b>Force at Yield point, Pounds</b>	<b>Deflection at Yield point, inches</b>
<b>12, 48" X 40"</b>	72 F, 50% RH	1	2800	1.05
	72 F, 50% RH	2	2700	0.97
		<b>Average</b>	<b>2750</b>	<b>1.01</b>
	90F, 90% RH	1	2300	0.95

### **Pallet 14**

EcoDuro Inc manufactures this 4-way pallet. It has a footprint of 48" X 40" and has a single layered deck of thickness 1" with cell size of 3/8"(core –26 lbs basis). The liner material is 69 lbs on basis weight. It has 3 stringers made from white color "Chipboard" with "EcoDuro" printed on it. The stringers are 0.1" thick and are stuffed with honeycomb blocks of dimensions 8.5" X 3.25" X 3.25" with cell size ½" and liner weight of 69 lbs. The stringers are punched holes of dimensions 8" X 2.75". These holes are at a distance of 9" from the ends. Figure 3-20 gives the view of the pallet.

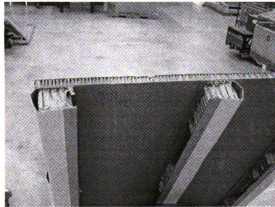


Figure 3-20: Bottom view of the deck and the stringers for Pallet 14.

Table 3-25 gives the compressive strength of the stringer under fixed platen test.

Table 3-26 gives the performance of the deck under standard Airbag Test until first yield point.

**Table 3-25: Compressive strength of the stringer for Pallet 14.**

Pallet Number, footprint	Conditioning	Sample	Force at Yield point, Pounds	Deflection at Yield point, inches
14, 48" X 40"	72 F, 50% RH	1	6103.4	0.24
	72 F, 50% RH	2	8062.1	0.26
		Average	7082.75	0.25
	90F, 90% RH	1	6594.1	0.3

**Table 3-26: Performance of the deck – Pallet 14.**

Pallet Number, footprint	Conditioning	Sample	Force at Yield point, Pounds	Deflection at Yield point, inches
14, 48" X 40"	72 F, 50% RH	1	1750	0.6
	72 F, 50% RH	2	1600	0.55
		Average	1675	0.575
	90F, 90% RH	1	1400	0.5

### **Pallet 15**

This pallet with footprint of 48" X 40" has top single layer deck of thickness 1" and cell size of 3/8"(core –26 lbs basis). The liner weight is 69 lbs on basis weight.

EcoDuro Inc manufactures it. It is 4-way pallet with 3 stringers of 0.08" thickness.

The stringers are made from white colored "Chipboard" and has "EcoDuro" printed on it. Stringers have holes punched into its wall of dimensions 8" X 2.75" at a distance of 9" from each ends. Stringers are stuffed with honeycomb blocks of dimensions 8.5" X 3.25" X 3.25", with cell size ½" and 69 lbs basis weight.

Figures 3-21 and 3-22 give two views of the pallet.

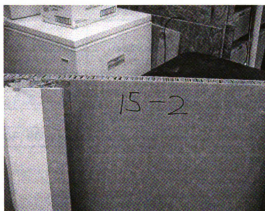


Figure 3-21: Bottom view of the Pallet 15.

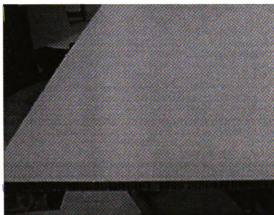


Figure 3-22: Top view of the Pallet 15.

Table 3-27 gives the performance of the stringers under the compressive load.

Table 3-28 gives the performance of the deck under the Airbag test until the first yield point.

**Table 3-27: Performance of the stringers for Pallet 15.**

Pallet Number, footprint	Conditioning	Sample	Force at Yield point, Pounds	Deflection at Yield point, inches
15, 48" X 40"	72 F, 50% RH	1	8742.5	0.31
	72 F, 50% RH	2	8784.3	0.3
		Average	8763.4	0.305
	90F, 90% RH	1	5943.5	0.38

**Table 3-28: Performance of the deck for Pallet 15.**

Pallet Number, footprint	Conditioning	Sample	Force at Yield point, Pounds	Deflection at Yield point, inches
15, 48" X 40"	72 F, 50% RH	1	1750	0.6
	72 F, 50% RH	2	1800	0.61
		Average	1775	0.605
	90F, 90% RH	1	1250	0.35

### **Pallet 16**

This pallet with footprint of 48" X 40" has a single layer deck of thickness 1.25" with cell size 3/8"(core –26 lbs basis) and liner weight of 90 lbs on basis weight. EcoDuro Inc manufactures it. The stringers are made from brown color recycled Kraft paper. The stringers are stuffed with honeycomb blocks of size 8.5" X 3.25" X 3.25" with cell size 1/2" and liner weight 69 lbs. The pallet is 4-way as stringers have been punched with holes of size 8" X 2.75" at 9" from each ends. Figures 3-23 and 3-24 give two views of the pallet.

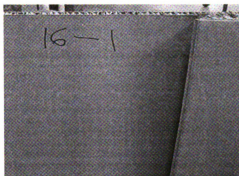


Figure 3-23: Stringer of the Pallet 16.

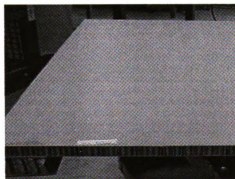


Figure 3-24: Deck of the Pallet 16.

Table 3-29 gives the performance of the stringers during the fixed platen test.

Table 3-30 gives the performance of the deck under airbag test until the first yield point is reached.

