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Lab-based Simulation of Carton Clamp Truck Handling - Frictional Characteristics between Corrugated Packages

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Abstract Carton clamps, one of forklift attachments, allow users to quickly handle shipping units such as unitized loads, large shipping cases, or crates without the requirement of pallets. As the use of palletless handling by clamp trucks increases, so does the need for simulation research on clamp truck handling. The frictional characteristics for various contact conditions of corrugated paperboards and their constituent boards were analyzed to obtain the data needed in the computer simulation for the handling of carton clamp truck. The overall mean of static-frictional coefficients between selected corrugated paperboards was 0.38 (±0.01), which was 1.3~1.6 times greater than 0.23~0.29 of the frictional coefficients between boards. The overall mean of static-frictional coefficients between the corrugated paperboards and the rubber contact pad was 0.82 (±0.02), which was about 1.1 to 2.8 times greater than 0.29~0.78 of the static-frictional coefficient between the linerboard and the rubber contact pad. The overall mean of kinetic-frictional coefficients between the corrugated paperboards was 0.35 (±0.01), and 0.76 (±0.02) between the corrugated paperboards and the rubber contact pad.

Keywords Corrugated paperboard, Carton clamp truck, Static-frictional coefficient, Frictional test, Dynamic-frictional coefficient, Frictional force-distance curve

Introduction

As environmental problems due to depletion of forest resources are on the rise, interest in reducing pallet usage or palletless handling has been increasing in all industries. Plastic and steel pallets are used as substitutes for wood pallets, but these pallets have a higher production cost than wood pallets, and have a large management cost.

Forklift truck, a typical handling machine, is suitable for handling of pallet-based freight, while a carton clamp truck is a machine that can handle freight without using pallets. This carton clamp trucks are highly efficient when used in conjunction with other handling machines, such as push/pull with slipsheets, and they can increase the space efficiency and reduce the management cost of the whole freight when applied in factories or warehouses[1)].

As the palletless handling by carton clamp truck has been gradually extended to various industries, the necessity of computer simulation for optimizing the clamping pressure is increasing as well. The biggest factor in determining this clamping pressure is the friction between the freight and the arm of carton clamp truck[2,3)].

The carton clamp truck is mainly intended for corrugated packaged freights. Therefore, in order to simulate the handling of the carton clamp truck, it is necessary to evaluate the frictional characteristics at the various contact conditions of the corrugated package during the handling. In addition, in order to improve the finite element analysis (FEA) efficiency, it is important to obtain the data on the frictional characteristics between the constituent boards of corrugated paperboard.

The corrugated paperboard, as shown in Fig. 1, has different mechanical properties in the machine direction (MD) (x) and cross-machine direction CD (y) in-plane and the thickness direction (z) in the out-of-plane due to the shape of the flute, The corrugated paperboard components (linerboard, corrugated medium) have orthotropic characteristics, because the paper fibres are oriented in the MD when the paper sheets are formed.

This study aims to analyze the frictional characteristics for various contact conditions of corrugated paperboards and their constituent boards in order to obtain the data for computer simulation for the handling of carton clamp truck. More specific goals are as follows.

(1) to analyze the static- and dynamic-frictional coefficients between corrugated packages

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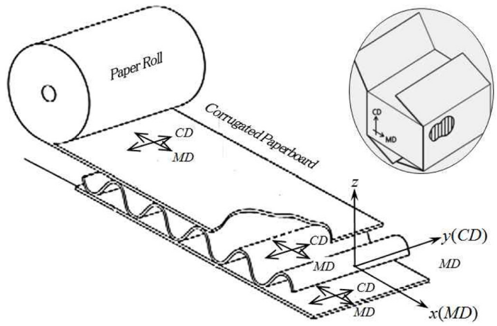


Fig. 1. Three principal material axes in corrugated paperboard and its components.

(2) to analyze the static- and dynamic-frictional coefficients between the rubber contact pad of carton clamp truck arm and corrugated packages.

Materials and Methods

1. Experimental materials

When a carton clamp truck handles corrugated packages, various contacts occur at the different locations as shown in Fig. 2. Considering the three types of corrugated flute (AB/F, BB/F, and A/F) and two grades of board combinations, the overall combination considering the orthotropic characteristics of the corrugated paperboard is shown in Table 1. In addition, when simulating corrugated packages, the corrugated paperboard should be represented by the simplified model with equivalent mechanical properties. Therefore, various contacts between the constituent boards of the corrugated paperboards were also included in this combinations (Table 1).

