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Polylactic Acid Coating Affects the Ring Crush Strength of Linerboards

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ABSTRACT

Paperboards used for linerboard of corrugated fiberboard box were coated with different concentrations of polylactic acid (PLA) solution and the effects of harsh environmental conditions such as high humidity and temperature (96% RH at 30℃ for up to 5 days), and freeze-thaw (-20℃ for a day and then thaw at room temperature for 30 min) conditions on the ring crush (RC) strength of the boards were investigated. One to five percent PLA solutions were coated onto SC manila linerboard (20 × 27 cm) using a No. 20 wire bar coater and the ring crush strength was measured using a computer-controlled Advanced Universal Testing System in accordance with TAPPI Test Method T 822 om-93. The RC strength increased significantly when the concentration of coating solution increased and appreciable changes were found when the concentration increased from 0 to 2% ($P<0.05$). Similar pattern of results was found after 5-day storage at 30℃ and 96% RH. Although such highly humid condition increased moisture content in the samples up to 3.95 from 0.97 times, the RC strength decreased in the range from 29.9 to 48.5%. The freeze-thaw treatment increased the moisture content only up to 1.27% and the reduction in the RC strength ranged from 21.1 to 28.1%. The results were promising: the samples coated with 5% PLA solution showed 29.9% reduction in the RC strength while that of control was 48.5% during highly humid condition stated above.

Keywords : linerboards, polylactic acid (PLA), ring crush strength, environment

1. Introduction

Corrugated fiberboard boxes provide a versatile and economical means to package food and nonfood materials for shipping and handling. Its application covers a wide range of usages and it represents more than 80% of the volume of all paper-based packaging materials in the world (1). Although the corrugated fiberboard is the most highly recyclable due to its composition of cellulose (2) and has an environmentally-friendly nature, the hydrophilic

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nature of cellulose results in less moisture resistant packaging material.

Currently most of agricultural produce are distributed using corrugated fiberboard boxes which are prone to absorb moisture from the environment. The boxes can absorb considerable amount of moisture especially under high humidity conditions and this leads to reduction in the physical and mechanical strength of paperboards. In order to avoid such possible corruption of boxes during storage and distribution, surface treatments such as sizing and coating can be applied (2).

Although a number of investigations were conducted to improve lipid barrier properties of paper (3-6), studies to improve water barrier properties of paper packaging materials are still limited. Generally, paper is coated with hydrophobic materials such as polyethylene (PE) or wax to increase the water resistance. However, such coating materials prohibit recycling of the coated paper after use due to their non-biodegradability or difficulty in separation from the base paper. Therefore, coating papers with biodegradable natural biopolymers such as alginate (2), soy protein (2, 4), corn zein (3), whey protein (5), and carrageenan (7) have been suggested for the purpose, but on the whole, their effects have been known to be very marginal due to their hydrophilic nature. This led to more effective study on paper coating material to increase the water resistance without sacrificing mechanical strength of paperboards.

One of the most promising polymers for such a purpose is poly(lactide) (PLA) because it is thermoplastic, biodegradable, and biocompatible and has high strength, high modulus, and good runnability (8, 9). PLA is synthesized from lactic acid, which is derived from renewable resources, such as corn or sugar beets (8). In addition to its environmentally-friendly nature, PLA can also be used for food contact surfaces and generally recognized as safe (GRAS). In addition, because the production cost has been lowered by new technology and large-scale production, the application of PLA has been extended to commodity areas such as packaging, textiles, and composite materials (9).

The main objective of this study was to test the effect of PLA coating on the ring crush strength of linerboard, being used as a linerboard of corrugated fiberboard boxes for food packaging, exposed to harsh environmental conditions such as high humidity and low temperature.

2. Experimental

2.1 Materials

SC manila linerboard (SK180, basis weight: 180 g/m^2) was obtained from Kyungnam Paper Manufacturing, Co., Ltd. (Yongin, Korea). Poly-L-lactide (PLA, Biomer® L9000) was obtained from Biomer Inc. (Krailling, Germany). PLA resins were dried in a vacuum oven at 60°C for 24 hr before use. Reagents used were of analytical grade.

