

# Performance And Appearance Of Packaging Grades Of Paper – Study On Quality Measurement Methods

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## ABSTRACT

Fibre-based packaging materials are widely used all over the world and are the leading material for packaging (about 40%). They have several important advantages in comparison to fossil based packaging, such as: biodegradability, recyclability, and renewability.

The features of paper and paperboard which make these materials suitable for packaging relate to performance and appearance. These features are determined by the type of paper and paperboard the raw materials used and the way they are processed. Achieving paper properties to meet today's packaging demands with available resources is perhaps the biggest challenge every paper maker and converter has to face. This paper analyses the various studies into how the Short span compression Test (SCT) method fares better than Ring Crush Test (RCT) method to predict Edge Crush Strength and Box Compression Strength of corrugated containers and whether the Optical surface topography measurement developed by Innventia, Sweden is better suited to printing performance than traditional air-leak measurement techniques. Controlling the processes to achieve optimum numbers for these properties improve the performance of the product while can also save on unnecessary quality related issues.

## INTRODUCTION

Corrugated packaging (material based packaging) and food packaging (content based packaging) are the two prominent segments in the Indian packaging industry. Units operating in both the segments are predominantly SME units. With constantly changing technologies, the onus is now on SMEs to gear up to higher levels of operations with higher efficiency and upgraded technology. This would be imperative for Indian packaging units to compete in the international arena

A wide range of paper and paperboard is used in packaging today – from light weight infusible tissues for tea and coffee bags to heavy duty boards used in distribution. Paper and paperboard are found wherever products are produced, distributed, marketed and used, and account for about one-third of the total packaging market. Approximately 20% of all paper and paperboard consumption used for packaging and over 50% of the paper and paperboard used for packaging is used by the food industry. Packaging made from paper and paperboard is found at the point of sale (primary packs), in storage and for distribution (secondary packaging).

Paper based packaging materials appear in the form of wrappings, sacks, boxes, cup, bags, trays and tubes. The features of paper and paperboard which make these materials suitable for packaging relate to performance and appearance. These features are determined by the type of paper and paperboard the raw material used and the way they have been processed. Performance and appearance can be related to measurable properties which are controlled in the selection of raw materials and the manufacturing process

### Performance

Performance properties are related to the level of efficiency achieved during the manufacture of the pack, in printing, cutting and creasing, gluing and the packing operation. Performance properties are also related to pack compression strength in storage, distribution, at the point of sale and in consumer use. Specific measurable properties include stiffness, short span compression(SCT) strength, tensile strength, wet strength, % stretch, tear strength, fold endurance, puncture resistance and ply bond strength. Other performance properties relate to moisture content, air permeability, water absorbency, surface friction, surface tension, ink absorbency etc. Chemical properties include pH, whilst chloride and sulphate residues are relevant for aluminium foil lamination. Curliness is easily evaluated but is a complicated issue as lack of flatness can arise from several potential causes, from the hygrosensitivity characteristics of the fibre, manufacturing variables and handling at any stage including printing and use. Neutrality with respect to odour and taint, and product safety are performance needs which are important in the context of paper and board packaging which is in direct or close proximity to food.

### Appearance

Appearance relates to the visual impact of the pack and can be expressed in terms of colour, smoothness and whether the surface has a high or low gloss (matte) finish. Colour depends on the choice of fibre for the outer surface, and also, where appropriate, the reverse side. The choice is among white, brown or grey. In addition some liners for corrugated board comprise a mix of bleached and brown fibres. Other colours are technically possible either by using fibres dyed to a specific colour or coated with a mineral pigment coloured coating. Where paper and paperboard is required for quality printing, it is usually coated on the print side during manufacture with a mineral based coating, usually white in colour, based on china clay or calcium carbonate. The reverse side may also be coated where two side printing is required.

### Performance of Corrugated Board Boxes.

The compression strength of a corrugated board box is by far the most significant measurement of its performance and is a direct measure of the stacking strength of corrugated board packages but, since the load-bearing properties of a box are often of decisive importance under modern transport conditions, it can also be said that the compression strength constitutes a general measure of the performance potential of a corrugated board package.

The BCT - method is a pure top to bottom load test which is as a rule carried out on empty sealed corrugated board boxes which are compressed between flat parallel plates in a compression tester at a constant compression rate, usually 10-13 mm/min. The force and the strain are recorded continuously until a compressive failure occurs. The maximum force attained is reported as the compression strength of the corrugated board box. The test is carried out in a standardized atmosphere, 23°C and 50%RH.

Numerous studies, initiated from the basic work conducted by McKee and Gander (1962) have been published indicating which properties of the corrugated board give the corrugated board box its compression strength. This was further extended to studies investigating which properties of substrates (paper) are critical to achieve desired strength in the corrugated board.

According to the McKee equation, the compression strength BCT of a corrugated board box of the Regular Slotted Box (RSB) design can be predicted from knowledge of:

1. The edgewise crush resistance of the corrugated board, the ECT- value in kN/m
2. The bending stiffness in the machine and cross-machine directions of the corrugated board,  $S_B^b$ , MD and  $S_B^b$ , CD in Nm
3. The periphery of the box, Z in m.

In general, the so-called McKee formula says:

$$BCT = k_1 \times (ECT)^x \times (S_B^b)^{1-x} \times Z^{2x-1}$$

The formula can, for corrugated board, be adapted to

$$BCT = k_1 \times (ECT)^{0.75} \times (S_B^b)^{0.25} \times Z^{0.5}$$

Where  $S_B^b$  is the geometric mean given by

$$S_B^b = \sqrt{S_{BMD}^b \times S_{BCD}^b}$$

In a simplified version of this equation, the bending stiffness is replaced by the thickness of the corrugated board, T

$$BCT = k_1 \times ECT^b \times T^{0.5} \times Z^{0.5}$$

k<sub>1</sub> and k<sub>2</sub> are constants chosen so that the product gives the BCT-strength in N.

