MANTECH Publications

Journal of Product Design, Quality Engineering & Technology
Volume 3, Issue 2, May-August 2018

# *Optimum Design & Analysis of Corrugated Sheet Box Size for an Industrial application*

***Sagar N. Garje[1], Kapil T. Patil [2], R.S. Pawar [3]***

*Student[1], Professor [2], Principal & Professor[3]*

*Department of Mechanical Engg[1, 2, 3]*

*SYCET, Aurangabad.[1, 2, 3]*

***Corresponding author's email id:** garje.sagar225@gmail.com[1]*

***Abstract***

*Corrugated cardboard boxes manufacture in large volumes for packaging applications and it has high demand due to strength and structural stability. While studying the different industrial boxes, we note that the deformation of the boxes and the strength are weak in the load bearing capacity. In this paper all deformations and strength will be calculated by reducing the clearance and changing the size of corrugated box. This is to discover using an optimization procedure to reduce the area and specific weight of corrugated cardboard using FEA (Finite element analysis). The present study focused on optimizing the corrugated cardboard box.*

***Keywords:*** *Corrugated sheet box, finite element analysis, packaging, strength, craft paper*

## INTRODUCTION

Corrugated packaging box is a container which is mostly used in goods packaging & transportation also it is economic, light weight, recyclable. Corrugated cardboard is a paper based on material that consisting of a fluted corrugated sheet and one or two flat linerboards. Corrugated linerboards are widely used in the manufacture of corrugated cardboard boxes & for agricultural tray. The corrugated board its origin is something different. In the Asia region China started to introduce and use corrugated box as the external packing box from early 1930s. At that time, 80% of the external packing boxes are wooden boxes, with cartons accounting for only about 20%. Now days with the development of packaging materials and machine industries, 90% packing boxes in use are corrugated boxes [1,3,4]. Corrugated board is used in significant quantities for packaging purposes, where its good weight-specific stiffness and strength properties are exploited in the construction of boxes and containers for the protection and the transport of goods. Since corrugated board is a sandwich structure consisting of a wavy core called flute and face sheets called liners it is prone to buckling both on the global level of the box walls and the local level of liner and/or flute [2]. The principal direction of elastic symmetry is defined as those of the paper constituents i.e. the machine direction (MD) cross direction (CD) and thickness direction (Z) (Fig. 1) the facing of the corrugated board are commonly noted as 'Liners' structural design of corrugated board package is currently base on empirical method that require manufacture of the board and package and strength test of actual package [5]. This paper aims to study different type of packaging material & find out best packaging material considering quality & cost, also reduce the clearance between the product and box dimension and get the optimum size of the *box*.

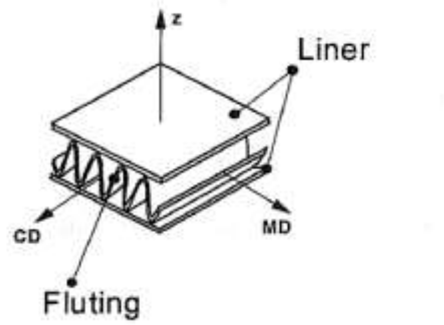


***Fig. 1: Single wall corrugated board and its principal direction [5]***

## METHOD

### Problem statement

The objective of this study different type of packaging material & find out best packaging material considering quality & cost, also reduce the clearance between the product and box dimension and get the optimum size of the box. Ford packaging based in Southern India is manufacturer of Corrugated Carton Boxes, Established in 2000. it is a type of packing industry. Their main products include many types of corrugated boxes as per the requirement of their customer. The boxes are made up of brown craft paper and the weight of the box is depending upon the GSM (grams per square meter) of paper. But during their design and manufacturing of the boxes they give more clearance between product and box dimension so, they got complain from their customers that the boxes are tear within small period of life, so their product may get damage. Due to maximum size of box while transporting the boxes including product the vibration produces at the lower side of box so; the vibration gets transferred all the faces due the product load impact on the boxes thus side of the box get tear.

**1. Paperboard boxes**

Paperboard is a lightweight paper-based material. It can be easily cut and manipulated to create custom shapes and structures. These features make it ideal to be used in packaging. It is produce by turning fibrous materials that come from wood or from recycled paper into pulp, and then bleaching it. Paperboard packaging available in various grades, each suitable for different packaging requirements [12].

**2. Corrugated boxes**

As per the structural of corrugated board, it is in the category of sandwich structures [1]. Corrugated boxes are the ones many probably consider as 'cardboard' as it produces the large shipping, shoe & storage boxes. What many people don't have an idea that corrugated boxes also come in different types depending on the durability and strength of the box. Identifying a certain corrugated material, however, is easy. How do you determine the material? Through its corrugated medium (also known as fluting). Identifying a corrugated material is easy. Corrugated board having 3 layers of paper in which an outside and inside liner and a corrugated medium (also known as fluting).

***Packing Type Base on Raw material & structure: -***

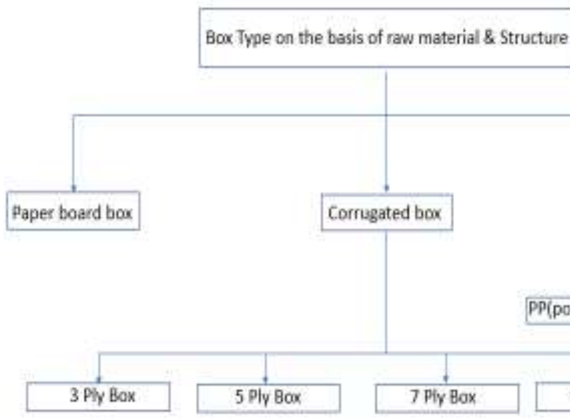


***Fig. 2: Types of corrugated board***

The corrugated medium that gives it strength and rigidity. The raw material that is used to make corrugated board is mostly recycled paper, manufacture in large high-precision machinery known as corrugators. These types of boards can have recycled and reused again and again as a source of pulp fiber. Corrugated boards are available in different types, single faced, double faced (3 ply), twin wall(5ply), triple wall(7ply) etc. They can be used to make packaging with different characteristics, performances, and strength. The board is cut and folded into different sizes and shapes to become corrugated packaging.

