Performance Evaluation Of Corrugated Packaging - A Key To Success For Papermakers And Corrugators

Tyagi Sanjay, Thapliyal B.P., Godiyal R.D., Kaushik Prachi & Kumar Manoj

Tyagi Sanjay

Thapliyal B.P.

Godiyal R. D.

Kaushik Prachi

ABSTRACT

Recent years marked an enormous change in field of paper based packaging especially in case of corrugated fiberboards. The developments in this area have placed a variety of demands for the corrugated box manufacturers, papermakers and printers. From the image of brown box for carrying goods, modern corrugated box has many new end uses which require specially designed features. Among other properties, strength characteristics of corrugated box are of great importance. They are necessary to perform the basic function of protecting the product during distribution and from the environment. Different performance parameters like bending stiffness, RCT, ECT, CMT, puncture test, BCT and PAT of liners, medium and corrugated box plays a crucial role in deciding their end use performance. As such, it become pertinent that these performance parameters should be examined carefully with great accuracy using standard test procedures under the specified condition of temperature and relative humidity. Various correlations among these parameters specially for product made from indigenous raw materials must be examined to decide the end use performance of corrugated box.

Key words: *corrugated box, RCT, ECT, BCT, liner, medium, PAT*

INTRODUCTION

Paper and paper board has been used widely as packaging material since long. The significance of paper and paper board are packaging material can be visualize by the fact that world wide today, upto 40% of all packaging is based on paper and paper board making it the largest packaging material used, by weight. Corrugated board is replacing other more traditional packaging materials partly because corrugated is cheaper per unit strength than other materials (Fig. 1) and partly because corrugated board is recyclable or biodegradable (1, 2, 3, 4). With the growth of consumer industry, growth of paperboard production in India as also increasing. Out of the total production of 14.99 million tons of paper/paper board and newsprint, packaging paper shares 8.29 million tons of total production, contributing 55% of total production in India. Recycled based mills alone produces 6.37 million tones of this production. Due to cyclic nature of the paper industry, the spurt and depression in growth was averaged out and estimates reflect a growth of 7.8% in production and 7.4% in consumption. Based on above figures, the projected production of paper in India in 2025 is expected to be 21.94 million tones and consumption around 23.51 million tones (approx.). Out of this figure, the expected growth rate for Industrial paper board is 10 for corrugated board & containers and 8% for carton board. (5).

Central Pulp & Paper Research Institute, Paper Mill Road, Nr. Himmat Nagar, Saharanpur- 247001(U.P.) India

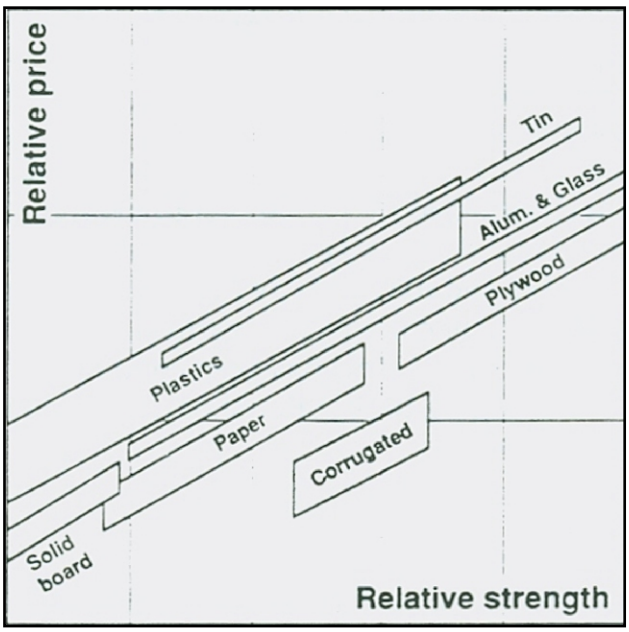

Fig. 1 Relative price verses relative strength of various packaging materials

(Source: Alf dr Ruvo, "Development trends in packaging", PRIMA supplement in Paper Europe, volume3, number 4, July 1991)