The theoretical background is that the bending stiffness of corrugated board to a very great extent is influenced by the distance from the neutral bending center line of the sheet to the centers of the surface liners, i.e. roughly the thickness of the board.

Note that the simplified equation obviously does not take into consideration the real bending stiffness, which in its turn depends on the tensile stiffness of the liner layers and in CD also the fluting medium, and this equation should not therefore be used to calculate BCT-strengths for comparison when different liner and fluting medium grades are involved. A box maker may therefore, expect that the Kraft liner manufacturer prefers to show the excellence of this product with the help of McKee's complete equation, whereas the fluting medium and test liner manufacturers will in all probability prefer the simplified equation.

The Edgewise Compression Test (ECT) value is by far the most important factor in determining the overall strength of the box. The relationship between the ECT of corrugated board to its components can be analyzed in many ways. A useful approach to predict the compression strength of the corrugated board is to sum the compressive strengths of the linerboard and medium. This approach gives good predictive accuracies, if based on appropriate statistical weighting factors.

The relationship between the ECT- value and the compression strengths of liner and fluting medium can in general be written:

$$ECT^b = k(\sigma_{c,L1}^b + \sigma_{c,L2}^b + \alpha \sigma_{c,F}^b)$$

Where  $\sigma_c^b$  is the compression strength, L1= liner1, L2= Liner 2...F= fluting medium,  $\alpha$  = flute take up factor and k is a constant

The problem is to find an acceptable value for the constant "k". Theoretically the sum of the compression strengths of liners and fluting media should be equal to the ECT-value, so that k = 1 or possibly slightly lower in order to compensate for the reduction in compression strength of the fluting medium caused by the corrugator, which is almost negligible. Reality is unfortunately a little more complicated. Because of the difficulty in determining the ECT of the board

and the compression strengths of liner and fluting medium under exactly the same measuring conditions, we have to live with a factor "k" which is a function of the chosen test methods. In addition, the statement that "the sum of the compression strengths of liner and fluting medium is equal to ECT" can be valid only if the strain to failure is equal for both liner and the fluting medium, and this is seldom the case.

The experimental work conducted at Pretoria University and the results generated were used to determine the linear regression constants in the Maltenfort model, correlating the measured ECT with the predicted ECT, using the SCT and RCT methods the obtained results are:

$$ECT = 0.7 (SCT_{L1} + SCT_{L2} + \dots + \alpha SCT_{F1} + \alpha SCT_{F2} + \dots)$$

This gave a correlation  $R^2_{SCT} = 0.9758$

$$ECT = 1.028 (RCT_{L1} + RCT_{L2} + \dots + \alpha RCT_{F1} + \alpha RCT_{F2} + \dots)$$

This gave a correlation  $R^2_{RCT} = 0.9625$

Where the ECT, SCT and RCT are in kN/m, the correlating constant k is dimensionless and  $\alpha$  is the flute take up factor.

**Table 1**  
**Fluting medium profile types (Twede & Selke, 2005:408-409)**

Flute profile type	Approximate height [mm]	Approximate take-up factor - $\alpha$
<b>F Flute</b> A very fine flute (also known as microflute), giving excellent flat crush resistance and rigidity	0.74	1.25
<b>F Flute</b> A fine flute with excellent flat crush resistance	0.99 - 1.80	1.29
<b>C Flute</b> A larger flute than 'B' offering greater compression strength but it may be crushed more easily	3.48 - 3.68	1.38 - 1.43
<b>B Flute</b> By far the most widely specified flute profile, due to its superb robustness (difficult to crush), good compression strength and compactness	2.21 - 3.00	1.32
<b>A Flute</b> The larger flute but seldom used at present	3.99 - 4.90	1.54

Recent work conducted by Popil, Coffin and Kaewmanee at Institute of Paper Science and Technology (Georgia University) followed the above approach and investigated the influence of linerboard bending stiffness and interflute buckling in ECT. It was concluded that the relationship between ECT and basis weight was weak and that paper compression strength measured by SCT method was a much better predictor of ECT

$$ECT = k(2\alpha SCT_{Liner})^b \times [\sqrt{D_{MD} D_{CD}} / b_f^2]^{f-b} + \alpha SCT_{Fluting}$$

Where SCT is the compression strength results of the liners and fluting medium papers used for the construction of the board, measured using the Short-span compression (SCT). The geometrical mean of the liners' bending stiffness in MD and CD is included as the square root of  $D_{MD}$ ,  $D_{CD}$  and it represents the flexural rigidity of the plate.  $b_f$  is the flute spacing,  $\alpha$  is the take-up factor and is specific to the type of fluting  $k$  and  $b$  are constants.

It is therefore, important that the test methods used to measure this property really measure what they are intended to measure, namely the pure compression strength unaffected by other properties. Faulty test methods and inadequate test instruments can easily give incorrect information.

### Short-Span Compression test (SCT)

In the measurement of the compression strength of liner and fluting medium according to the "short (span) compression test" method (SCT) shown in Fig.1. The paper sample is placed between two clamps with a 0.7 mm free clamping length. When the clamps are moved towards each other, the length is reduced and the stresses in the strip increase. Since the sample is short in relation to its thickness, the slenderness ratio is low and buckling is prevented. Consequently failure occurs due to compression

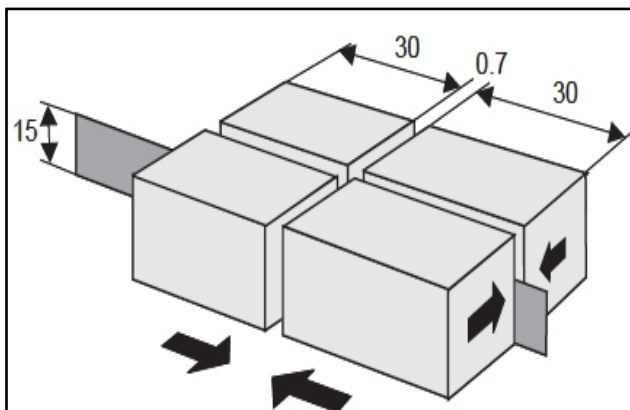


Fig. 1 - The SCT measurement method

### Ring Crush Test (RCT)

In the Ring Crush Test (RCT) method, the test strip 12.7 mm wide and 152 mm long (½" x 6") is formed into a ring (Fig.2) when it is inserted into an annular gap in a special holder. The width of the gap is adapted to the thickness of the test sample