**Table 3-29: Performance of the stringers for Pallet 16.**

Pallet Number, footprint	Conditioning	Sample	Force at Yield point, Pounds	Deflection at Yield point, inches
16, 48" X 40"	72 F, 50% RH	1	9042.5	0.3
	72 F, 50% RH	2	8843.7	0.27
		Average	8943.1	0.285
	90F, 90% RH	1	6739.2	0.24

**Table 3-30: Performance of the deck for Pallet 16.**

Pallet Number, footprint	Conditioning	Sample	Force at Yield point, Pounds	Deflection at Yield point, inches
16, 48" X 40"	72 F, 50% RH	1	3100	1.05
	72 F, 50% RH	2	3250	1.1
		Average	3175	1.055
	90F, 90% RH	1	2450	0.85

### Pallet 17

This pallet is manufactured by L & F Inc. The footprint is 48" X 40" and single layer deck is 1.25" thick. The cell size is 7/16"(core –33 lbs basis) and the liner is 69 lbs on basis weight. Stringers are made from brown color recycled Kraft paper and are stuffed with honeycomb blocks of dimensions 8.5" X 3.25" X 3.25" having a cell size of ½" with liner material of 42 lbs. Stringers are 0.2" thick and have holes of dimensions 8" X 2.75" punched at 9" from each end. The pallet is 4-way. Figures 3-25 and 3-26 give two views of the pallet.



Figure 3-25: Stringer of the pallet 17.



Figure 3-26: Bottom view of the Pallet 17.

Table 3-31 gives the performance of the stringers when fixed platen test is performed. Table 3-32 gives the performance of the deck when airbag test is performed. It is a measure of the load at first yield point.

**Table 3-31: Performance of the stringers for Pallet 17.**

Pallet Number, footprint	Conditioning	Sample	Force at Yield point, Pounds	Deflection at Yield point, inches
17, 48" X 40"	72 F, 50% RH	1	8715.9	0.31
	72 F, 50% RH	2	9312.1	0.3
		Average	9014	0.305
	90F, 90% RH	1	6661.7	0.34

**Table 3-32: Performance of the deck for Pallet 17.**

Pallet Number, footprint	Conditioning	Sample	Force at Yield point, Pounds	Deflection at Yield point, inches
17, 48" X 40"	72 F, 50% RH	1	2900	0.95
	72 F, 50% RH	2	2750	0.88
		Average	2825	0.915
	90F, 90% RH	1	2200	0.7

### **Pallet 18**

This pallet has unexpanded honeycomb single layer deck of approximate thickness 19/16" with cell size of 3/8"(core –26 lbs basis) and liner weight of 69 lbs on basis weight. It is a 4-way pallet with footprint of 48" X 40". The three stringers are 0.16" thick and made of "Chipboard" with "EcoDuro" written on it. Stringers are stuffed with honeycomb blocks of dimensions 8.5" X 3.25" X 3.25" with cell size of 1/2" and liner of 69 lbs. Each stringer has two holes of dimensions 8" X 2.75" punched at 9" from each end. Figure 3-27 gives the bottom view of the pallet. EcuDuro Inc. manufactures this pallet.

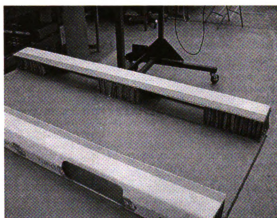


Figure 3-27: Stringers of the pallet 18.

Table 3-33 gives the performance of the stringers during the fixed platen test.

Table 3-34 gives the performance of the deck during the airbag test, which is the measure of the load till the first yield.

**Table 3-33: Performance of the stringers for Pallet 18.**

Pallet Number, footprint	Conditioning	Sample	Force at Yield point, Pounds	Deflection at Yield point, inches
18, 48" X 40"	72 F, 50% RH	1	10344.6	0.25
	72 F, 50% RH	2	10348.5	0.24
	Average		10346.55	0.245

**Table 3-34: Performance of the deck for Pallet 18.**

Pallet Number, footprint	Conditioning	Sample	Force at Yield point, Pounds	Deflection at Yield point, inches
18, 48" X 40"	90F, 90% RH	1	2450	0.95

### **Pallet 19**

EcoDuro Inc manufactures this pallet. It has two layers of deck made by cross-laminating two  $\frac{1}{2}$ " thick decks of cell size  $\frac{1}{2}$ " (Core –33 lbs basis) with liner material of 42 lbs basis weight. The footprint is 40" X 40" and is 2-way. The stringers are made from white colored "Chipboard" that is fully stuffed with honeycomb rails of dimension 40" X 3.25" X 3.25" with cell size  $\frac{1}{2}$ " and liner material 69 lbs basis weight. Figures 3-28 and 3-29 gives two views of the pallet.

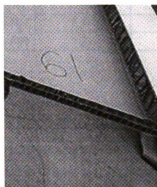


Figure 3-28: The cross-laminated deck of Pallet 19.

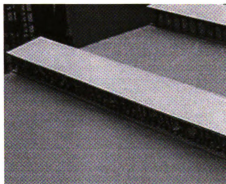


Figure 3-29: Stringers of 2-way Pallet 19.

Table 3-35 gives the performance of the stringers during fixed platen test.

Table 3-36 gives the performance of the decks during the airbag test, which is a measure of the load until first yield point.

