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Original Article

Analysis of cracking potential and micro-elongation of linerboard

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ABSTRACT

Folding cracks of linerboards in relation to their micro-elongation and the forming conditions were studied using an industrial linerboard machine with a top former. The experiments consisted of the study of various forming conditions by manipulating the jet/wire speed ratio to produce linerboard with differences in fiber structures that were related to the cracked and uncracked products. The results showed that changes to the jet/wire speed ratio of about 0.01–0.02 to improve the tested folding endurance in the machine direction potentially produced folding cracks in the linerboard, which indicated an ambiguous interpretation of the foldability tests. The delaminated cracked layers were found to have a high folding endurance and tensile strength, while the decrease in the micro-elongation formulated in this study was found to be related to cracking. A lower micro-elongation of about 350–500 μm/N·g was found in a range of products with folding cracks.

Introduction

Cracking of corrugated containers under the folding process is a crucial problem producing defect products and reducing the production capacity of the converting process, as the folding cracks result from an inappropriate creasing condition, a low moisture content of the folded sheets (Whitsitt and Mckee, 1966; Whitsitt, 1974; Hartikainen, 1998; Gooren, 2006) and an inferior strength of linerboards (Mcgrattan, 1990).

In Asia, testliner is a major grade of linerboard produced from recycled fibers (Kaviranta, 2000). These fibers have a large variation in quality and cause instability in the board-making processes and consequently produce inferior products with the folding crack problem. The folding cracks regularly occur crossing the fiber orientation because this direction has a lower elongation under the tensile forces (Niskanen et al.,1998; Fellers, 2009). It has been reported that the folding cracks can be minimized by optimization of the linerboard-forming conditions to manipulate the fiber structures (Odell, 2001). However, the linerboards consist of various layers formed by the separate forming sections and various types of fiber sources (Kaviranta, 2000). The oriented fibers are also affected by many variables including the slice opening of the headbox, the stock consistency, the dewatering pressure and the velocity of the jet-to-wire speed (Baum, 1991; Nordström and Norman, 1994; Ullmar and Norman, 1997; Shakespeare, 1998; Gigac and Fiśerová, 2009). These make it difficult to maintain the quality of each layer in the linerboard structure, and potentially produce inferior foldability products. Industrially, the foldability of a linerboard is determined using laboratory folding tests. However, corrugated containers produced using linerboard with high folding endurance and strength properties still have cracking problems in the folding process.

In order to reduce the severe folding cracks on the linerboards, this study was setup to establish the correct properties to use in the determination of foldability in linerboards, and to examine the cracking potential in the forming operations by manipulating the jet/wire speed ratio to produce linerboard with different fiber structures and to relate these to the cracked and uncracked products. The relationship between the cracking regions and the forming conditions was used to confine the former operating window in order to avoid operations beyond the cracking zones.

Materials and methods

The experiment consisted of two parts. First, the sources of folding cracks were analyzed using industrial linerboard products. The second part of the study involved using the linerboard machine to produce linerboard samples with various structures and fiber orientations. The cracking potential of the trial linerboards under the former operating conditions were determined and related to their micro-elongation as formulated in this study.

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Analysis of cracked linerboard products

Industrial linerboards including the claimed and unclaimed products with a basis weight of 125–185 g/m^2 were sampled. The cracking line was observed using a stereo microscope and a scanning electron microscope. The top layers of samples were delaminated and analyzed to investigate the correlation between their mechanical properties and the cracking. The tensile strength was tested according to the ISO 1924-2 standard method (International Organization for Standardization, 2011). The folding endurance was determined according to the ISO 5626 standard method (International Organization for Standardization, 2011).

