Evaluation of compressive test methods for paper using a mathematical model, based on compressive test for corrugated board

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Abstract

There are several methods for the measurement compressive strength of linerboard and fluting medium paper. The results of different method can vary up to 30% and more for same material sample and the biggest challenge is to determine compressive strength uninfected by other properties. It still isn't specified which method is technically more correct. The Short-Span Compressive Test (SCT) method is assumed to be more accurate. However, the Ring Crush Test (RCT) method is still widely use despite that it is established it is affected by buckling load of test specimen. In this study these two different methods were performed to measure the compressive strength of corrugated board's components. The results were implemented in Maltenfort equation for prediction of board compressive strength. The accuracy of methods was evaluated by comparing predicted compressive strength with measured board edgewise compressive strength (ECT). The result confirmed that SCT method is more successful for predicting compressive strength of corrugated board and therefor, more accurate.

Key words: compression testing, linerboard, fluting medium, corrugated board, Ring Crush Test, Short-Span Compressive Test, Edge Crush Test

1. Introduction

Mechanical resistance of packaging depends on the strength of the packaging material used; i.e. it depends on the paper components that the corrugated board is made of. Mechanical consistency of the packaging, as well as protection of the product inside, depends on compressive strength. Compressive strength is the largest compressive force that a test specimen tolerates without failing. It is one of the most important properties of paperboard (Niskanen, 2008).

Compressive strength of linerboard and/or fluting medium can be measured in various standardized ways: Ring Crush Test (RCT), Short span Compressive Test (SCT) and Corrugated Crush Test (CCT). Most common methods are RCT and SCT. Both measurements are supposed to measure the same property but results can vary up to 30% and more for same material sample (Markstrom, 1999). Principles of method are different; hence results differ because in most cases buckling cannot be prevented. SCT is considering the most reliable compressive strength measurement method however RCT specifications are still widely used as the primary strength characteristic for linerboard and fluting medium (Dimitrov and Heydenrych, 2010). SCT method uses a 0.7 mm length of a specimen which excludes any bending and buckling is prevented while RCT is a combination of compression and buckling failure (Fellers and Donner, 2002). It still isn't specified which method is technically more correct therefore the practice of using RCT method continues.

Compressive strength of linerboard and fluting medium directly depends on compressive strength of the corrugated board (van Eperen et al., 1983; Whitsitt, 1985; Markstrom 1999, Popil et al., 2004). Compressive strength of corrugated board is measured with Edgewise Crush Test (ECT) method. The ECT of corrugated board is used as a primary quality control parameter since it correlates to box stacking strength (McKee and Gander., 1962; Whitsitt, 1988). The ECT is mainly dependent on the compressive

properties of the components as predicted by mathematical model known as Maltenfort equation (1) (Markstrom, 1999). It can be estimated using components' compression strength, measured either with RCT or SCT method:

$$ECT = k(\sigma_{c,L1} + \sigma_{c,L2} + \alpha\sigma_{c,F}\ldots) \quad (1)$$

where σ_c is the compressive strength in cross machine direction (CD) of boards' components, linerboard and fluting medium, α denotes take up factor of the specific fluting profile used (the ratio of the length of fluting medium to the length of liner), and the constant *k* should be always equal to unity, regardless of the paper compression strength test used (this is theoretically, if there would not be test errors).

The aim of this research is to estimate which method for compressive strength testing of linerboard and fluting medium gives better predictive accuracy based on Maltenfort equation; Ring Crush Test or Short span Compressive Test, compared to measured board compression strength values using Edgewise Crush Test. The paper confirm that proposed model which uses SCT strength provides significantly better predictor of the ECT then use of the RCT measured values.

2. Material and Methodology

Principle for compressive strength testing according to the RCT method implicated a sample of paper placed into a ring formation and subjected to an increasing edge compression force until it breaks (***, 2016). The main problem is how to prevent the buckling of a thin sample. There is discontinuity point; hence the ends of test specimen are not banded together as shown on Figure 1 (Niskanen, 2008). The RCT data is the average of 10 tests in CD. Measurements were made according to TAPPI – T 822 using L&W Crush Tester.

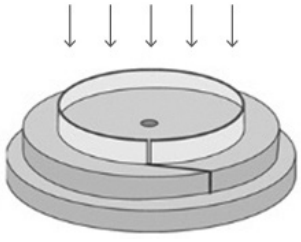

Figure 1. Test specimen in ring formation of RCT method

Compressive strength principle for testing according to the SCT method evaluates the short span compression properties of the paperboard. A test specimen is compressed in the length direction by two clamps 0.7mm apart, until rupture occurs as Figure 2 illustrates. Therefore the buckling is prevented and the compressive properties and strength of paper can be evaluated (Ek et al, 2009). The SCT data is the average of 20 tests in CD direction. Measurements were made according to ISO 9895:2008, for paper and board – compressive strength – Short span test using L&W Short span Compressive Test.

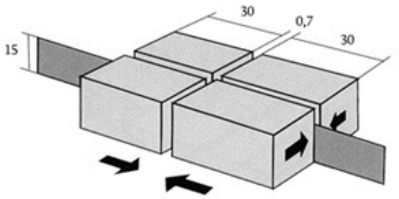

Figure 2. Principle of SCT method

A test specimen of prepared sample of corrugated board at ECT method is placed on its edge between parallel platens, one of which traverses towards the other and is connected to a load cell. Load direction is parallel to the flutes or the cross direction of the board (Figure 3). The ECT data is the averages of 10 tests according to ISO 3037:2013; for corrugated fibreboard - determination of edgewise crush resistance (unwaxed edge method). L&W Crush Tester was used.