**Table 3-35: Performance of the stringers of Pallet 19.**

Pallet Number, footprint	Conditioning	Sample	Force at Yield point, Pounds	Deflection at Yield point, inches
19, 48" X 40"	72 F, 50% RH	1	13382.9	0.43
	72 F, 50% RH	2	12531	0.46
	Average		12956.95	0.445

**Table 3-36: Performance of the decks of Pallet 19.**

Pallet Number, footprint	Conditioning	Sample	Force at Yield point, Pounds	Deflection at Yield point, inches
19, 48" X 40"	72 F, 50% RH	1	2400	1.08
	90 F, 90% RH	2	1200	0.43

### **Pallet 20**

EcoDuro Inc. manufactures this pallet. The footprint is 43" X 43". It has two layers of deck made by cross laminating two ½" thick decks of cell size ½"(Core –33 lbs basis) and liner material of 42 lbs on basis weight. This is a 2-way pallet. The stringers are 0.12" thick and made from white "Chipboard" material that is fully stuffed with honeycomb of dimension 43" X 3.25" X 3.25" with cell size ½" and liner material 69 lbs. Figures 3-30 and 3-31 gives the views of the pallet.



Figure 3-30: Cross-laminated deck of Pallet 20.

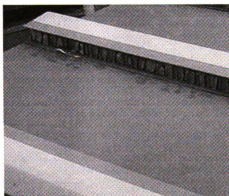


Figure 3-31: Stringers of the Pallet 20.

Table 3-37 gives the performance of the stringers during the fixed platen test.

Table 3-38 gives the performance of the decks during the airbag test, which is a measure of the load until first yield point is reached.

**Table 3-37: Performance of the stringers of Pallet 20.**

Pallet Number, footprint	Conditioning	Sample	Force at Yield point, Pounds	Deflection at Yield point, inches
20, 48" X 40"	72 F, 50% RH	1	13295.7	0.3
	72 F, 50% RH	2	13505.9	0.28
	Average		13400.8	0.29
	90F, 90% RH	1	10219.4	0.87

**Table 3-38: Performance of the decks of Pallet 20.**

Pallet Number, footprint	Conditioning	Sample	Force at Yield point, Pounds	Deflection at Yield point, inches
20, 48" X 40"	72 F, 50% RH	1	2000	0.7

#### 4. Results and Data Analysis

Table 4-1: Performance of Decks.

Table 4-1: Performance of Deck				
Pallet No	Conditioning			
	72 F & 50% RH		90 F & 90% RH	
	Load, Pounds	Deflection, inches	Load, Pounds	Deflection, inches
1	1650	0.57	1400	0.5
2	1625	0.52	1400	0.5
3	1700	0.59	1200	0.37
4	3000	1.2	2300	0.95
5	1600	0.5	1250	0.21
6	1800	0.6	1300	0.45
7	2300	0.68	1700	0.5
8	6375	1.78	5300	1.65
9	2450	0.8	2050	0.72
10	2400	0.8	1700	0.58
11	1575	0.47	1600	0.53
12	2750	1.01	2300	0.95
14	1675	0.58	1400	0.5
15	1775	0.61	1250	0.35
16	3175	1.06	2450	0.85
17	2825	0.92	2200	0.7
18			2450	0.95
19	2400	1.08	1200	0.43
20	2000	0.7		

**Table 4-2: Performance of Decks for 0.5" deflection.**

Table 4-2: Performance of Deck for 0.5 inch deflection				
Pallet No	Conditioning			
	72 F & 50% RH		90 F & 90% RH	
	Load, Pounds	Deflection, inches	Load, Pounds	Deflection, inches
1	1447.37	0.5	1400.00	0.5
2	1562.50	0.5	1400.00	0.5
3	1440.68	0.5	1621.62	0.5
4	1250.00	0.5	1210.53	0.5
5	1600.00	0.5	2976.19	0.5
6	1500.00	0.5	1444.44	0.5
7	1691.18	0.5	1700.00	0.5
8	1790.73	0.5	1606.06	0.5
9	1531.25	0.5	1423.61	0.5
10	1500.00	0.5	1465.52	0.5
11	1675.53	0.5	1509.43	0.5
12	1361.39	0.5	1210.53	0.5
14	1443.97	0.5	1400.00	0.5
15	1454.92	0.5	1785.71	0.5
16	1497.64	0.5	1441.18	0.5
17	1535.33	0.5	1571.43	0.5
18			1289.47	0.5
19	1111.11	0.5	1395.35	0.5
20	1428.57	0.5		

**Table 4-3: Performance of Stringers.**

Table 4-3: Performance of Stringers				
Pallet No	Conditioning			
	72 F & 50% RH		90 F & 90% RH	
	Load, Pounds	Deflection, inches	Load, Pounds	Deflection, inches
1	8966.35	0.29	6700.9	0.32
2	9377.35	0.32	6818	0.38
3	12046.05	0.31	7848.8	0.3
4	6661.8	0.24	5026.8	0.24
5	12060.4	0.45	9034.2	0.42
6	11050.55	0.31	7071.8	0.32
7	17921	0.3	14330.1	0.29
8	17845.65	0.57	12553.5	0.59
9	10561.4	0.23	7040.3	0.3
10	10215.45	0.27	7309.2	0.27
11	17232	0.47	12045	0.55
12	7385.75	0.56	5908.8	0.54
14	7082.75	0.25	6594.1	0.3
15	8763.4	0.31	5943.5	0.38
16	8943.1	0.29	6739.2	0.24
17	9014	0.31	6661.7	0.34
18	10346.55	0.25		
19	12956.95	0.45		
20	13400.8	0.29	10219.4	0.87

