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A Review Study on Various Types of Flute Shapes Used in Corrugated Paperboards Used for Packaging.

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Abstract

The markets are demanding better packaging for finished products. Packaging covers a minimal cost compared to the product to be delivered. However, it is essential to maintain quality. Electronics, readymade garments industries and even the food industries require such packaging for protection from adverse conditions. The fall in the sale of a particular stock of a product occurs when physical damage is prominent and thus removing the aesthetic looks of the product. Suppliers prefer corrugated paperboards since they are lightweight, easy to handle, and fully recyclable. The clients can also customize the product according to their requirements. The key principle of these paperboards is based on sandwich-like structures made of flute-shaped corrugated medium. Flutes are differentiated into multiple types accordingly to minimize the usage of material and costs. Multiple numbers of high precision machine tools are used to manufacture them. The lineup contains an assembly of a single face, double backer, heating and drying, longitudinal cutter and plier. Heat, pressure and moisture are applied to retain the flute structure which is contained within two sheets of linerboards. Thus, it provides a better bending stiffness. Mechanical reaction will vary according to the varying flute shape.

Keywords
Corrugated paperboard, Flutes, Packaging, Mass Production, Production engineering.

Introduction
Product packaging in the industry is multi-faceted and can go a long way in securing a product's future. Therefore, manufacturers should not overlook the importance it holds. The critical aspects of the packaging are that it provides protection against adversaries, displays and promotes the product, attracts buyers, and differentiates the product from the competitors. [1] A commonly seen packaging we can see in the market is the corrugated boxes. These are extensively used for agricultural produce, food products, electronics, delivery, and many more. These boxes are designed to protect products from mechanical impacts, have enhanced load-bearing capabilities, is light weight and recyclable. This makes them not only the optimum packaging solution but also environment friendly. In-order to make it an even more sustainable form of packaging, various experimental and modeling tools have been used to investigate the design and mechanical performance. Good design of vented packaging is essential in optimizing the cooling and ventilation uniformity, minimizing quality deterioration of packed products, and maintaining the box's mechanical integrity. [2] We will now further investigate the performance and integrity improvement of the box in this text.

Literature Review

Types of Packaging Material in the Industry:
There are various types of packaging material out there on the market with their own use for different cases.
Some mentionable packaging materials are given below:

1. **Corrugated Boxes**:
    - Corrugated boxes are staple in the packaging industry.
    - They are bought in preformed shapes such as squares or rectangles. They can be made according to customer requirements.
    - Commonly packed products are food, electronic items etc.

2. **HDPE/PET/Rigid Packaging**:

- Derived from polyethylene, high-density polyethylene and polyethylene terephthalate are harder and more rigid plastics than other plastics.
- Both materials offer excellent moisture resistance while maintaining a rigid protective structure.
- Some of the most common uses for HDPE and PET are bottles and Jugs.

3. **Aluminum Packaging**:
   - The most commonly used and recognized application for aluminum packaging are aluminum cans and containers.
   - Foil packaging is used in medical, food, beverage, cosmetic and many other industries as a barrier protector.
   - The foil helps to protect products from moisture, sunlight, and other external elements.
4. **Glass/Jars**:
   - Glass is preferred by some companies because it is 100% recyclable and very commonly reused for new containers over and over.
   - Alcoholic and Non-Alcoholic drinks make up a large portion of the glass packaging market. Other industries that consistently use glass packaging are cosmetics and personal care, food and condiments, and even home decor and candles.
5. **Stretch Film**:
   - Stretch film is one of the most common packaging materials in the world.
   - It protects products from collapse or damage during the shipping process. Stretch film achieves this goal with what is called "load containment."
   - Load containment is achieved with stretch film by one of two means. The film is applied to the pallet or load with human labor via a tool called a stretch film dispenser, or it is applied with a manual, semi-automatic, or fully automatic stretch wrap machine. [3][4]

Manufacturing of Paperboards: A series of machines use the corrugated paper box. The primary device used to manufacture the primary material is the corrugator machine. This Machine consists of sub-assembly's single facer, double backer, heating, and drying section. It also includes a longitudinal cutter, cross-section, and a plier. Initially, the raw material is softened and humidified using high-pressure steam. [2]

