Engineered Paperboards for Boosting Packaging Performance




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Summary :

Packaging touches our daily lives and has evolved over generations from leaf wrappings to barrels to modern day plurality of diverse materials and processes to create and customize them for specific needs. Packaging is considered to be the first moment of truth while engaging a consumer with the product. The appearance and functionality is critical to determining whether a consumer makes a purchase decision. Creating an impactful connection with the consumer at the point of sale is a matter of strongly and effectively communicating how the product will perform. With the surge in consumerism and the fact that the young generation is now quickly embracing new lifestyles, major changes are occurring in the way the products are being purchased. These changes are resulting in significant increase in demand for improved packaging performance beyond functionality. These changes are augmenting the print quality requirements for packaging. Vibrant full tone printing is by far the most pertinent way of reproducing appealing graphics on a package. While on the other hand sustainability being the key focuses everywhere, the packaging industry is forced to increase its reliance on renewable sources of packaging material such as coated paperboards. Paperboard being a complex stochastic structure of fibre and coating materials it is not indeed very surprising that engineering paperboards for improved packaging performance is unarguably a challenging task. Full tone solid colour offset printing on paperboards is often confronted with challenges such as print delamination. Thus it is extremely important for the paper industry to beable to find more accurate ways of performing real time characterization of print delamination of paperboard at the paper making stage for avoiding value addedlosses during downstream printing and packaging operations. While there are a range of traditional test methods for evaluating the delamination strength of paperboards however they fail to uniquely characterize print delamination behaviour. This paper introduces z-direction shear strength property of paperboards and demonstrates its impact over the print delamination behaviour.

Keywords : Paperboard, Packaging, Full Tone Printing, Print Delamination, Z-Direction Shear Strength.

Introduction :

With the advent of growing consumerism packaging is poised to play a pivotal role and is going to be the game changer in the market place. Paperboard is the most intuitive choice for packaging material since it not only provides a range of formidable packaging solutions but also it boosts the carbon foot prints of the final product. Functional and aesthetic performance of paperboard goes hand in hand so as to offer vibrant packaging solutions.Coated paperboards are considered to be top of the line cellulose basedmaterials which are extensively used for aesthetically appealingconsumer packaging. One of most important properties of coated paperboardsfor such applications is full tone offset printability. The coated paperboards must be printed without defects and the visual appearance must be of high quality.Print delamination during offset printing adverselyaffectsthe print quality and it has strong dependence upon coated paperboard structure. An accurateestimation of the print delamination before printing during the papermaking stage can be useful in discerning its dependence on various parametersof the papermaking process.

Print delamination is resulted from the cohesive force that develops between the offset printing ink and the coated paperboard at the exit of the printing nip between the blanket and impression cylinder. This phenomenon is known as the ink-tack delamination, Franklin (1). Offset printing ink is mainly composed of pigments, binders, ink vehicle and additives. After application of the ink to the paperboard surface, the ink vehicle or the low viscosity oils present in the ink gets absorbed by the coated substrate. This causes rapid increase of the ink-tack of the remaining layer of ink on the coated paperboard surface and exerts very high shear stress upon the coated paperboard surface at the exit of printingnip, Ercan and Bousfield (2). Consequently bending of the sheetis caused at the exit of printing nip between the blanket and impression cylinder as shown in the figure 1 (a) below.

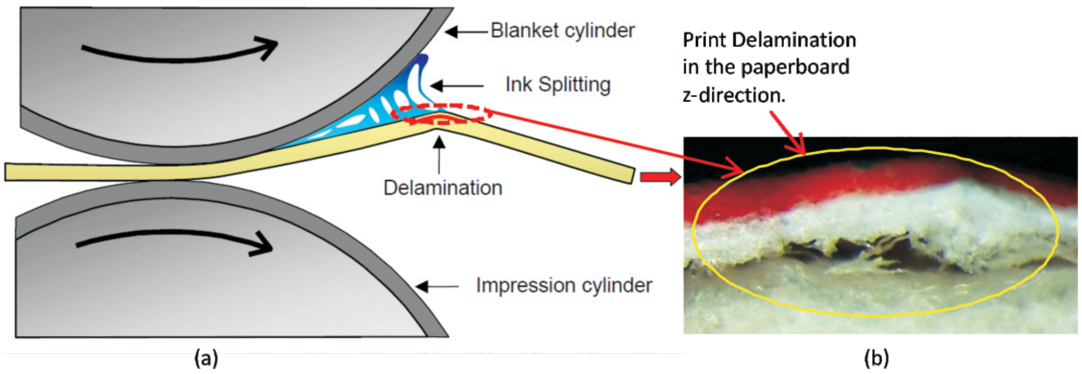


Figure 1 (a): Schematic illustration of the print delamination mechanism during offset printing process. (b): Cross-sectional microscopic image of delaminated paperboard where the top layer is de-bonded from the under / middle layer of the paperboard