2.2 Paper coating

Linerboard was coated with PLA coating solution according to the method established by Rhim et al. (10). The PLA coating solution was prepared by dissolving PLA resin into chloroform: One to five grams of PLA resin was added to a constantly stirred 100 mL of chloroform. The PLA was dissolved by constant stirring using a magnetic stirrer until completely dissolved and clear for 2-5 hrs. Coating solutions prepared were then applied onto SC manila linerboard (20 × 27 cm), which was previously conditioned at 23°C, 11% RH for 2 hr and then at 23°C, 50% RH for 24 hr according to TAPPI method T402, using a No. 20 wire bar coater (SA-203 Wire Bar Coaters, Donghak Machine Co., Ltd., Korea).

Linerboard was mounted on a flat glass plate by applying masking tape around the paper edges to prevent wrinkling of paper during coating. A spoonful of each coating solution was loaded on the prepared paper and spread over the paper using a No. 20 wire bar coater. The coated linerboards were dried under ambient conditions for 24 hr.

2.3 Moisture content measurement

Moisture content of test samples was measured using the oven drying method (105℃ for 24 hr).

2.4 Ring crush test

All paper samples were cut into strips (12 mm × 153 mm) using a ring crush cutter. Samples were then divided into two groups; one stored at -20℃ for a day and thawed at room temperature for 30 min and the other stored at 30℃ and 96% RH for 5 days prior to the tests. Each strip of samples was placed in the crush tester and the ring crush strength was measured using a computer-controlled Advanced Universal Testing System (model LRXPlus, Lloyd Instrument Limited, Fareham, Hampshire, UK) at room temperature in accordance with TAPPI Test Method T 822 om-93. A 500-Newton (N) load cell was used, with the crosshead speed of 50 mm/min. At least ten specimens for each paper sample were tested, and their mean values were reported.

2.5 Statistical analysis

Statistics on a completely randomized design were determined using the General Linear Models procedure using the Statistical Analysis System (SAS Inst. Inc., Cary, NC, USA). Mean property values were separated ($P<0.05$) with the Duncan's multiple range test.

3. Results and Discussion

3.1 Effect of PLA concentration

Usually ring crush test is used as the standard test for the linerboards of corrugated fiberboard boxes to predict the stacking strength of those boxes. Studies indicate that the test serves as a better predictor of final board and box performance as compared with the short span compressive test.

Figure 1 presents the effects of PLA coating and its concentration on the ring crush (RC) strength of the linerboards. The RC strength increased significantly ($P<0.05$) by coating with PLA. The extent of increase in the RC strength of the linerboard was varied depending on the concentration of PLA coating solutions, which increased 1.5~1.9 times compared with uncoated control linerboard. The RC strength of the

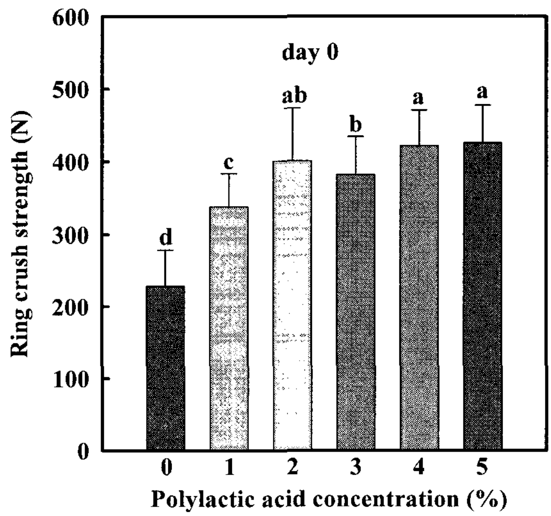

Fig. 1. Effect of PLA coating on the ring crush strength of linerboards. Means (±standard deviations) with different letters are significantly different according to Duncan's multiple range test ($P<0.05$).

linerboard increased significantly by coating with low level of PLA concentration of 1 or 2%. However, further increase in the concentration up to 4 or 5% did not show any further increase in the RC strength. This result indicates that 2% coating solution is the optimum concentration for the coating of the linerboard to increase in the RC strength. Such increase in the RC strength of the linerboard by PLA may be caused by the increase in the stiffness of the linerboard through PLA coating. Coating with PLA increased the thickness and coating weight of linerboards as the concentration of PLA-coating solution increased. Interestingly, the coating thickness and coating weight of the sample increased linearly with the increase in the PLA concentration except for 4 w/v % coating.

Scanning electron microscopy test (10) of PLA-coated linerboard indicated that the surface smoothness of PLA coated linerboard improved by covering the pores of the cellulose fibers with PLA and Rhim et al. (10) also demonstrated that the thickness of linerboard increased from 2 to 18% through coating with 1 to 5% of PLA coating solution, which might be attributable to the increase in the stiffness of the PLA-coated linerboards.