In the experimental design, a large refrigerator package (weight: 1,760 N, dimension: L×W×D = 1003×980×1880 mm) [Fig. 2(a) and (b)] and an electric boiler package (weight: 294 N, dimension: L×W×D = 864×514×333 mm) [Fig. 2(c)] were chosen as the target corrugated packages.

2. Experimental apparatus and methods

A multipurpose friction tester fabricated for this study is shown in Fig. 3. This test device consisted of the upper and lower plates, which causes relative motion by bringing two specimens to face contact, specimen holders, the traction device of an upper plate, and a pressure imposing device equipped with a load cell and an air cylinder. The device was connected with the existing UTM (KST-1000U, KST Inc., Korea) to control the traction speed and to analyze frictional force-distance curve.

When designing the device, the traction direction of the plate and the contact surface between the two specimens should be in the same plane so that the deviation between the tractional and frictional force due to the torque and stick-slip generated during the test is minimal[4].

The actual contact area between the two plates was 30×30 cm, and the normal forces were 196, 392, and 589 N, so that the normal pressures were 2.18, 4.36, and 6.54 kPa. The normal pressure range was determined by considering the standard pressure of 2.2 ± 0.6 kPa[4] and clamping pressure applied in the current carton clamp handling of target corrugated packages.

The traction speed of the upper plate during the test was 20 mm/s[4,6]. Before testing, specimens of corrugated paperboars and their constituent boards were pretreated for 48 hours[5], and samples of rubber contact pads for 5 hours[6,7], respectively, at standard condition (23℃-RH 50%).

3. Analysis method

When the lower plate is fixed and the upper plate is towed at a constant speed, the traction force is continuously measured as a frictional force, and the ratio of the frictional force to the normal force applied perpendicular to the two plates is the frictional coefficient at that moment. In particular, the ratio for the initial resistance (speed 0) of the movement is the static-frictional coefficient[4].

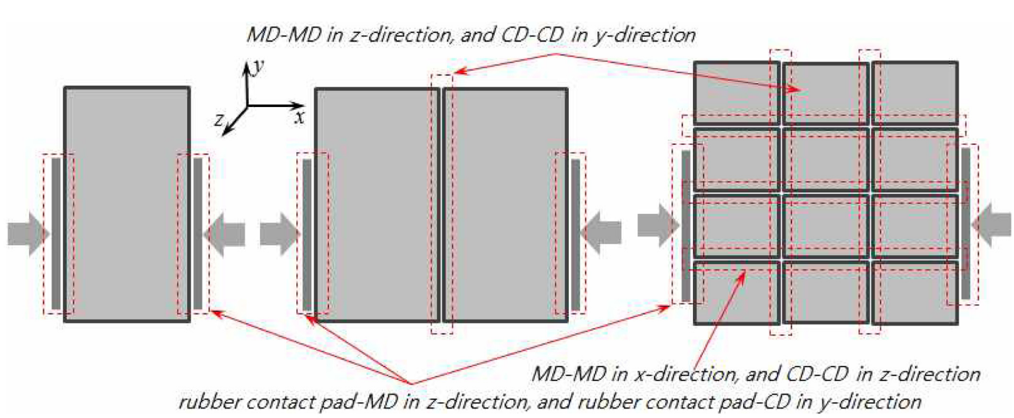
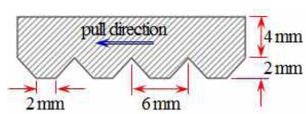


Fig. 2. Frictional contact conditions in carton clamp handling of target corrugated packages.

