# Coefficients of Friction for Apple on Various Surfaces As Affected by Velocity

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ABSTRACT

The static and dynamic coefficients of friction were determined for two apple cultivars against four different surfaces (masonite, rubber, paper, plastic) at surface moving velocities of 0.42 to 16.67 mm/s. Over this range of velocities, friction coefficients increased by 30 to 100%. Sliding velocity affected dynamic coefficient more than preloading velocity affected the static coefficient. Differences between the tested surfaces were most pronounced at the intermediate velocity of 4.17 mm/s. The effect of velocity and surface varied inconsistently between the two cultivars.
KEYWORDS: Apple, Friction coefficient, Velocity, Sliding surface

## INTRODUCTION

Optimum design of equipment and systems for producing and delivering fresh fruit requires information about various physical properties such as the coefficient of friction. The sliding of fruit against machine parts or another product during handling often reduces product quality. That frictional characteristics depend on many factors has already been recognised by Mohsenin (1986) and (Puchalski and Brusewitz, 1996a). Cooper (1962) determined the static and dynamic (kinetic) coefficients of friction of apples while rolling on various surfaces. The coefficient of friction for apples on various surfaces was reported by Vis et al., (1969). Chen and Squire (1971) said that the dynamic coefficient of friction of oranges increased with higher sliding velocity on metal and masonite surfaces. The higher friction coefficients were greater on pre-conditioned surfaces than on clean surfaces. Puchalski and Brusewitz (1996b) found that preloading velocity in the range of 0.33 to 8.33 mm/s significantly affected the static coefficient of friction, but sliding velocity did not affect the dynamic coefficient of watermelons on six different surfaces. Schaper and Yaeger (1992) measured the static and dynamic coefficients of friction of potatoes on nine types of materials. The coefficients were lowest for potatoes on polyethylene sheet and highest on galvanized steel. Moisture affected the static coefficients more than the surface material whereas surface materials affected dynamic coefficients more than moisture for beans and peanuts (Chung and Verma, 1989). The objective of this study was to determine the effect of preloading velocity on the static coefficient and sliding velocity on dynamic coefficient of friction for four different surfaces and two apple cultivars.

## MATERIALS AND METHODS

Two apple cultivars were selected having different size and surface characteristics (Table 1). 'McLemore' skin was more yellow when fully ripe and had less dense tissue than 'Gala'. The fruit were harvested from an eastern Oklahoma commercial orchard at their optimum maturity based on flesh firmness and color on 24 July ('McLemore') and 15 August ('Gala'). The apples were handpicked, placed in produce paper trays (20 cells/tray) and packed into cardboard fruit boxes (60 apples/box). Care was taken to minimise fruit damage during transport. Apples were sorted by mass and dimension to obtain greater uniformity of fruit on a specific test date. The apples were placed into storage at 6$^{o}$C, 95 % RH for 2 to 25 days. Apples were removed from storage 12 h before friction measurement to allow them to reach room conditions (24$^{o}$C and 55 % RH). 'McLemore' were tested starting on 29 July and 'Gala' starting on 18 and 29 August and 9 September against all friction surfaces. Additionally, 'McLemore' was tested on 25 July and 4 August against only masonite. For each beginning test date, it took one-to-four days to obtain all friction measurements for all four surfaces.

Table 1. Apple characteristics; mean (M) and standard deviation (S.D.) for N=240.

| | Measurement | Mass, g | | Dimension, mm | | | | Moisture Content, % | | Firmness, N | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cultivar | date | | | Min | | Max | | | | | |
| | | M | S.D. | M. | S.D. | M. | S.D. | M. | S.D. | M. | S.D. |
| McLemore | 25 July | 151.4 | 17.3 | 72.1 | 2.8 | 74.0 | 3.2 | 85.2 | 1.3 | 55 | 13 |
| | 29 July | 155.6 | 13.2 | 73.1 | 2.3 | 74.9 | 2.4 | 84.8 | 0.8 | 53 | 12 |
| | 4 Aug | 148.6 | 13.0 | 71.3 | 2.6 | 74.3 | 2.9 | 84.1 | 0.8 | 48 | 14 |
| Gala | 18 Aug | 160.1 | 13.4 | 70.7 | 2.3 | 72.7 | 2.4 | 83.3 | 1.2 | 67.6 | 7.8 |
| | 29 Aug | 145.3 | 9.4 | 69.2 | 5.7 | 70.5 | 2.2 | 82.7 | 0.9 | 62.3 | 13.3 |
| | 9 Sep | 140.0 | 8.5 | 66.9 | 0.8 | 68.9 | 1.2 | 82.8 | 1.4 | 61.3 | 11.8 |

