Introduction to Corrugated Boxes

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Design Steps for Stacking Strength...

Material → Structure of Single Unit → Structure of Unit Load
History of Corrugated Boards

- **1871** Albert Jones patented the first idea of a fluted paper
- **1874** Oliver Long suggested the creation of the single face board
- **Late 1870**, Machinery was developed to make corrugated board
- **1890** Another liner was added which resulted the first single wall corrugated board
Corrugated Board Basics

Components:

- Linerboard
- Corrugating Medium
- Adhesive

- Linerboard and medium are characterized using Basis Weight Grades

- **Basis Weight**: Weight of the board in lbs per 1000 sq. ft.
Corrugated Board Basics

- Most common medium is the 26 lbs / 1000 sq./ft.
- Basis weight grade specified board is characterized by weight and Mullen burst strength.

<table>
<thead>
<tr>
<th>Corrugating Medium Grades (lbs. /1000ft²)</th>
<th>Linerboard Grades (lbs. /1000ft²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>Basis Weight Grades</td>
</tr>
<tr>
<td></td>
<td>Burst Strength (Psi)</td>
</tr>
<tr>
<td>26 (most common)</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>33</td>
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<td>38</td>
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<td></td>
<td>42</td>
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<tr>
<td></td>
<td>69</td>
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<tr>
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<td>90</td>
</tr>
</tbody>
</table>
Corrugated Board Basics

- Corrugated Board Types
  - Single face board
  - Single wall board
  - Double wall board
  - Triple wall board

- Corrugated Flute Types
  - 'A' flute: 3/16 in. NOT COMMON
  - 'B' flute: 1/8 in.
  - 'C' flute: 5/32 in.
  - 'E' flute: 1/16 in.
  - 'F' flute: 1/32 in.
## Corrugated Board Basics

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>A-flute</th>
<th>C-flute</th>
<th>B-flute</th>
<th>E-flute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stack Strength</td>
<td>Best</td>
<td>Good</td>
<td>Fair</td>
<td>Poor</td>
</tr>
<tr>
<td>Printing</td>
<td>Poor</td>
<td>Fair</td>
<td>Good</td>
<td>Best</td>
</tr>
<tr>
<td>Die Cutting</td>
<td>Poor</td>
<td>Fair</td>
<td>Good</td>
<td>Best</td>
</tr>
<tr>
<td>Puncture</td>
<td>Good</td>
<td>Best</td>
<td>Fair</td>
<td>Poor</td>
</tr>
<tr>
<td>Storage Space</td>
<td>Most</td>
<td>Fair</td>
<td>Good</td>
<td>Least</td>
</tr>
<tr>
<td>Score/Bend</td>
<td>Poor</td>
<td>Fair</td>
<td>Good</td>
<td>Best</td>
</tr>
<tr>
<td>Cushioning</td>
<td>Best</td>
<td>Good</td>
<td>Fair</td>
<td>Poor</td>
</tr>
<tr>
<td>Flat Crush</td>
<td>Poor</td>
<td>Fair</td>
<td>Good</td>
<td>Good</td>
</tr>
</tbody>
</table>
Corrugated Board Basics

- **Double wall corrugated**
  - Provides extra strength to the box
  - Allows the utilization of the advantages of multiple board types
- BC or AB-flute board:
  - B-flute side prints better
  - A or C-flute side strengthens
Corrugated Board Basics

- The Corrugated **Board Grade** identifies the liner and medium combination.

- Outside liner - Medium(Flute type)- Inside liner
  - Example
    - 42-26C-42
    - 56-33C-56
    - 33-26B-33-26C-33

- Board grade identifies specific performance attributes of combined board
Corrugated Board Mechanical Properties

- **Burst Strength test (TAPPI 810)**
  - Measure the resistance of the corrugated board against rupture
  - Measures the strength of the liners

- **Edge crush test (TAPPI T811)**
  - Measures the strength in the flute direction
  - Used to determine box stacking strength
Design Steps for Stacking Strength...

Material

Structure of Single Unit

Structure of Unit Load
Box Basics

Major Flap

Minor Flap

Crease or Score

Depth

Length

Width

Manufacturer’s Joint

Manufacturer’s Joint
Corrugated Box - Sizes

- **Common footprint** was developed to create standard footprint in the retail sector
- Most popular: **600mm x 400mm**
- Fit 5 boxes on a 1,200mmx1,000mm pallet
- Fractions:
  - 300mmx400mm
  - 300mmx200mm
  - Etc.
Corrugated Shipper - Styles

- **FEFCO Corrugated Box Standard**
- **Styles:**
  - 01 - commercial rolls and sheets
  - 02 - slotted- type boxes
  - 03 - telescope- type boxes
  - 04 - folder- type boxes and trays
  - 05 - slide- type boxes
  - 06 - rigid- type boxes
  - 07 - ready- glued cases
  - 09 - interior fitments

[Image of corrugated box styles]
Corrugated Shipper - Styles

- **0201** Regular Slotted Container (RSC)
- **0200** Half Slotted Container (HSC)
- **0427** Roll End Tray with locking Cover
- **06** Bliss Style
- **0711** Pre-glued Auto Bottom with RSC Top Flaps
How Corrugated Folds:
### Carrier Rules

- **Truck:** National Motor Freight Classification (NMFC)
- **Rail:** Uniform Freight Classification (UFC)
- Requires all box to comply with the requirements and have the Box Certificate.