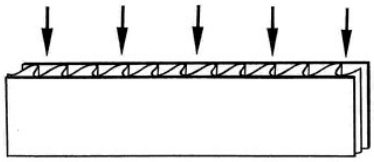

Figure 3. Test specimen consisted of cutting samples parallel to the flute direction (CD)

To determine correlation between compressive strength of corrugated board and its components, two single wall (double face) boards with B flute were analysed. Board known as quality 271 was analysed with its component's paper: two linerboards, 125 g/m² and 120 g/m²; and one medium 100 g/m² and board known as quality 276 with its component's paper: two linerboards, 180 g/m² and 170 g/m²; and one medium 150 g/m².

3. Results and Discussion

Results of compressive strength of linerboard and fluting medium measured with the RCT and SCT method are summarized in Table 1 and Table 2. As it was expected strength is increasing as basis weight of papers increase. Although these two methods are measuring the same property, outcomes are different. According to results it can be deduced that paper at RCT method had suffered certain failure, therefore measured values are lower up to 16%.

Table 3 obtained the ECT measured results of compressive strength of single wall corrugated boards known as quality 271 and quality 276, both with B flute.

Table 3. Test specimen results for ECT

	$\bar{x}$ (kN/m)	σ	max (kN/m)	min (kN/m)	median (kN/m)
Board 271	2,50	0,06	2,63	2,40	2,51
Board 276	4,81	0,09	4,98	4,65	4,815

Comparisons are made with values of the predicted ECT calculated from equation (1) and actual ECT values obtained from Crush tester. The compression strength of linerboard and medium, measured by the short span compressive method uses constant k=0,6982; and for ring crush data uses k=1,028 (Seth, 1985; Dimitrov and Heydenrych, 2010). Take up factor for B flute amounts α=1,25.

Table 4. Predicted and calculated differs of ECT values

Method for ECT prediction	predicted ECT (kN/m)	empirical ECT (kN/m)	differ (%)
ECT from RCT (quality 271)	3,03	2,50	21,2
ECT from SCT (quality 271)	2,58	2,50	3,2
ECT from RCT (quality 276)	5,47	4,81	13,7
ECT from SCT (quality 276)	4,91	4,81	2,07

Predicted ECT values calculated from equation (1) differ from actual ECT values, depending on the selected testing method. According to results summarised in Table 4 disagreements of actual values from predicted values are larger for RCT data. Predicted ECT from RCT measured results differ by 21,2% for quality 271 and 13,7% for quality 276. An error in prediction for RCT occurs possibly in buckling failure. The expected ECT from SCT data is more precise. Predicted ECT from SCT measured results differ by 3,2% for quality 271 and 2,07% for quality 276. This statistically indicates that useful predictive model for ECT is better suited from SCT strength.

Table 1. Test specimen results for the RCT and the SCT of board 271 in CD

	RCT (CD)				SCT (CD)				
Paper	$\bar{x}$ (kN/m)	σ	max (kN/m)	min (kN/m)	$\bar{x}$ (kN/m)	σ	max (kN/m)	min (kN/m)	differ (%)
Medium 100 g/m²	0,97	0,12	1,17	0,81	1,08	0,12	1,17	0,81	-10,18
Linerboard 1 120 g/m²	1,27	0,05	1,34	1,19	1,48	0,14	1,68	1,42	-14,18
Linerboard 2 125 g/m²	1,37	0,07	1,42	1,24	1,59	0,14	1,70	1,47	-13,83

Table 2. Test specimen results for the RCT and the SCT of board 276 in CD

	RCT (CD)				SCT (CD)				
Paper	$\bar{x}$ (kN/m)	σ	max (kN/m)	min (kN/m)	$\bar{x}$ (kN/m)	σ	max (kN/m)	min (kN/m)	differ (%)
Medium 150 g/m²	1,63	0,33	2,59	1,45	1,92	0,13	2,1	1,69	-15,10
Linerboard 1 170 g/m²	1,78	0,28	2,18	1,33	2,09	0,18	2,54	1,9	-14,83
Linerboard 2 180 g/m²	1,85	0,18	2,11	1,53	2,22	0,33	3	1,9	-16,66

4. Conclusion

An analytical model that combines the compressive strength of the linerboards and fluting medium provides an important predictive accuracy for ECT data and reliable ECT information contribute to the paperboard packaging product with optimized mechanical properties at minimal cost without compromising the protection function of the packaging.

The ECT value of corrugated board was measured and analysed in this paper in three different methods for chosen approach of evaluating selected measurement techniques. Direct measured board edgewise compressive strength values were used to provide guidance for the interpretation and qualification of testing results of two most common methods for compressive strength testing of linerboard and fluting medium, the RCT and the SCT method. Measured results of each method were implemented in mathematical model of Maltenfort equation, calculated and gained results were compared to actual ECT values. Comparison showed that the SCT data used in mathematical model relates better to the ECT prediction since the gained result of Maltenfort equation with SCT data is nearly identical to direct measured ECT value. Additionally, it is expected that RCT data implicate buckling load which is seen as increased value of the ECT obtained from the RCT measured values. The analysis presented in this paper is a contribution to SCT method and implies substitution of RCT method which is still significantly used as relevant indicator of compressive strength of paper.

5. References

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