The angle of bending of the paperboard in the z-direction as shown above in figure 1 (a)is governed by the distance to whichthe paperboardsurface sticks onto the offset blanket cylinder after the ink transfer. This distance is in turn governed by the rate of increase of the ink tack of the ink film present on top of the coated paperboard surface after the ink transfer. The faster the ink tackincreasesafter being transferred on the coated paperboard surface the larger is the distance to which the paperboard sticks onto the offset blanket before getting released out of the printing nip. The larger the distance of sheet sticking the higher is the degree of sheet bending at the exit of the printing nip. Finally print delamination is yielded if the cohesive force between the printed ink film and the blanket cylinder exceeds the layer bonding strength within the paperboard closer to the printing surface. Therefore the print delamination depends on the material properties of the paperboard and it is manifested in the form of bubble like appearance from the top view and from the side view it can be clearly seen that the top layer of the paperboard is de-bonded from the under or the middle layer of the paperboards as shown in figure 1 (b) above.

A range of test methods have been developed over the years for testing the delamination strength of paperboards such as Z-direction tensile strength, TAPPI standard test methodT541 (3) andScott Bond test, TAPPI standard test method T569 (4). Unfortunately these tests fail to adequately characterize the print delamination behaviourLundh and Fellers, (5). A plausible explanation of the failure of these test methods in characterizing print delamination of paperboards could be that none of these tests simulate thez-direction shear stress conditions that are representative of theshear induced stressesexerted in the z-direction of the paperboardsat the exit of a printing nip.

Characterization ofthe damage mechanism of the print delamination of coated paperboards can thus be enhanced by considering the z-direction shear strength of paperboards. Paperboard is an engineered material which often consists of different plies and interfaces. This generates an out-of-plane (ZD) profile that can be designed for optimal functionality or cost performance, Nygards *et. al.*(6). Often commercial paperboards are made with a bulky middle ply, since this gives high bending stiffness with a minimum amount of fibres. The functionality of coated paperboards is governed byoffset printability. The literature identifies shear strength profile can be powerful tool for improving the performance of paperboards and the studies have been conducted by Carlsson *et al*. (7), Nagasawa *et al*. (8) and Doeung *et al*. (9), where the aim has been to identify deformation and damage mechanisms. It can be concluded that out-of-plane of z-direction behaviour, mainly ZD tension and shear, contribute to the improved creasablity of paperboards. The development of the notched shear test by Nygårds *et al*. (10 and 11) has opened up the possibility to evaluate shear strength profiles in the cross section or z-direction in the context of print delamination. The test can be used on different paper grades, such as paperboard, liner, fluting, newsprint and copy paper, Nygårds and Malnory, (12). Huang and Nygårds (13) have also suggested that the test can be used both as a quality control test and as a measure of local shear strength that can be used as input in material models.

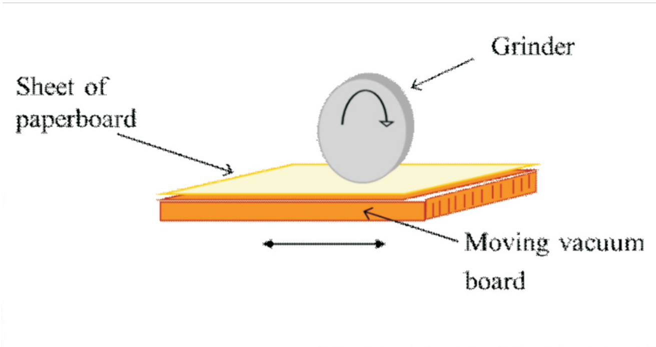
Different paperboards are characterized in terms of their z-direction shear strength and itsperformance with respect to print delamination behaviour has been shown in this study. It has been demonstrated that a good control over the z-direction shear strength of the paperboard yields superior resistance to tack induced print delamination.