3.2 Change in moisture content

Figure 2 shows the moisture content of linerboards with or without PLA coating and it also shows the harsh treatments of the linerboards such as storage at high temperature and humidity (30°C, 96% RH) and storage at freezing condition (-20°C). Initially, the moisture content of linerboard seems to be increased by coating with PLA and it increased with the increase in PLA concentration. This seemingly strange result can be explained by the fact the PLA coating film still includes certain amount of chloroform solvent. Rhim et al. (11) demonstrated using differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA) measurement that solvent cast PLA film entrapped up to 13.7% of chloroform solvent in the PLA films prepared with 5% PLA solution.

The abuse conditions of high temperature and humidity and freezing increased the moisture content of the linerboard significantly as shown in Fig. 2. Especially, the high humidity conditions caused the profound increase in the moisture content. Generally, it is well known that exposure

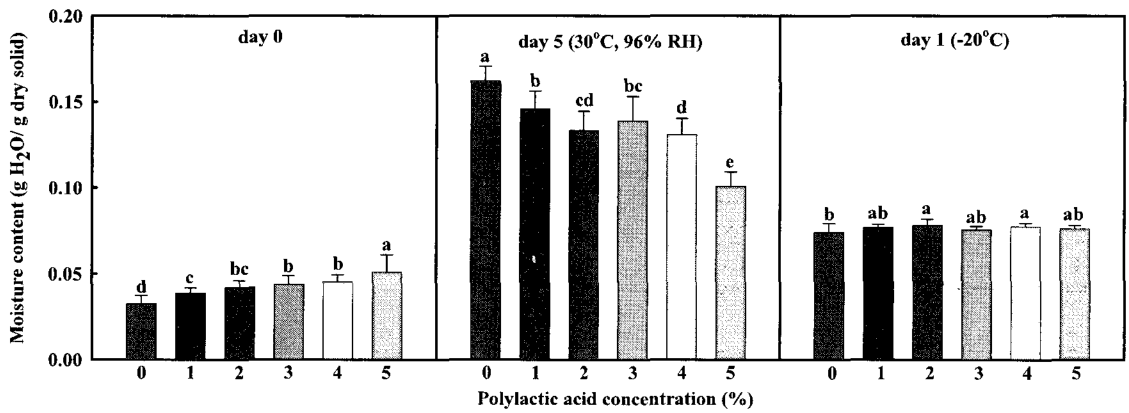

Fig. 2. Comparison of ring crush strength as affected by different treatments. Means (±standard deviations) within the same storage condition with different letters are significantly different according to Duncan's multiple range test ($P<0.05$).

to humidity weakens a corrugated fiberboard box because corrugated board readily absorbs moisture, which tends to reduce its rigidity. It is actually board moisture content which affects strength but moisture content is related to humidity. The greater the humidity, the weaker the box. For corrugated boxes and paper based packaging in general, are known to lose more than 30% of their strength at 95% RH (12). It is interesting to note that the degree of increase in moisture content of the linerboards stored at the abuse conditions of 30℃ and 96% RH for 5 days was reduced by PLA coating. This trend was more pronounced with higher concentration of PLA coating. This is mainly due to the hydrophobic nature of the PLA (8, 9). Freezing the linerboard increased the moisture content of the linerboards regardless of PLA coating or not. In addition, no significant difference in the moisture content was observed between linerboards coated with different amounts of PLA.

3.3 Change in ring crush strength

Figure 3 shows the effect of storage in the same abuse conditions of linerboards coated with or without PLA. As observed in Fig. 1, the initial RC strength of PLA coated linerboards measured at room temperature (20℃) increased significantly compared to that of the uncoated control linerboard (P<0.05). As expected, use of linerboards under the abuse storage conditions reduced the RC strength remarkably. The reduction of RC strength was more pronounced in the samples treated with high temperature and high humidity condition due to higher moisture absorption during storage. On the average, the percent change of the RC strength was 36% and 25% for the samples treated with high temperature and humidity and freeze-thaw, respectively. This indicates that PLA coating did contribute to the increase the RC strength of the linerboards considering the fact that higher MC did not prevent the sample from decreasing in the RC strength. At high temperature and high humidity condition, the samples without PLA- coating absorbed significantly more moisture than the other coated samples (P<0.05). The MC decreased appreciably with the increase in the concentration of PLA, indicating that PLA was more effective to prevent moisture absorption at high humidity conditions. At freezing condition, the MC was less affected by PLA concentration

