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EFFECT OF FORMATION HYDRODYNAMICS ON MECHANICAL PROPERTIES OF CONTAINER MATERIALS

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ABSTRACT

The objectives of this study were to compare the mechanical and physical properties of the sheets made using the Vortigen technology (a non-conventional technique that creates very high number vortices in a fluid flow mixture of water, fibers, and chemical additives) with those produced from a conventional method of papermaking and to provide insight into the impact of formation hydrodynamics on sheet properties. The results of formation, ultrasonic stiffness, and creep/accelerated creep measurements of the Vortigen sheets as compared with the standard sheets are presented. Samples of Vortigen (V) and standard (S) sheets (4 samples from each group) were obtained from papers produced on a pilot machine. Formation measurements (that provides a measure of density distribution in a sheet) were performed using a formation tester which is based on beta particle absorption. Measurements of creep and accelerated creep were made at a constant relative humidity (RH) of 80% and a cyclic RH between 30% and 80% for strips cut along the machine direction (MD) and cross machine direction (CD, which is perpendicular to MD) directions.

There was a significant difference between the distributions of basis weights for the two types of papers. The mean coefficient of variation in grammage for the V samples was 8.97 while that for the S samples was 12.60. The mean MD/CD stiffness ratios for the V and S samples were 1.1 and 1.6, respectively. The mean Z-direction longitudinal specific stiffness corresponding to the V samples were 18% greater than the corresponding value for the S samples. The MD strips from the S samples exhibited the smallest creep while the CD strips from the S samples exhibited the largest creep. Creep values corresponding to the Vortigen sheets were between the extreme values of the standard samples. The results of this study indicated that because of the influence of formation hydrodynamics on fiber orientation and formation, in general, the stiffness properties (and specifically the CD stiffness) of the Vortigen samples were greater than those of the standard samples.

Key words: physical properties, paper physics, creep, stiffness measurements, image analysis, ultrasonic techniques.

INTRODUCTION

Vortigen technology focuses on improvement of formation in paper products, specifically in high basis-weight (mass per unit area) papers used for paperboard making. The mechanism of formation improvement using the Vortigen technology is described elsewhere [1], and is based on modification of the conventional head-box tubes by replacing them with a specific tube design that produces multidirectional flow of fiber suspension due to the effect of turbulent forces which have components in all three directions (MD, CD, and ZD being along out of plane direction). This technique results in a relatively uniform orientation distribution of fibers, thus, an isotropic sheet [2]. It has been reported that as a result of this improvement, many of the physical and mechanical properties of a sheet are improved. If this is the case, a significant economic advantage (e.g., saving in product cost per unit of strength) in paperboard products is anticipated. The head-box of a conventional paper machine is composed of straight tubes that produce a unidirectional stock flow (mixture of water, fibers, and chemical additives) pattern and result in a preferential orientation of fibers along the machine direction (MD). Aidun [1] has demonstrated that streaks on the forming table in a conventional paper machine which are caused by nonuniform secondary flows in the head-box as well as fluid dynamics of the free surface flow on the forming table are responsible for development of certain type of small-scale non-uniformities in basis weight, moisture, and stiffness properties. This study was conducted to characterize mechanical and physical properties of the sheets made by the Vortigen technology and compare them with those made by the conventional methods of papermaking (using a conventional head-box).

MATERIALS AND METHODS

Fully restrained dried samples were obtained from Vortigen and Standard sheets produced on a pilot machine operating at a speed of 573 m/min. After conditioning, physical and mechanical properties corresponding to four samples (two circular and two rectangular sheets) from each paper type were measured and analyzed. The mean basis weight and mean density for Vortigen and standard samples were 107 g/m^2 and 109 g/m^2; and 0.83 g/cm^3 and 0.79 g/cm^3, respectively. The following equations were used to calculate the distribution of basis weight using a formation tester based on beta particle counts:

$$w = w_{avg} \frac{\ln\ (\beta_i / \beta_{air})}{\text{avg}\,[\ln\ (\beta_i / \beta_{air})]} \tag{1}$$

