Effects of Moisture content on Box Compression Strength : FBA BCT Loss Factors

Recent interest has arisen on the effects of moisture contact on the compression strength of boxes. High humidity environments as commonly encountered in Southeastern US or refrigerated food storage warehouses, obviously weaken boxes. Therefore box design for high humidity conditions require compensation for the resulting strength loss usually by producing boxes with higher basis weight, using wet strength resin additives or adhesives or application of surface barrier coatings. It is useful and instructive for box design considerations to quantify the expected strength loss as a function of the equilibrated moisture content of corrugated board and so minimize box failure in high humidity applications.

Here, we show how understanding the effect of moisture or ambient humidity on paper can predict box performance.

The author has previously provided SCT (short span compression) moisture correction formula for industry clients based on measurements of softwood unbleached kraft linerboard samples at various moistures, summarized in Figure 1.

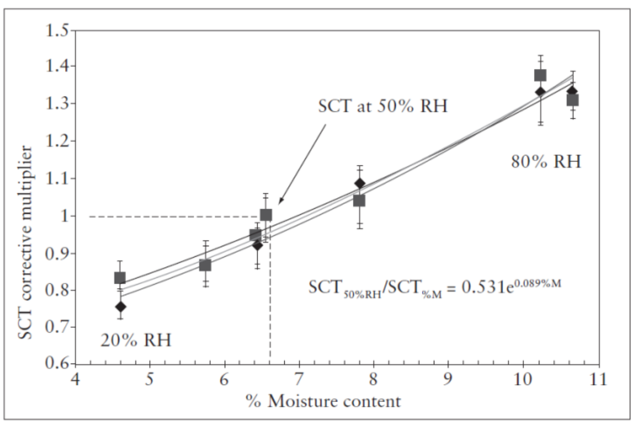

Figure 1. SCT corrective factor for unbleached kraft sample equilibrated at different RH % environments all at 23 degrees C.

The main result in Figure 1 is best presented in the simplified form as:

$$SCT_{50}/SCT_{M} = M \times 0.07 + 0.47 \qquad (1)$$

SCT_{50} is the SCT for a sample equilibrated at 50 % RH and SCT_{M} is the SCT at a wet basis moisture content M expressed in %. Equilibrium moisture content M, expressed as a percentage on a wet basis for paper (softwood unbleached kraft) follows the relationship:

$$M = 0.135\,(RH) + 0.59 \qquad (2)$$

So the dependence of SCT on RH using equations (2) and (1) is:

$$SCT_{50}/SCT_M = 0.00945 \times (RH) + 0.51 \quad (3)$$

Thus to a good approximation, the incremental % change of SCT with RH is simply $\Delta(SCT) = \Delta(RH)$ e.g., a 10 point change in RH will produce a 10% change in SCT. Some materials can be expected to be less or more hygroscopic so (2) should be considered as an approximation. Detailed in the pulp and paper technical literature, it is known that softwood is more sensitive to moisture than hardwood, virgin pulp more so than recycled, and chemical pulps more than mechanical. However, these differences can be regarded as insignificant for the purposes of the current discussion.

Consider that the edge compression strength of corrugated board (ECT) is related to SCT by the Maltenfort-Seth formula expressed here for simplicity for a C-flute single-wall board:

$$ECT = 0.7\{(2 \times SCT_l + 1.43 \times SCT_m)\} \quad (4)$$

The subscripts '*l*' and '*m*' in (4) denote SCT for the linerboard facings and fluted medium respectively.

BCT is also approximated to good approximation by the simplified form of the McKee equation:

$$BCT = 5.87 \times ECT \times \sqrt{(Z \times t)} \quad (5)$$

Z being the perimeter footprint (length + width) x 2 of the box, t the caliper. The units in (5) for BCT, ECT, Z, and t are lbs., lbs./in, and inches respectively. Therefore, from the preceding series of equations, the linear relationship between RH, M, SCT, ECT and BCT all indicate that BCT will be proportionally affected linearly by a change in RH i.e.,a 10 point change in RH, will change SCT by 10%, accordingly so will ECT and BCT also change by 10%.

Indeed, the linear inter-dependence of RH, M, SCT, ECT and BCT are reflected in the upper limit of the BCT loss factors currently published by the FBA:

ENVIRONMENTAL FACTORS		
	COMPRESSION LOSS	MULTIPLIERS
Storage time under load	10 days - 37 percent loss	0.63
	30 days - 40 percent loss	0.60
	90 days - 45 percent loss	0.55
	180 days - 50 percent loss	0.50
Relative humidity, under load (cyclical RH variation further increases compressive loss)	50 percent - 0 percent loss	1.00
	60 percent - 10 percent loss	0.90
	70 percent - 20 percent loss	0.80
	80 percent - 32 percent loss	0.68
	90 percent - 52 percent loss	0.48
	100 percent - 85 percent loss	0.15
	Source: USDA Forest Product Lab	

For example, at 80% relative humidity BCT loss from the Table above indicates a 32% loss. Equation (3) at 80% RH produces SCT_{50}/SCT_{M} = 1.27 implying that a loss of BCT of 27% can be expected in good agreement with the Table given that SCT, ECT and BCT all have a variability cv % of about 7 %.

The example given above would suggest that knowledge of the moisture adsorption characteristics (M vs RH) of a grade of paper coupled with its compression strength dependence of moisture SCT vs M would be a first order prediction for the BCT dependence on moisture.

Are the FBA BCT loss factors good enough ?

Private communication from the USDA FPL in Wisconsin has suggested that the variability increases and BCT falters at higher humidity beyond 50% which is seemingly attributable to effects of folding and scoring and thus deserving further investigation. However, in the author's recent experience with one commercial sample set consisting of single-wall heavy-weight corrugated equilibrated to 12% at 4 deg. C 80% RH, intended for food products cold storage, BCT test values follow the McKee prediction within experimental agreement. Generalizations cannot be confidently extended to include multi-wall boards without experimental further confirmation. Furthermore, equation (2) which is the relationship between equilibrated moisture content M and RH, may be significantly positively or negatively impacted by present-day attempts to improve strength/basis-weight such as the inclusion of newer encapsulating additives, designer fillers, nanocellulose, etc.

The need for further research in these areas can be stated to be obvious. RBI has the experience, capability and laboratory facilities to delve into this topic, provide the research and the measurements. For further information contact the author at: Roman@gatech.edu, 404 894 9722

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