**Table 4-4: Performance of Stringers for 0.5" deflection.**

Table 4-4: Performance of Stringers for 0.5 inch deflection				
Pallet No	Conditioning			
	72 F & 50% RH		90 F & 90% RH	
	Load, Pounds	Deflection, inches	Load, Pounds	Deflection, inches
1	15459.22	0.5	10470.16	0.5
2	14652.11	0.5	8971.05	0.5
3	19429.11	0.5	13081.33	0.5
4	13878.75	0.5	10472.50	0.5
5	13400.44	0.5	10755.00	0.5
6	17823.47	0.5	11049.69	0.5
7	29868.33	0.5	24707.07	0.5
8	15654.08	0.5	10638.56	0.5
9	22959.57	0.5	11733.83	0.5
10	18917.50	0.5	13535.56	0.5
11	18331.91	0.5	10950.00	0.5
12	6594.42	0.5	5471.11	0.5
14	14165.50	0.5	10990.17	0.5
15	14134.52	0.5	7820.39	0.5
16	15419.14	0.5	14040.00	0.5
17	14538.71	0.5	9796.62	0.5
18	20693.10	0.5		
19	14396.61	0.5		
20	23104.83	0.5	5873.22	0.5

**Table 4-5: Loss of strength of decks.**

Table 4-5: Loss in strength of Decks					
Pallet No	Conditioning				Loss in Strength, %
	72 F & 50% RH		90 F & 90% RH		
	Load, Pounds	Deflection, inches	Load, Pounds	Deflection, inches	
1	1650	0.57	1400	0.5	15.2
2	1625	0.52	1400	0.5	13.8
3	1700	0.59	1200	0.37	29.4
4	3000	1.2	2300	0.95	23.3
5	1600	0.5	1250	0.21	21.9
6	1800	0.6	1300	0.45	27.8
7	2300	0.68	1700	0.5	26.1
8	6375	1.78	5300	1.65	16.9
9	2450	0.8	2050	0.72	16.3
10	2400	0.8	1700	0.58	29.2
11	1575	0.47	1600	0.53	-1.6
12	2750	1.01	2300	0.95	16.4
14	1675	0.58	1400	0.5	16.4
15	1775	0.61	1250	0.35	29.6
16	3175	1.06	2450	0.85	22.8
17	2825	0.92	2200	0.7	22.1
18			2450	0.95	
19	2400	1.08	1200	0.43	50
20	2000	0.7			
Average Loss in strength, after neglecting the high value of 50% and the negative value					21.8

**Table 4-6: Loss in strength of stringers.**

Table 4-6: Loss in Strength of Stringers					
Pallet No	Conditioning				Loss in Strength, %
	72 F & 50% RH		90 F & 90% RH		
	Load, Pounds	Deflection, inches	Load, Pounds	Deflection, inches	
1	8966.35	0.29	6700.9	0.32	25.3
2	9377.35	0.32	6818	0.38	27.3
3	12046.05	0.31	7848.8	0.3	34.8
4	6661.8	0.24	5026.8	0.24	24.5
5	12060.4	0.45	9034.2	0.42	25.1
6	11050.55	0.31	7071.8	0.32	36
7	17921	0.3	14330.1	0.29	20
8	17845.65	0.57	12553.5	0.59	29.7
9	10561.4	0.23	7040.3	0.3	33.3
10	10215.45	0.27	7309.2	0.27	28.4
11	17232	0.47	12045	0.55	30.1
12	7385.75	0.56	5908.8	0.54	20
14	7082.75	0.25	6594.1	0.3	6.9
15	8763.4	0.31	5943.5	0.38	32.2
16	8943.1	0.29	6739.2	0.24	24.6
17	9014	0.31	6661.7	0.34	26.1
18	10346.55	0.25			
19	12956.95	0.45			
20	13400.8	0.29	10219.4	0.87	23.7
Average reduction in strength					24.9

## 5. Comparison

**A:**

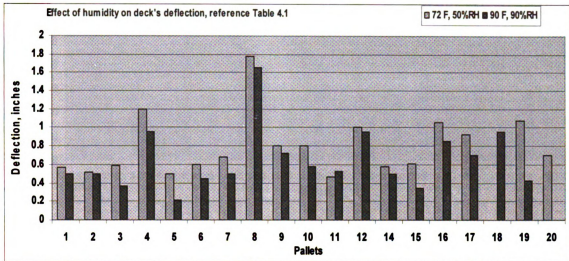


Figure 5-1: Effect of humidity on deck's deflection, reference Table 4.1

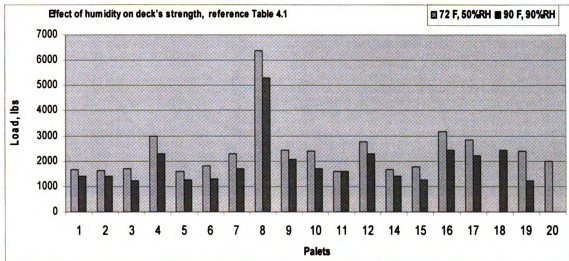


Figure 5-2: Effect of humidity on deck's strength, reference Table 4.1

**B:**

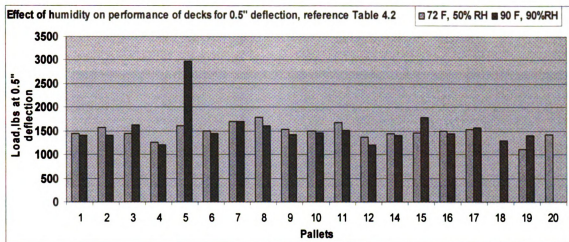


Figure 5-3: Effect of humidity on performance of decks for 0.5" deflection,  
reference Table 4.2