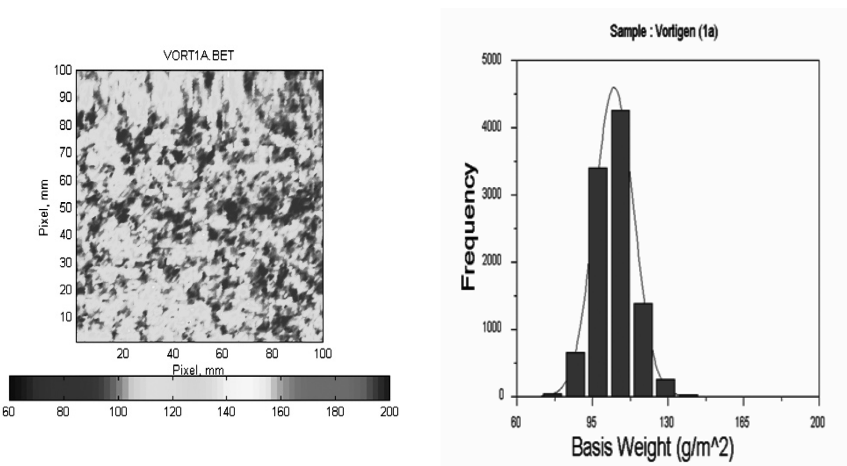
where

$$\text{avg}\,[\ln\ (\beta_i / \beta_{air})] = \frac{\sum_{i=1}^{n} [\ln\ [\ (\beta_i / \beta_{air})]}{\text{n}} \tag{2}$$

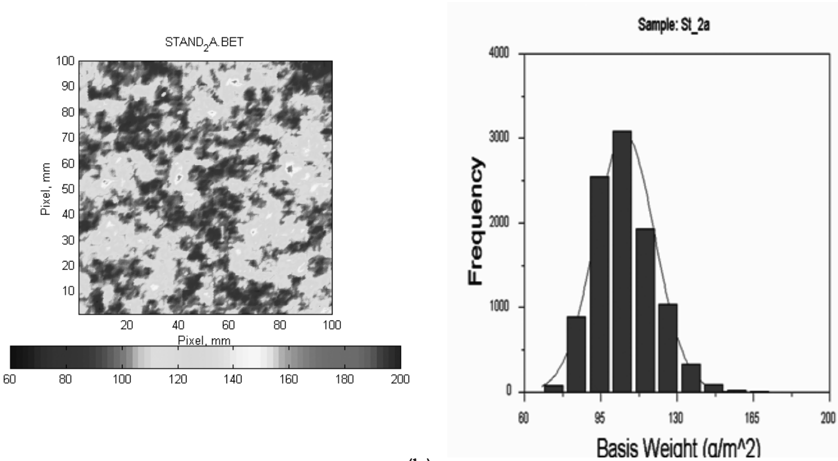
In the above equations w_{avg} is the average basis weight, β_i and β_{air} are beta counts at a point on a paper sample and that corresponding to air respectively, n is number of points on the sample at which beta counts were obtained. A computer program in MATLAB was developed that reads the matrix of beta counts created by the formation tester and applies equation (1) to generate a two-dimensional color image and a histogram corresponding to the distribution of basis weight. Stiffness properties were measured using ultrasonic technique. Creep and accelerated creep were determined at a constant relative humidity (RH) of 80% and a cyclic RH between 30% and 80% for strips cut along the MD and CD directions of each sheet according to methods described in previous studies [3-6].

RESULTS

Shown in Figure 1 are the results of formation measurement performed using a beta particle absorption technique (distribution of w in equation 1) for a sheet of paperboard made by the Vortigen technology and a standard sheet with approximately the same value of average basis weight.



(a)



(b)

Figure 1. Comparison between images obtained from mass formation measurement for a Vortigen sheet (a) and a standard sample (b).

Note that the Vortigen sheet has a narrower band that the standard sheet. The mean coefficient of variation in basis weight for all Vortigen samples was 8.97 while that for the standard samples was 12.60. Shown in Figures 2 and 3 are the mean values of elastic stiffness ratio and geometric mean of in-plane elastic stiffness for Vortigen and standard sheets, respectively. Figure 2 shows that the Vortigen samples had similar elastic stiffness along the in-plane directions.

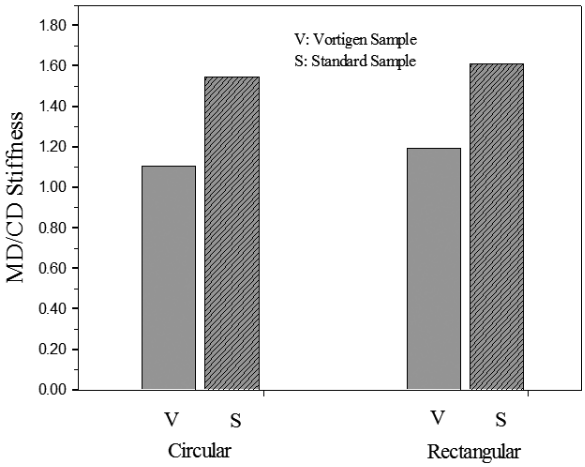


Figure 2. Mean stiffness ratio for circular and rectangular sheets corresponding to the Vortigen and standard samples.