Table 1. Experimental design for the frictional test

Specimens[1)]	Test tracks[2)]	Normal pressure (kPa)	Contact orientations
RCP	CP **A**_DW_AB/F	2.18, 4.36, 6.54	CD, MD
RCP	CP **A**_DW_BB/F	2.18, 4.36, 6.54	CD, MD
RCP	CP **B**_DW_AB/F	2.18, 4.36, 6.54	CD, MD
RCP	CP **B**_DW_BB/F	2.18, 4.36, 6.54	CD, MD
RCP	CP **C**_SW_A/F	2.18, 4.36, 6.54	CD, MD
RCP	CP **D**_SW_A/F	2.18, 4.36, 6.54	CD, MD
RCP	Linerboard_KLB175	3.27	CD, MD
RCP	Linerboard_SK180	3.27	CD, MD
CP **A**_DW_AB/F	CP **A**_DW_AB/F	2.18, 4.36, 6.54	CD-CD, CD-MD, MD-MD
CP **A**_DW_BB/F	CP **A**_DW_BB/F	2.18, 4.36, 6.54	CD-CD, CD-MD, MD-MD
CP **B**_DW_AB/F	CP **B**_DW_AB/F	2.18, 4.36, 6.54	CD-CD, CD-MD, MD-MD
CP **B**_DW_BB/F	CP **B**_DW_BB/F	2.18, 4.36, 6.54	CD-CD, CD-MD, MD-MD
CP **C**_SW_A/F	CP **C**_SW_A/F	2.18, 4.36, 6.54	CD-CD, CD-MD, MD-MD
CP **D**_SW_A/F	CP **D**_SW_A/F	2.18, 4.36, 6.54	CD-CD, CD-MD, MD-MD
Linerboard_KLB175	Linerboard_KLB175	3.27	MD-MD, CD-CD, CD-MD
Linerboard_SK180	Linerboard_SK180	3.27	MD-MD, CD-CD, CD-MD
Linerboard_KLB175	Linerboard_K180	3.27	MD-MD, CD-CD, CD-MD
Linerboard_K180	Linerboard_K180	3.27	MD-MD, CD-CD, CD-MD
Linerboard_SK180	Linerboard_S120	3.27	MD-MD, CD-CD, CD-MD
Linerboard_S120	Linerboard_S120	3.27	MD-MD, CD-CD, CD-MD

Note: 1) Rubber contact pad (RCP) : Hi-NBR (IRHD_71, tensile strength_17.6 MPa, elongation_410%)
2) Corrugated paperboard (CP) **A** : KLB175/3K180/KLB175, CP **B**: SK180/3S120/SK180, CP **C**: KLB175/K180/KLB175, CP **D**: SK180/S120/SK180, KLB175 (40% UKP + 30% AOCC + 30% KOCC), K180 and S120 (100% KOCC), SK180 (outer liner contained 20% UKP + 80% KRCC), UKP = unbleached kraft pulp, KOCC = Korean old corrugated container, AOCC = American old corrugated container



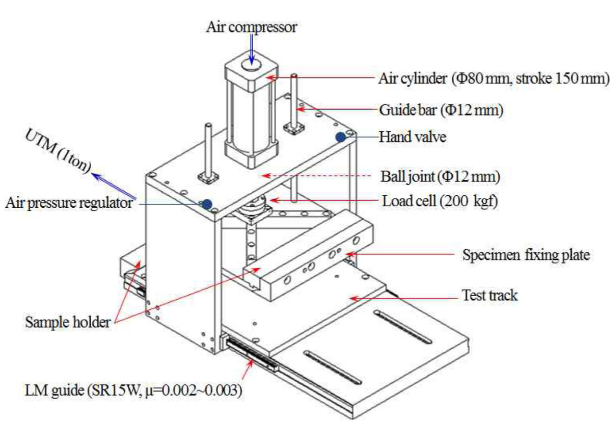


Fig. 3. Test apparatus designed for frictional test.