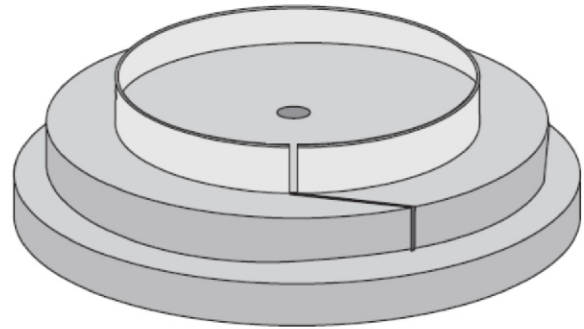


Fig.2 RCT sample placement

### Concora Crush Test (CCT) for fluting

In the Corrugated Crush Test (CCT), or Concora Corrugated Test method, the test strip is first corrugated in a laboratory corrugator, after which it is clamped vertically into a jig having the same profile as the rollers of the corrugator.

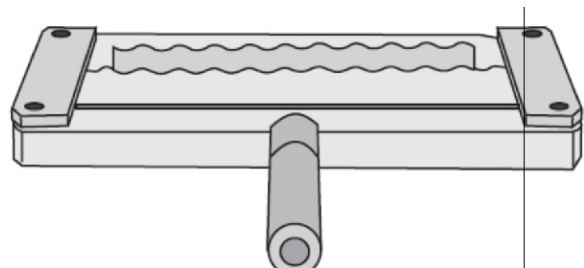


Fig.3 CCT sample holder

### Concora Liner Test

In the Crush Linear Test (CLT) or Concora\* Liner Test method, a straight test strip is held in a vertical position in a special holder.

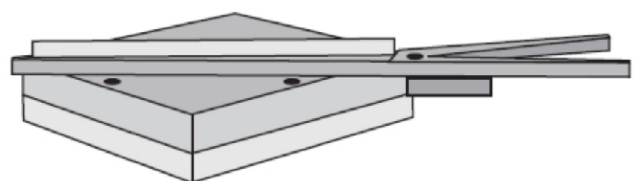


Fig. 4 CLT sample holder

The last three different designs of sample holders have a single purpose, namely to reduce the slenderness ratio of the test piece and thus prevent failure by buckling. From a material physics and measurement technology point of view none of these three methods is however satisfactory for the following reasons:

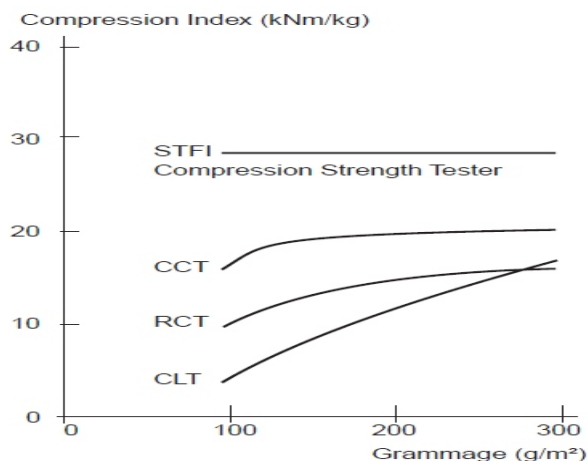
The upper edge of the test piece is not clamped but rests freely against the upper test plate, and this always may cause the test piece to be crushed at this edge. It is very difficult to make the test plates and the edges of the test piece absolutely parallel. If the lack of parallelism is great, stress concentrations will develop in certain parts of the test piece. Besides these disadvantages, the CLT test with its large slenderness ratio is unsuitable since considerable buckling always occurs. The great disadvantage of the RCT test is the buckling which occurs especially at the ends of the ring-formed test piece. In the CCT test, edge effects arise at the two vertical edges and the compression strength can also be affected by the heating and moulding in the laboratory corrugator.

### Comparison between different compression strength test methods

Below figure shows the results of a comparison between the four different methods for determining the compression strength of liner and fluting medium. The sheets were in this case manufactured from a typical liner pulp in grammages between 100 and 300 g/m<sup>2</sup> and wet pressed in the same way to a density of about 750 kg/m<sup>3</sup>. In the figure, the compression which is theoretically independent of grammage, is plotted against the grammage.

The relative ranking of the methods is clearly evident.

The CLT- and RCT-methods in particular show strongly increasing values with increasing grammage, which must



**Fig. 5 Comparison of compression methods**

indicate that at low grammages failure has arisen through buckling and not through compression failure as was intended. These methods thus do not in this grammage range measure the material property required. The CCT-method appears to give a constant value at different grammages. The results, however, lie on too low a level, about 60 % of the level given by the SCT-method which also gives a compression index independent of grammage. Some of this reduction can probably be ascribed to the weakening effect of the corrugator, although such a strength-reduction should be more apparent at the higher than at the lower grammages.

According to Fellers and Donner (2002: 481-521), the main challenge for all compression strength tests of paper is to introduce a compressive force into the plane of the sheet in a way that causes a pure in-plane compression deformation and failure. Often out-of-plane bending and buckling is evident. This problem is overcome to some extent by either using a short-span, by supporting the specimen against out-of-plane deformations.

### RCT vs. SCT

The analysis conducted by many authors, including Seth (1984), Dahl (1985) Rennie (1995), Batelka (2000) Ju, Gurnagul and Shallhorn (2005), Frank (2003 & 2007) demonstrate that:

- The RCT and the STFI SCT are not interchangeable test methods
- The failure mode is not the same for the two tests
- The tests are measuring different compressive strength properties of the paperboard affected by different paper mill process changes
- A universal formula to convert SCT to RCT has failed because there is no simple relationship between the two values as they are dependent on furnish and type of forming in the paper machine.