**3. Plastic boxes**

Plastic is used in a wide range of products, from spaceships to paper clips. Many traditional materials such as wood, leather, glass, ceramic, and so on, have already been replaced by plastic. PP corrugated plastic sheet made from impact co-polymer of polypropylene. It is a hollow profile sheet consisting of two flat walls connected by vertical ribs. PP corrugated plastic sheet, also known under the names of PP hollow sheet, corrugated plastic Sheet, Corflute, Cartonplast sheet, Correx sheet, PP board, and Flute board and so on.

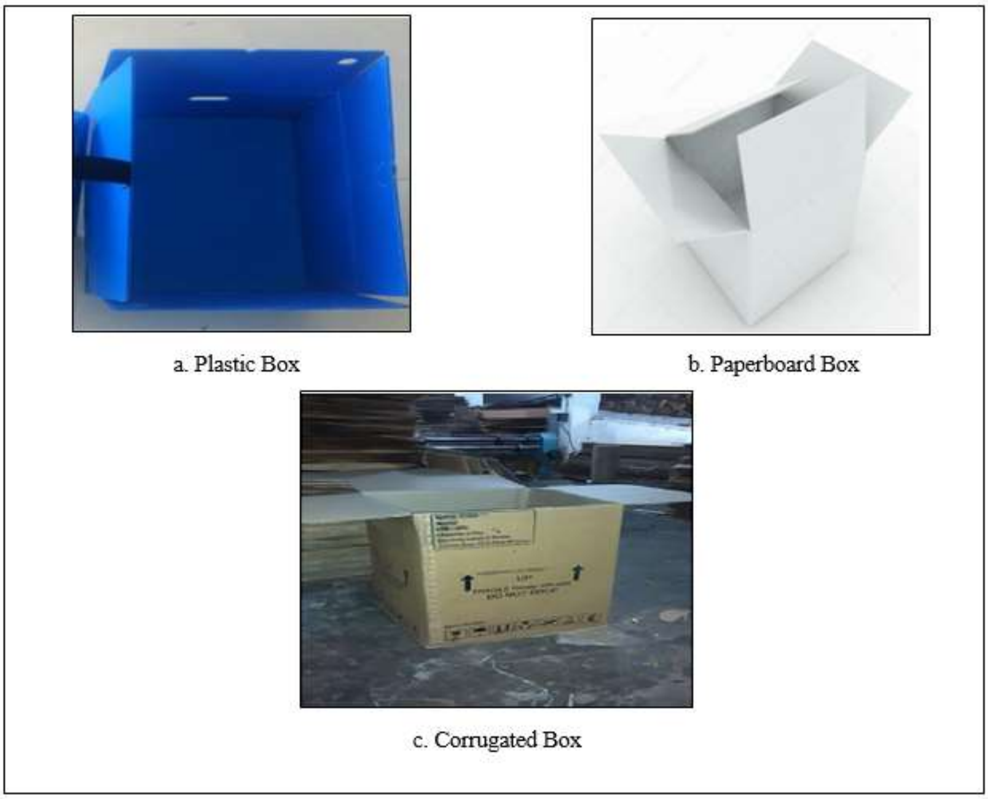


***Fig. 3: Different type of Box***

**Design & Testing of Box: -**

Considering above all type of material, we design two boxes first one is 660mm x 630mm x 910mm size & second is 430mm x 430mm x 280mm with all material type for industrial product of dimension 620mm carry out drop test & vibration test to finalize box for industrial product. (All boxes dimensions are in mm)

**1. Drop Test of Packing Box:**

The cardboard drop test is usually carried out on a full corrugated box by dropping the box total of 10 times from a certain height. This process simulates the shipping environment during which packaged product can be subject to all kinds of falling, swinging, shaking, etc. After dropping, the inspector can see how the box is kept during shipping and foresee any damage that may occur during shipping. The professional product inspection companies often use the drop test of box to evaluate the quality of packaging.

There are different standards used for the drop test of corrugated box. Many entities have their own standards, such as the International Safe Transit Association (ISTA) and American Society for Testing and Materials (ASTM), which are slightly different from each other. This test only carried out on packaged product and does not simulate shipping conditions like moisture, corrosions.

**2. Vibration Testing:**

Structural vibration testing and analysis contributes to progress in many sector, including aerospace, automotive manufacturing, wood and paper production, power generation, defense, consumer electronics, telecommunications and logistic. The most common application is identification and sup pression of unwanted vibration to improve quality of product 590mm x 870mm & 400mm x 400mm x 250mm respectively and.