<table>
<thead>
<tr>
<th>Maximum Weight of Box and Contents (lbs.)</th>
<th>Maximum Outside Dimensions, (Length + Width + Depth) (in.)</th>
<th>Minimum Bursting Test (lbs. per sq in.)</th>
<th>Minimum Edge Crush Test (lbs. per sq in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Single Wall</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>40</td>
<td>125</td>
<td>23</td>
</tr>
<tr>
<td>35</td>
<td>50</td>
<td>150</td>
<td>26</td>
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<tr>
<td>50</td>
<td>60</td>
<td>175</td>
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<tr>
<td>65</td>
<td>75</td>
<td>200</td>
<td>32</td>
</tr>
<tr>
<td>80</td>
<td>85</td>
<td>250</td>
<td>40</td>
</tr>
<tr>
<td>95</td>
<td>95</td>
<td>275</td>
<td>44</td>
</tr>
<tr>
<td>120</td>
<td>105</td>
<td>350</td>
<td>55</td>
</tr>
<tr>
<td><strong>Double Wall</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>80</td>
<td>85</td>
<td>200</td>
<td>42</td>
</tr>
<tr>
<td>100</td>
<td>95</td>
<td>275</td>
<td>48</td>
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<tr>
<td>120</td>
<td>105</td>
<td>350</td>
<td>51</td>
</tr>
<tr>
<td>140</td>
<td>110</td>
<td>400</td>
<td>61</td>
</tr>
<tr>
<td>160</td>
<td>115</td>
<td>500</td>
<td>71</td>
</tr>
<tr>
<td>180</td>
<td>120</td>
<td>600</td>
<td>82</td>
</tr>
</tbody>
</table>
Basics of Mechanics of Corrugated Box
Compression

**Definition:** compression load resulting from static (warehouse stacking) or dynamic (clamping) load on a container or other package.
Compression
What is box compression strength?

**Definition:** Resistance of the box against compression forces applied perpendicularly to one or more of its faces.
Box Compression Strength can be determined in two ways:

- **Calculated** using simplified McKee equation
- **Measured** using a short term box compression test
Box Compression Test (BCT):

Where:

- ECT – edge crush test (lbf/in)
- P – box perimeter (2L + 2W) (in)
- Z – caliper of combined corrugated board (in)

Calculation is not applicable for all size and construction.

Mainly applies to RSC, HSC, or Telescopic Boxes.

**BCT = 5.87 ECT \sqrt{PZ}**
Measurement of Box Compression Strength

Short-Term Compression

- **ASTM D642** - Compression Test for Shipping Containers
  
  (https://www.astm.org/Standards/D642.htm)

**Procedure**

- Apply preload
  - 50lb for single wall box
  - 100lb or 500lb for double or triple wall box

- Recommended: 5 samples
- Record load and deflection (500lb @ 0.5” or 1000psi)
- Test until **visual** failure
- Failure of the box does not mean that the package failed
Load-Deflection Curve

- Pre-load
- Force at failure
- Deflection at failure
- Buckling
Failure Modes Based on Aspect Ratio

- Always run the tests until visible failure occurs!
Design Steps for Stacking Strength...

1. Material
2. Structure of Single Unit
3. Structure of Unit Load
Determining Stacking Strength

- **Stacking Strength** - the amount of load that the box can safely hold.

\[
\text{Stacking Strength} = \frac{BCT}{\text{Safety Factor}}
\]
Determining Stacking Strength

- Influencing factors:
  - Product and package interaction
  - Humidity
  - Time
  - Stacking misalignment
  - Pallet overhang
  - Transportation

- Fix safety factors or Retention Analysis are used to account for these influencing factors
Determining Stacking Strength

- **Fixed safety factor**: often used when the exact conditions that the package will be subjected to are not known.

- Range of safety factors can be found in **ASTM D4169**

- **Depends on**:
  - Assurance level
  - Package type
  - Transportation mode
    - Warehouse (static)
    - Vehicle (dynamic)
Determining Stacking Strength

- **Assurance Levels:**
  - The levels are determined based on
    - the product value,
    - the desired level of anticipated damage that can be tolerated,
    - the number of units shipped,
    - the knowledge of the shipping environment, or
    - other criteria

- **ASTM Assurance Levels:**
  - Level 1 - Low probability, High intensity events (more severe than Level 2)
  - Level 2 - (Commonly used)
  - Level 3 - High probability, low intensity events (less severe than level 2)
Example 1

Safe Stacking Strength using **Fixed Safety Factor** method:

- Suppose you compression test a package in the lab under standard conditions and get a compression strength of 800 lbs. The package is made out of corrugated box without any rigid internal supports. The client want to use Assurance Level II.