Fig 1: Corrugating Machine

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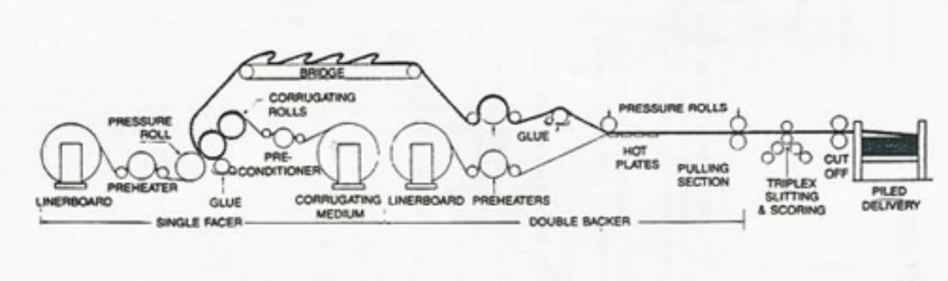

Fig 2: Segment of the Machine tool.

Features of a Corrugator Machine are:

1. Mill Roller
2. Pre-Heater
3. Single Facer
4. Preconditioner
5. Mill Roll Stand
6. Bridge
7. Mill Roll Stand
8. Web Break
9. Web Guide
10. Triplex Heater
11. Glue Machine
12. Double Face
13. Steam Chest
14. Top Belt
15. Bottom Belt
16. Driving Drum
17. Motor
18. Chain and pulley Mechanism.

Critical Parameters of Process:

1. Fluting Roll Profile (A, B, C, etc.)
2. Roll Temperature and pressure
3. Viscosity of Adhesive
4. The relative speed of the liner
5. Pre-heat condition of the liner

The fluting medium is conditioned with heat and steam to make it pliable enough to accept and retain the fluting's shape. The fluting shape is pressed into the medium using two profiled rolls by forming the fluting medium on one profiled roll utilizing a vacuum. The corrugation of the fluting medium and the starch adhesive is applied to the corrugations' tips. The medium is combined with liner, conditioned to bring the same temperature and moisture content as the fluting medium. After passing through a drying section, the board is matured and cooled before being slit to the required width and cut to the necessary length. Scores (creases) may also be applied to the board in the MD of the corrugator. The single facer's speed is more than that of the double backer, and the excess board accumulates in a bridge system between the two lining stations balancing the difference in speed. Starch adhesive preparation is an essential element for the orderly running of the process. [2]

Steps used by the Machine.

Step 1: The single liner is connected to the Machine via a roller.
Step 2: Two liners are flued and corrugated using adhesive

Step 3: The final corrugated paper is rolled up into another reel.