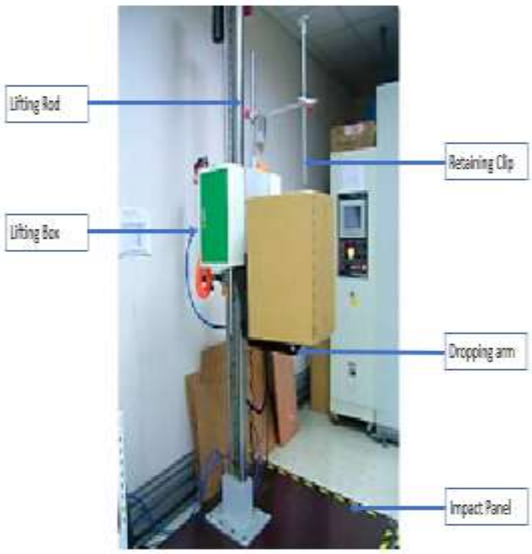


***Fig. 4: Drop Test Machine***

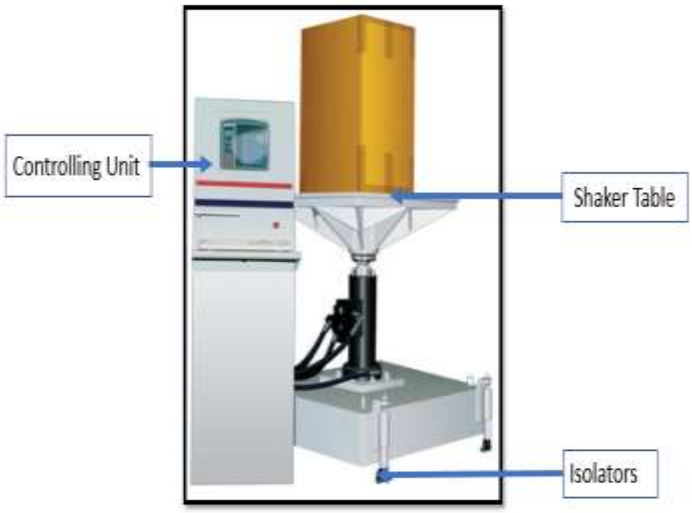


*Fig. 5: Vibration Test Machine*

## Result of Tested a Box

*Table 1: Result of Drop Test & Vibration Test of Various Boxes*

| Material Type | Dimension (mm) | Drop Test | Vibration Test | % of Failure | Remark |
|---|---|---|---|---|---|
| Paper Box | 660 x 630 x 910 | Fail | Fail | 90 | Box not suitable to use |
| | 430 x 430 x 280 | Fail | Fail | | |
| Corrugated Box 3 Ply | 660 x 630 x 910 | Fail | Fail | 50 | Box not suitable to use |
| | 430 x 430 x 280 | Fail | Fail | | |
| Corrugated Box 5 Ply | 660 x 630 x 910 | Fail | Fail | 30 | Box not suitable to use |
| | 430 x 430 x 280 | Fail | Fail | | |
| Corrugated Box 7 Ply | 660 x 630 x 910 | Fail | ok | 10 | Changes in clearance in between Box & product, we can redesign to use |
| | 430 x 430 x 280 | ok | Fail | | |
| Corrugated Box 9 Ply | 660 x 630 x 910 | ok | ok | 2 | Box is ok to use but cost is high |
| | 430 x 430 x 280 | ok | ok | | |
| Polypropylene Box | 660 x 630 x 910 | Fail | Fail | 20 | Box not suitable to use & cost is double than corrugated box |
| | 430 x 430 x 280 | Fail | Fail | | |
| Polyethylene Box | 660 x 630 x 910 | Fail | Fail | 30 | Box not suitable to use & cost is double than corrugated box |
| | 430 x 430 x 280 | Fail | Fail | | |

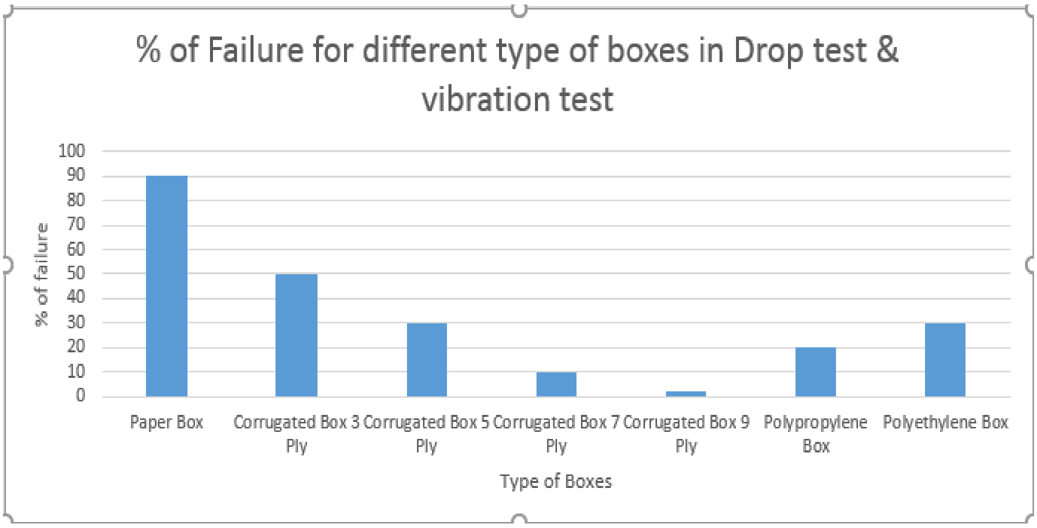


***Fig. 6: Percentage of Failure for different type of boxes***

As per the above graph we got result for drop test & vibration test, in this 9 ply corrugated box have two failure percentage and it is ok to use but its manufacturing cost is high & 7ply corrugated box have failure percentage are 10% & having less cost to manufacture so we select this 7 ply box to redesign to get optimum size of the box to remove the vibration & impact load of the box.

**Properties of corrugated sheet box**

***Table 2: Property of corrugated sheet box***

| | |
|---|---|
| Density (kg/m3) | 404.5 |
| Poisson's ratio | 0.01 |
| Young's modulus (MPa) | 7600 |
| Thermal expansion (k dg) | 3.75 E-6 |

**Experimental and numerical analysis for corrugated sheet box**

**Experiments on Product 1**

*Product No.1* (Motherson Company)

Dimension (mm)

Product dimension:

Length x width x height:

620mm x 590mm x 870mmCurrent Box

*Dimension for Product 1*

*Outer dimension of box:* 660mm x 630mm x 910mm

*Inner dimension of box:* 650mm x 620mm x 900mm

*Weight of product:* 30 kg   Box type: 7 Ply

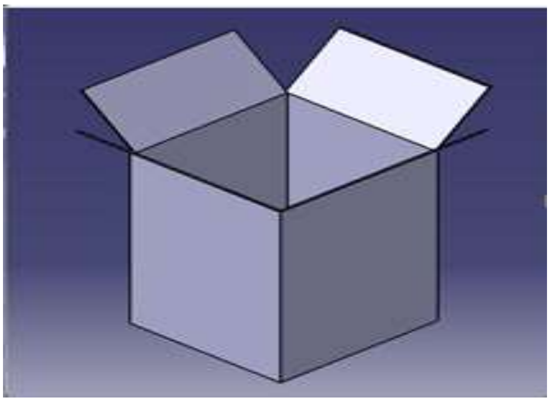

***Fig.7: cad model of box***

**Area of the Box:**

A = (W+H+13) x (2W+2L+48) [10]

= (630+910+13) x (1260+1320+48)

= 4160124 mm²

A = 4.1 m²

**Weight of the Box:**

W=Area x Used paper

Used paper for outer layer is 200gsm and for inner layer is 120gsm and for flute paper it is 40% more than that of plane paper as the box is 7ply so there are 4 plane layers and 3 flute layers are present.