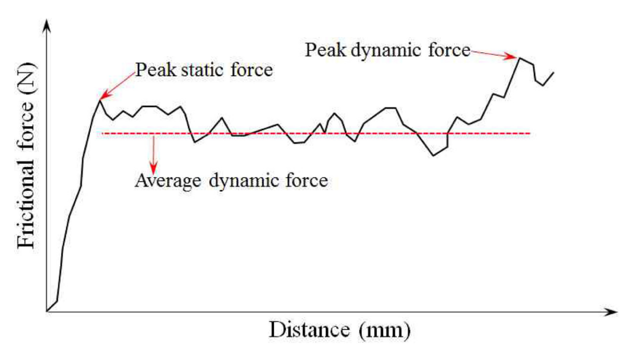


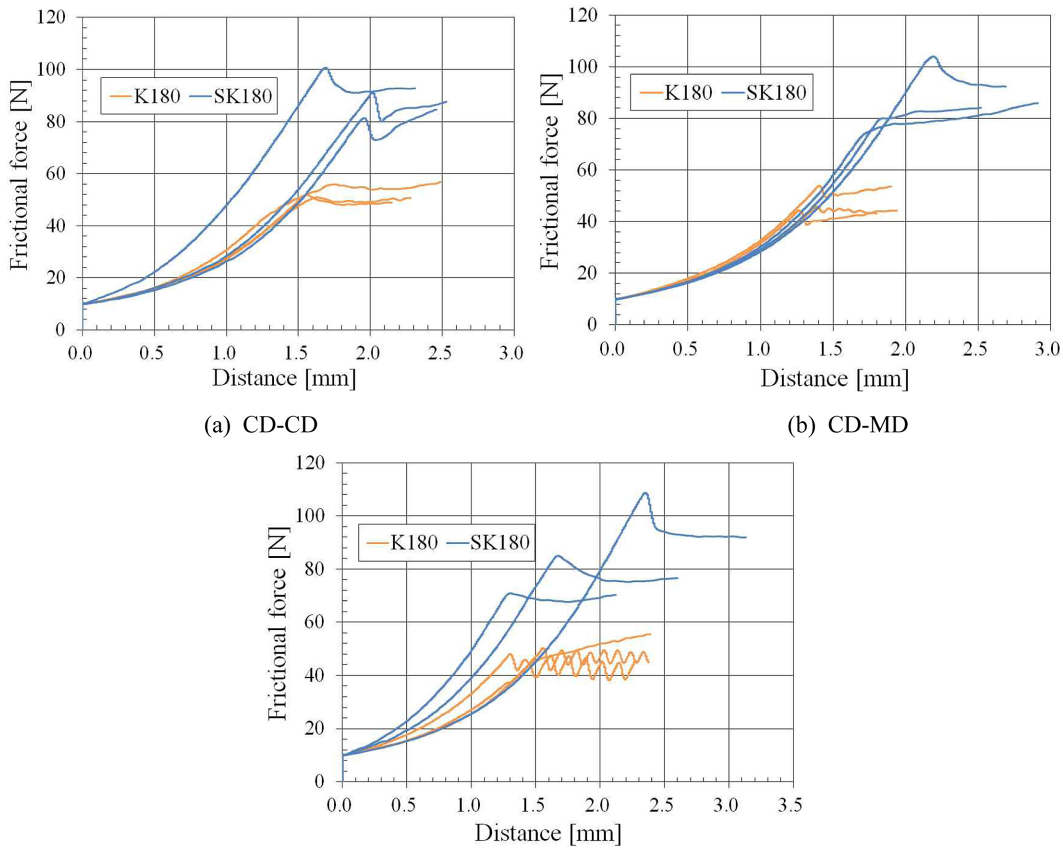
Fig. 4. Typical frictional force-distance curve in frictional test.

The kinetic-frictional coefficient is the ratio of the dynamic frictional force required to slide the contacted surface to the normal force applied to the two surfaces perpendicularly, and is usually calculated through the application of the average dynamic force as shown in Fig. 4.

Results and Discussion

1. Frictional force-distance curve

Fig. 5 shows the frictional force-distance curves at three contact orientations (CD-CD, CD-MD, MD-MD) between the constituent boards of corrugated paperboards (K180, SK180), and Fig. 6 shows the frictional force-distance curves for various contact orientations between corrugated paperboards [CP



(a) CD-CD (b) CD-MD

(c) MD-MD

Fig. 5. Frictional force-distance curves at various contact orientations between constituent boards of corrugated paperboard [normal pressure, 3.27 kPa].

B (BB/F, DW)].

In the contact between constituent boards (Fig. 5), the force values after peak static force fluctuate at contacts except for the contact between MDs, which coincides with the fiber orientation of board and the traction direction. On the other hand, in the contact between corrugated paperboards, the force value after peak static force was generally mild regardless of the contact orientation. This suggests that the effect of the fibers orientation on the frictional characteristics is greater at the constituent board than at the corrugated paperboard.