Friction measurements were made using a custom made device for single samples. The basic principle of the friction tester (developed by Puchalski and Brusewitz, 1996a) is a stationary sample holder and a horizontally moving friction surface above the sample. The sample holder was connected through a pivoting arm to a counter weight to produce the required normal force. A rigid, flat friction surface 0.1 m wide and 0.6 m long was bolted to the underside of a pulling plate supported by a precision rail and linear bearing to minimise friction. The friction surface was pulled horizontally by the Instron's vertically moving crosshead with a nonstretching 1.0-mm diameter steel cable through a pulley. The Instron's crosshead was set at a velocity that was considered the preload velocity for static coefficient and sliding velocity for the dynamic coefficient. The six velocities selected were; 0.42, 0.83, 1.67, 4.17, 8.33 and 16.67 mm/s. The four friction surfaces used were; rough side of construction-grade tempered masonite, rubber like that used for agricultural conveyors, paper like that found on unwaxed cardboard, and plastic boxes. All surfaces were cleaned by compressed air before each test to remove any contamination from previous tests. Testing was done at constant normal force of 17 N over a travelling distance of 40 mm.

Analog values of friction force and time (displacement) data from the Instron universal testing machine were digitised and sent by a data acquisition system to a personal computer. Data were sampled at the rate of 5,10 or 20 Hz, in proportion to the sliding velocity. During a test run, the digitised friction force data were used to compute the friction coefficients.

The static and dynamic coefficients of friction were computed by the formula:

$$\mu = F/N \qquad (1)$$

where: $\mu$ - coefficient of friction,
$F$ - friction force,
$N$ - normal force.

Once the test was started, force increased with time as the surface resisted movement until it started to move at which time the force declined slightly. This first peak force was used to calculate the static coefficient of friction. Thereafter, the friction force tended to level off and that was considered the dynamic coefficient of friction (Schaper & Yaeger ,1992). After friction measurements, flesh firmness was determined destructively on one cheek of each apple using an Effegi™ firmness tester with an 11.1 mm diameter probe. Ten replicates were run for each combination of six velocities, four surfaces and two cultivars.

## RESULTS

### The effect of surface type and cultivar

ANOVA showed that both coefficients of friction were significantly affected by sliding velocity, surface type and cultivar. The main effects were all significant at the 0.05 probability level and the interactions were all significant for friction dynamic coefficient of 'Gala' (Table 2). Static and dynamic coefficients of friction data for 'Gala' and 'McLemore' are shown in tables 3 and 4, respectively. The static coefficients ranged from 0.261 to 0.475, 0.284 to 0.415, 0.207 to 0.307 and 0.462 to 0.941 for apples against masonite, paper, plastic and rubber, respectively. The dynamic coefficients were 0.246 to 0.497, 0.207 to 0.452, 0.182 to 0.577 and 0.519 to 1.031 for the same surfaces, respectively.

There were significant differences in the coefficients of friction between the two cultivars. 'Gala' had higher static and dynamic coefficients of friction on rubber and paper and lower on masonite than 'McLemore'. Among the surface materials tested plastic, with a very smooth surface, showed the lowest static and dynamic friction coefficients for both cultivars. Rubber, having the softest surface, had the highest values. Standard errors for replications were 0.015, 0.018, 0.017 and 0.038 for static and dynamic coefficients of friction against masonite, paper, plastic and rubber respectively.

Table 2. Analysis of variance probabilities for significant F values of static and dynamic coefficient of friction