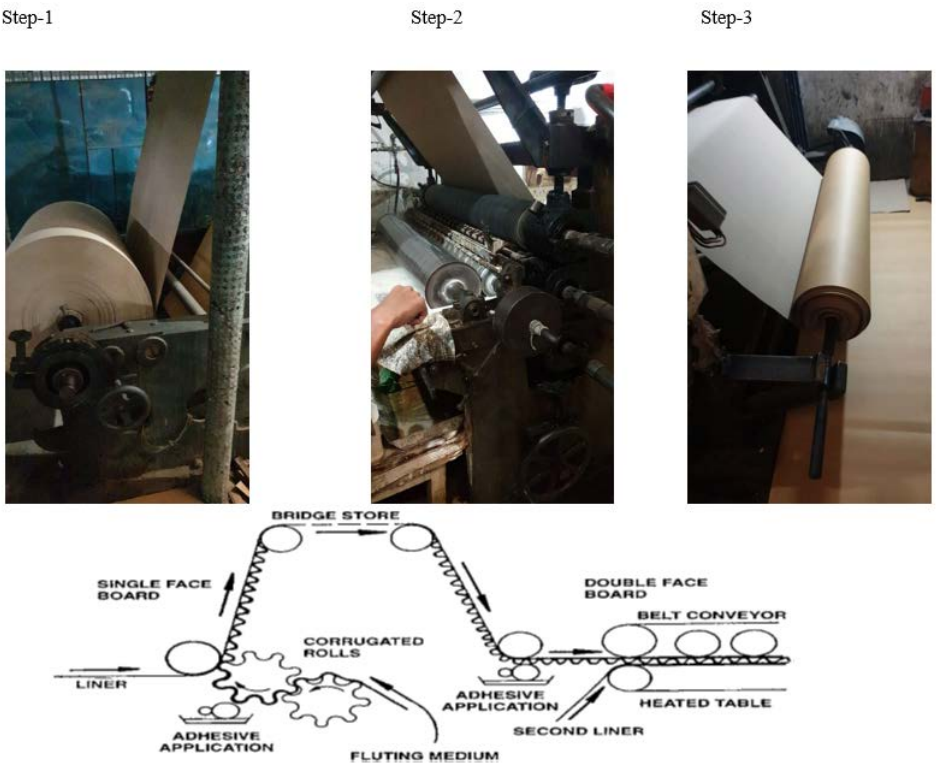

Fig 3: Production of corrugated fibreboard (courtesy of The Institute of Packaging)

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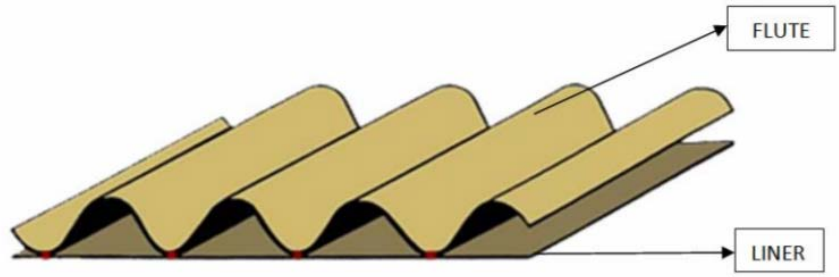

Fig 4: Corrugated sheet [5]

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A final paper board consists of two outside papers known as liner board and a different flute-like structure within the liner boards known as a flute. The final product is known as a single wall corrugated paper board with three distinct

layers. However, the Machine can be upgraded using other auxiliary devices available to increase the number of layers. [6] The speed of the operation and the corrugation rollers' diameter can be interchanged to produced flutes of different shapes and sizes. The flutes that are made can be characterized by letters A, B, C, E, or F.[7] The paperboard's board grades are based upon weight (mass per unit area), flute type the liner material used. The flutes act as a stabilizer in supporting a heavy load. The extra space in between acts as a cushion for whatever is placed in between.

A-Flute: The maximum flute size; thus, the eternal facing line board is quite thick. The product contains excellent stacking property, therefore mostly used for delicate items.

B- Flute: The height of the arcs is lower and more flutes are accommodated per foot. The flat surface enables high-quality printing to be done.

C-Flute: The most widely used corrugated container is made using this flute type. This offers good stacking and printing properties.

E-Flute: The most significant number of flutes per foot without the highest crush resistance along with high-quality printing capability. The flutes variation depends on the packaging of the paperboard

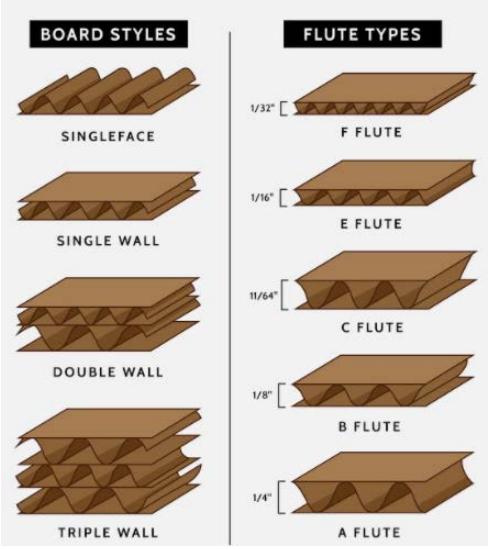

Fig 5: flute types

used. A-flute is generally used for heavy-duty boxes. B-flute is used in cases where there is no need for high compression strength, but high compression is preferred in C-flute. Finally, E and F flutes are used for manufacturing smaller sized boxes. Corrugated paperboard can resist adverse conditions such as buckling due to high stacking strength. The air space allows easy movement of air, thus works as a thermal insulator. It also protects against fluctuating atmospheric conditions. [2]