Analysis of cracking potential in paperboard machine operations

The production of linerboards was carried out using a four-ply Fourdrinier machine at Thaicane Paper PLC, Thailand. The top ply, which is a cracking layer, was produced with various structures while the other layers were kept constant. The major stock component of the top ply consisted of unbleached softwood kraft pulp and bleached hardwood kraft pulp having a freeness of 350 mL. The other layers were made from old corrugated container pulp. The linerboards were produced at a basis weight of 125 g/m^2 with the top ply having a basis weight of 40 g/m^2. The stock consistency was controlled at 0.3% with a headbox slice opening of 15 mm. The wire speed was operated at 625 m/min. The jet velocity was controlled in the range 563–656 m/min (jet/wire ratio 0.90–1.05) producing a top layer with various structures and fiber orientations. The dewatering pressure, pressing conditions and drying conditions were kept constant. The tested samples including the delaminated top ply and the whole sheet were analyzed. The tensile strength was determined according to the ISO 1924-2 standard method (International Organization for Standardization, 2011), and the folding endurance was determined according to the ISO 5626 standard method (International Organization for Standardization, 2011). The cracking potential under the operating conditions of the former was analyzed using the micro-elongation which was formulated in this study.

Results and discussion

Cracked product analysis

Cracking of the corrugated container samples was found during the folding process. The folding crack occurred on the top-ply of the linerboard crossing the machine direction (MD) where the fiber was oriented in this direction, as shown in Fig. 1. Microscopic examination of the cracking line showed that the fibers were broken without any loosening of their network indicating a sufficient bonding strength.

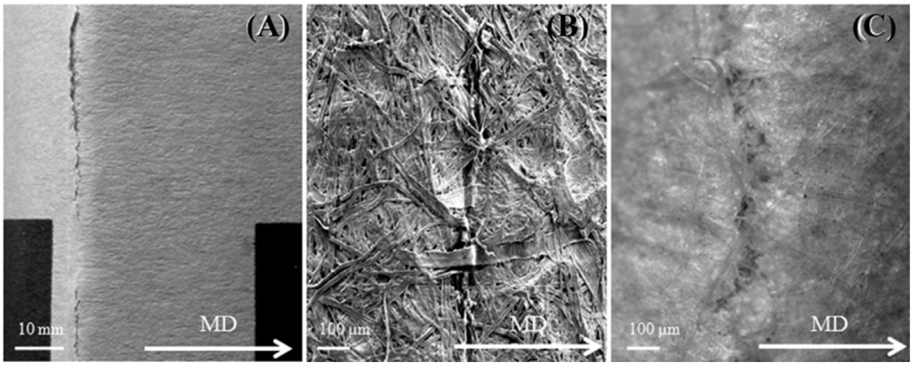

Fig. 1. Cracked product features (A) having a cracking line along the folding direction (B). The folding crack occurred on the weaken fibers and the top layer (C) of linerboard (MD = Machine direction).