For upper layer 200x1=200gsm

Inner layer 120x3=360gsm

For flute layer 168x3=504gsm

Since the total paper is 1064gsm

Weight = 4.1 x 1064

= 4426.32

Weight of box is 4.4 kg

| | |
|---|---|
| Weight of box in n | 4.4 x 9.81 |
| --------------------------- | = ------------- = 68.9249N/M |
| Width of the box in m | 0.640 |

For parts specified by Edge Crush Test (ECT):

**Burst test:**

*The burst test carried out at industry given result as –*

Compressor tester applied over square specimen of 7 ply sheet (1 X 1m), holding sheet in fixed supports at extreme edges. The specimen burst is 474.3 KPa.

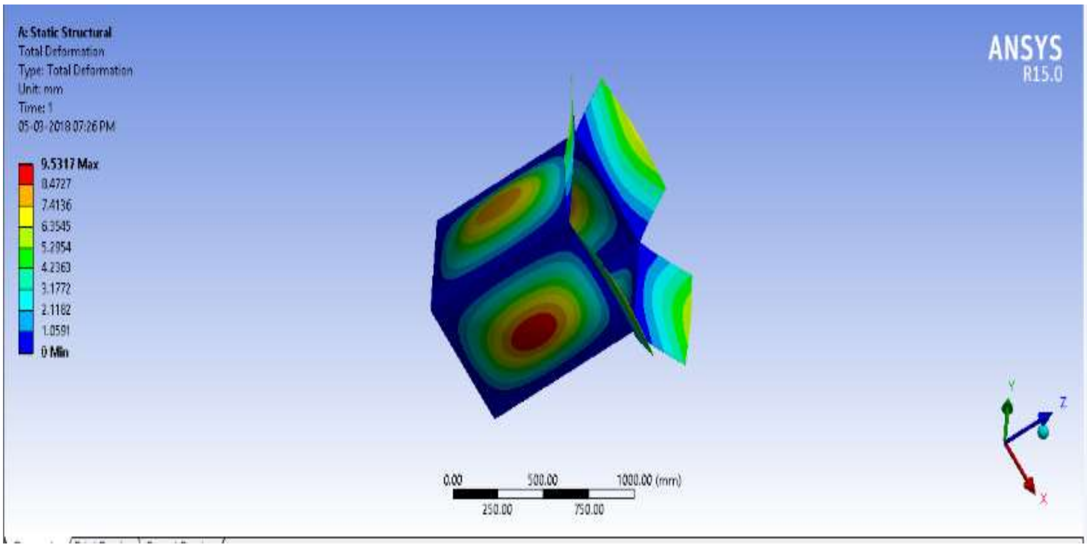


*Fig.8: Total Deformation of box 1*

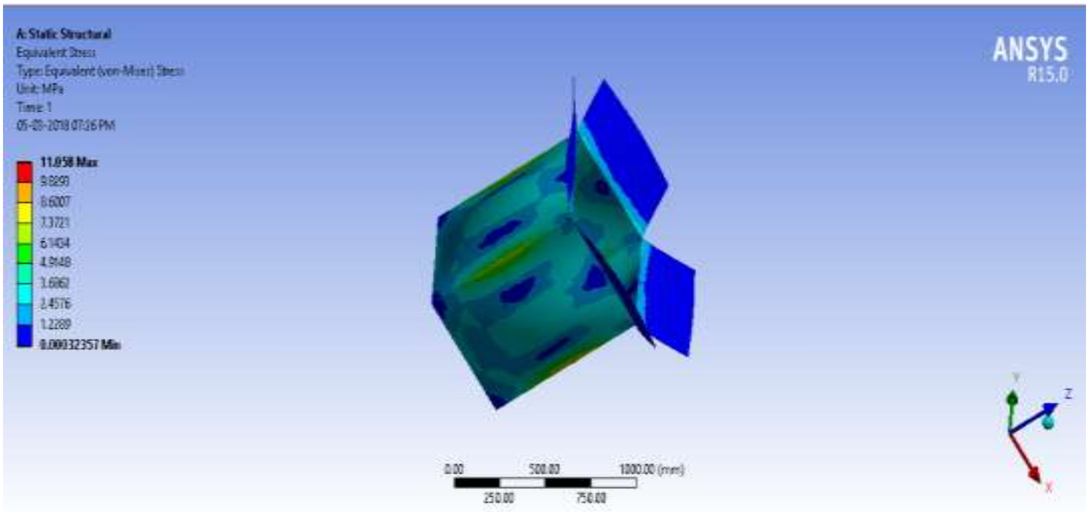


*Fig.9: Equivalent Stress of box 1*

**Design of Boxes on Trial and Error Basis for Box 1**

**First Consideration:**

Outer dimension of box: 650mm x 620mm x 900mm

Inner dimension of box: 640mm x 610mm x 890mm

Area of the Box:

A = (W+H+13) x (2W+2L+48) [10]

= (620+900+13) x (1240+1300+48)

= 405044 mm²

A = 4.0 m²

Weight of the Box:

W=Area x Used paper

W= 3.9 x 1064

= 4303.92

Weight of box is 4.3 kg

For parts specified by Edge Crush Test (ECT):

$$\frac{\text{Weight of box in n}}{\text{Width of the box in m}} = \frac{4.3 \times 9.81}{0.620} = 68.099 \text{ N/M}$$