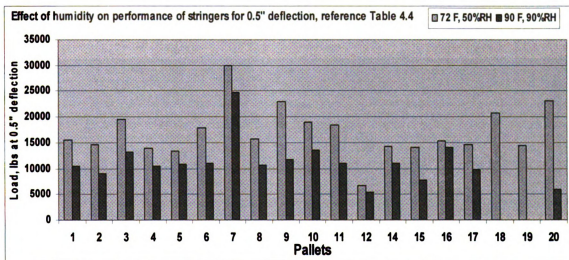


Figure 5-4: Effect of humidity on performance of stringers for 0.5" deflection,  
reference Table 4.4

C:

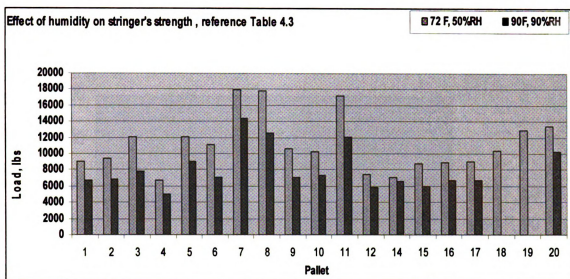


Figure 5-5: Effect of humidity on stringers strength, reference Table 4.3

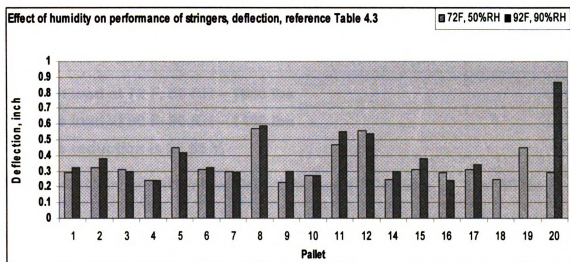
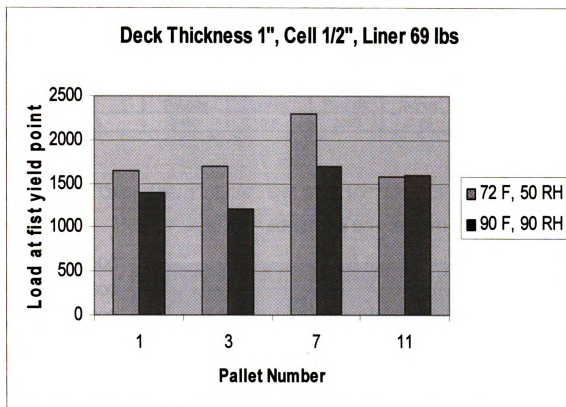


Figure 5-6: Effect of humidity on performance of stringers deflection, reference Table 4.3

**D:**



**Average load at 72 F, 50 RH – 1900 lbs**

**Average load at 90 F, 90 RH – 1400 lbs**

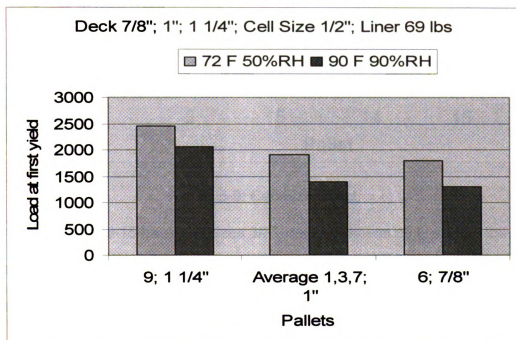
**Average reduction is 23.55 %**

**Figure 5-7: Comparison: Pallets-Deck thickness 1"; Cell Size 1/2", liner 69 lbs.**

**E:**

**Table 5-1: Loss in strength of deck for Pallet 9 due to conditioning.**

Pallet No.	Conditioning				Loss in Strength, %
	72 F & 50% RH		90 F & 90% RH		
	Load, Pounds	Deflection, Inches	Load, Pounds	Deflection, Inches	
9	2450	0.8	2050	0.72	16.3



**Figure 5-8: Comparison of loss in strength in decks due to conditioning.**

Comparison of loss in strength in decks due to conditioning at 90 % RH and at 90 F for 24 hours, for Pallets of different deck thickness – Pallet 6 ( 7/8" thick), Pallet 9 ( 1 1/4" thick) and average of Pallets 1,3 and 7 with deck thickness 1". Pallet 11 with deck thickness 1" is not included in this chart.

**E:**

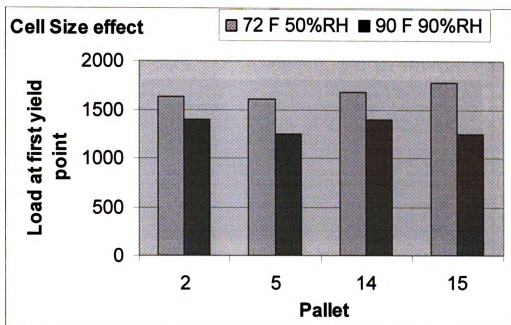


Figure 5-9: Cell Size effect.

Pallets 2, 5, 14 and 15 have cell sizes 3/8", deck thickness of 1" and 69 lbs Liner.

Average 72 F, 50 RH – 1700 lbs

Average 90 F, 90 RH – 1325 lbs

**G:**

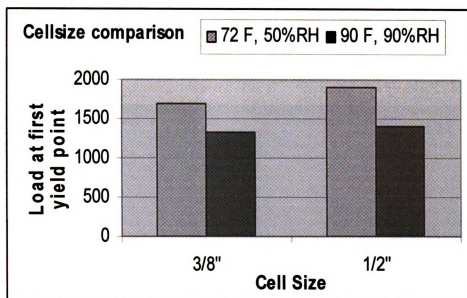


Figure 5-10: Comparison of average strength of Pallets with cell sizes 3/8" and

1/2".