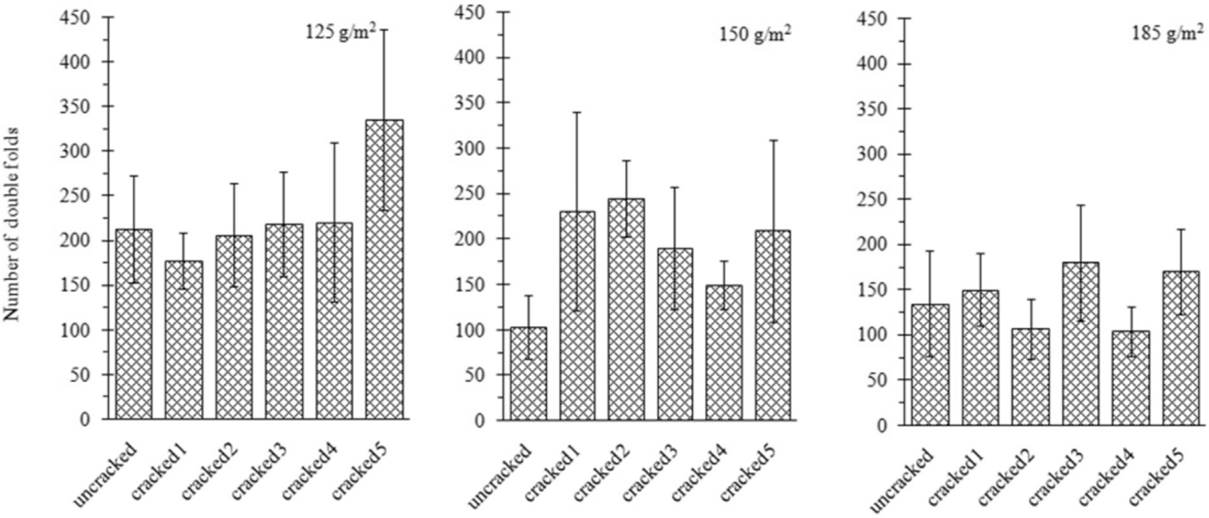

Fig. 2. Number of double folds of cracked and uncracked linerboard products tested in machine direction. Error bars indicate ± SD.

Examination of the mechanical properties of the linerboards found no distinct differences between the uncracked and cracked linerboards in folding endurance and tensile strength, as shown in Figs. 2–4. These results were not useful for the interpretation of the paper structure in relation to its mechanical properties.

Deeper analysis was carried out using delaminated top ply where the cracking was located. The results showed that the MD tensile strength of the top ply was higher, whereas the unclaimed linerboards had a lower strength. The MD/cross machine direction (CD) tensile ratio of the uncracked linerboards was in the range 1.5–1.6, while the same ratio of cracked products was in the range 1.8–2.4, as shown in Fig. 5.

In summary, product analysis found that the folding cracks of linerboards under the converting process resulted from the paper

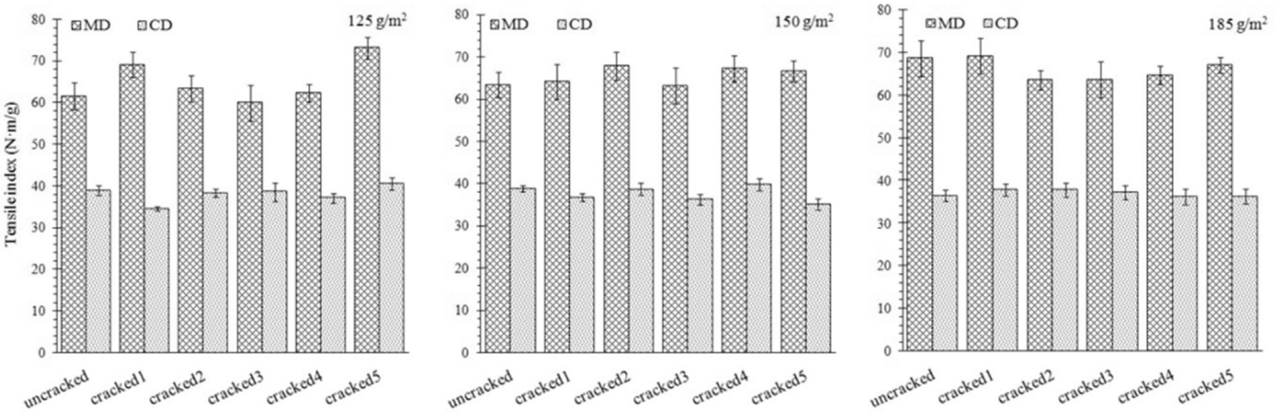

Fig. 3. Tensile strength of cracked and uncracked linerboard products. Error bars indicate ± SD (MD = machine direction; CD = cross machine direction).