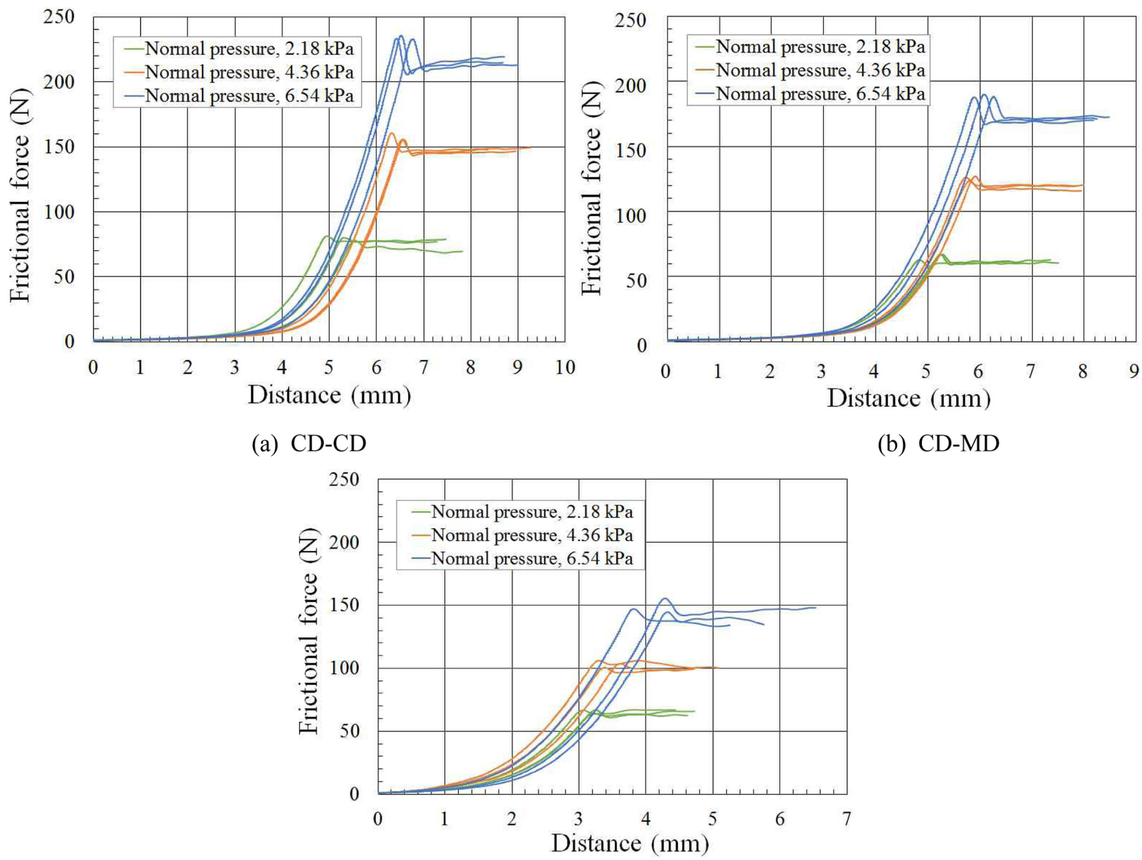
In the contact between corrugated paperboards (Fig. 6), as the applied normal pressure increases, the difference between peak static force and average dynamic force increases. More detailed analysis is needed as to whether this affects the difference between the static- and dynamic-frictional coefficients. Fig. 7 shows experimental photograph.

2. Frictional characteristics between the constituent boards of target corrugated paperboards

Fig. 8 shows the frictional characteristics for various combinations of constituent boards of the target corrugated package. In all combinations of constituent boards, the static-frictional coefficient were lowest in contacting between MDs, followed by CD-MD and CDs (Table 2). The fibers are arranged in MD when producing the board. When the two boards come in contact with the MDs, the fiber orientation and the traction direction are coincident with each other, which is considered to produce a small frictional coefficient due to the reduction of the frictional force. In addition, when the boards are in contact with the CDs, the fiber orientation and the traction direction are perpendicular, so that the frictional force is increased, resulting in a large static-frictional coefficient. These results turned out that the frictional coefficient for the contact between boards is related to the fiber orientation of the board, which is in good agreement with Park et al.[2].

The difference of frictional coefficients between the different boards was small, and the mean static-frictional coefficients for all the boards of this study were about 0.23 (±0.01) in the contact between MDs, and about 0.26 (±0.01) in the contact between CD and MD, and 0.29 (±0.01) in the contact between CDs, respectively.

On the other hand, the selected linerboards (KLB175, SK180) showed similar static-frictional coefficients upon con-



(a) CD-CD (b) CD-MD

(c) MD-MD

Fig. 6. Frictional force-distance curves at various contact orientations between corrugated paperboards [CP **B** (BB/F, DW)].