Table1: Flute properties

Flute types	properties	Flute height (mm)	Take – up factor	Wave length (mm)	Flute/m length of the corrugated board web
A	• Large flutes • Seldom used	4.8	1.5-1.55	8.3-10	110
B	• Good compactness • High compressive strength	2.4	1.3-1.35	6.1-6.9	150
C	• Edges can be crushed easily	3.6	1.4-1.45	7.1-7.3	130
E	• Excellent flat crush resistance	1.2	1.15-1.25	3.2-3.6	290
F	• Known as micro-flutes with excellent properties.	.5-.8	1.15-1.25	2.3-2.5	400-550

Effect of structural design on corrugated boxes strength: Corrugated packaging is required to have

1. Appearance.
2. Mechanical characteristics.
3. Protecting the product inside.

Overall packaging performance is affected by:

1. Quality control protocol.
2. Machine precision.
3. Human factor in production.
4. The engineering properties of liner, medium and adhesive.
5. Warehouse storage and transportation conditions.

In order to improve the design and manufacturing of corrugated boxes, it is essential to have a clear and sound understanding of these factors affecting box performance. Resistant to buckling and can be made to exhibit considerable stacking strength, making it an ideal choice for the fresh produce industry. Depending on the product's loading requirements inside a box, a corrugated board can be manufactured to have higher compressive strength by adding layers of the flute. The box compression test (BCT) constitutes a general measure of a corrugated board package's performance potential. The compressive load and crosshead displacement are recorded continuously until collapse occurs. The edge crush test (ECT) is used to evaluate the corrugated board's compression strength in the directions of the flutes. It gives information on the ability to resist crushing. The ECT of a corrugated sample is tested according to T 811om-02. The box resistance to vertical compression is the parameter that gives the best account of the effects of transport and storage conditions and the stackability of the packages. The ECT and its relationship to compression and stacking strength play a crucial role in corrugated box performance.[2]

Challenges or hazards: So far, we have gone, now it's time to talk about the challenges we face in this packaging sector. The most challenging factor now is the high pricing of raw materials. Typically, kraft paper is carried 70% of the input, whose price has increased by 12%. Industries are facing a crisis that could end up the business.[9]
The main reasons for rising of price of packaging is-

- Price of paper and materials
- Labour costs, wage increase
- Number of manufacturing processes
- Inefficient machinery / conversion costs

- Cost of transit / logistics
- Sub-contracting / reselling
- General overhead rises

So, the question is how can industries mitigate this inevitable price rising?

- Price can be reduced by analyzing the material (strength, compression testing, stack strength, burst limits) and check if it is possible to make a cheap, lightweight board with the same performance. It is switching from a double grade walled to a heavy fluted single wall without noticeable performance loss.
- Efficient use of material or custom-sized boxes such as a tailored box smaller can reduce the price as it would reduce the amount of void inside the box so that less material would be needed. Also, the volumetric shipping cost would reduce.
- Converting the traditional box system to a self-containing lock system, the amount of tape used to seal the box will be less. Also, much quicker assembly possible, the overall price will reduce, and efficiency will be higher.
- Inefficient machinery will cause a bottleneck to the production line, which increases the cost, so proper maintenance is needed.
- Using a proper board grade that means choosing optimum material according to the requirements will reduce the cost. [10]

Mechanical hazard: The wet pressing process increases the density but reduces thickness. Higher densification results in a reduction in bending stiffness of the linerboards and edge compression resistance of a corrugated box [11]. About 15% reduction in edge compression strength of corrugated paperboard was occurred due to a decrease in thickness of about 30%. If flute height is reduced by about 20%, edge compression strength and bending stiffness would be reduced to 3%. This is caused by excessive tension on the fluting medium.[12]. Flute factures when high pressure is applied on the top and bottom of the flute tips. It is not easy to determine the depth of the damage of the handling and distribution environment. Various hazards such as uneven load, vibration, shocks, sudden drops from the vehicle, etc., can occur by handling packages, storage, and transportation. Analysis of the types of hazards will consequently help to design containers that could withstand effectively.