Paper and paperboard is most widely used and most commonly recognized packaging material. The main type of paper and paper board based packaging are:

- Bags, wrapping and infusible tissues eg. Tea and coffee bags, sachets, pouches, over wrap, sugar and flour bags, carrier bags
- Multiwall paper sacks
- Folding car tins and rigid boxes
- Corrugated and solid fiberboards boxes
- Paper based tubes, tubes and composite containers
- Fiber drums
- Liquid packaging
- Labels
- Sealing tapes
- Cap liners (sealing wads) and diaphragms (membranes)

Paper and paper board packaging is widely used because it meets the criteria for successful packaging namely to

- Contain the product
- Protect goods from mechanical damage
- Preserve products from deterioration
- Information to customer / consumer
- Provide visual impact through graphical and structural design.

Paper and paper board meet these needs because they have appearance and performance properties which enable them into a wide range of cost effective packaging structure e.g. they are printable, varnish able and can be laminated to other materials. They have physical properties which enable them to be made into flexible, semi rigid and rigid packaging by cutting, creasing, folding, forming, winding, gluing etc.

Paper and paper board packaging is used over wide temperature range, from frozen- food storage to temperature of boiling water and heating in microwave and conventional ovens. For food grade packaging, paper and paper board is made permeable to water, water vapour, aqueous solution and emulsions, organic solvents, fatty substance (except grease -resistance papers), gases such as oxygen, carbon dioxide and nitrogen, aggressive chemicals and volatile vapors and aromas. They acquire barrier properties and extended functional performance such as heat sealability, heat resistance, grease resistance, product release etc. by coating, lamination and impregnation. Materials used for this purpose for extrusion coating are polyethylene (PE), polypropylene (PP), polyethylene terephthalak (PET or PETE), ethylene vinyl alcohol (EVoH) and polymethyl pentene (PMP), lamination with plastic films or aluminum foil and by treatment with wax, silicon or fluorocarbon. (6, 7, 8)

Besides this with consideration to environmental and waste management issues, paper and paper board packaging has important advantage that the main raw material used in paper and paper board packaging is wood or agro residues which is naturally renewable resources and after their use as end product they can be recovered and recycled.

Technical Requirement of Paper and Paper Board for Packaging

Packaging protects and identifies the product for customer / consumers, for which certain functional requirement to be met.

- Correlating with the needs of printing, its conversion into packages and their use in packing, distribution, storage, product protection and consumers use.
  All papers and paper board properties depend on the ingredients used e.g. type and amount of fiber and other materials, together with the manufacturing process. These properties of the paper and paper board are related to the visual appearance and technical performance of packaging incorporating such materials.
- Appearance that relates to color, visual impression and the needs of any processes such as printing which have a major impact on the appearance of the packaging.
- Performance that relates to strength, product /

consumer protection and the efficiency of all the production operations involved in making and using the packaging.

In the present paper we are discussing some of the major strength properties which are useful for the functionability of paper board especially the corrugated fiber board.

Corrugated fiber board packaging

Corrugated fiber board packaging in terms of weight, is the commonest type of paper and paper board based packaging. It function is mainly the protection of products during distribution. The popularity of corrugated board as packaging material is primarily because of its high strength-to- weight ratio. This mean that corrugated is exceptionally strong considering its light weight. The reason of strength of corrugated box lies in the fact that the fluted medium separates the two liners and when stood on end, the flutes act as columns. We all know that columns have been used for structural support for centuries.