| Coefficient Of friction | Independent variable | Cultivar | | | |
|---|---|---|---|---|---|
| | | Gala | | McLemore | |
| | | F | P | F | P |
| Static | Velocity, Sp | 108.63 | <0.001 | 32.06 | <0.001 |
| | Surface, S | 1526.23 | <0.001 | 517.44 | <0.001 |
| | Measurement date, MD | 18.48 | <0.001 | 7.54 | 0.001 |
| | SpxS | 29.12 | <0.001 | 1.49 | 0.109 |
| | SpxMD | 0.94 | 0.499 | 1.50 | 0.143 |
| | SxMD | 11.91 | <0.001 | | |
| | SpxSxMD | 2.045 | 0.001 | | |
| Dynamic | Velocity, Sp | 323.70 | <0.001 | 41.21 | <0.001 |
| | Surface, S | 2888.40 | <0.001 | 718.40 | <0.001 |
| | Measurement date, MD | 118.58 | <0.001 | 12.92 | <0.001 |
| | SpxS | 36.92 | <0.001 | 7.39 | <0.001 |
| | SpxMD | 6.84 | <0.001 | 0.46 | 0.918 |
| | SxMD | 8.71 | <0.001 | | |
| | SpxSxMD | 2.33 | <0.001 | | |

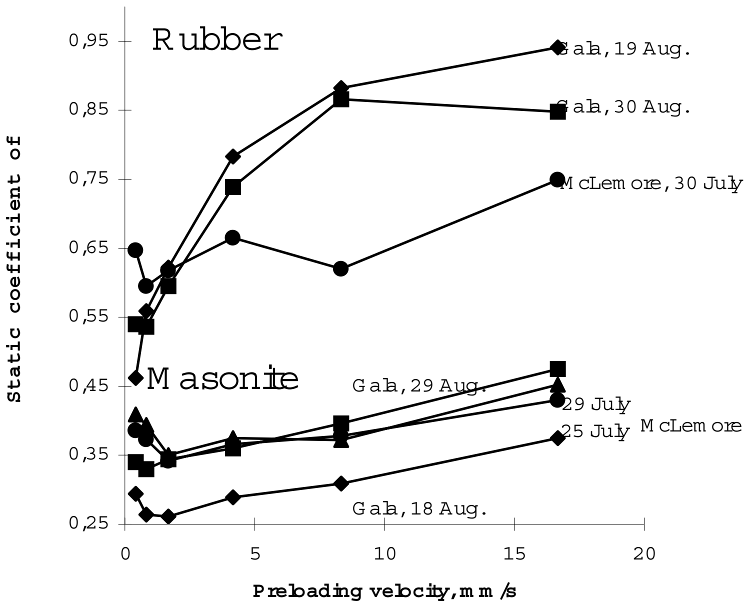
The effect of velocity

The analysis of variance showed a significant effect of preload velocity on the static and sliding velocity on dynamic coefficient of friction (table 2). Generally, the static and dynamic coefficients of friction for both cultivars decreased as the velocity increased from 0.42 to 1.67 mm/s and then significantly increased (fig.1 and 2). The lowest static coefficients for ‘Gala’ occurred at 0.83 and 1.67 mm/s against masonite, paper and plastic respectively (table 3). ‘McLemore’ also had the lowest static coefficients of friction at 0.83 and 1.67 mm/s but for different friction surfaces i.e., for plastic, rubber, masonite, and paper (table 4). The lowest dynamic coefficient occurred at 0.42 mm/s for ‘Gala’ and 0.83 mm/s for ‘McLemore’ against all friction surfaces, except for paper. For both cultivars, sliding velocity affected the dynamic coefficient more than the preloading velocity affected the static coefficient of friction on rubber and plastic. This effect was more pronounced for ‘Gala’ than for ‘McLemore’. The average increases in dynamic coefficient of friction on rubber and plastic over the range of 0.42 to 16.67 mm/s were 88 and 67 % of its lowest value for ‘Gala’ and ‘McLemore’, respectively. The largest changes in static coefficient of friction for Gala occurred at 4.17 mm/s preloading velocity on masonite as an effect of test date (table 3). The highest changes in dynamic coefficient of friction were sliding velocities over 4.17 mm/s on masonite and plastic. Coefficients of variation ranged from 18.5 to 23.4 %.

Table 3. Static and dynamic coefficient of friction as affected by velocity (as a preloading for static and sliding for dynamic) and friction surface for ’Gala’ (data N=30 were averaged over three test dates)