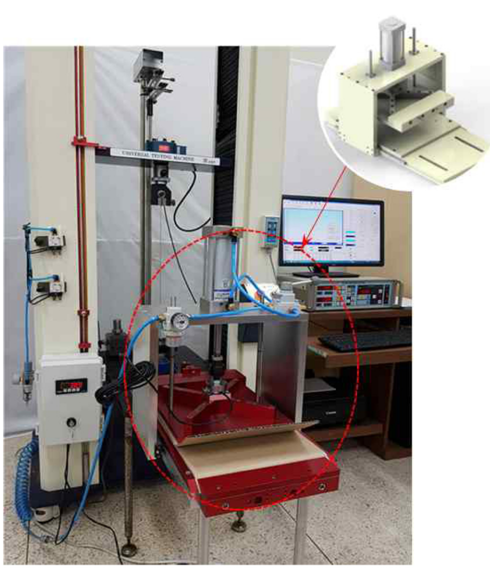


Fig. 7. Experiment photograph.

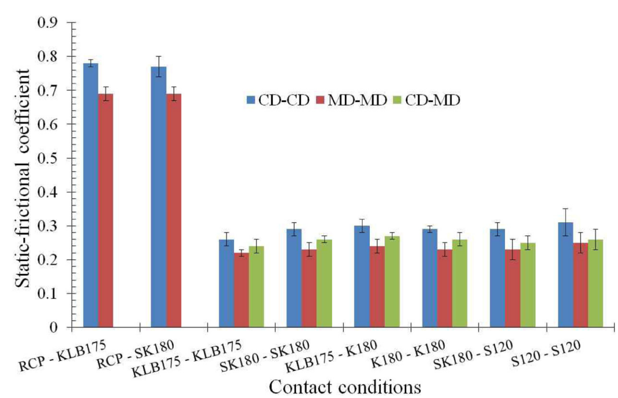


Fig. 8. Static-frictional coefficients at various contact orientations between paperboards constituting of target corrugated packages.

tact with the rubber contact pad (Table 2). However, the static-frictional coefficient (0.78) of these linerboards at CD contact was about 13% higher than that at MD contact (0.69) (Fig. 8 and Table 2).

3. Frictional characteristics between target corrugated paperboards

Based on the standard pressure of 2.2 kPa in measuring the frictional coefficient of paper and board[4], the frictional coefficient is measured by increasing the normal pressure to two times (4.36 kPa) and three times (6.54 kPa) of the standard pressure. These normal pressure levels, however, did not

Table 2. Mean comparison by Duncan's multiple range tests for static-frictional coefficients

Various contact type	Contact orientations	Flute type	Linerboard or board combination[3)]
Between linerboards	CD-CD[a], CD-MD[b], MD-MD[c]	-	-
Between RCP and linerboard	CD[a], MD[b]	-	KLB175[a], SK180[a]
Between corrugated paperboards	CD-CD[a], CD-MD[a], MD-MD[a]	AB/F[a], BB/F[a], A/F[a]	Group 1[a], Group 2[b]
Between RCP and corrugated paperboard	CD[a], MD[a]	AB/F[a], BB/F[b], A/F[c]	Group 1[a], Group 2[a]

Note: t-test for paired samples from Fig. 8-10
[a,b,c]letters indicate the statistical difference in rows (significant level at 5%).
1) **Group 1**: CP **A** (AB/F) + CP **A** (BB/F) + CP **C** (A/F), **Group 2**: CP **B** (AB/F) + CP **B** (BB/F) + CP **D** (A/F) in Table 1.

affect the frictional coefficient. Therefore, in this study, the frictional coefficients between corrugated paperboards were averaged (Fig. 9 and 10).

The frictional coefficients in different contact directions between corrugated paperboards were found to be similar (Fig. 9 and Table 2), which is due to the combined effect of the outer linerboard with orthotropic characteristics and flute structure of corrugated paperboard. That is, the frictional coefficient between the boards is small in the contact between MDs. On the contrary, in the case of the corrugated paperboard, since the flutes of the corrugated paperboard interlock with each other in the contact between MDs, the frictional coefficient is large. Therefore, there is no difference in the frictional coefficient according to the contact direction between the corrugated paperboards because of these opposing characteristics of the corrugated paperboard. This phenomenon is considered to have similar frictional coefficients depending on the contact direction of the corrugated paperboard even when the corrugated paperboard is in contact with the rubber contact pad (Fig. 10 and Table 2). However, the difference in frictional coefficient according to the flute type of corrugated paperboard in contact with the rubber contact pad was clear. In other words, A/F corrugated paperboard was the largest under the same conditions, followed by BB/F and AB/F (Fig. 10 and Table 2).