Corrugated boxes are erect and packed manually or automatically. The packaging can be erected, filled and closed or formed around the product and closed. To ensure packing **line** efficiency, corrugated fiberboard boxes also referred to as 'cases' and 'cartons' have to present flatness, structural stability and suitability for closure

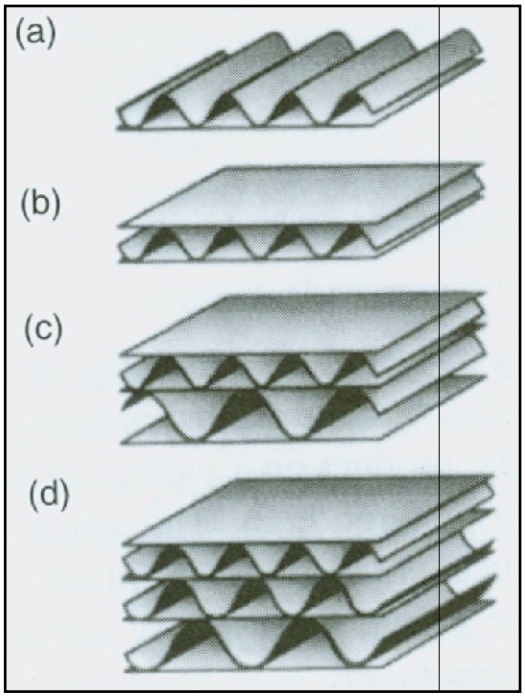

Figure 2. Corrugated boards (a) single face (b) single wall (c) double wall and (d) triple wall

Structure of Corrugated Board

Corrugated board has a sandwich material structure. It comprises a central paper (called the corrugating medium or simply the medium) which has been formed using heat, moisture and pressure in a corrugated i.e. fluted, shape on a corrugators and one or two flat papers (called liners) have been glued to the tips of the corrugations. The sandwich can be formed in several ways. If one liner is used, the product is known as 'single faced' (Fig. 2a). If two liners are used, one on either side of the fluting, the product is known as 'single wall' or double faced (Fig.2b). The combination of two media or fluting and three facing is called doubled wall (Fig. 2c) and combination of three media and four facing is called triple wall (Fig. 2d)

Corrugated board is normally made in one of the nine flute i.e. D,K,A,C,B,E,F,G and O. The flute size is defined by the pitch, the number of flutes per unit length and the take up factor. The pitch can be defined as the distance between two fluting tips while take-up factor is the length of the medium (fluting) material used in a corrugated fiber board structure compared with the length facing. Table 1 represents the different corrugated flutes

Table 1
Corrugated Flutes profiles

Flutes	Average Number of flutes/ m	Pitch	Take up factor
D	75	14.96	1.48
K	95	1.70	1.50
A	110	8.60	1.53
C	129	7.95	1.42
B	154	6.50	1.31
E	295	3.50	1.24
F	310	2.40	1.22
G	350	1.80	1.21
O	360	1.25	1.14

(Sourse: 'Technical Corrugating Roll Data',BHS Corrugated brochure by Edmund Bradatsch and Lothar Jobst July 2000)

Approximately 70% of all the corrugated paper board made worldwide is C flute, B flute is the next most common board utilization. The most common double wall board is a combination of B flute and C flute with 69 lbs 337 g/m2) liners on each extreme, with 42 lb.(204 g/m2) liner in between and 26 lb (127 g/m2) medium. This is generally referred as 275 lb (124kg) BC double walled corrugated paper board.

Properties of corrugated paper board and their test procedure

The following a partial list of properties important to corrugated containers and test procedure used to check these properties.

(i) Weight per unit area (grammage) and thickness (caliper)

The grammage is the weight of one square meter of corrugated board (g/m^2) measured under standard conditions. It can be evaluated from the component paper grammage using a simple liner formula for single wall corrugated fiber board.