Also according to Whitsitt (1985)

- The SCT is coming to wider use
- The SCT is simpler, more accurate appears to have many advantages
- Ring Crush is more complex test than the Short Span Type because of its cylindrical geometry
- There are also differences in mode of failure, as commented by other authors



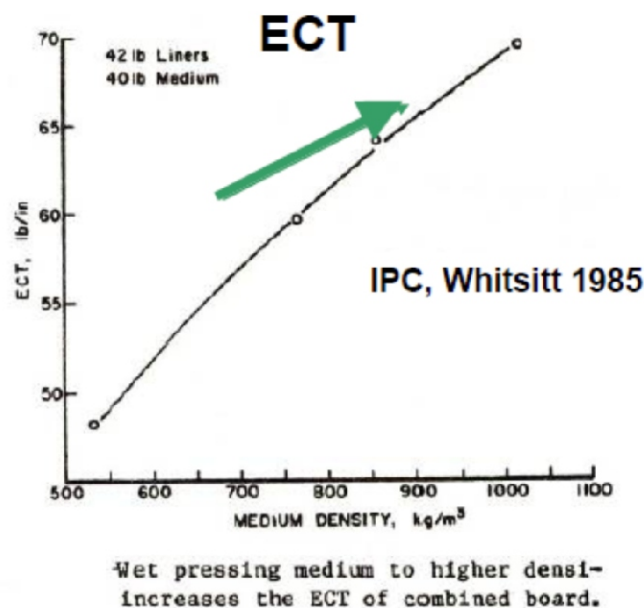
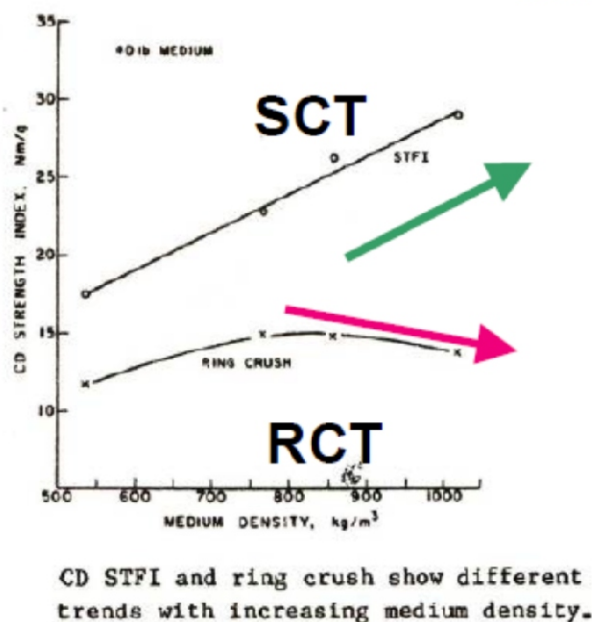


Fig. 6 Linear relation SCT - ECT

## CONCLUSION

In Ring Crush Tests on lightweight materials failure occurs by buckling. On heavy weight materials failure occurs at the loaded edges, which are weakened by cutting as the specimens are prepared. Whitsitt further claimed that because of the differences between the tests, no single relationship would hold between them under all papermaking conditions. For example, when fluting medium is wet pressed to varying degrees, the results show that CD ring crush exhibits a maximum at intermediate densities of around 750 850 kg/m<sup>3</sup>, whereas the SCT results increase steadily over the density range. The ECT results achieved with these mediums increased in the same way as the SCT results. Thus the SCT results were more indicative of the fluting medium contribution to ECT than the RCT results.

## Appearance for better printing

Printed packaging is used to provide information to the final consumer and plays an important role in the presentation and advertising. Some of this information is legally required, such as weight, vendor details, information about composition, description of contents and presence of allergens and nutritional details, etc. In addition, printing is carried out for decorative and protective purposes.

## Excellent print quality

It is essential that paperboard for graphical applications should provide excellent print quality. To achieve this, the

paperboard must meet stringent requirements in terms of its appearance and performance during the printing process. The ability of the board to fulfil these requirements is referred to as printability. High print quality is, in the main, characterised by uniform print results, high ink gloss and true colour reproduction.

It is no secret that printing related issues are the most complex of the complaints that any paper manufacturer has to deal with. Majority of papers produced are meant for printing. With packaging grades of papers the excellent print quality is a necessity to highlight the value of the product inside, especially in the case of consumer goods where the product needs to stand out. The importance of a surface suitable for high quality printing cannot be understated.

To achieve uniform print in both half and full tones it is essential that both the ink transfer and ink setting are adequate. Good ink transfer from the ink carrying plate to the paperboard is essential. To achieve uniform ink transfer and setting it is important that the paperboard has a coating layer with an even thickness; this is of particular importance for blade coating, and a high degree of uniformity. A rough baseboard surface prior to coating causes local variations in coat weight that lead in turn to variations in calendering and glazing. A well-controlled coating operation contributes to uniform print results by ensuring a monitored coat weight and a controlled coating composition.

As the printing industry continues to reduce cost and

improve the speed and quality of printing machines, the effective measurement of print quality becomes increasingly important. However, it is difficult to define print quality objectively because the concept of print quality is subjective and depends highly on the perception of potential observers.

In the commercial printing industry, a great number of printing machines that follow different printing techniques have been invented. The printing industry can be classified into six main types of printing techniques, namely: offset, screen, letterpress, flexography, gravure, and digital printing.

Previous researches have shown that main paper factors affecting print quality included paper surface and structural properties, such as surface roughness, electrical resistivity, moisture content, thickness, thermal conductivity, and optical properties such as brightness and opacity. The formation of paper, types of fibers used (hardwood or softwood), coat weight and formulations, amount of fillers/additives, and calendering conditions during papermaking are parameters that control paper properties. These parameters alter the surface morphological properties such as roughness and optical properties such as paper reflectance.

The surface properties of paper that have a direct influence on printing can be classified as Optical and physical.