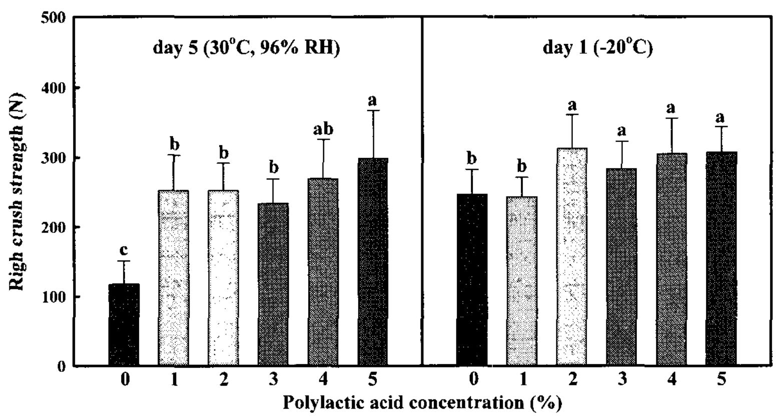

Fig. 3. Effect of harsh environments on the moisture content of PLA-coated linerboards. Means (±standard deviations) within the same storage condition with different letters are significantly different according to Duncan's multiple range test (P<0.05).

(Fig. 2).

It is interesting to note that the PLA-coated linerboard samples stored at 30℃ and 96% RH retained the general characteristics of the initial PLA-coated linerboards even after 5-day storage. In other words, the RC strength increased with the increase in the PLA concentration in general. This is in good agreement with the result of moisture content measurement in Fig. 2.

4. Conclusions

The following conclusions may be drawn from the results:

(1) The mechanical property such as RC strength of linerboards could be modified and improved by surface coating with PLA.

(2) The RC strength increased significantly when the PLA concentration increased and the PLA coating was effective to prevent moisture absorption even at very humid conditions.

(3) The improved RC strength of the linerboards can be exploited in the preparation of water resistant corrugated fiberboard boxes for the storage and distribution of high moisture foods such as fresh agricultural products.

Acknowledgements

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Literature Cited

1. Twede, D. and Selke S. E. M., Corrugated fiberboard structure and properties, in "Cartons, Crates and Corrugated Board", DEStech Pub. Inc., pp. 401-431 (2005).
2. Rhim, J. W., Lee, J. H. and Hong, S. I., Water resistance and mechanical properties of biopolymer (alginate and soy protein) coated paperboards, Lebensm.-Wiss. u.-Technol. 39:806-813 (2006).
3. Trezza, T. A. and Vergano, P. J., Grease resistance of corn zein coated paper, J. Food Sci. 59:912-915 (1994).
4. Park, H. J., Kim, S. H., Lim, S. T., Shin, D. H., Choi, S. Y. and Hwang, K. T., Grease resistance and mechanical properties of isolated soy protein-coated paper, J. Am. Oil Chem. Soc. 77:269-273 (2000).
5. Han, J. H. and Krochta, J. M., Physical properties and oil absorption of whey-protein-coated paper, J. Food Sci. 66:294-299 (2001).
6. Lin, S. Y. and Krochta, J. M., Plasticizer effect on grease barrier and color properties of whey-protein coatings on paperboard, J. Food Sci. 68:229-233 (2003).
7. Rhim, J. W., Hwang, K. T., Park, H. J., Kang, S. K. and Jung S. T., Lipid penetration characteristics of carrageenan-baed edible films, Korean J. Food Sci. Technol. 30:379-384 (1998).
8. Garlotta, D. A., Literature review of poly(lactide), J. Polym. Environ. 9:63-84 (2001).
9. Drumright, R. E., Gruber, P. R. and Henton, D. E., Polylactic acid technology, Adv. Mater. 12:1841-1846 (2000).
10. Rhim, J. W., Lee, J. H. and Hong, S. I., Increase in water resistance of paperboard by coating with poly(lactide), Pack. Technol. Sci. (Submitted for publication) (2006).
11. Rhim, J. W., Mohanty, A. K., Singh, S. H., and Ng, P. K. W., Effect of the processing methods on the performance of polylactide films: Thermocompression versus solvent casting. J. Appl. Polym. Sci. 101: 3736-3742 (2006).
12. McKinlay, A. H., Corrugated boxes, in "Transport Packaging", 2nd ed. pp. 59-85, Institute of Packaging Technologists, Naperville, IL., USA (2004).