Grammage = $L_1 + (a \times F) + L_2$

Where L_1 and L_2 are the liners, F is the medium and 'a' is take-up factor. The take- up factor defines the length of the medium (fluting) material used in a corrugated fiberboard structure compared with the length of the facings.(Table 1)

The thickness (caliper) is measured under 20 kPa pressure Average value of thickness for different flutes in given Table 2

Table 2
Average caliper (thickness) for different corrugated board grades

Flutes	Caliper (thickness) in mm
D	8.0
K	6.5
A	4.8
C	4.2
B	2.8
E	1.7
F	1.2
G	1.0
O	0.7

Why measuring the corrugated caliper is important?

Caliper is an indirect measure of the compression stacking of corrugated boxes. Low caliper is usually the result of poorly formed flutes or crushed flutes and often results in poor corrugated box performance. Each grade of corrugated has a caliper target based on the depth of the flutes in the corrugated rolls and on the thickness of the liners and medium used. Whenever the caliper of given grade of board is less than the target value, it failed to achieve the maximum strength potential. There are only two things we can do to maximize caliper: from the flutes to the maximum potential of the corrugated rolls and not to crush the flutes after we have formed them. There are lot of opportunities to crush flutes in corrugated box plant especially when they passes through a nip between the rolls, occurring at many places on a corrugators an on box finishing equipment. Therefore, caliper control must be controlled in box plant. Everyone who operates the box plant should be fully aware of effect of different converting equipment on caliper of flutes.

(ii) Strength Properties

The strength and durability of corrugated board lies in the strength of the components it made up of. It is amazing that several flexible pieces of paper and board when combined together converts into something very rigid. A 20 x 20 x 20 200 lbs ($976 g/m^2$) test C- flute corrugated box can withstand almost 900 lb of weight before failing, yet it weighs only 2.5 lb. Given below, the description of few major strength properties important for measuring the performance of any corrugated board.

a. Bursting Strength

Corrugated paper board is subjected the burst testing just as paper board is . The significance of the burst testing is just as paper board is. The significance of the burst test if combined board is primarily an indication of the character of the materials used in the manufacturer of the box. Depending on nature and grammage of the liners, large range of quantities from 800 to 8000 kPa is available. On the other hand, this test gives no direct information regarding the ultimate performance of the design or construction of a finished container. This test correlates very poorly with actual performance of the container in shipment. The bursting strength of the paper board is to critical importance as a control test in the paper board mill since the conformity of the finished container is generally controlled by burst strength. Triple wall corrugated board can not be tested suitably by the burst test method. Testing of double wall is of questionable accuracy since it is rarely possible to get sufficiently simultaneous burst of the multiple facing. For single wall corrugated board, the following equation is applied

Burst Strength = $L_1 + L_2 + 100$
Where L_1 & L_2 are the burst strength of the liners in kPa.

b. Rigidly or bending stiffness

It relates the force required to defect a flat specimen of corrugated board through a given angle. The standard unit of bending stiffness is Nm and corrugated board sample is tested according to ISO 5628.

Experimentation carried out with different grammage and qualities of liners shows that (10)

- C Flute has higher bending stiffness than B Flute
- Corrugated fiber board based on kraft liner has a higher bending stiffness than test liner of same grammage
- Bending stiffness increases with increasingly liner grammage

c. Ring Crush Test

In ring crush test, sample of paper or cardboard is placed in the ring formation and subjected to successively edge compression force until it breaks. The resistance force is measured. The CL value is expressed as force divided by the sample's length. The test strip is formed into a ring when it is inserted into an annular gap in a special holder. The width of gap is adjusted to the thickness of test samples.

d. Edge Crush test

The edge crush test (ECT) is used to evaluate the compression strength of the corrugated board as per ISO 3037. A sample of corrugated board is subjected to increasing force, parallel to the flutes, until it breaks. The ECT value is expressed as the breaking force divided by the sample width. The edgewise compression strength of specimens with flutes and vertical columns relate directly to the top to bottom compressive strength of corrugated shipping container. This method is used for comparing the edge wise compression strength of different lots of similar board or for comparing different materials combinations

e. Flat crush test and hardness

One of the main criteria for the stability of the corrugated board is the ability to retain its structure and its geometry. The flat crush test (FCT) makes it possible to evaluate any classify the performance of the fluting in accordance with the type and basis weight. The test when conducted as per as per 3035 is a measure of the resistance of the flutes in corrugated board to crushing applied perpendicular to the surface of the board under prescribed conditions. This test gives the intrinsic performance of the flutes predicted by the Concora Medium Test (CMT) and by basis weight. The FCT thus records how appropriate the fluting medium is for processing on the corrugators. (Fig. 3)