### Optical properties

Colour ( $L^*$ ,  $a^*$ ,  $b^*$ ), Gloss, Brightness, Whiteness, Opacity, Fluorescence

### Physical Properties

Thickness, surface roughness (smoothness), permeability,

sizing, curliness, stiffness, moisture, formation, ink pick, ink absorption, dynamic contact angle, fan out, wax pick

Of the physical properties the micro and macro surface roughness has a direct influence on the quality and visual appearance of the printed surface. The problems faced by printers that do not have a good printable surface are: Missing dots, mottling, uneven print density.

Printability is the sum of all the properties of the paper or board that create the conditions for good print quality. Runnability is the property of the material that makes it technically possible to make good use of the material in the printing press. Knowledge of the printing process is essential in order to optimise the properties of the paper or board. Different printing processes place different demands on the surface smoothness, surface strength and absorption capacity of the substrate.

### METHODS FOR ROUGHNESS MEASUREMENT

Paper smoothness is the evenness and uniform flatness of the surface and plays an important role in print image quality. As illustrated in below figure, rougher surfaces have larger peaks and valleys as compared to smoother surfaces. The absence of these surface irregularities allows ink particles to adhere to the surface more uniformly, creating a better image. In addition, an increase in smoothness results in an increase in print density with little or no mottle. It should be noted that in general, a print density loss is observed with rougher papers

When a board is printed, ink does not reach the deep craters on the surface leading to missing dots, whereas the less deep valleys accumulate excess ink to cause mottling.

Traditional methods for roughness measurements have been:

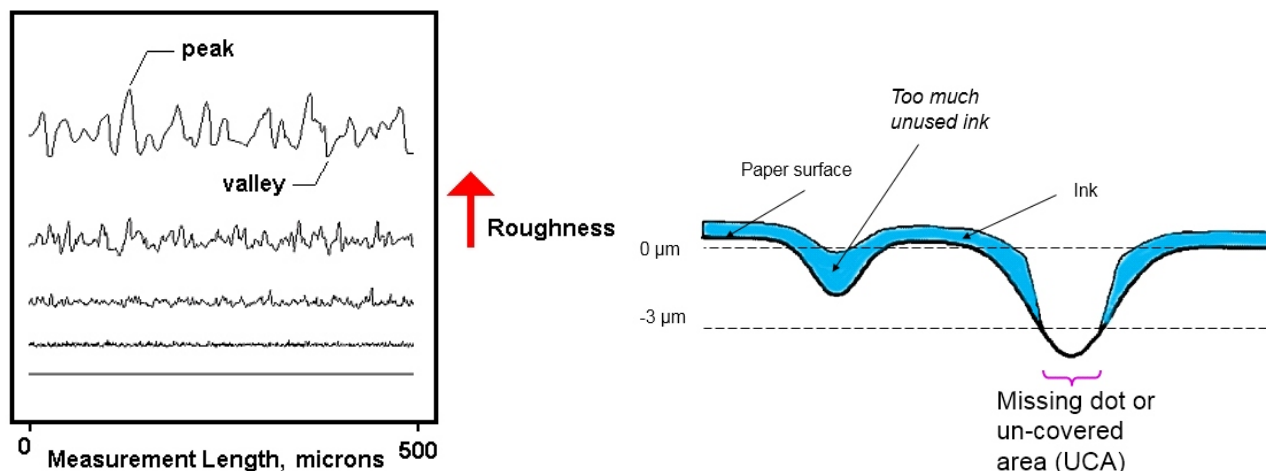


Fig. 7 Surface Unevenness scales

## Air Leak

Bendtsen or Sheffield roughness, Gurley smoothness, PPS Roughness, Stylus Roughness, These methods are quick (except Gurley) and are measured over a large area, though the actual measurement takes place only between the edge of the measuring head and the paper.

## Stylus and Laser

The Emveco stylus method, Laser and Chromatic aberration

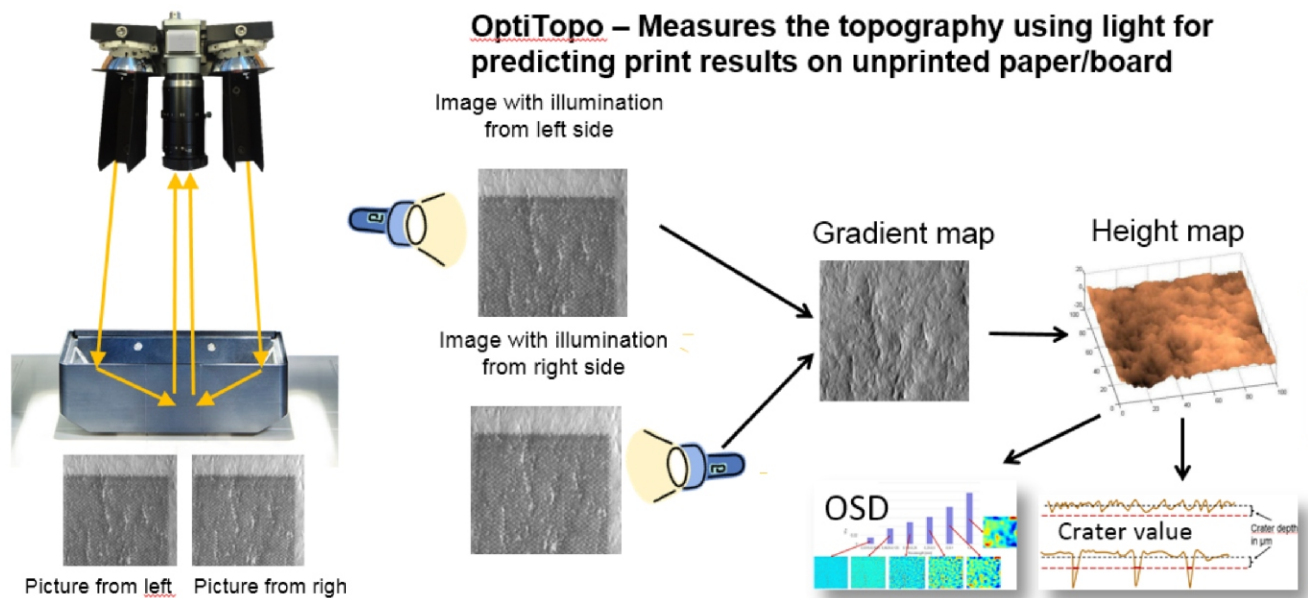
These methods make measurements in a linear manner. While number of measurements is sufficient statistically, not enough regions is covered and the method is slow