- How much is the safe stacking strength of the package in a warehouse?
Example 1

Safe Stacking Height using **Fixed Safety Factor** Method:

- BCT = 800 lbs.
- Safe Stacking Strength = ?

\[
\text{Safe Stacking Strength} = \frac{800}{4.5} = 177.78 \text{ lb}
\]
Determining Stacking Strength

Retention Analysis:
- Aimed at evaluating the compression strength retained by the package in the presence of the debilitating influences

\[
\text{Safety Factor: } \left( \frac{1}{H \cdot T \cdot PP} \right)
\]

H – Humidity
T – Storage Time
PP – Pallet Pattern
Determining Stacking Strength

Retention Analysis:

- **Humidity Factor (H)**
  - Humidity weakens the box because of absorption
  - 85% Relative Humidity (RH) is common in warehouse across the U.S.

<table>
<thead>
<tr>
<th>RH</th>
<th>0%</th>
<th>25%</th>
<th>50%</th>
<th>55%</th>
<th>60%</th>
<th>65%</th>
<th>70%</th>
<th>75%</th>
<th>80%</th>
<th>85%</th>
<th>90%</th>
<th>95%</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>125</td>
<td>110</td>
<td>100</td>
<td>96</td>
<td>91</td>
<td>86</td>
<td>81</td>
<td>75</td>
<td>68</td>
<td>60</td>
<td>48</td>
<td>29</td>
</tr>
</tbody>
</table>
Determining Stacking Strength

Retention Analysis:

- **Storage Time Factor (T)**
  - Box weakened due to fatigue
  - Common to store loads up to 90 days.

<table>
<thead>
<tr>
<th>Time</th>
<th>T</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>100%</td>
</tr>
<tr>
<td>6 hrs</td>
<td>87</td>
</tr>
<tr>
<td>12 hrs</td>
<td>79</td>
</tr>
<tr>
<td>1 day</td>
<td>76</td>
</tr>
<tr>
<td>2 days</td>
<td>73</td>
</tr>
<tr>
<td>3 days</td>
<td>70</td>
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<tr>
<td>4 days</td>
<td>68</td>
</tr>
<tr>
<td>5 days</td>
<td>67</td>
</tr>
<tr>
<td>10 days</td>
<td>66</td>
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<tr>
<td>15 days</td>
<td>64</td>
</tr>
<tr>
<td>20 days</td>
<td>61</td>
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<tr>
<td>30 days</td>
<td>57</td>
</tr>
<tr>
<td>60 days</td>
<td>53</td>
</tr>
<tr>
<td>90 days</td>
<td>52</td>
</tr>
<tr>
<td>180 days</td>
<td>50</td>
</tr>
<tr>
<td>1 yr</td>
<td>46</td>
</tr>
<tr>
<td>2 yrs</td>
<td>46</td>
</tr>
</tbody>
</table>

![Graph showing % Compression Retention over Storage Time in Days](image-url)
Determining Stacking Strength

Retention Analysis:

- **Pallet Pattern Factor (PP):**
  - Column stacked and aligned: 8% loss
  - Column stacked and misaligned: 10-15% loss
  - Interlocked: 40-60% loss
  - Overhang: 20-40%
  - Deck board gap: 10-25% loss
  - Excessive handling: 10-40% loss
Example 2

Corrugated box strength: 800 lb

\[
H (85\%) = 0.60 \\
T (90 \text{ days}) = 0.55 \\
PP (\text{Column stacking, misaligned}) = 0.85 \\
PP (\text{Deckboard gap}) = 0.75
\]

\[
Stacking \text{ Strength} = \frac{800 \text{ lb}}{1} \div \left( 0.60 \cdot 0.55 \cdot 0.85 \cdot 0.75 \right) = \frac{800}{4.76} = 168 \text{ lb}
\]
Example 3

Corrugated box strength: 800 lb

- H (85%) = 0.60
- T (90 days) = 0.55
- PP (interlock stacking) = 0.40
- PP (Deckboard gap) = 0.75
- PP (Overhang) = 0.80

Stacking Strength = \( \frac{800 \text{ lb}}{\left( \frac{1}{0.60 \cdot 0.55 \cdot 0.40 \cdot 0.75 \cdot 0.80} \right)} = \frac{800}{12.6} = 63.4 \text{ lb} \)

62% Reduction
Box Analysis in PDS 6.1

Container Type: Corrugated Box

Box Style: Regular Slotted Container (RSC) #0201
Combined Board Type: Singlewall
Flute Profile: C-Flute
Caliper: 0.156 in.
ECT (lb/in): 32
Simplified Mckee Box Crush Capacity: 555 lbs.
Stacked 1 Unit Load High:
   Max Uniform Box Loading: 60 lbs.
   Rigid Surface Safety Factor: 9.3

Load Stabilizers
Wrap: Stretch Wrap

Box Outside Dimensions: 16.000 X 12.000 X 10.000 in.
Weight per Box: 20.0 lbs.
Total Weight of Load: 720 lbs.
Weight of Complete Unit Load: 762 lbs.

Number of Boxes per Layer: 9
Number of Layers per Unit Load: 4, Column Stacked
Number of Boxes per Unit Load: 36
THANK YOU FOR YOUR ATTENTION

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APRIL 23, 2020