The FCT Satisfactory for single faced or single wall corrugated board but should not be used for double wall or triple wall board. The FCT is a measure of the flute rigidity of the corrugated board. A high FCT value indicated a good combination of the flute formation and at least adequate medium strength. A low flat crush value indicates a number of faulty conditions. Among these are low strength medium, leaning flutes and/or crushed flutes. Care must be taken when measuring flat crush resistance of finished containers to ensure that the measure of resistance adequately simulates the reaction to crushing force observed during the container's actual use- This method generally does not simulates these conditions- therefore, the correlation may be low between flat crust and the ability of the box to perform in the field. (11)

In order to evaluate properly the performance of soft board, the hardness of corrugated board is other important criterion. Hardness is the resistance of the board in early stage of FCT. It relates to the real strength of the flutes whereas FCT is late yield point.

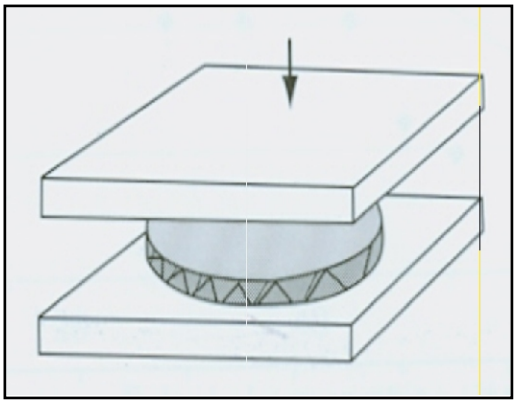

Figure 3: Flat crush corrugated board testing

f. Concora Medium Test

The Concora Medium Test (CMT) is described in ISO 7263. It is a test of compression of the paper after fluting in fluting apparatus as shown in Fig (4). In this test, a sample is corrugated between heated corrugating rolls. The flute is fixed and held together by pressure sensitive tape, so that single sided corrugated board is imitated. The corrugated board is imitated. The crushing force is applied perpendicular to the paper's plane and the breaking force is measured. The CMT value is the maximal force the sample can with stand before it breaks. Research shows that there is a good linear relationship between FCT of the board and CMT strength of flutes.

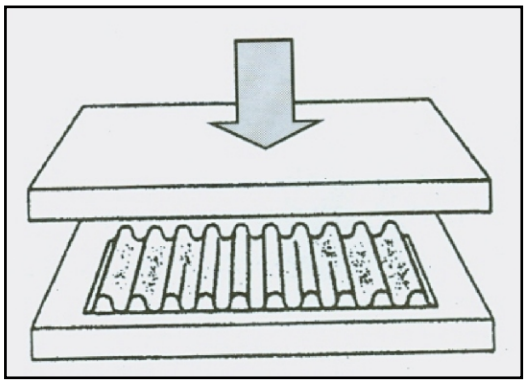

Figure 4: Concora medium test apparatus

g. Adhesion Test and Score cracking

The Pin adhesion Test (PAT) is used to evaluate the bonding between the fluting and liner. Adhesion resistance is the maximum force required to separate the linerboard from the fluting with the help of special sample holder. Pins are inserted between the flutes and the force required to breakdown the adhesion is measured in Newtons per meter (N/m). The glue bonding of the tips of the fluting to the liner is very important for the performance of the corrugated structure throughout its life in packing, storage and distribution. Single face bonding is quite different to the bonding on the double backer due to difference in morphology of the adhesion deposit between single face and double backer. In single face bonding, the adhesive is distributed on each side f the flute tip. In double backers, the adhesive deposit is placed on the top of the tip. This difference in position comes from the difference in the technology used for the application of the fluting to the liner. (Figure 5)