| Friction | | Friction surface * | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Coefficient | | Masonite | | | Paper | | | Plastic | | | |
| | velocity (mm/s)* | 18 Aug. - 9 Sep. | | | 20 Aug. - 11 Sep. | | | 21 Aug. - 12 Sep. | | | 19 A |
| | | Min | Max | C.V., % | Min | Max | C.V., % | Min | Max | C.V., % | Min |
| Static | 0.42 | 0.294 | 0.340 | 7.5 | 0.307 | 0.365 | 10.1 | 0.225 | 0.232 | 2.2 | 0.462 |
| | 0.83 | 0.264 | 0.330 | 11.8 | 0.309 | 0.338 | 5.0 | 0.213 | 0.242 | 6.6 | 0.536 |
| | 1.67 | 0.261 | 0.344 | 14.9 | 0.309 | 0.353 | 6.8 | 0.207 | 0.250 | 10.8 | 0.559 |
| | 4.17 | 0.289 | 0.406 | 17.0 | 0.294 | 0.364 | 11.8 | 0.217 | 0.234 | 3.5 | 0.644 |
| | 8.33 | 0.309 | 0.412 | 14.8 | 0.310 | 0.382 | 11.5 | 0.244 | 0.282 | 7.2 | 0.865 |
| | 16.67 | 0.375 | 0.475 | 12.2 | 0.376 | 0.415 | 5.7 | 0.267 | 0.307 | 7.0 | 0.832 |
| Dynamic | 0.42 | 0.256 | 0.302 | 8.5 | 0.253 | 0.266 | 2.7 | 0.182 | 0.192 | 2.7 | 0.519 |
| | 0.83 | 0.246 | 0.312 | 12.8 | 0.258 | 0.320 | 10.6 | 0.193 | 0.225 | 7.6 | 0.656 |
| | 1.67 | 0.280 | 0.377 | 15.3 | 0.296 | 0.383 | 12.9 | 0.210 | 0.270 | 12.4 | 0.744 |
| | 4.17 | 0.307 | 0.469 | 20.9 | 0.301 | 0.378 | 11.4 | 0.257 | 0.393 | 20.9 | 0.846 |
| | 8.33 | 0.335 | 0.497 | 19.3 | 0.320 | 0.452 | 20.9 | 0.285 | 0.432 | 21.6 | 0.956 |
| | 16.67 | 0.323 | 0.465 | 18.5 | 0.297 | 0.395 | 18.9 | 0.360 | 0.577 | 23.4 | 0.985 |

* Significant at 5 % level



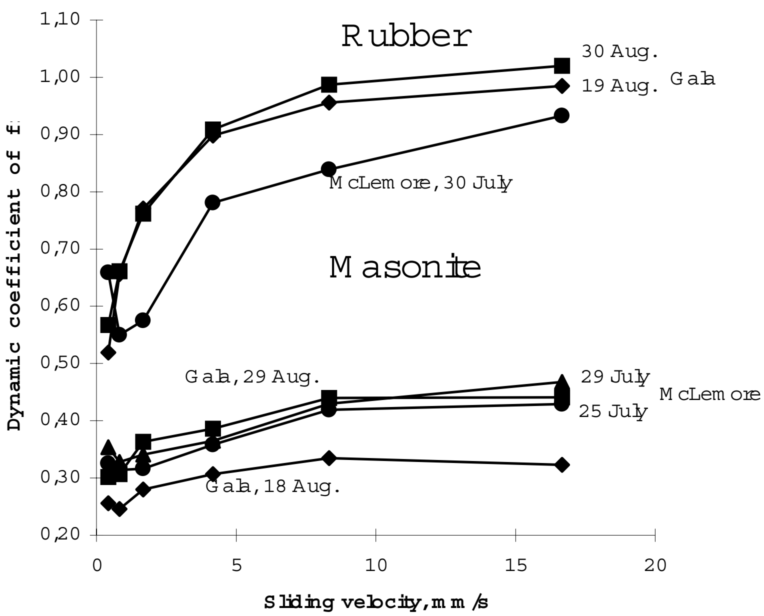




Fig. 1. Effect of velocity (preloading for static and sliding for dynamic) on static and dynamic coefficients of friction on masonite and rubber surfaces for two measurements dates for 'Gala' and 'McLemore' apples.

