Effect of Environmental Conditions on Performance of Corrugated Sheet Boxes Manufacturing Process

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Abstract: ***Corrugated sheet material is very sensitive to the environmental conditions, especially moisture. The present study focuses on the mechanical behavior of corrugated sheet box board at different humidity and temperature conditions. The objective of this study is to study the important properties of corrugated sheet boxes at different climatic conditions and also to study the influence of the properties of corrugated sheet paper on the properties of corrugated board and box at various environmental conditions. The mechanical performance test carried out under controlled atmospheric conditions where the temperature (^{0}C) range was studied from 20^{0}C to 50^{0}C and the relative humidity (Rh) range was studied from dry condition 30% Rh to severe condition 90% Rh. The results tested showed that the maximum compressive load of empty corrugated sheet box sealed exposed to moisture content decreased with the increase of temperature and relative humidity. In general it is observed in paper, corrugated sheet board and boxes that have optimum combined properties are obtained at moisture content level at 7-8% and hence moisture content of 7-8% may be the ideal value for corrugated sheet paper used in corrugated packaging industry.***

Keywords: ***atmospheric conditions, corrugated sheet box, temperature, relative humidity.***

I. INTRODUCTION

Relevance to industry: This study will be beneficial to the manufacturer of corrugated sheet boxes, packaging consultant and the end users. This will also help the corrugated packaging industry to take the least cost approach to overcome the loss of strength at different environmental conditions.

Corrugated board/box industry started in India around early 1950˝s. The industry has witnessed phenomenal growth in volume from almost zero to about 4 million tons in 60+years. Corrugated boxes protect wide range household goods, defense stores and so on. The largest segment however is food industry including fresh fruits and vegetables and processed foods. Packing of fresh flowers is a developing market [1].

Corrugated cardboard pertaining to papers family has been used extensively in the field of product packaging and transportation up to now. Its employment does not cease increasing each year and covering the various types of packing. The success is due to the virtues of this material: good protection of the product, low cost and can be recycles as well as biodegradable. Biodegradable product are more and more demanding as being a major concern again the protection of the environment and hence respect a durable development. The corrugated cardboard is an orthotropic sandwich with the surface plies (facing) providing bending stiffness, separated by a light weight bending core (fluting) that provides shear stiffness. For a better optimization and diversification of the use of corrugated cardboard, knowledge of its mechanical characteristics and failure is necessary. Corrugated cardboard is very sensitive to atmospheric condition; especially the effect of moisture is very obvious on the mechanical behavior of the corrugated cardboard. The interrelated study has been carried out by some researchers [2, 3, and 4]

Corrugated sheet paper is a mat of cellulose fibers arranged in cris-cross fashion and held together by hydrogen bonds and other secondary forces. The extent and speed of water absorption, depends upon ambient relative humidity and ambient temperature. Corrugated sheet are hygroscopic in nature, i.e. cellulose does absorb or desorbs moisture from / to the ambient atmosphere to attain equilibrium with it.

The absorption/desorption of moisture from atmosphere results in the change in properties of corrugated sheet as it is believed that water absorption/desorption results in changes in the secondary forces. Similarly the temperature variations also alter the equilibrium and believed to result in property changes which in turn change the physical and mechanical properties of corrugated sheet.

In country like India wide variations in climatic conditions are prevalent in different parts of the country at a given time and hence, it is desirable that corrugators and users of the boxes have firsthand knowledge of likely property variations of raw materials.

There is no adequate information available to the corrugating fraternity as how and to what extent the properties of different corrugated sheet paper vary with environmental conditions [1].

II. CORRUGATED SHEET BOX MANUFACTURING PROCESS

Small industrial units are industries with limited scale of manufacturing operations, producing a product or few products with limited levels of employment and investment and are many in number than large scale industries. In many developing countries, the roles of these industries are crucial as they provide employment to a large number of people. Breaking the size barrier (limited levels of employment and investment) is a measure of success of the small - scale industries. Small-scale industries are dependent for their equipment and process technology on a limited number of resources that start with:

(a) The entrepreneurs' own technical expertise probably gained during earlier stages of paid employment.

(b) Large firms that provide the technology as a component within a sub-contracting arrangement.
(c) Government institutions desirous to support a measure of indigenous Technology.

The demand for the products of small-scale industries is crucial to their growth. Therefore this work focuses on process re-engineering of a small-scale industry for economical and competitive production.
Cardboard packaging is one of the most widely used forms of packaging. The corrugated cardboard is stiff, strong and light in weight material made up of layers of brown craft paper. These brown craft paper rolls are transported to a corrugation machine where this paper gets crimped and glued to from corrugated cardboard called as single face corrugated board and then this single face corrugated board is cut according required dimension on the cutting machine. According to requirement by adding another corrugating medium and a third flat printed liner creates a double wall corrugated board or triple wall corrugated boards on gluing or bonding machine called as 3ply 5ply and 7ply.

Raw material required for manufacturing of corrugated sheet boxes:
The various raw materials and process required for manufacturing of corrugated sheet boxes are shown in Fig.1

- **Paper Reel**

Reels of liner and flute weighing from 200kg to 300kg are imported from "LAXMI PAPER MILLS" and "SBM MILLS".