H:

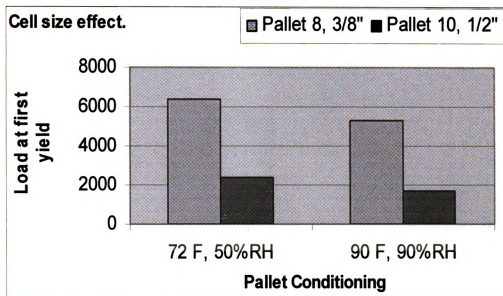


Figure 5-11: Comparison of cell size effect on Pallets 8, 10.

For pallet 8 and 10, the deck is 1 1/4" thick and the liner is 90 lbs. The cell size is 3/8" and 1/2" respectively.

I:

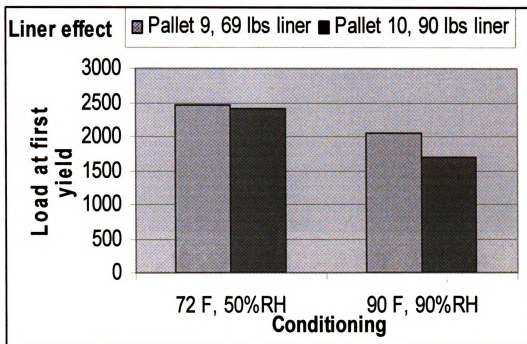


Figure 5-12: Comparison of Liner effect for Pallets 9 and 10 with decks 1 1/4".

J:

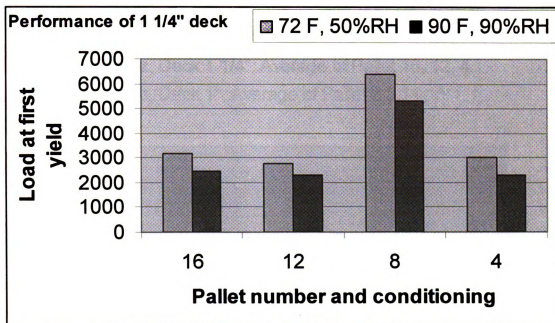


Figure 5-13: Performance of decks for Pallets 16, 12, 8 and 4.

Average 72 F, 50 RH – 2975 lbs    Average 90 F, 90 RH – 2350.

**K:**

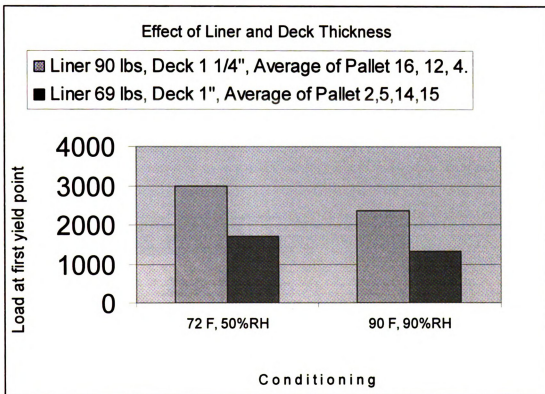


Figure 5-14: Combined effect of Liner and Deck thickness.

Average values being compared for cell size 3/8".

L:

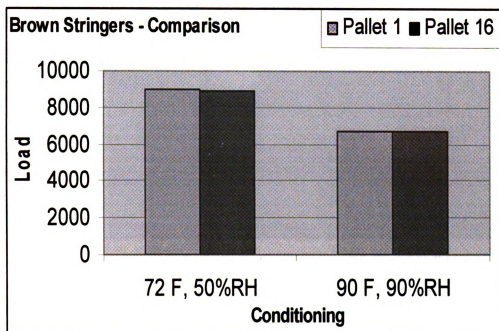


Figure 5-15: Stringer Comparison: 0.12" – Brown colored.

0.12" Brown colored, Form Board, 4-way- Stuffed with 3 Honeycomb Blocks 8.5" X 3.25", 3.25"; 69 lbs liner with core 33 lbs.

**M:**

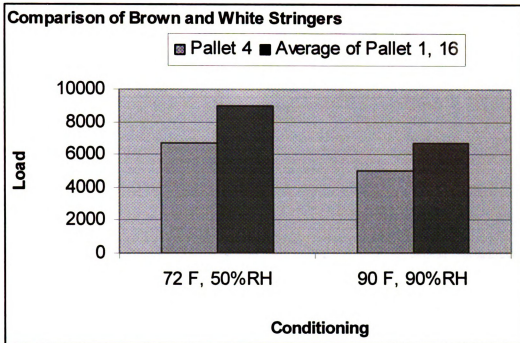


Figure 5-16: Stringer Comparison: 0.12" – White colored.

0.12" – White colored, Chip Board, and Brown colored – Form Board 4-way-  
Stuffed with 3 Honeycomb Blocks 8.5" X 3.25", 3.25"; 69 lbs liner with core 32  
lbs.

**N:**

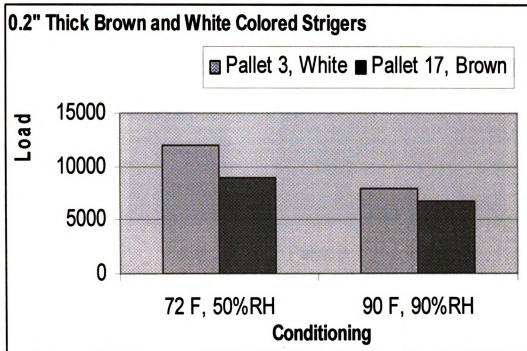


Figure 5-17: Stringer Comparison: 0.2" Thick brown and white colored.