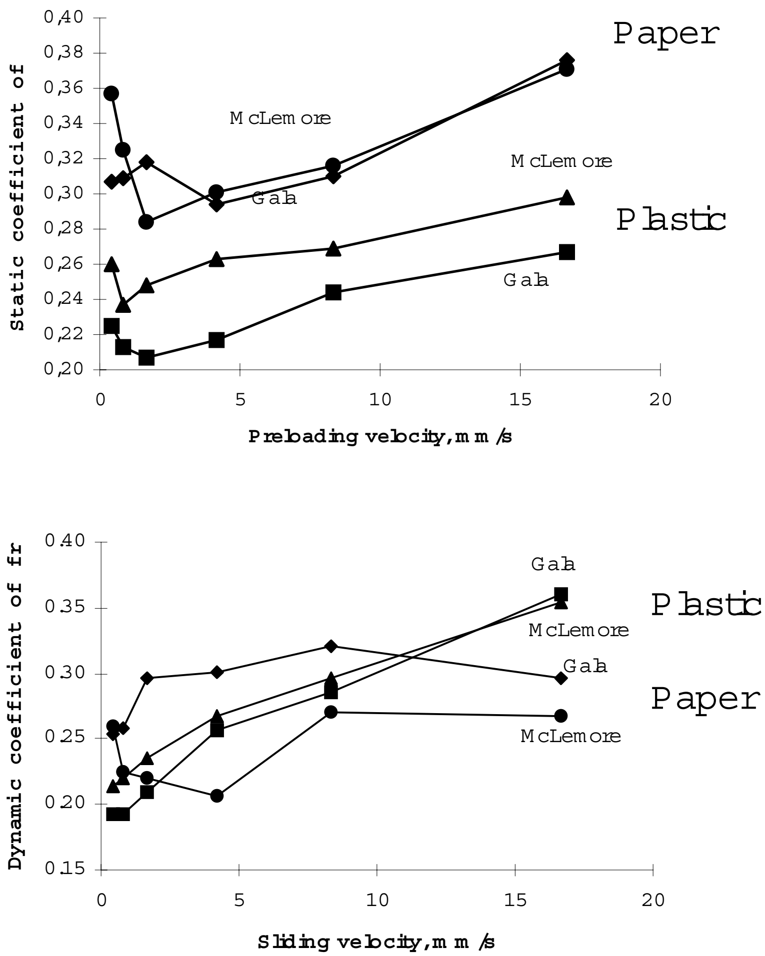



Fig. 2. Effect of velocity (preloading for static and sliding for dynamic) on static and dynamic coefficients of friction on paper and plastic surfaces for ‘Gala’ and ‘McLemore’ apples.

Table 4. Static and dynamic coefficient of friction as affected by velocity (as a preloading for static and sliding for dynamic) and friction surface for 'McLemore' on test date starting 29 July (N=10)

| Friction coefficient | Velocity (mm/s) | Friction surface * Masonite Mean | Masonite S.D. | Paper Mean | Paper S.D. | Plastic Mean | Plastic S.D. | Rubber Mean | Rubber S.D. |
|---|---|---|---|---|---|---|---|---|---|
| Static | 0.42 | 0.409 | 0.031 | 0.358 | 0.039 | 0.260 | 0.038 | 0.647 | 0.051 |
| | 0.83 | 0.394 | 0.032 | 0.325 | 0.032 | 0.237 | 0.028 | 0.595 | 0.076 |
| | 1.67 | 0.350 | 0.027 | 0.284 | 0.023 | 0.248 | 0.036 | 0.618 | 0.119 |
| | 4.17 | 0.375 | 0.036 | 0.301 | 0.038 | 0.262 | 0.036 | 0.666 | 0.101 |
| | 8.33 | 0.372 | 0.041 | 0.316 | 0.029 | 0.269 | 0.016 | 0.621 | 0.058 |
| | 16.7 | 0.452 | 0.045 | 0.371 | 0.041 | 0.298 | 0.036 | 0.749 | 0.117 |
| Dynamic | 0.042 | 0.354 | 0.019 | 0.260 | 0.052 | 0.214 | 0.023 | 0.659 | 0.066 |
| | 0.83 | 0.329 | 0.031 | 0.225 | 0.025 | 0.220 | 0.019 | 0.550 | 0.109 |
| | 1.67 | 0.341 | 0.029 | 0.220 | 0.031 | 0.235 | 0.035 | 0.575 | 0.114 |
| | 4.17 | 0.365 | 0.035 | 0.207 | 0.022 | 0.267 | 0.042 | 0.781 | 0.114 |
| | 8.33 | 0.430 | 0.047 | 0.271 | 0.058 | 0.297 | 0.052 | 0.839 | 0.092 |
| | 16.67 | 0.468 | 0.053 | 0.268 | 0.053 | 0.353 | 0.055 | 0.933 | 0.059 |

* Significant at 5 % level

<u>Relationship between the friction coefficient and velocity</u>

The effect on the friction coefficient of velocity for the two apple cultivars against various friction surfaces are shown in figures 1 and 2. A regression analysis was performed to find the best fitting equations. Determination coefficients, $R^2$ from regression analyses for 'Gala' are given in table 5. Similar results were found for 'McLemore' (data not presented). In general, for all measured dates correlation coefficients were lowest for static and dynamic coefficients on paper and highest for static friction on masonite and rubber and for dynamic friction on plastic and rubber surfaces.