- **Pasting Gum**

Starch based gum powder is mixed with water in the ratio of 1:4.

- **Stitching Coil**

Aluminum stitching coils are brought from "ADVANCED TECHNO WIRE LTD."

- **Printing Paint**

Gloss based solvent ink is used for printing.

Manufacturing Process

Fig. 1. Showing Corrugated Sheet Manufacturing Process

III. SAMPLES

Sample Requirement
More than 85% of paper consumed in the corrugated industry has grammage (GSM) in the range of 100-180(g/m^2) and bursting factor (BF) in the range of 12 – 30. The types of paper used as a sample is furnish from four different sources. They are

- Recycled (Imported waste-based)
- Recycled (Indian waste-based)
- Agro-based
- Imported

Mechanical properties of paper used for corrugated sheet boxes also depend upon the method and machinery of manufacture. Hence paper sample for this study is considered from two different mills. Taking into consideration all these factors, the sample requirements of boxes have been worked out.
Box sample were manufactured with following specifications. Regular slotted containers (RSC) or generally called "Universal type boxes" are the most widely manufactured corrugated fiber board boxes in India and hence for the study regular slotted containers were chosen.
Following two sizes of the boxes were finalized:
Size A- 18" X 18" X 9" Size B- 18" X 9" X 18" the sizes are preferred because they are economic, between them they represent the typical production segment in India, ease of manufacture and further sizes were so selected that there is substantial difference in the perimeter and height of the boxes, which could be useful in evaluating the role of perimeter and height of the boxes in contributing to the compression strength.

IV. TESTING

Atmospheric Conditions
The temperature (t) is fixed at 20^0C, 30^0C, 40^0C and 50^0C respectively, and the relative humidity (RH) conditions used vary from dry condition (50%Rh) to severe conditions (90%Rh) for different samples, kept 12 hours as shown in Table. I. Once the equilibrium was reached, the specimens were weighed. Within 5 minutes, compression strength tests were carried out on specimens of corrugated cardboard box sealed by the means of compression testing machine,

XYD-45K under various controlled conditions varying from 50% RH to 90% RH [5]. The samples were conditioned at five different environmental or climatic conditions before evaluation of properties.

Table .I Showing Five Different Environmental Conditions

Sr. No.	Conditions	Temperature (^{0}C)	Relative Humidity (Rh) (%)
1	Ambient	28^{0}C to 34^{0}C	52 to 61 %
2	Tropical	40 ^{0}C	90 %
3	Standard	27 ^{0}C	65 %
4	Extreme	55 ^{0}C	30 %
5	Cold	20 ^{0}C	50 %

Test Conducted on corrugated Sheet Boxes Box Compression Strength Test (BCT)

This test measures the resistance of corrugated fiber board containers to compressive forces as shown in Table II and Table III.

These compressive forces are related to some of those exerted on containers in stacks or encountered during transportation. The test also gives fairly good indication of the load a particular corrugated container may be able to withstand in service as shown in Table IV and V.

BOX COMPRESSION STRENGTH (BCT) (SIZE: 18"x 9"x 18")

Table. II Showing **BCT**

Sr. No.	SAMPLE DETAILS		RESULTS Peak Load (Kgs)				
	Source	Number of Samples	Ambient* Rh and Temperature	30% Rh & 55^{0}C	50% Rh & 20^{0}C	65% Rh & 27^{0}C	90% Rh & 40^{0}C
1	RECYCLED(IMP)	21	120.3	167.8	152.4	139.4	103.9
2	RECYCLED(IND)	40	93.9	120.6	106.7	96.3	72.4
3	AGRO	72	120.7	181.5	143.5	134.2	93.2
4	IMPORTED	09	120.5	164.3	145.4	140.1	96
	OVERALL	142	**113.9**	**158.6**	**137**	**127.5**	**91.4**
* Temperature T Range= 28-34^{0}C, Relative Humidity Rh Range= 55-65%							

Table. III Showing **Peak Load (Kg/cm)(Perimeter)(18"x 9"x 18")**

Sr.No.	SAMPLE DETAILS		RESULTS Peak Load (Kg/cm)(Perimeter)(18"x 9"x 18")				
	Source	Number of Samples	Ambient* Rh and Temperature	30% Rh & 55^{0}C	50% Rh & 20^{0}C	65% Rh & 27^{0}C	90% Rh & 40^{0}C
1	RECYCLED(IMP)	21	0.85	1.1	0.99	0.95	0.75
2	RECYCLED(IND)	40	0.64	0.8	0.74	0.63	0.5
3	AGRO	72	0.81	1.21	0.99	0.95	0.64
4	IMPORTED	09	0.96	1.35	1.11	0.97	0.65
	OVERALL	142	**0.82**	**1.12**	**0.96**	**0.88**	**0.64**
* Temperature T Range= 28-34^{0}C, Relative Humidity Rh Range= 55-65%							

BOX COMPRESSION STRENGTH (BCT) (SIZE: 18"x 18"x 9")