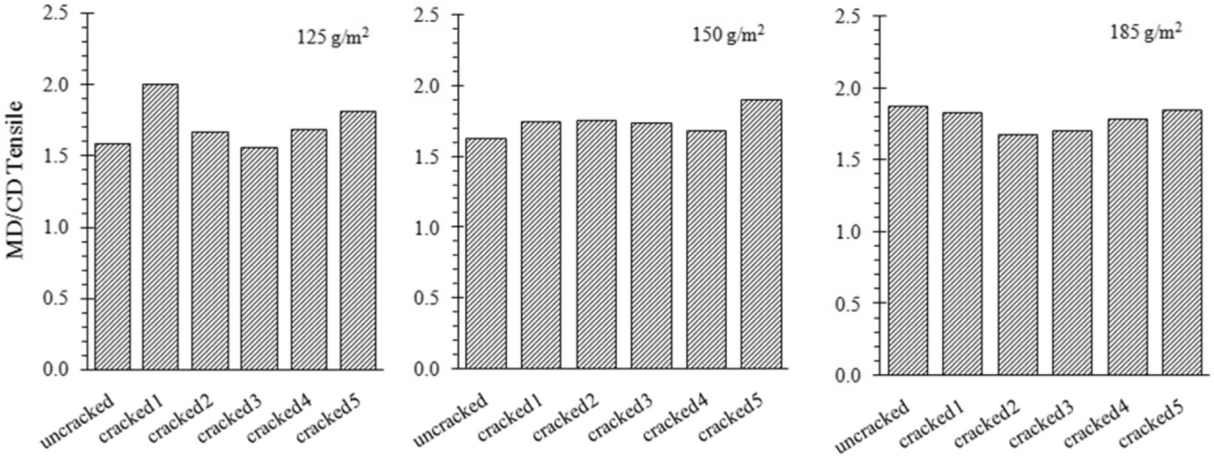

Fig. 4. Whole sheet MD/CD tensile ratio of cracked and uncracked linerboards (MD = machine direction; CD = cross machine direction).

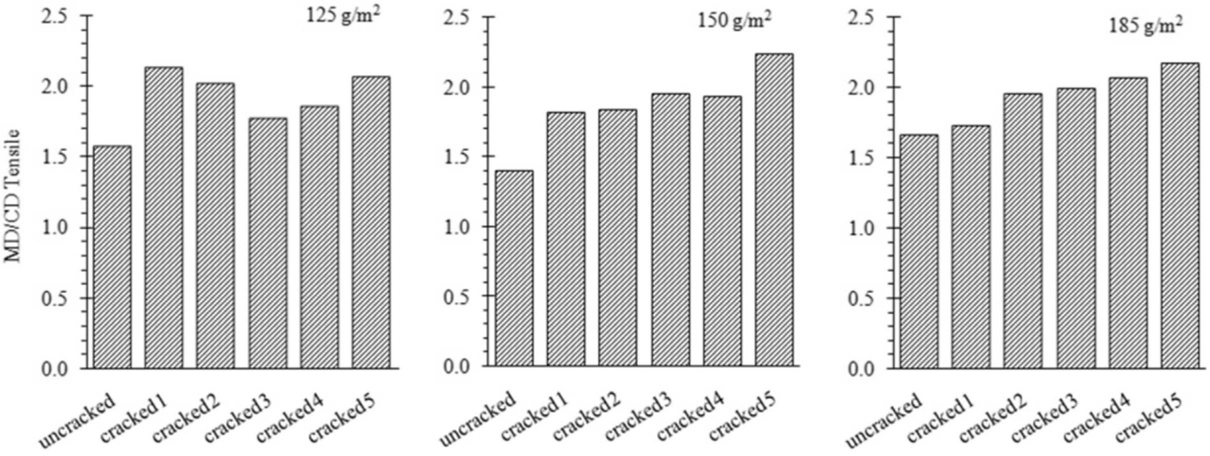

Fig. 5. Top ply MD/CD tensile ratio of cracked and uncracked linerboards (MD = machine direction; CD = cross machine direction).

properties which were related to the quality control and papermaking processes. The linerboard properties of high folding endurance with a strong tensile strength in the machine direction tested in the laboratory were found to produce folding cracks crossing the fiber orientation. More detailed analysis was required to specify the cracking layer to prevent interaction with other layers which caused the ambiguous test results (Figs. 2–4). The results showed clearly that these claimed products had an MD/CD tensile ratio of the cracking layer higher than 1.75–3.0 which indicated instability of the paper machine operation.