Materials and Methods

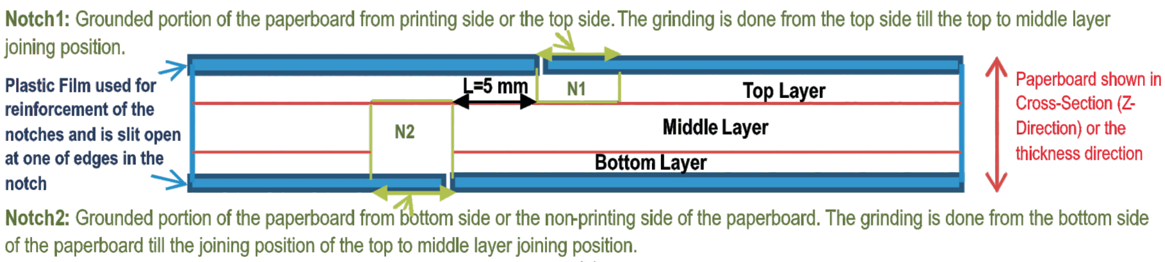
A large set of offset printed samples were selected from a library of print delamination complaint samples. These samples exhibited varying degree of print delamination in the full tone areas of the print and it represented virgin CTMP fibre based coated folding box boards (FBB) of substances ranging from 270 to 420 g/m^2.The samples were categorized as either good or bad depending upon the visual perception of print delamination on initial inspection. Each sample set constituted thirty different samples and the corresponding unprinted portions of the samples were evaluated for various strength properties.The objective of this study is to estimate the shear strength of the paperboard at the top to middle layer interface and understand whether it can distinguish the good and the bad sample in terms of the print delamination characteristics. But it is difficult to measure the stress-strain behaviour in Z-direction of the paperboard with high accuracy due to the smaller thickness. The uneven thickness & porous structure of the surface also make it difficult to ensure homogeneous deformation during loading. The following section provides a detailed method that is adopted for the measurement of shear strength of paperboards at the top to middle layer joining position since the print delamination occurs at the layer interface position in the Z-direction.

Shear Strength

The specimens needed to characterize the shear strength were made according to the procedure described by Nygårds *et al*. (11). The double notch specimen used to measure shear strength profiles has two notches that are made from opposite sides of the sheets. These have traditionally been made by using a high speed grinding wheel as shown in figure 2(a). Great attention was put on making the notches meet at a certain position in the Z-direction of the paperboard as illustrated in figure 2 below. The grinding depth in relation to the top side or the printing side of the paperboard has been regulated in such a manner that the paperboard is ground from the top layer till the joining position of the top to middle layer and it is denoted as *N1* in the figure 2(b) below. While at the same the grinding depth from the opposite side or the non-printing side is regulated in such a manner that it is ground from the bottom side of the paperboard till the middle layer to top layer joining position and is denotedby*N2* in the figure 2(b) below. However the notches are separated laterally by a distance of 5 mm and denoted by *L* in the figure 2(b) below.The paperboard specimen was laminated with a plastic film to prevent failure due to the notches.



(a)



(b)

Figure 2 (a) : Schematic three dimensional representations of the making notches into the paperboard using a grinding wheel. (b): Schematic side view illustration of the centre part of the double notchedpaperboard specimen.

For each paperboard 5 samples in MD and CD were tested and each of the paperboard samples were ground till the top to middle layer interface in relation to the top side of the paperboard andvice-verse in relation to the bottom side of the paperboard.After grinding the paperboard samples from both top and bottom sides the samples were subjected to standard L&W tensile testing, TAPPI standard test methodT494 (14) for deriving the shear strength of the sample as shown below in the figure 3 below. The sample size for the tensile testing being 15 mm wide and 100 mm long and position of the notches in relation to the tensile test strip can be found from figure 3 below.

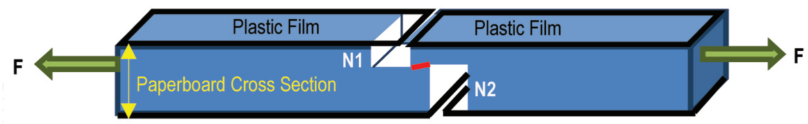


Figure 3: Schematic three dimensional illustration of the tensile testing of the double notch paperboard specimen.

The figure 4 above shows the top view photograph of the double notched paperboard sample before and after the tensile testing. It can be clearly seen that the sample breakage during tensile loading happens right at the middle of the two notches which is what is schematically denotedby red coloured line in the figure 3 above.