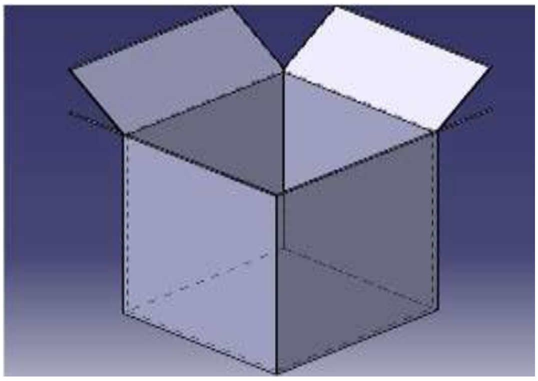

***Fig.10: Cad model of first consideration box 1***

**Numerical Result for first consideration**

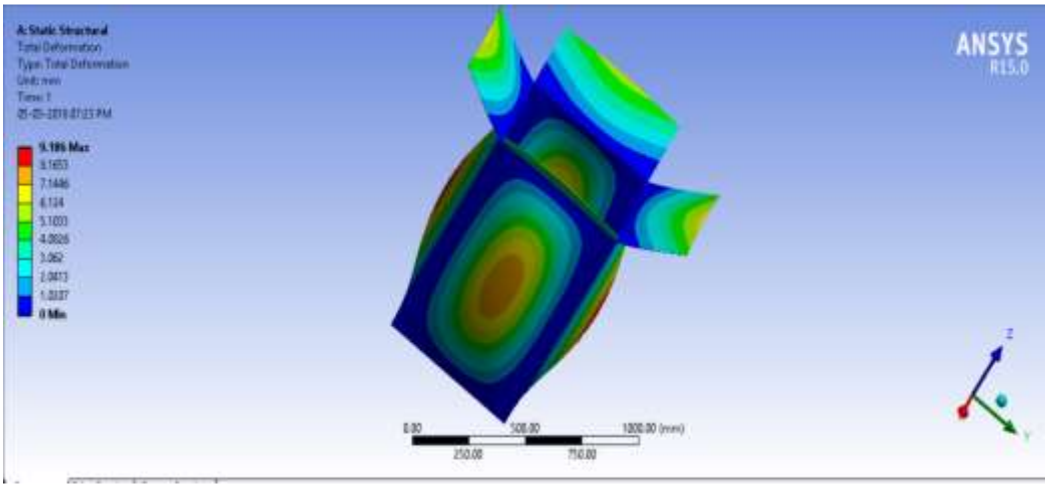


***Fig.11: Total deformation of first consideration box***

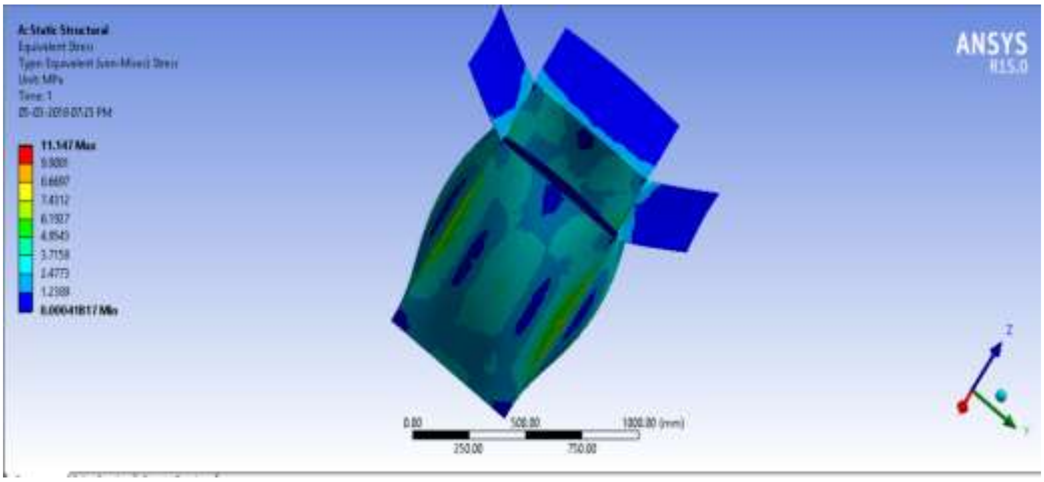


*Fig.12: Equivalent Stress of first consideration box*

## Optimum Dimension of Corrugated Sheet Box1

*Table 3: Optimum Dimension of Box 1*

| Dimension (mm) | Area ($m^2$) | Weight (Kg) | Minimum bursting test(BCT) (kpa) | Minimum edge crush test(ECT) (N/m) | Deformation (m) | Stress (Mpa) |
|---|---|---|---|---|---|---|
| 660 x 630 x910 | 4.1 | 4.4 | 474.3 | 68.92 | 0.009532 | 11.058 |
| 650 x 620 x900 | 4 | 4.3 | 474.3 | 68.1 | 0.009186 | 11.147 |

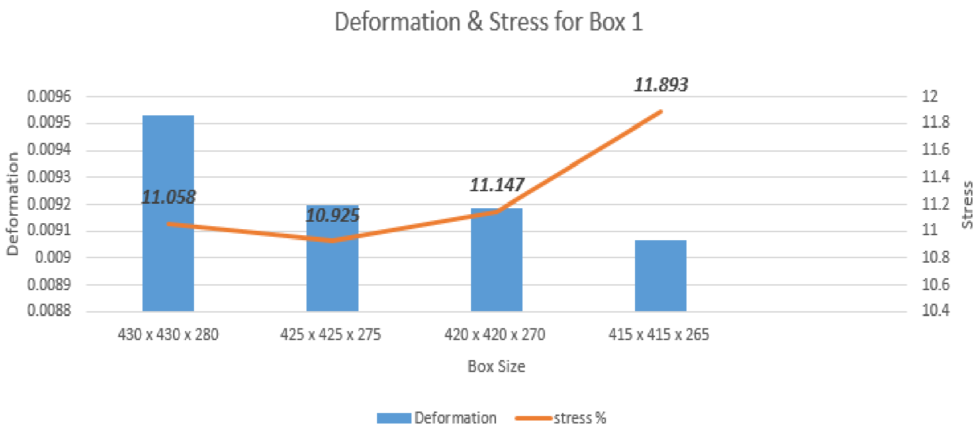


*Fig.13: Pareto of Deformation & stress for box 1*

From above graph we get clarity that 650 x 620 x 900 boxes have optimum dimension for box 1. In the above chart blue bar shows the deformation value & red line shows the stress value on same box. Also 650 x 620 x 900 box results are validating by drop test & vibration test & we found its ok to use in manufacturing industry.