O:

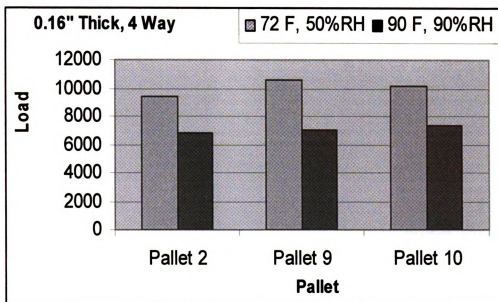


Figure 5-18: Stringers Comparison (EcoDuro Inc.): 0.16" – White color.

0.16" – White color, Chip Board, 4-way- Stuffed with 3 Honeycomb Blocks 8.5" X 3.25", 3.25"; 69 lbs liner with core 33 lbs.

Average Value 72 F, 50 RH – 10051.4 lbs    90 F, 90 RH – 7055.8 lbs.

**P:**

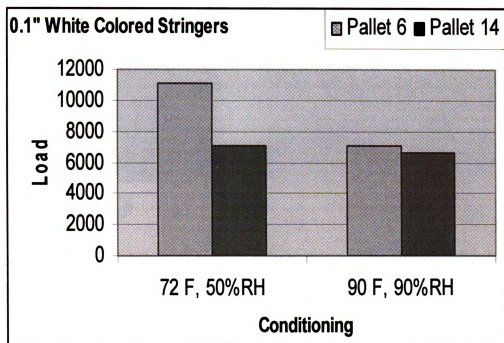


Figure 5-19: Stringers Comparison (EcoDuro Inc.): 0.1" – White color.

0.1" – White color. Chip Board, 4-way- Stuffed with 3 Honeycomb Blocks 8.5" X 3.25", 3.25"; 69 lbs liner with core 33 lb.

Average Value 72 F, 50 RH – 9066.65 lbs      90 F, 90 RH – 6833 lbs.

**Q:**

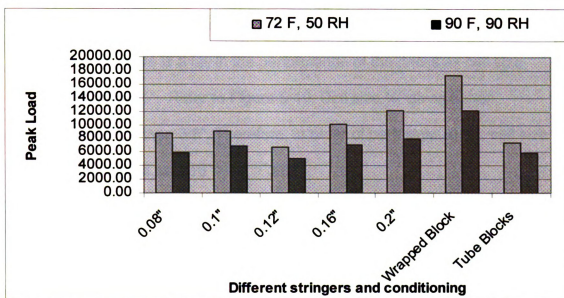


Figure 5-20: Comparison of Stringers, Tube and Wrapped Blocks.

## **6. Conclusions**

- Cell size 7/16" gives the best results as compared to 3/8" and 1/2".

However, there is a fall in the performance of the decks as cell size approaches 1/2". Refer to Figure 5-10. Cell size 1/2" gives better performance than 3/8". Therefore, in order of performance the cell size can be ranked as 7/16" > 1/2" > 3/8".

- Liner thickness 69 lbs is better than 90 lbs. The reasons can be:
  - Fiber contents and their directions.
  - Adhesion of fibers with one another.
  - The "glue", applied for joining liners (top and bottom) to honeycomb structure.
  - The effect of this "polymeric glue" on the fibers of the liners.
- Deck thickness affects the load capacity of the pallet. 1 1/4" gives higher values than 1" and 7/8".
- As relative humidity goes up there is a fall in the strength of the pallets. After conditioning for 24 hrs at 90% relative humidity and at 90 degrees F, the fall in strength for decks and stringers is 20% and 24% respectively.
- Laminated Decks may give better results but depends upon the variables like thickness of laminating decks and cell size.
- It is difficult to predict the performance of Stringers with 100 % confidentiality. The variation in tested values is from: 8000 lbs to 17000 lbs and depends upon the type of stuffing's used.
- Chipboard stringers perform better than Form-board stringers.

- Fully stuffed stringers for 2-way entry pallets fail at 18000 lbs.
- The bearing surface offered by the honeycomb stuffing blocks in a typical 4 way pallets is about:  $8.5" \times 3.25" \times 9 \times 2 \times 0.8 = 397.8$  sq inch or about 400 sq inches. Refer to Table 6-1 and 6-2 that gives portions of Table 1-1 and Table 4-2.

Table 6-1: Portions of Table 1-1.

Table 1-1: Paper Honeycomb Pallets Testing Protocol, School of Packaging, Michigan State University.								
No	Manufacturer	Pallet foot print	Approximate Deck Thickness	Cell size	Liner weight	Structure	Description of the rails	Quantity
1	EcoDuro Inc.	48 X 40	1"	1/2"	69	Single	0.12" rails - 4 way	6
2	EcoDuro Inc.	48 X 40	1"	3/8"	69	Single	0.16" rails - 4 way	6
3	EcoDuro Inc.	48 X 40	1"	1/2"	69	Single	0.2" rails - 4 way	6
14	EcoDuro Inc.	48 X 40	1"	3/8"	69	Single	0.1" rails - 4 way	6
15	EcoDuro Inc.	48 X 40	1"	3/8"	69	Single	0.08" rails - 4 way	6

Table 6-2: Portions of Table 4-2

Table 4-2: Performance of Deck for 0.5 inch deflection				
Pallet No	Conditioning			
	72 F & 50% RH		90 F & 90% RH	
	Load, Pounds	Deflection, inches	Load, Pounds	Deflection, inches
1	1447.37	0.5	1400.00	0.5
2	1562.50	0.5	1400.00	0.5
3	1440.68	0.5	1621.62	0.5
14	1443.97	0.5	1400.00	0.5
15	1454.92	0.5	1785.71	0.5

Average compressive force for 0.5" deflection for decks of pallet 1, 2, 3, 14 and 15 is

1400 pounds for 72 F and 50%RH. Therefore, failure stress can be stated as:

$$\text{"Failure Stress"} = \frac{\text{Compressive Load}}{\text{Bearing Area}} = \frac{1400}{400} = 3.5 \text{ pounds per square inch.}$$

Similarly, refer to Table 6-3 and 6-4 that shows portions of table 1-1 and Table 4-2.