Corrugation quality is negatively affected by excessive use of adhesive materials during bonding; corrugate paper may face wash boarding that causes low print quality, wrapping of the board, crushing the board due to damping fluting medium.[2] Web tension affects the corrugating process as it goes through the labyrinth of the coils. The maze's excessive speed would cause poor corrugation due to not getting enough time for flute formation, which results in poor bonding between the linerboards.

Environmental Hazard: Corrugated boxes harm the change of humidity on the strength of the materials. Moving products from one place to another cause change in the environment, which affects the moisture content of the box, stiffness, and lifespan of the material. [3] Some articles showed that increasing moisture content from 7.7% to 16.4%, edge compressive strength reduces by 42.6%, and puncture resistance reduces by 9.09%, compressive strength reduces by 52%.[13] Moisture also weakens the highly porous paper fibers, which reduces paperboard strength. Uncontrollable water can lead to many problems. Too much humidity softens the paperboard resulting from collapsing and fluting exposure after production, while low humidity causes the paperboard to break easily because of being crisp. So, the moisture content is crucial in the production of corrugated paperboard. To avoid this, an alternative material is needed that is lightweight and waterproof to environmental fluctuations. Temperature also affects the quality of the corrugated paper board. The humidity of the paper is affected by the weather. Therefore, the corrugated paper board's product range is equipped with pre-heaters that can be used to adjust the water content of the paperboard. Low corrugating roll temperature could create white glue-lines on the paperboard, and the consequences are: adhesive appearing white, low bonding strength, no gelatinization.

Materials made from 100% recycled sources produce a low-grade product used in less demanding applications, such as interior packaging, newsprint, and other paper products. Moreover, the recycling process is extremely labor and energy-intensive, and the final product may not fully meet the technical requirements of the end-users. To solve this, the manufacturing process typically uses at least 40 percent of fibers direct from trees to provide the necessary strength.[11]

Vibration Hazard: When packages are being transported by truck, rail, aircraft, products undergo several vibrations affected by road roughness, speed of the vehicle, axles, and suspension of the car. The pulse occurs when the acceleration of the vehicle is more than the gravity. In stacked flow, the top of the stacked cartons experiences more impact of acceleration. Properties of vibration such as vibration transmissibility, resonant factor, damping ratio, and dynamic stress should be considered for protective and more efficient packaging. The **table 3** is given below shows the range of vertical frequency and maximum acceleration encountered in transportation. Appropriate handling and proper packaging reduce the losses of the product due to vibration.

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Impact hazard: This usually occurs in the warehouse during improper handling, forklift, and the warehouse's shelf package. This results in the

Fig 6: MBT test

bursting or bruising of the box. Opening of package cover causes to lose functionality, distortion in shape, reduce stacking abilities. Appropriate precautions should be taken against sudden impact to prevent damage. Adequate cushioning can reduce damage significantly.

Compression hazard: When the bottom of the stack is not significantly strong to withstand the carton's load stacked on it, a compression hazard occurs. A package can encounter both static and dynamic compression. Static compression occurs when the box is stacked vertically for a large amount of time. Dynamic compression occurs when moving forces are being pressed against the object, and it occurs due to vibration and shocks in the transport. To get rid of this problem, boxes should not be stacked up above their design specification. They are using the robust package on the bottom that can withstand the static compression.

Table2: effects of vibration and maximum acceleration experienced by box.