Cracking potential in paperboard machine operations

Four-ply linerboards with a basis weight of 125 g/m^2 were produced with a top ply basis weight of 40 g/m^2. The top ply was engineered to the various fiber orientations indicated by the MD/CD tensile ratio. The mill trials were performed at a jet/wire ratio ranging from 0.90 to 1.05 which produced the different structures of the fiber network having an MD/CD tensile ratio in the range 1.5–3.0 which was related to the cracked and uncracked products, as shown in Fig. 6.

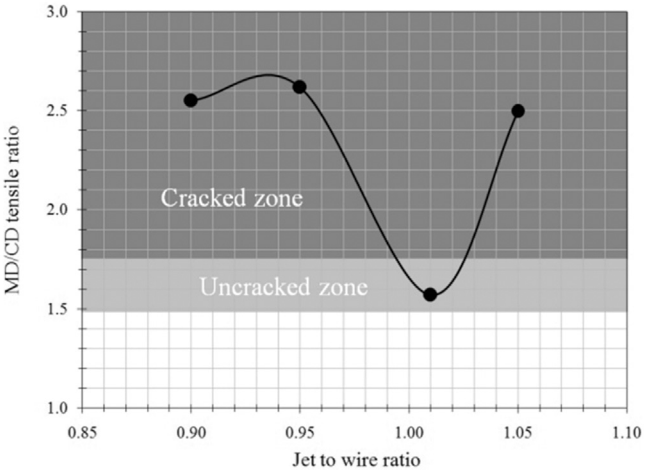

Fig. 6. MC/CD tensile ratio of the top ply of linerboard as a function of the manipulated jet to wire ratio related to the cracked product zones (MD = machine direction; CD = cross machine direction).

Fig. 7 shows the mill operation setup to maintain the required MD folding endurances by the manipulation of the jet/wire speed ratio of the top-ply former. Increasing the speed differences between the jet and wire increased the fiber orientation which resulted in an improvement in the MD tensile strength and consequently enhanced the folding endurance. However, increasing the folding endurance through manipulating the jet/wire ratio by about 0.02 from the minimum fiber orientation potentially produced linerboard in the cracking zone, as shown in Fig. 6.

Fig. 8 shows a comparison of the elongation values in various structures of linerboard obtained from the standard tensile test and that calculated based on Equation (1):

$$l_\mu = \frac{L}{F \cdot A \cdot W} \qquad (1)$$

where l_μ is the micro-elongation (μm/N·g), L is the stretch at break (μm), F is the breaking force (N), A is the area of specimen (m^2), and W is the basis weight (g/m^2).

At various MD/CD tensile ratios of 1.5–3.0 (Fig. 8), the elongation obtained from the standard test was 2.4–2.7% with no distinct differences. This might result in the wrong interpretation with regard to the cracking problem.

However, the current study hypothesized that the elongation would occur at the micro level, which could not be determined by normal testing. Therefore, micro-elongation of the linerboard was formulated according to Equation (1).

The results showed clearly that changing the fiber orientation from the minimum point to maximum orientation (corresponding to changing the MD/CD tensile ratio from 1.5 to 3.0) reduced the elongation of the top ply from 700 to 350 μm/N·g. Where the elongation was lower than 500 μm/N·g, the linerboard was in the cracking zone, which indicated that these products might crack in the folding process, as shown in Fig. 9.

The cracking potential analysis under the former operations showed that the machine was very sensitive to the manipulated jet/wire ratio (Fig. 6). Speed differences between the jet and wire of about 15–20 m/min (a jet/wire ratio of 0.02) from the normal operation potentially produced linerboard cracking. The study found that when the pulp quality fluctuated, the required mechanical properties of linerboard were maintained by manipulating the jet/wire ratio of the top ply. The results showed an improvement in the tested MD folding endurance by increasing the jet/wire