Score cracking effects occurs in the corrugated plants while converting the corrugated board sheets. Strain- stress can occur in folding and erecting the case. For checking the score quality, a sample is placed on a U- shaped support and pressed by a thin strip, exactly above a sore, until it breaks. The ratio between the scored and unscored value gives the score ratio.

h. Box Compression Test

One of the primary function of a shipping container is to resist stacking loads during ware housing and /or shipping. This stackability of corrugated boxes is best determined by box compression test (BCT) expressed as DaN or kg. BCT is the top to bottom compression strength. To conduct this test, the container is placed between the platens of the test machine and compressed at a rate of 0.5 in/min. The maximum load and deflection at failure is recorded. The most widely known formula which links the box compression strength with the mechanical properties of its component is derived by Mckee and Gander (12) as

Box Compression strength = $K \times ECT^a \times FS^b \times D^c$
Where D is the dimension of box (perimeter), FS is the flexure stiffness of the board, ECT is the edge crush test of board and K, a, b and c are empirical constants.

Box dimensions has an important role in determining the stackability and this should be taken into account while designing the box based on perimeter and height together with basis weight of corrugated board. For the given box dimensions, the BCT value of corrugated board package depends both on ECT and flexural stiffness of the combined board.

Factors negatively affecting the top load Compression strength:

The ability to withstand and hold a load in a static or dynamic

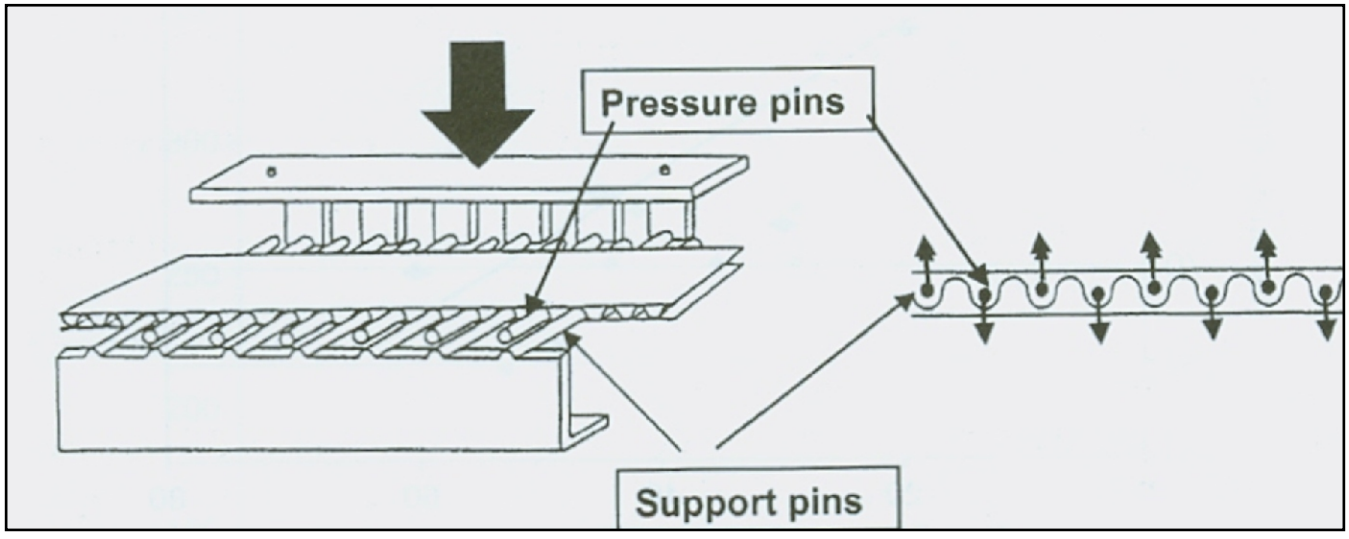

Figure 5: Pin Adhesion Test

environment is single most highly sought property in corrugated paperboard boxes. However, there are many factors involved in the distribution of products in boxes that will adversely affect the ability of box to withstand top load. Some of these factors are discussed below.