Considering the fact the samples were laminated from both sidesit provides adequate reinforcement at the notches and consequently the shearing zone is limited to the portion of paperboard in between the two notches. As the notches are made in such a manner that they meet in the plane of the top to middle layer joining position hence the tensile loading exerts shear stress to the top to middle layer interface position and the test result indicates the shear strength of the top to middle layer bonding zone.

The shear strength can be found from the following equation.

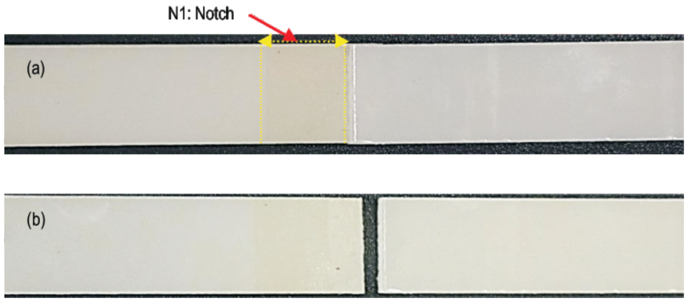


Figure 4(a): Top view of the laminated double notch paperboard specimen before tensile testing. (b): Top view of the laminated double notch paperboard specimen after tensile testing.

$$\tau = \frac{F}{A} = \frac{F}{WXL} \quad \text{.......... Equation 1}$$

Where, τ = Shear strength which is expressed in units of kN/mm^2

F = Tensile strength recorded by the L&W tensile tester

A = Area of the shear zone

W = Width of the shear zone = 15 mm (Width of the specimen)

L = Length of the shear zone = 5 mm (Lateral distance between the notches)

Besides shear strength the same set of good and the bad sample set has also been subjected to the traditional paperboard delamination strength evaluation using the Z-direction tensile test and the Scott bond test.The results from the proposed shear strength evaluation of the good and the bad set of samples are presented in conjunction to the traditional Z-direction tensile strength and the Scott bond strength in the following section.

Results

The shear strength is measured for the paperboard samples of wide range of substance at the top layer to middle layer interface joining position according to the method described in the previous section for the good and the bad sample sets in both machine direction and cross machine direction. The data has been analysed using statistical multivariate analysis and the summarized main effects are presented in the figure 4 below.

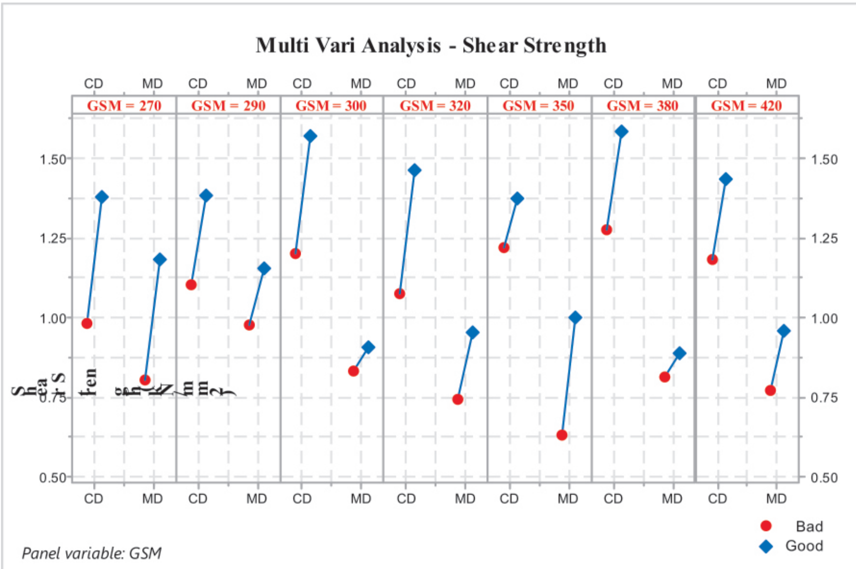


Figure 4: Multivariate chart of shear strength for the "Good" and "Bad" Sample Sets versus GSM and grain direction is presented

Summary of analysis of variance is presented in table 1 below in terms of the statistical significance level of shear strength as a response to different factors namely "Sample Type: Good and Bad", "Grain Direction: CD and MD" and "GSM: 270, 290, 300, 320, 350, 380 and 420"

Table 1: Statistical summary ANOVA shear strength versus sample type, grain direction and substance

Sr	Factor	Levels	Test Statistic (P-Value)
1	Sample Type	2 (Good and Bad)	0.000
2	Grain Direction	2 (CD and MD)	0.000
3	GSM	7 (270, 290, 300, 320, 350, 380 and 420)	0.581