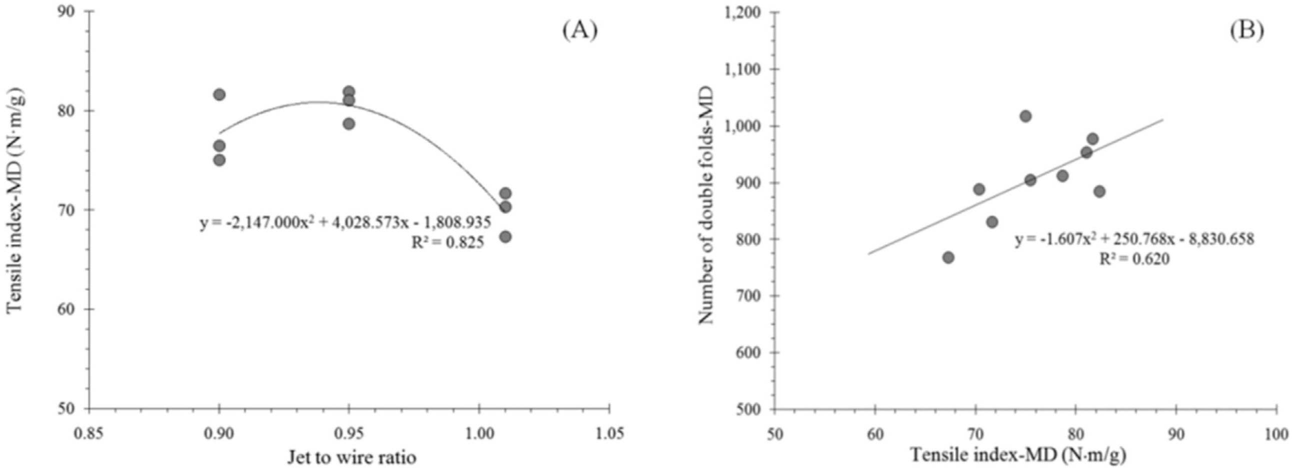

Fig. 7. MD-Tensile strength of top ply as a plotted line for the function of the manipulated jet to wire ratio (A) and number of double folds as a function of the tensile strength of the linerboard (B) (MD = machine direction; CD = cross machine direction; R^2 = proportion of variability in the data).

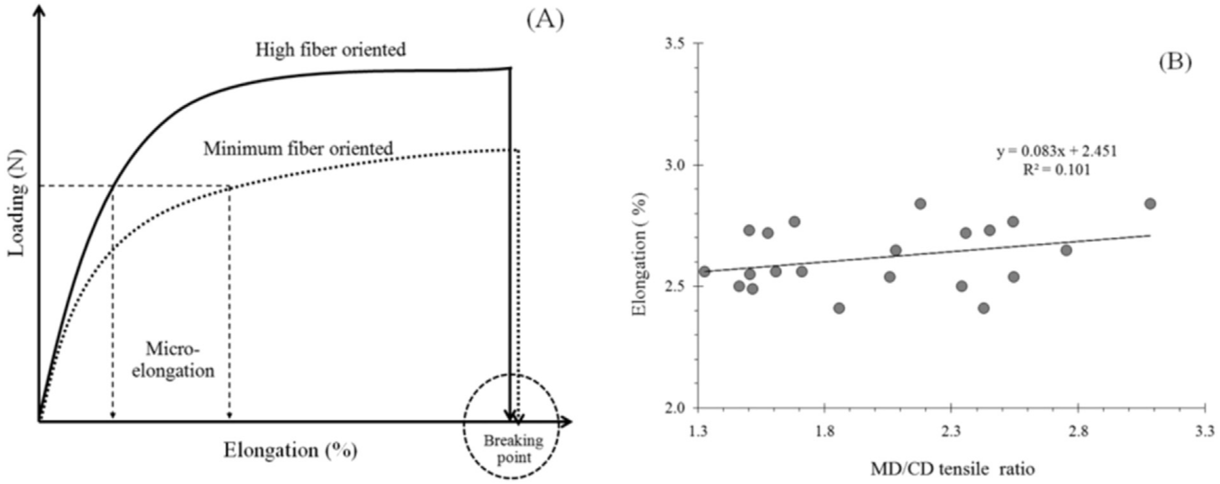

Fig. 8. Stress–strain curve obtained from tensile testing (A) and elongation of linerboard obtained from the standard tensile test as a plotted line for the function of the tensile MD/CD ratio (B) (MD = machine direction; CD = cross machine direction; R^2 = proportion of variability in the data).