Table. IV Showing Peak **Load (Kgs)**

Sr.No.	SAMPLE DETAILS		RESULTS Peak Load (Kgs)				
	Source	Number of Samples	Ambient* Rh and Temperature	30% Rh & 55^{0}C	50% Rh & 20^{0}C	65% Rh & 27^{0}C	90% Rh & 40^{0}C
1	RECYCLED(IMP)	21	156.2	201.6	180.3	173.8	137.4
2	RECYCLED(IND)	40	117	146.5	135.8	114.6	90.7
3	AGRO	72	148.6	221.1	180.7	174	116.5
4	IMPORTED	09	176.4	247.7	203	176.7	118.4
	OVERALL	142	**149.6**	**204.2**	**175**	**160**	**116**
* Temperature T Range= 28-34^{0}C, Relative Humidity Rh Range= 55-65%							

Table. V Showing Peak Load (Kg/cm)(Perimeter)(18"x 18"x 9")

Sr.No.	SAMPLE DETAILS		RESULTS Peak Load (Kg/cm)(Perimeter)(18"x 18"x 9")				
	Source	Number of Samples	Ambient* Rh and Temperature	30% Rh & 55^0C	50% Rh & 20^0C	65% Rh & 27^0C	90% Rh & 40^0C
1	RECYCLED(IMP)	21	0.88	1.23	1.11	1.02	0.76
2	RECYCLED(IND)	40	0.69	0.86	0.78	0.7	0.53
3	AGRO	72	0.88	1.32	1.05	0.98	0.68
4	IMPORTED	09	0.88	1.2	1.06	1.02	0.7
	OVERALL	142	**0.83**	**1.16**	**1**	**0.93**	**0.67**
* Temperature T Range= 28-34^{0}C, Relative Humidity Rh Range= 55-65%							

Moisture Content (%)

Moisture content in corrugated sheet board is significant for its effect on such properties as printability, shrinkage, dimensional stability and physical strength as shown in Table VI. Gann Moisture Meter Hand held digital moisture meter imported from Germany for instant moisture results.

Table. VI Showing BCT Values

Sr.No.	SAMPLE DETAILS		RESULTS Moisture(%)(Original)				
	Source	Number of Samples	Ambient* Rh and Temperature	30% Rh & 55^0C	50% Rh & 20^0C	65% Rh & 27^0C	90% Rh & 40^0C
1	RECYCLED(IMP)	21	7.8	4.86	7.61	8.41	12.8
2	RECYCLED(IND)	40	7.61	5.5	7.39	8.56	13.68
3	AGRO	72	7.74	5.53	7.48	8.61	13.71
4	IMPORTED	09	7.81	5.54	7.43	8.67	13.61
	OVERALL	142	**7.74**	**5.36**	**7.48**	**8.56**	**13.45**
* Temperature T Range= 28-34^{0}C, Relative Humidity Rh Range= 55-65%							

V. Results and Conclusions

Based on the Box Compression Test (BCT) and Moisture Content for the various samples of corrugated sheet boxes carried for different ambient temperatures and different ambient relative humidity

1. The BCT values decrease as the relative humidity of the atmosphere increases. The decrease is sharp beyond 65 % Rh.
2. The Corrugated Boxes from all the sources show the similar pattern.
3. The Corrugated Boxes made from imported papers gives the best BCT values, closely followed by agro based samples. However, agro based samples are most sensitive to relative humidity variations showing the maximum drop at the higher relative humidity.
4. The average BCT values obtained at ambient conditions are in between 65% Rh and 27^{o}C to 90% Rh and 40^{0}C but very nearer to former.
5. The BCT values of boxes of both size expressed in terms of load in kgs/cm of the perimeter, are as shown in Table VII:

Table. VII Showing BCT Values

Sr. No.	Size (cm)	Perimeter (cm) (2L +2W)	Atmospheric Conditions				
			Ambient Rh and Temp	30% Rh & 55^0C	50% Rh & 20^0C	65% Rh & 27^0C	90% Rh & 40^0C
			Peak Load (kgs/cm of the perimeter)				
1	(45.74 x 45.74 x 22.9)	183	0.82	1.12	0.96	0.88	0.64
2	(45.74 x 22.9 x 45.74)	137.3	0.83	1.16	1.0	0.93	0.67

It is clear from the table that BCT depends more on perimeter of box. The height plays the marginal role in contribution to the BCT.

1. BCT values at different atmospheric conditions show gradual decrease as the relative humidity is increased, regardless of the temperature of the surrounding atmosphere.
2. Moisture content of the samples increases as the relative humidity of the surrounding atmosphere increases.
3. All samples show the similar moisture pattern.
4. The increase in moisture content is steep after 65% Rh in case of all the samples.
5. Moisture content is marginally affected by the temperature alone.
6. The moisture content of samples tested at ambient conditions are in between 50% Rh and 20^{0}C and 65% Rh and 27^{0}C but nearer 50% Rh and 20^{0}C.
7. It is observed in boxes that the optimum value of BCT are obtained at Moisture content level at 7-8% and hence Moisture content of 7-8% is the ideal Moisture content for corrugated Boxes Packaging Industry.

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