## Optical Topography

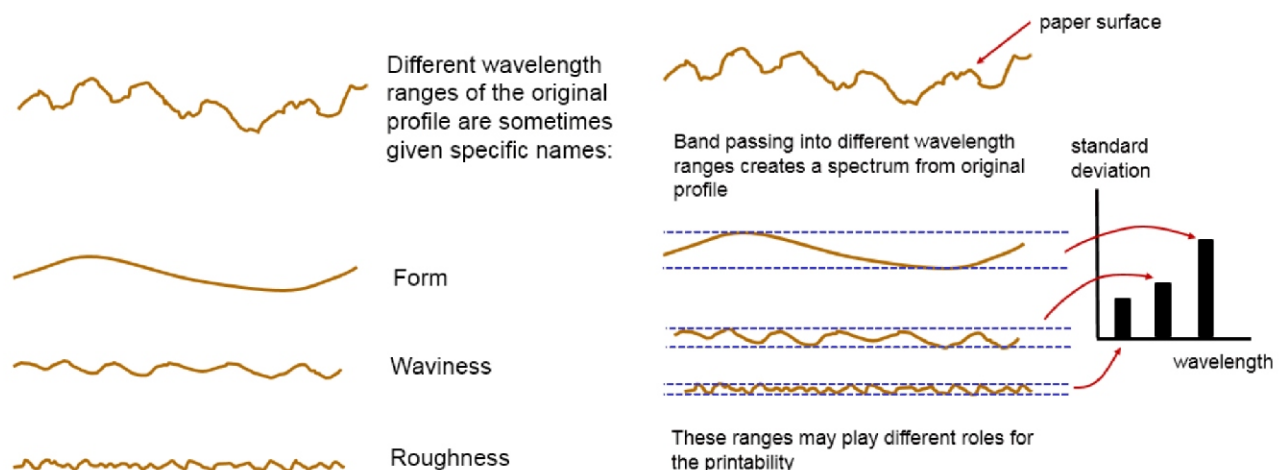
This method, developed by Innventia (Previously STFI) Sweden provides a quick non-destructive method which also correlates very well with printing performance and applicable for all types of papers.

In this paper, study was conducted on the merits of the OptiTopo method against the traditional methods. Special focus was made to determine how the OptiTopo method could co-relate with the printing related problems where the air-leak methods such as PPS and Bendtsen were not good at predicting.

The principle of Optical Topography (OptiTopo) is to analyse the surface of the sample by taking pictures under inclined low angle lighting. Low angle lighting enhances the



**Fig. 8 Concept of Optical Topography**



**Fig. 9 Classification of different wavelengths**

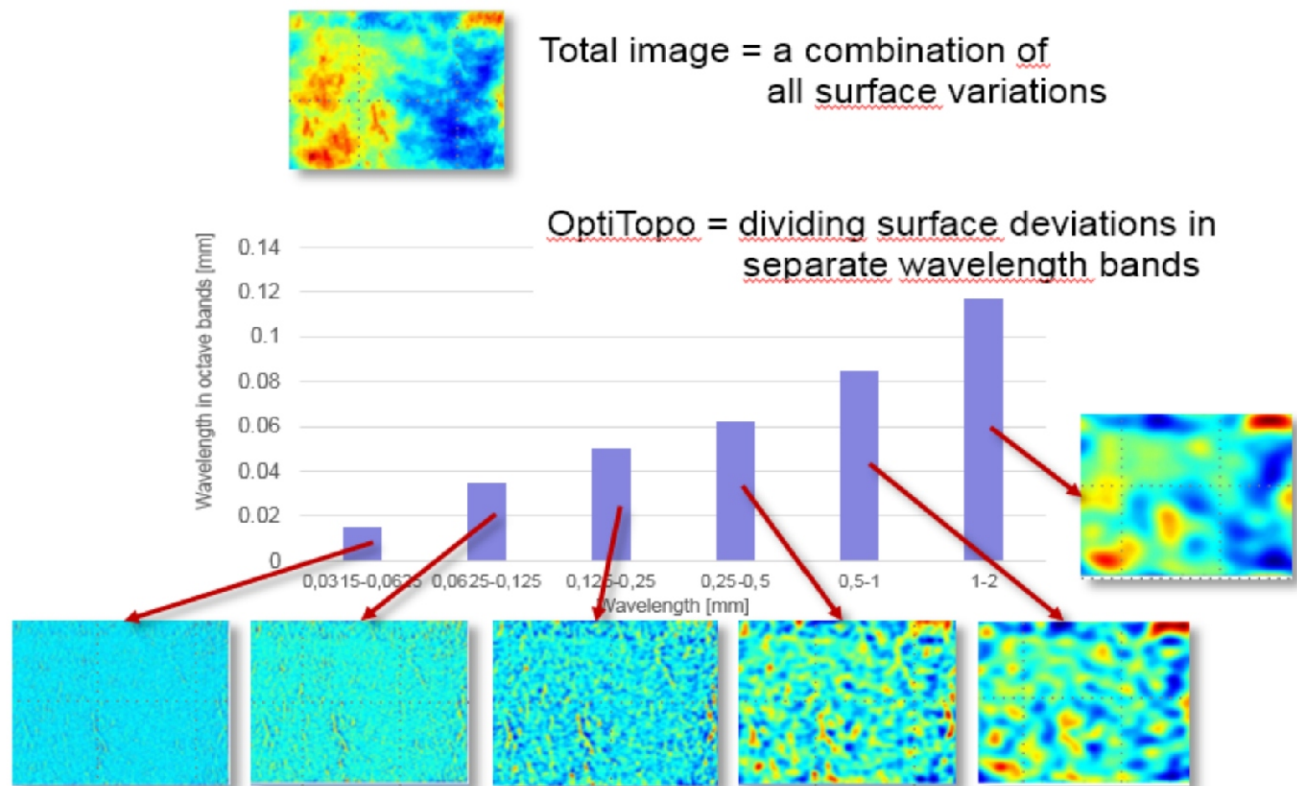


surface unevenness enabling a better digital evaluation of the surface.