Substantial agreement has been observed between the visual perception of print delamination over the printed samples and the shear strengthat the top to middle layer interface which has been deduced from the tensile testing of the corresponding unprinted double notched paperboard samples.The results imply that the ink tack inducedshear loading of the paperboard samples at the exit of the printing nipmaylead to print delamination when the paperboards shear strength at the top to middle layer interface is not adequate enough to withstand the shear stresses involved in the offset printing process. Another interesting elucidation from the results is that though the shear strength is significantly lower in machine direction than the cross machine direction yet the behaviour with regard to the sample type is consistent for both the grain directions. It should also be noted that the change in substance is yielding statistically insignificant shear strength differences among the different samples. Insensitivity of the top-middle interface shear strength to grammage changes can be explained from the fact that the top ply substance is generally consistent across various grammages of the total paperboard.

The results from the traditional Z-tensile and the Scott bond testing of the same set of samples are presented the figure 5 (a) and 5 (b) below. Considering the fact the Z-tensile testing is performed over circular samples therefore the grain direction of the paperboards is ignored here.

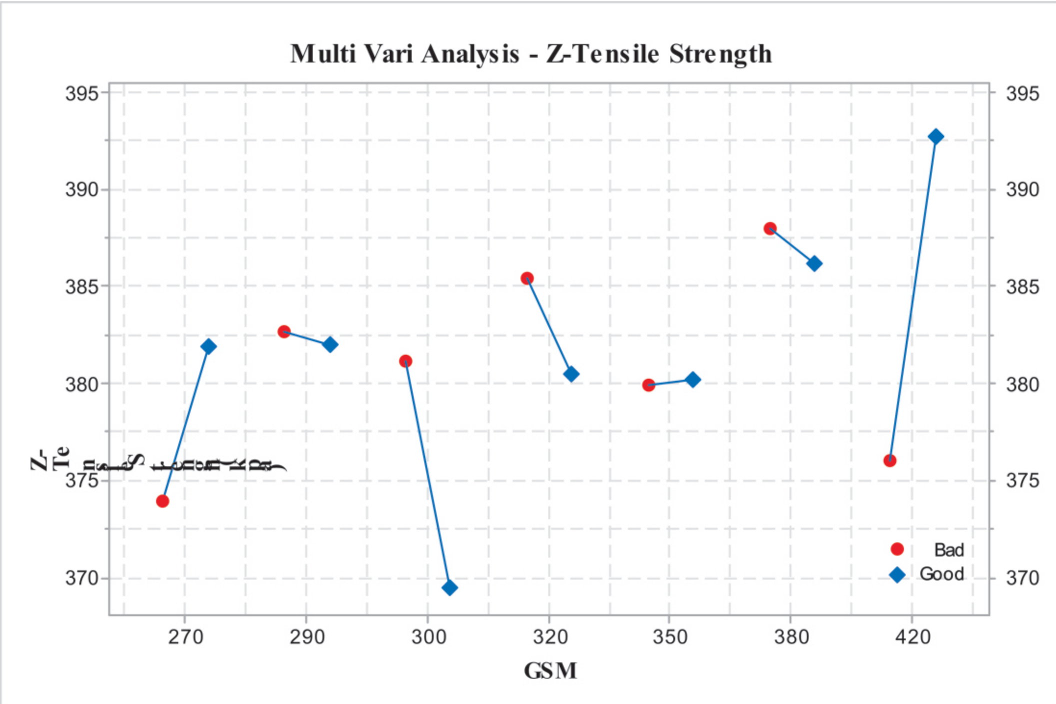


Figure 5(a): Multivariate chart of z-tensile strength for the "Good" and "Bad" Sample Sets versus GSM is presented.