Transport Mode	Vibrating System	Frequency Range	Maximum Acceleration
Rail cars	Vertical suspension Lateral suspension Rolls Structural	2-7 .7-2 1 50-70	.5 .8 .1 .3
Trucks	Suspension Unsprang suspension Structural and tyres Damaged suspension	0-7 10-20 50-100 >100	.5 .3 .3
Trucks on flat cars	Vertical Rolls	2-4.6 .7-3.1	1 10
Aircraft	Propeller Jet	2-10 100-200	.5 .5
ships	Sea Engines	.1-.2 100	.2 .4

Corrugated box testing methods:

- Bursting Strength Test
- Edge Crush Test 2 Single
- Water Resistance of the Gluing
- Cobb Sizing Tester
- Paper Grammage and Thickness
- Puncture Resistance
- Scuff Resistance Test
- Box Compression Test
- Chemical Analysis in Corrugated Box Testing

Bursting testing method: The Mullen test or Bursting Strength Test checks the toughness of corrugated board walls when pressure is applied. A rubber diaphragm is used to apply pressure to the walls until it bursts. The bursting strength is measured in Kilograms per square centimeters.

Edge Crush Test: One of the most popular methods to test the stacking strength of corrugated packages. The sides of the box are made of sheets containing three or more layers. Generally, a thin sheet with grooves and ridges is sandwiched between two flat sheets. These grooves and ridges, also called flutes, provide anisotropic strength to a box. This means the containers can bear a more significant force from one direction. Edge crush test, right test, or flat crush test helps determine this. In this test, force is applied to one side of the box, perpendicular to the ridges, until the package gets crushed. In the Ring Crush test, a ring cut out from the pack is used to test the same. While in the flat crush test, excessive force is applied on one side.

Fig 7: ECT test

Water resistance of the Gluing: For specific applications, the FEFCO 9 standard is used to test the water-resistance of corrugated cardboard boxes' gluing. In this test, the corrugated board is immersed in water and exposed to the glue lines to check the strength of the bond and moisture absorption.

Cobb-Sizing Tester: Raw material used for manufacture the corrugated fiberboard tends to absorb water. This test determines the degree to which water is absorbed. At first, the corrugated board is immersed in water. Water is squeezed out of the sample employing pressure. Depending on the quality, all water is not removed, although a heavy roller is pressing the board. The weight difference is called the Cobb value. The lower the value, the more it can resist water.

Paper Grammage & Thickness: Grammage and thickness are two fundamental properties of corrugated boards. When more pudding is needed, a higher thickness box is used. The flutes of the corrugated board are more considerable and pack more air in them. Thick boards are perfect for heavy-duty shipping. Thin panels with dense flutes have high grammage. They are easier to fold, lightweight, suitable for printing. These boxes are needed when packaging is rigid and compact.

Puncture Resistance: this test shows how well a box can handle the impact made by a pyramid or triangularly shaped weight.

Scuff Resistance Test: This test is performed to check how well labels or prints can handle scuffing or abrasion. A coated surface like paper, films, paperboards, and other printed materials are tested in this process. This test is mostly applicable for pharmaceuticals or medical industries where legibility is the prime interest.

Box Compression Test: They are also known as the Container compression test, a test to check how much load the box can take on top of it without deformation. It provides a good idea about how many boxes can be stacked together without damaging the lower ones.

Chemical Analysis in Corrugated Box Testing: For specific applications where the fiberboard's nature and its resistance to certain chemicals are checked, chemical analysis is performed. This analysis involves microscopic examination of the board, moisture content, pH of the board.[14]

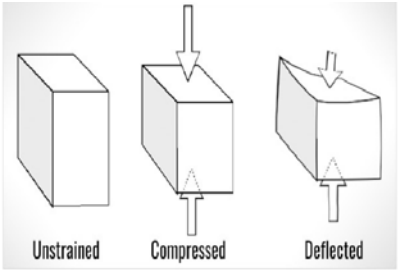

Fig 8: deformation tests

Conclusion:

Corrugated boxes are widely used as the ultimate mode of cargo transportation. Much research and development can be done on this topic to make it stronger, long lasting and reliable. A few points can be mentioned:

1. Stronger, effective and environment friendly adhesive use,
2. Honeycomb flute incorporation and
3. Simulation based extensive research.

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