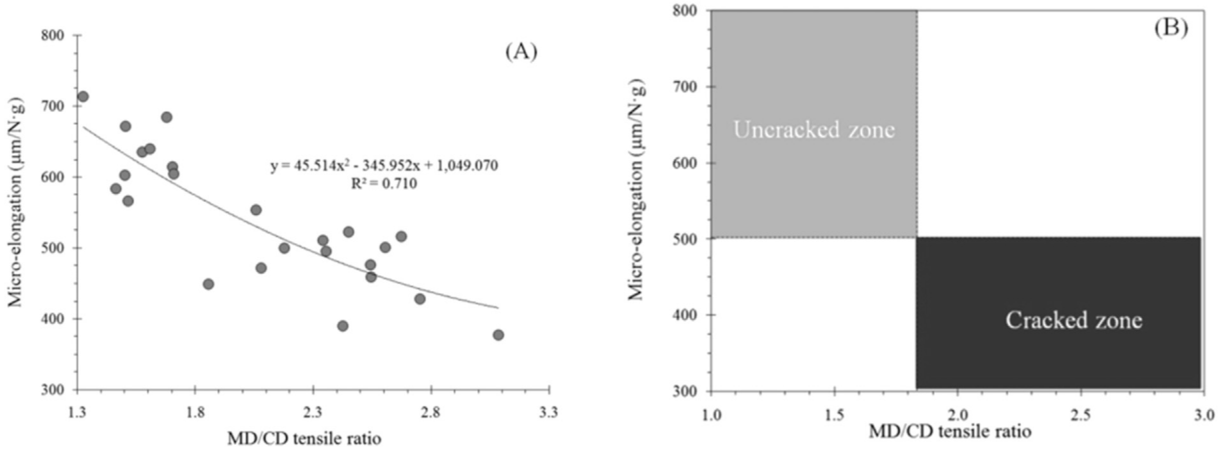

Fig. 9. Micro-elongation of top-ply linerboards obtained from Equation (1) as a plotted line for the function of MD/CD tensile ratio (A) and the classification on the uncracked and cracked zones based on the micro-elongation values (B) (MD = Machine direction; CD = Cross machine direction; R^2 = proportion of variability in the data).

speed ratio by about 0.01–0.02 could maintain this required property, but it reduced the elongation of the products.

The investigation of the elongation of various linerboard structures produced within the operating window of the former was not possible using the standard tensile test. Thus, a new formulation was proposed to determine the micro-elongation of linerboard based on Equation (1) which represented the amount of strain of the linerboard at a micro level at a given tensile force (Fig. 9). It was found that reducing the jet/wire ratio from 1.00 to 0.90 substantially reduced the micro-elongation of the linerboard from 700 to 350 µm/N·g where an elongation lower than 500 µm/N·g had the potential to crack in the folding process.

The study showed clearly that superior foldability of linerboards could be obtained by increasing the elongation with optimum tensile strength and folding endurance. Linerboard having high strength properties with a lower elongation especially in the fiber-oriented direction had the potential to crack in the folding process.

In conclusion, analysis of folding cracks found that they occurred in the top ply of linerboards and crossed the fiber orientation where the former was sensitive to the manipulated jet/wire speed ratio. Changes in the jet/wire speed ratio of 0.01–0.02 potentially produced folding crack products. The delaminated cracked layers were found to have a high folding endurance and tensile strength, while the micro-elongation was found to be decreased related to the paper structure. A lower micro-elongation of about 350–500 µm/N·g resulted in cracking products. Linerboards with superior foldability had a high elongation with optimum strength properties. The obtained results could be applied for the evaluation of linerboard foldability and in the control of former operations under optimum conditions.

Conflict of interest

There is no conflict of interest.

Acknowledgments

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