**Experiments on Product 2**

Product No.2 (Gestamp Company)

Dimension (mm)

**Product dimension**

Length x width x height: 390mm x 390mm x 240mm

Current Box Dimension for Product 1

Outer dimension of box: 430mm x 430mm x 280mm

Inner dimension of box: 420mm x 420mm x 270mm

Weight of product: 20 kg   Box type: 7 Ply

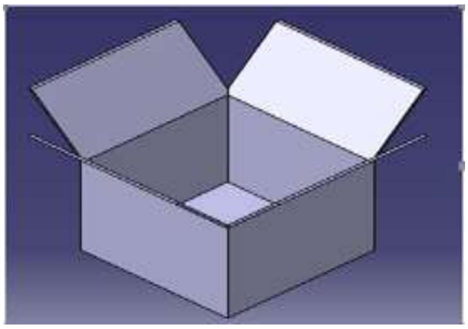

*Fig.14: Cad model of actual box 2*

**Area of the Box:**

A = (W+H+13) x (2W+2L+48) [10]

= (430+280+13) x (860+860+48)

= 1278264 mm²

A = 1.2 m²

**Weight of the Box:**

W=Area x Used paper

Used paper for outer layer is 200gsm and for inner layer is 120gsm and for flute paper, it is 40% more than that of plane paper as the box is 7ply so there are 4 plane layers and 3 flute layers are present.

For upper layer 200x1=200gsm

Inner layer 120x3=360gsm

For flute layer 168x3=504gsm

Since the total paper is 1064gsm

Weight = 1.2 x 1064

= 1360

Weight of box is 1.3 kg

**For parts specified by Edge Crush Test (ECT):**

$$\frac{\text{Weight of box in n}}{\text{Width of the box in m}} = \frac{1.3 \times 9.81}{0.430} = 31.0286 \text{ N/M}$$

**Numerical result of current dimension box 2**

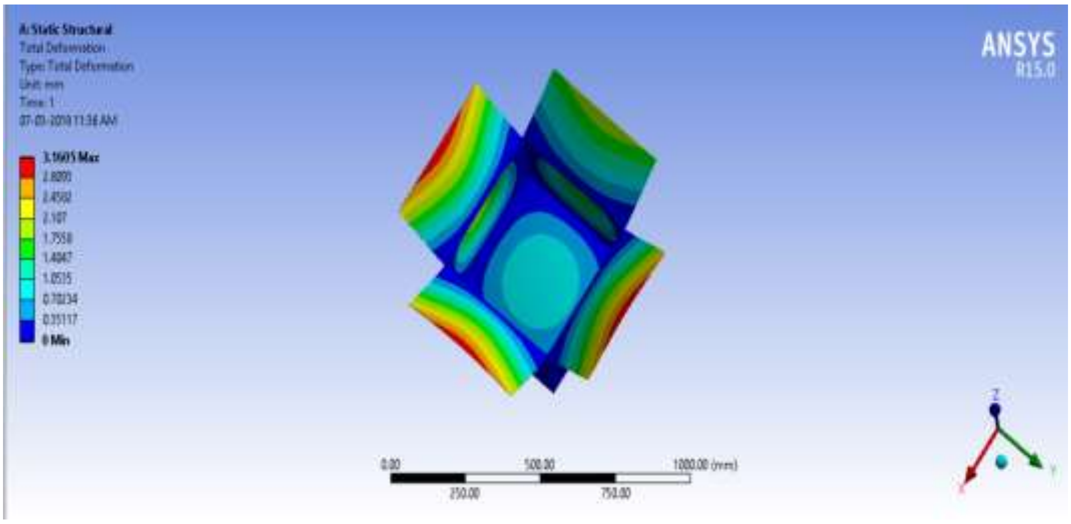


*Fig.15: Total deformation of actual box 2*

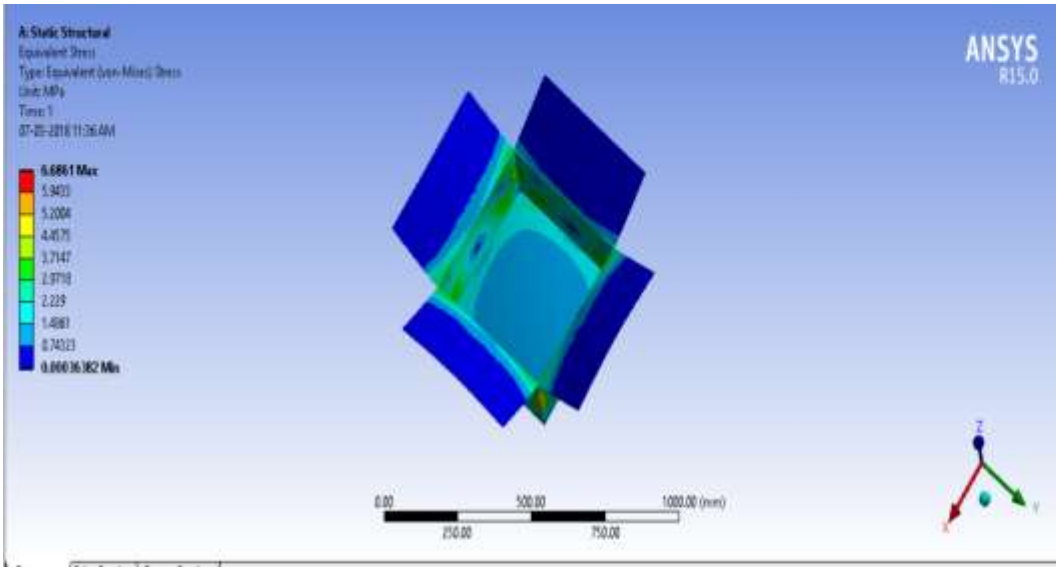


*Fig16: Equivalent stress of actual box 2*

**Design of Boxes on Trial and Error Basis for Box 1**

**First Consideration:**

Outer dimension of box: 420mm x 420mm x 270mm

Inner dimension of box: 410mm x 410mm x 260mm

**Area of the Box:**

A = (W+H+13) x (2W+2L+48) [10]