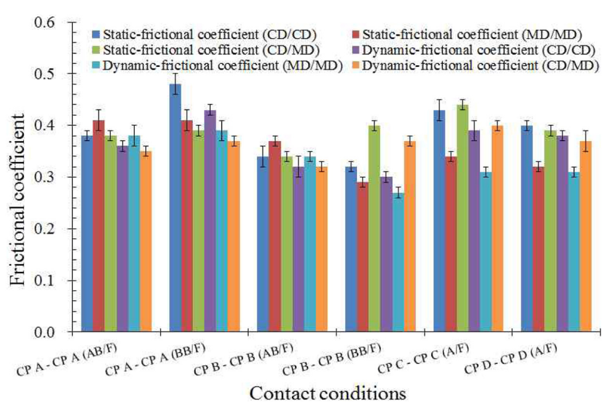


Fig. 9. Frictional coefficients between target corrugated paperboards.

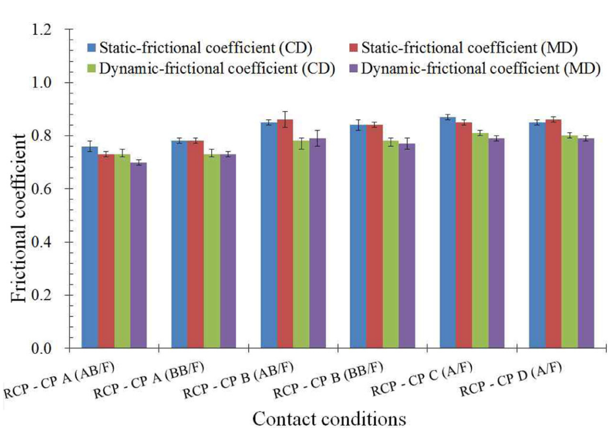


Fig. 10. Frictional coefficients between rubber contact pad and target corrugated paperboards.

The overall mean of static-frictional coefficients between selected corrugated paperboards was about 0.38 (± 0.01), which was 1.3~1.6 times greater than 0.23~0.29 of the frictional coefficients between boards. On the other hand, the overall mean of static-frictional coefficients between the corrugated paperboards and the rubber contact pad was 0.82 (±0.02), which was about 1.1 to 2.8 times greater than 0.29~0.78 of the static-frictional coefficient between the linerboard and the rubber contact pad.

The overall mean of kinetic-frictional coefficients between the corrugated paperboards was 0.35 (±0.01), and 0.76 (±0.02) between the corrugated paperboards and the rubber contact pad.

Conclusions

In this study, the frictional characteristic at various contact conditions of corrugated paperboards and their constituent boards were analyzed to obtain the data needed in the computer simulation for the handling of carton clamp truck. The results of this study are summarized as follows.

1. The difference of frictional coefficients between the dif-

ferent boards at various contact conditions was small, and the mean static-frictional coefficients were about 0.23 (±0.01) in the contact between MDs, and about 0.26 (±0.01) in the contact between CD and MD, and 0.29 (±0.01) in the contact between CDs, respectively.

2. The selected linerboards (KLB175, SK180) showed similar static-frictional coefficients upon contact with the rubber contact pad. However, the static-frictional coefficient (0.78) of these linerboards at CD contact was about 13% higher than the value at MD contact (0.69).

3. The overall mean of static-frictional coefficients between selected corrugated paperboards was about 0.38 (±0.01), which was 1.3~1.6 times greater than 0.23~0.29 of the frictional coefficients between boards.

4. The overall mean of static-frictional coefficients between the corrugated paperboards and the rubber contact pad was about 0.82 (±0.02), which was about 1.1 to 2.8 times greater than 0.29~0.78 of the static-frictional coefficient between the linerboard and the rubber contact pad.

5. The overall mean of kinetic-frictional coefficients between the corrugated paperboards was 0.35 (±0.01), and 0.76 (±0.02) between the corrugated paperboards and the rubber contact pad.

Acknowledgements

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