Table 6-3: Portions of Table 1-1.

Table A: Paper Honeycomb Pallets Testing Protocol, School of Packaging, Michigan State University.								
No	Manufacturer	Pallet foot print	Approximate Deck Thickness	Cell size	Liner weight	Structure	Description of the rails	Quantity
4	EcoDuro Inc.	48 X 40	1 1/4"	3/8"	90	Single	0.12" rails - 4 way	6
9	EcoDuro Inc.	48 X 40	1 1/4"	1/2"	69	Single	0.16" rails - 4 way	6
10	EcoDuro Inc.	48 X 40	1 1/4"	1/2"	90	Single	0.16" rails - 4 way	6
16	EcoDuro Inc.	48 X 40	1 1/4"	3/8"	90	Single	0.12" rails - 4 way	6
17	L & F Inc.	48 X 40	1 1/4"	7/16"	69	Single	0.2" rails - 4 way	6

Table 6-4: Portions of Table 4-2.

Table 4-2: Performance of Deck for 0.5 inch deflection				
Pallet No	Conditioning			
	72 F & 50% RH		90 F & 90% RH	
	Load, Pounds	Deflection, inches	Load, Pounds	Deflection, inches
4	1250.00	0.5	1210.53	0.5
9	1531.25	0.5	1423.61	0.5
10	1500.00	0.5	1465.52	0.5
16	1497.64	0.5	1441.18	0.5
17	1535.33	0.5	1571.43	0.5

Average compressive force for 0.5" deflection for decks of pallet 4, 9, 10, 16 and 17 is

1462 pounds for 72 F and 50%RH. Therefore, failure stress can be stated as:

$$\text{"Failure Stress"} = \frac{\text{Compressive Load}}{\text{Bearing Area}} = \frac{1462}{400} = 3.65 \text{ pounds per square inch.}$$

## 7. Photographs

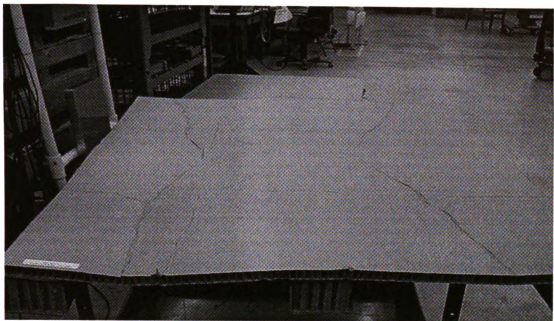


Figure 7-1: Pallet 1.

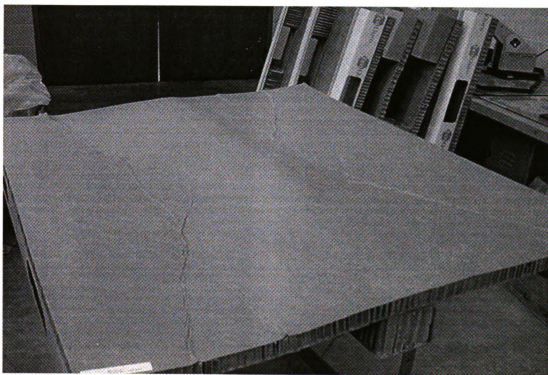


Figure 7-2: Pallet 8.

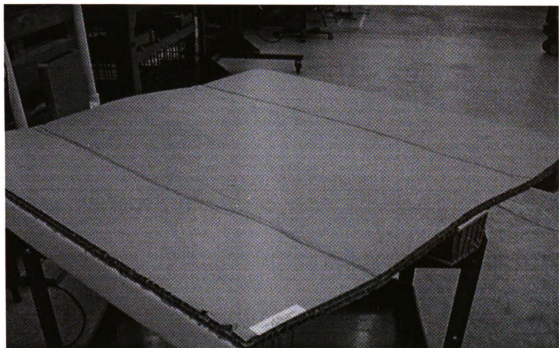


Figure 7-3: Pallet 19.



Figure 7-4: Stringer of 8.

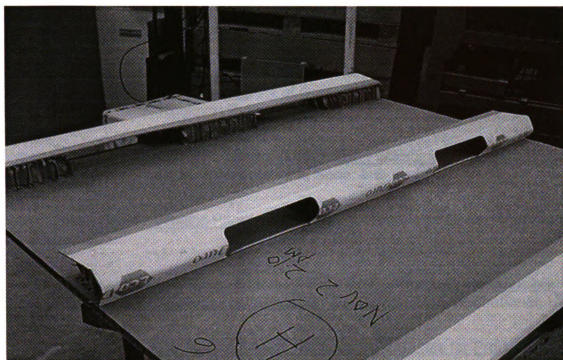


Figure 7-5: Pallet 6.



Figure 7-6: Pallet 16.

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