= (420+270+13) x (840+840+48)

= 1214784 mm²

A = 1.2 m²

**Weight of the Box:**

W = Area x Used paper

W = 1.2 x 1064

= 1276.8

Weight of box is 1.2 kg

**For parts specified by Edge Crush Test (ECT):**

$$\frac{\text{Weight of box in n}}{\text{Width of the box in m}} = \frac{1.2 \times 9.81}{0.420} = 30.1898 \text{ N/M}$$

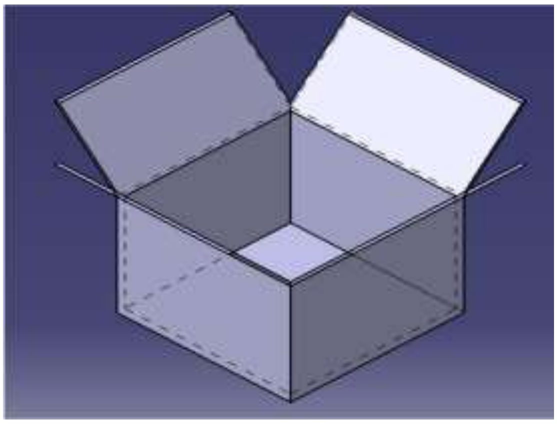

***Fig.17: Cad model of first consideration box2***

**Numerical Result for first consideration:**

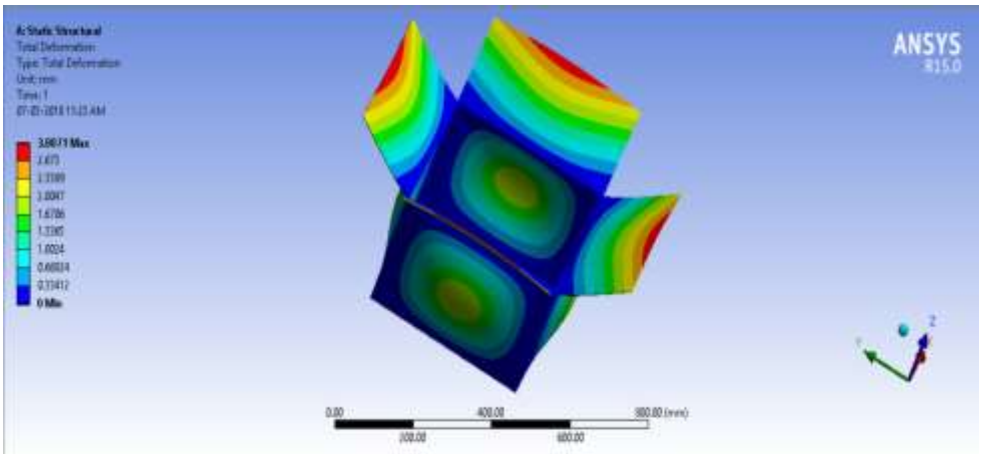


***Fig.18: Total deformation of first consideration box 2***

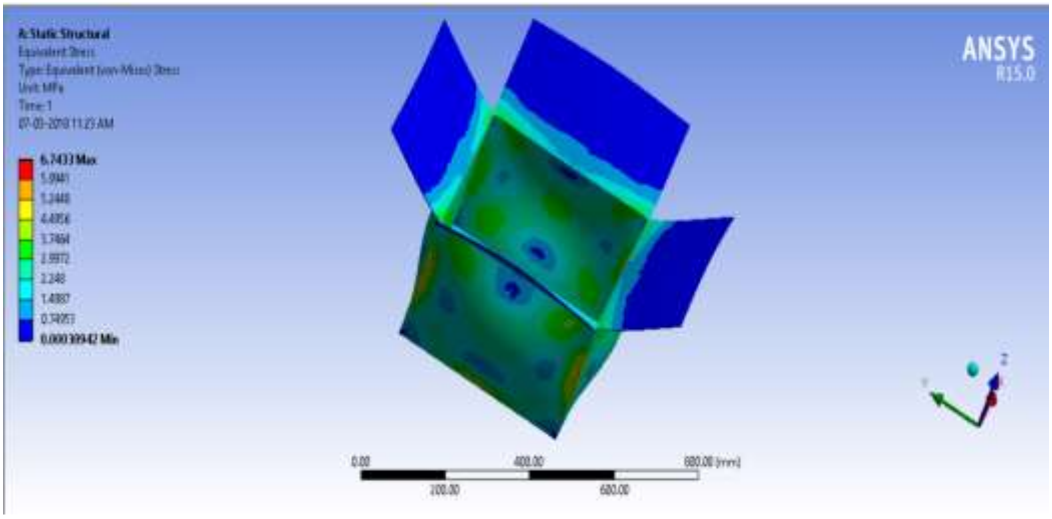


*Fig.19: Equivalent stress of first consideration box 2*

## Optimum Dimension of Corrugated Sheet Box 2

**Table 4: Optimum Dimension of Box 2**

| Dimension (mm) | Area ($m^2$) | Weight (Kg) | n bursting te (kpa) | edge crush (N/m) | Deformation (m) | Stress (Mpa) |
|---|---|---|---|---|---|---|
| 30 x 430 x 28 | 1.27 | 1.36 | 474.3 | 31.0286 | 0.0031605 | 6.6861 |
| 20 x 420 x 27 | 1.21 | 1.29 | 474.3 | 30.1898 | 0.0030071 | 6.7433 |