(a). Humidity

Since corrugated board is made up of hydroscopic material, it is clear that higher level of humidity in atmosphere tends to affect paperboard properties adversely. Fig (5) gives some indication of relationship between top load compression strength and moisture content of paperboard.

(b) Age

If everything remains constant, then number of days the same box is under compression, tends to loose the compression strength of box at an alarming rate. This is primarily due to creep within the cellulose fiber structure of the paper and the corrugated material itself. The rate of decay of the strength properties is dependent on the temperature of the aging process, although the relationship is not direct. As a thumb rule, a corrugated box subjected to top load compression will lose 50% of its stacking strength over six months period.

(c) Misalignment

Corrugated containers stacked one on top of the other will have a certain compression strength as a stack column. Misalignment of that column can result in as much as 29% decrease in overall compression strength of the box. Figure (6).

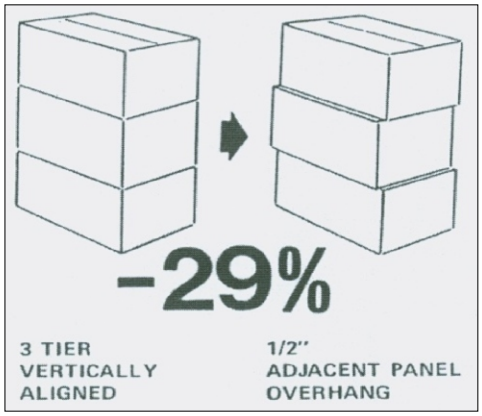

Figure 6: Effect of misalignment on compression strength of corrugated box

(d) Column stack verse Interlock

How the stacking of boxes is done on the pallet greatly affect the compression strength of the box. Figure (7) shows two pattern of stacking. Vertically column stack and Interlocked stack. Compared to vertically column stack, 45% compression strength is reported to decrease when same boxes are stacked in interlocked pattern.

(e) Pallet Overhang

If boxes are stacked on a pallet with as little as one inch overhang, upto 32% of the compression strength of the container can be lost. Figure (8).