A Digital height map of the area scanned is prepared by image analysis and the surface unevenness is classified

and separated to different wavelengths using bandpass filters :

Each band plays a different role in the process of printing.



- OSD – value (OptiTopo Surface Deviation)**

The surface roughness in the **fine scale** is important to printing. Useable for **all** type of paper and board products.

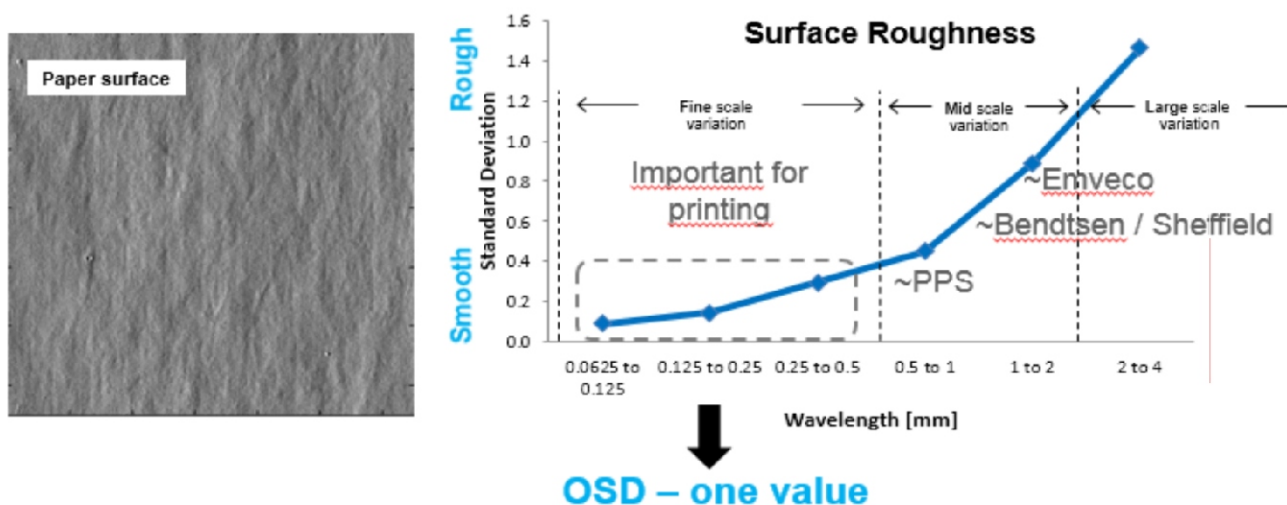


Fig. 11 Fine scale variation that is important for printing

The deviation from a perfect plane is determined as surface deviation at different wavelength bands and is recalculated into on a scale from fine to large scale variations called OSD (OptiTopo Surface Deviation). The OSD value covers all the roughness bands and is therefore applicable to all kinds of papers from the very smooth coated papers to sack paper and tissue.

Another useful parameter from the analysis is the Crater depth. The crater value is the amount of surface consisting of deep craters below a certain depth. Knowing the surface percentage of deep craters helps predict the print quality

and reveals the risk for uncovered areas and missing dots in flexo and gravure printing, as deep craters in the paper surface will remain unprinted in the printing process. The surface variation is divided in fine (-1.5  $\mu\text{m}$ ), mid (-3.0  $\mu\text{m}$ ) and large intervals (-5  $\mu\text{m}$ ) as some intervals are important for certain grades of paper while others are not. The fine scale is the most important for printing.

Study was made on 20 different kinds board samples (10 coated and 10 uncoated) of various grammages and the Bendtsen roughness and small-scale roughness values were recorded. While the overall values did match with the