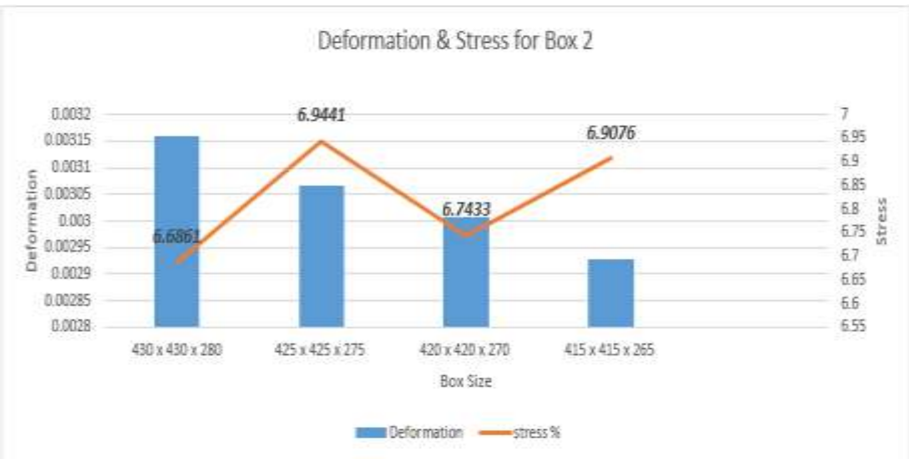


*Fig.20: Pareto of Deformation & stress for box 2*

From above graph we get clarity that 420mm x 420mm x 270mm mm boxes have optimum dimension for box 2. In the above chart blue bar shows the deformation value

& red line shows the stress value on same box. Also, 420mm x 420mm x 270mm box results are

validating by drop test & vibration test & we found its ok to use in manufacturing industry.

## CONCLUSIONS

An experimental study of failure of corrugated box during transportation, it observes that the deformation of the boxes and strength are weak in load bearing capacity. Therefore, in this paper all the deformation and strength will be calculate by reduce the clearance and change in dimension of actual corrugated box. This study shown the optimization of finite element analysis method on the reducing the clearance between product and box dimension. With reducing the dimension deformation occurred in finite element analysis result is very small that is within permissible results. From above graph we get clarity that 650mm x 620mm x 900mm and 420mm x 420mm x 270mm boxes have optimum dimension for box 1 & 2 respectively. Also, both box results are validating by drop test & vibration test & we found its ok to use in manufacturing industry.

From above experiment it concludes that there is maximum stress found on the actual box with respect to product dimension by using FEM and found from compressor tester machine, after reducing the clearance between the product and box dimension we get the difference stress values, to get the optimum size where the stress and deformation are minimum values are found that dimension will get the optimum size of box.

## REFERENCES

**I.** Jing Chena, Yao-li Zhanga, Jian Sunb "An Overview of the Reducing Principle of Design of Corrugated Box Used in Goods Packaging" Procedia Environmental Sciences 10 ( 2011 ) 992 – 998

**II.** Daxner, Flatscher, and Rammerstorfer, F.G. "Optimum Design of Corrugated Board under Buckling Constraints" COEX Seoul, Korea, (2007).

**III.** Arsalan Jamialahmadi "Experimental and numerical analysis of the dynamic load distribution in a corrugated packaging system" mechanical engineering at blekinge institute of technology, (2008)

**IV.** Tomas Nordstrand "Analysis and Testing of Corrugated Board Panels into the Post-

 

buckling Regime" SCA Research, Box 716,851 21 Sundsvall, Sweden, (2003).
P. Patel, Nordstrand, T. and Carlsson, L.A. "Local Buckling and Collapse of Corrugated Board under Biaxial Stress"

**V.** Composite Structures, Vol. 39, No. 1-2, pp. 93-110, (1997).

**VI.** T. Nordstrand, Blackenfeldt, M. and Renman, M "A Strength Prediction Method for Corrugated Board Containers" Report TVSM-3065, Div. of Structural Mechanics, Lund University, Sweden, (2003).

**VII.** Zhiguo Zhang, Tao Qiu, Riheng Song and Yaoyu Sun "Nonlinear Finite Element Analysis of the Fluted Corrugated Sheet in the Corrugated Cardboard" Hindawi Publishing Corporation Advances in Materials Science and Engineering, (2014).

**VIII.** Adeeb A. Rahman "Adhesive in the buckling failure of corrugated fiberboard: a finite element investigation" Department of Civil Engineering Eastern Mediterranean University Vol. 1: 533-539, (1998).

**IX.** R. C. McKee, J. W. Gander, and J. R. Wachuta "Flexural stiffness of corrugated board" The Institute of Paper Chemistry, Appleton, Wisconsin

**X.** Orgen departmental of environmental quality's(DEQ's) Business packaging waste prevention project, state of Oregon, (2006).

**XI.** M. A. Jiménez-Caballero, I. Conde, B. García, E. Liarte "Design of Different Types of Corrugated Board Packages Using Finite Element Tools" C/ María de Luna 7-8, 50007 Zaragoza, SPAIN, (2009).

**XII.** Tobi Fadiji, Tarl Berry "Investigating the Mechanical Properties of Paperboard Packaging Material for Handling Fresh Produce Under Different Environmental Conditions: Experimental Analysis and Finite Element Modelling" Journal of Applied Packaging Research: Vol. 9: No. 2 , Article 3, (2017).

**XIII.** F.T.S. Chan • H.K. Chan • K.L. Choy "A systematic approach to manufacturing packaging logistics" Springer-Verlag London Limited, (2005).

**XIV.** Jong-Whan Rhim "Effect of Moisture Content on Tensile Properties of Paper-based Food Packaging Materials" Food Sci. Biotechnol. 19(1): 243-247, (2