(f) Rough Handling

Mishandling including dented vertical edges on the

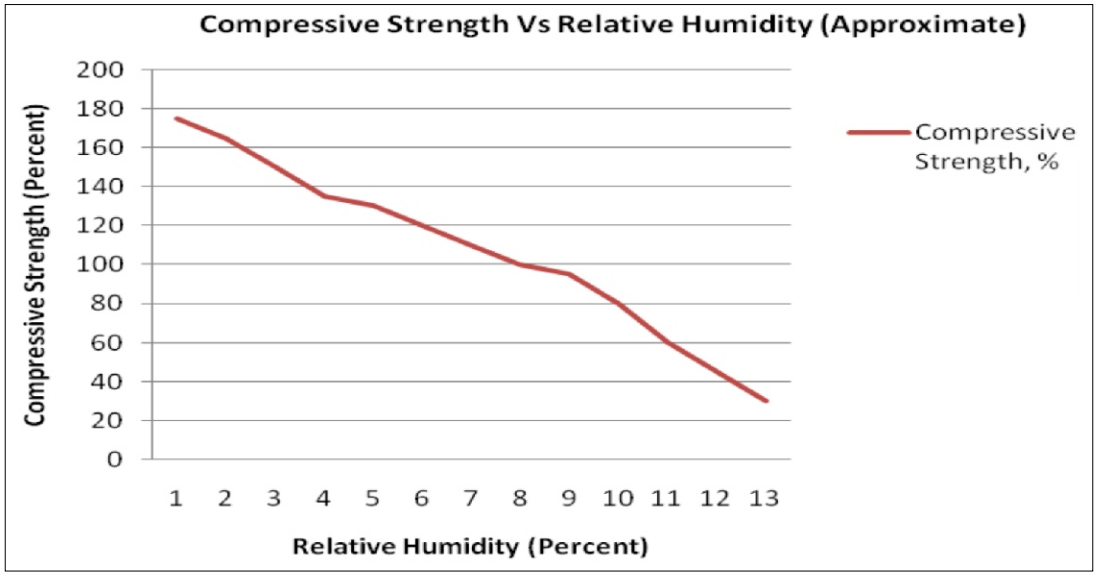

Figure 5; Effect of relative humidity o compressive strength propertyof corrugated boards

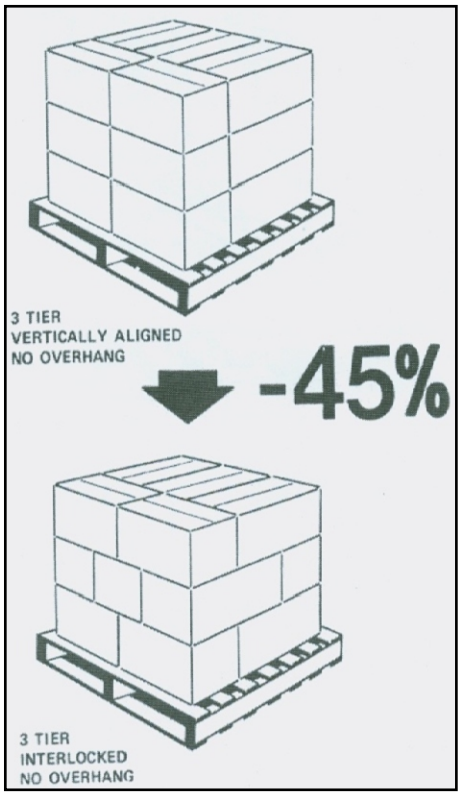

Figure 7: Compresion strength of corrugated box as a function of stackability

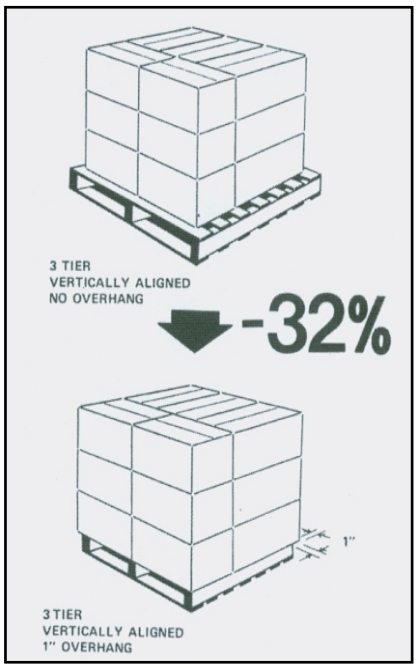

Figure 8: Effect of pallet overhanging on compression strength of corrugated boxes.

container can result in as much as 50% decrease n the box compression strength when compared to the virgin container.

CONCLUSION

The growing market has placed demands upon the corrugated case producers for better quality case in terms of strength, visual image, recycled fiber, water vapor resistance, new end uses, closer tolerance, shorter orders and better service. This in turn has placed demands on the papermaker for liners and fluting medium for better strength, more uniformity, better surface finish, closer control of moisture profile, use of more recycled fiber and better wound reels.

For achieving above points it become very essential to evaluate the performance parameters of corrugated boxes at every stage of production and converting. This should be done by adopting the correct procedure of testing of liner, medium and corrugated box with state of art equipments by following standard test methods.

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