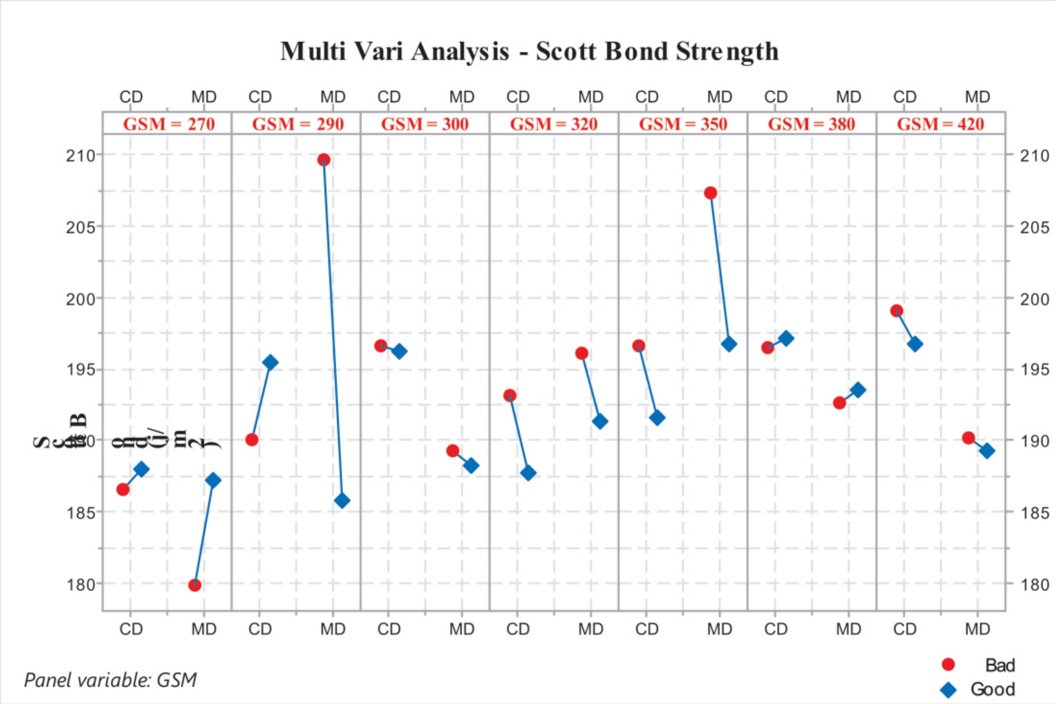


Figure 5 (b) : Multivariate chart of Scott bond strength for the "Good" and "Bad" Sample Sets versus GSM is presented.

The test statistics from the analysis of variance is presented in table 2 below in terms of the statistical significance level of Z-tensile strength as the response to different factors namely "Sample Type: Good and Bad" and "GSM: 270, 290, 300, 320, 350, 380 and 420". Similarly table 3 presents the statistical significance level of Scott bond strength as the response to same set of factors while additionally including the grain direction as the factor.

Table 2: Statistical summary ANOVA Z-tensile strength versus sample type and substance and ANOVA Scott bond strength versus sample type, grain direction and substance

Response	Factor	Levels	Test Statistic (P-Value)
Z-Tensile Strength	Sample Type	2 (Good and Bad)	0.829
	GSM	7 (270, 290, 300, 320, 350, 380 and 420)	0.743
Scott Bond Strength	Sample Type	2 (Good and Bad)	0.442
	Grain Direction	2 (CD and MD)	0.492
	GSM	7 (270, 290, 300, 320, 350, 380 and 420)	0.906

Unlike shear strength data, both Z-tensile strength and the Scott bond strength data exhibits very poor relationship with the visual perception of print delamination. Similar results have been reported by previous researches, Hallback *et. al.* (15) and Girlanda *et. al.* (16).

The literature provides the argument that the Z-tensile strength may yield misleading results in terms of characterizing print delamination due to undesired local stress concentration owing to the presence of discontinuities around the perimeter of the circular samples.

The Scott bond test measures the energy required to delaminatepaperboard samples. Though it finds wide spread application in the paper industry however this test method suffers from serious limitations when it is desired to characterize issues such as print delamination since this test reports a combined effect of both shear and tensile loading in the test piece. The delamination energy reported here includes both the energy forseparation of two surfaces and the plastic deformation energy, Hallabck (15). However the characterization of tack induced print delamination can be improved by adequately defining the shear component alone. This genesis explains superior relationship of the proposed shear strength method with shear induced print delamination behaviour.

Conclusion

This paper demonstrates that the measurement of shear strength at the point of top and middle layer interface of multilayer coated paperboards can be a reliable method for characterizing thelocal stress conditions prevalent in the ink tack-induced print delaminationprocess during full tone offset printing. The proposed shear strength method has been shown to provide superior estimationof the print delamination behaviour than the traditionally used paperboard strength measurement methods such as Z-tensile and Scott bond strength tests. The methods proposed in this work can serve as an in situ quality control and developmenttool during the manufacturing of coated paperboard grades on paper machines for improved packaging performance.

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