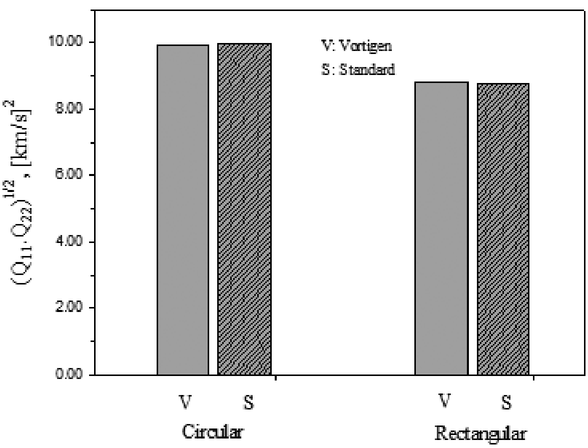


Figure 3. Geometric mean of in-plane elastic stiffness for circular and rectangular sheets corresponding to Vortigen and standard samples.

A tensile creep test was conducted for MD and CD samples for both sheets subjected to a constant relative humidity (RH) of 80% then followed by a cyclic RH between 80 and 30% RH. All tests were carried out at the same load level. The results, shown in Figure 4 indicates that the smallest and the largest creep values corresponds to the MD standard and the CD standard, respectively. The creep values of Vortigen sheets measured along the CD and MD directions were between the two extreme values corresponding to the standard samples. Interestingly, the geometric mean creep response (Figure 5) for both sample types are the same in both the constant and cyclic regimes.

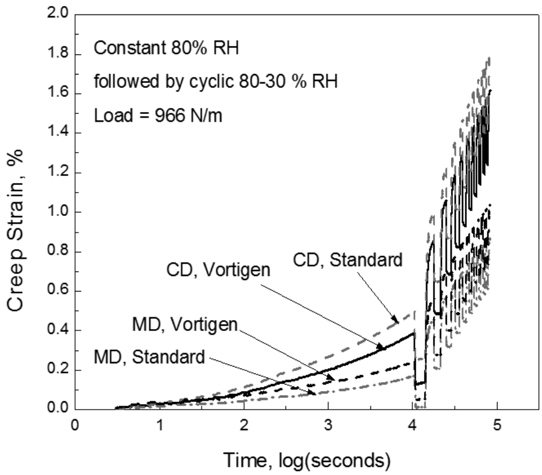


Figure 4. MD and CD creep curves for Vortigen and standard sheets.

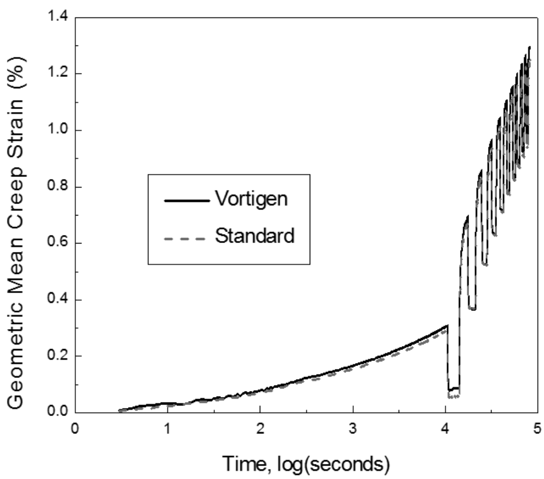


Figure 5. Geometric Mean Creep response for Vortigen and standard sheets.

CONCLUDING REMARKS

1. In paper making process using a conventional head-box, the hydrodynamic forces involved in the forming process tend to orient the fibers along the machine direction (MD). In a head-box retrofitted with the Vortigen system, the flow characteristics in the forming process are modified to create shear in the mean flow and turbulent fluctuations along the cross machine (CD) and out of plane (ZD) directions to improve fiber dispersion and to control fiber orientation. This creates a sheet with more isotropic fiber orientation, superior formation, and consequently higher strength properties along in-plane cross-machine direction.

2. The results show that compared to a standard forming system, a sheet with the same basis weight produced with the Vortigen system has a higher number of fibers orientated along the CD direction resulting in both higher CD elastic stiffness and CD creep stiffness. Since the geometric mean stiffness and the geometric mean creep response were equivalent for both sheet types, it appears that the increase in strength along the CD in a Vortigen sheet is obtained by transferring part of the strength from the machine direction to the cross machine direction. However, since paper generally fails at its weakest link, making the sheet more uniform and isotropic would be very beneficial; specifically in linerboards in which a great portion of functional loads are generally exerted along the cross machine (CD) direction.

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