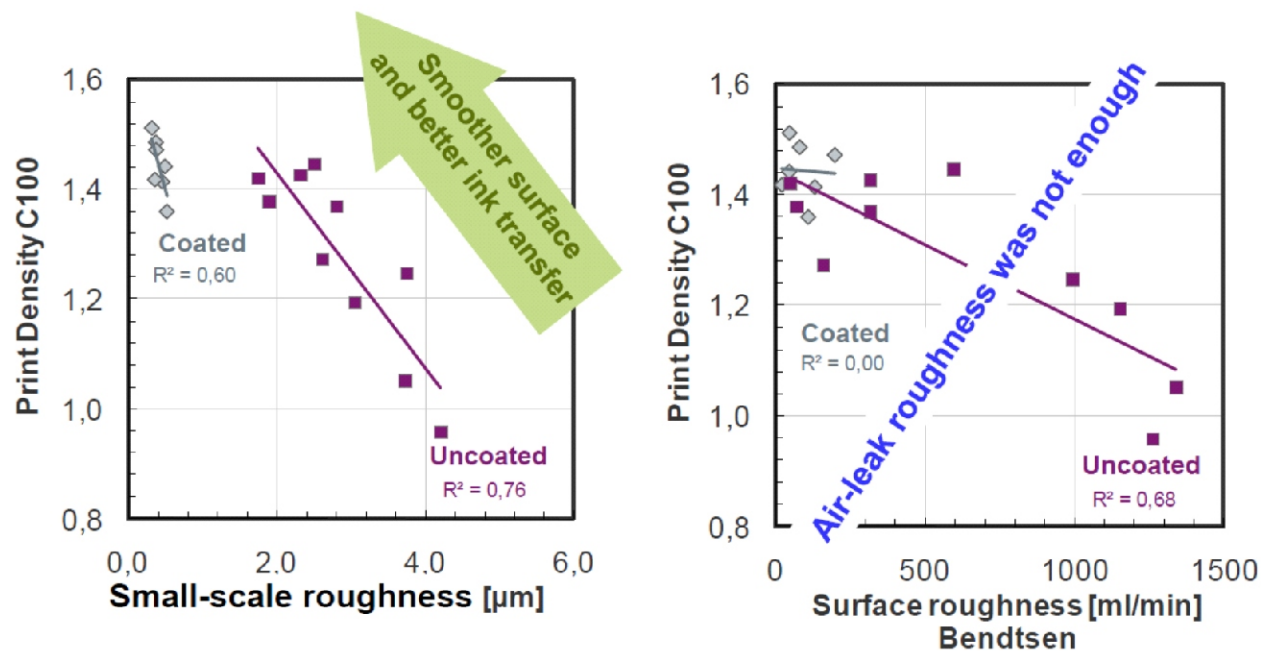


Fig. 12 Print Density vs. Roughness methods

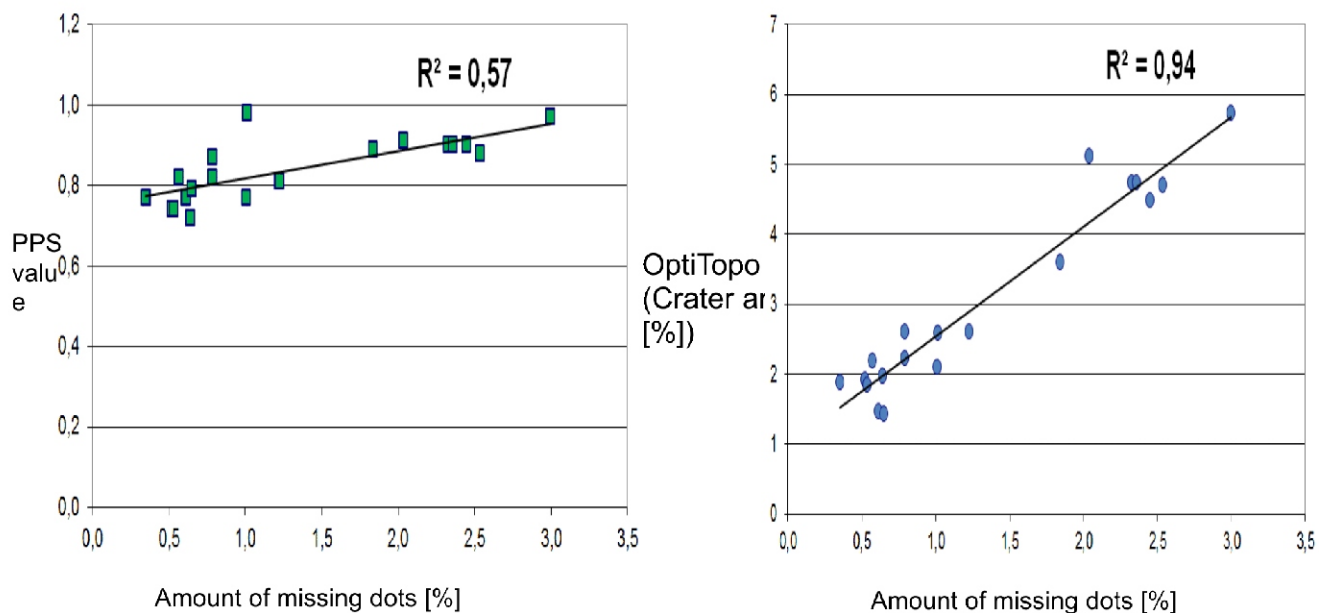


Fig. 13 Missing dots vs. Roughness methods

roughness, it was observed that the correlation between the OptiTopo measurements (Fig.12) and the print density results were much better than with Bendtsen roughness.

Another case study was made at with the PPS and OptiTopo methods and compared with Missing dots encountered in Rotogravure printing. 19 samples of different roughness were printed with Cyan 25% full-scale gravure print. The missing dots were manually counted.

The results clearly showed that the Optical Topography method was very much suited to predict missing dots during printing as compared to the traditional PPS method.

## CONCLUSION

The study clearly establishes that the Optical surface topography measurements a good method to check the printability of paper and paperboard for packaging in complement to the other traditional air-leak methods and its significance lies in the ability to better predict printing related problems beforehand thereby avoiding costly claims. One should however also remember that there are other properties that are also responsible for the print result such as difference of coating layer thickness, compressibility, ink refusal (chemical), settings on the printer, the ink properties...etc.,

## SUMMARY

The relationship between the corrugated board box compression strength (BCT) and its components characteristics can be analyzed in many ways. Some of the reported relationships between paper and board properties have become progressively more complex as the models have been refined to take into all of the important structural and component characteristics.

As boxes are generally being transported at different climatic conditions stacked on top of each other, when environmental conditions change, the compression strength of the boxes change. A corrugated box loses 50-60% or more of its short term top load box compression strength when the relative humidity is increased from 50% to 90%. The major factor affecting the stacking performance of corrugated containers is the moisture content of the board.

The ECT-value can be increased and thereby the BCT-value for a box of a given size by using liners and fluting media with a higher compression strength or by a higher grammage of identical raw material. In the McKee formula for BCT of corrugated board boxes, the ECT-value is raised to the power 0.75.

Print density, non-uniformity or print mottle strongly depends on the paper structure, which is influenced by filler distribution. Fillers such as precipitated calcium carbonate (PCC), ground calcium carbonate (GCC), and kaolin are commonly used at the wet-end of paper machines for making paper opaque, brighter and smoother at a minimum cost. However, due to the dewatering processes involved in the paper formation, an anisotropic distribution of fillers within the cross section of paper can result. Besides surface roughness, print mottle and image transfer are also highly dependent on thickness and mass density of paper. Research has shown that the spatial variation among fillers and coatings and spatial caliper variations can cause non-uniform transfer of the ink to the substrate and have an effect on the print densities of the transferred image

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