Table 5. Determination coefficients $R^2$ of regression analyses of friction coefficient vs. velocity (preloading for static and sliding for dynamic) against various friction surfaces on different measurement dates for Gala

| Friction Coefficient | Friction surface | Measurement date | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 18 Aug. | | | 29 Aug. | | | 9 Sep. | | |
| | | Linear | Polyn. | Power | Linear | Polyn. | Power | Linear | Polyn. | Power |
| Static | Masonite | 0.88 | 0.91 | 0.53 | 0.99 | 0.99 | 0.78 | 0.85 | 0.94 | 0.92 |
| | Paper | 0.69 | 0.95 | 0.32 | 0.88 | 0.88 | 0.62 | 0.68 | 0.95 | 0.86 |
| | Plastic | 0.87 | 0.87 | 0.53 | 0.88 | 0.89 | 0.80 | 0.76 | 0.77 | 0.45 |
| | Rubber | 0.78 | 0.97 | 0.98 | 0.73 | 0.99 | 0.92 | 0.76 | 0.93 | 0.81 |
| Dynamic | Masonite | 0.61 | 0.96 | 0.87 | 0.73 | 0.96 | 0.95 | 0.51 | 0.95 | 0.87 |
| | Paper | 0.31 | 0.85 | 0.71 | 0.42 | 0.50 | 0.66 | 0.46 | 0.95 | 0.84 |
| | Plastic | 0.97 | 0.99 | 0.94 | 0.95 | 0.98 | 0.99 | 0.87 | 0.96 | 0.97 |
| | Rubber | 0.63 | 0.89 | 0.92 | 0.89 | 0.95 | 0.99 | 0.78 | 0.99 | 0.98 |

Polynomial equations produced the highest correlations between coefficient of friction and velocity for all tested friction surfaces. However, linear and power equations provided an excellent fit against plastic ($R^2$ =0.76 to 0.97) and rubber surfaces ($R^2$ = 0.81 to 0.98). Since the polynomial equation was the single best equation, it was selected as the single equation to compare regression coefficients among friction surfaces (tables 6 and 7). Rubber had the highest regression coefficients for the static and dynamic coefficients of friction while plastic had the lowest coefficient. Regression coefficients for "c" appear to be a good parameter to assess a friction material's relationship between velocity and friction coefficient. Rubber having the highest "c" value is a material having high risk of damage, while plastic with smallest "c" value has less risk of damage to fruit.

Table 6. Regression coefficients of polynomial equation ($y = a\ x^2 + b\ x + C$) between friction coefficient and velocity (preloading for static and sliding for dynamic) against friction surfaces for 'Gala' (on 18 Aug. test date)

| Friction Surface | Friction coefficient | Regression coefficient a | b | C | $R^2$ |
|---|---|---|---|---|---|
| Masonite | Static | -0.0003 | 0.002 | 0.27 | 0.91 |
| | Dynamic | -0.0008 | 0.018 | 0.24 | 0.96 |
| Paper | Static | 0.0005 | -0.005 | 0.31 | 0.95 |
| | Dynamic | -0.0007 | 0.014 | 0.25 | 0.85 |
| Plastic | Static | -0.0000005 | 0.0024 | 0.21 | 0.87 |
| | Dynamic | -0.0003 | 0.015 | 0.19 | 0.99 |
| Rubber | Static | -0.0030 | -0.077 | 0.48 | 0.97 |
| | Dynamic | -0.0034 | 0.080 | 0.57 | 0.89 |

Table 7. Regression coefficients of polynomial equation ($y = a\,x^2 + b\,x + C$) between friction coefficient and velocity (preloading for static and sliding for dynamic) against friction surfaces for 'McLemore' (on 29 July test date)

| Friction Surface | Friction coefficient | Regression coefficient a | b | C | $R^2$ |
|---|---|---|---|---|---|
| Masonite | Static | 0.0008 | -0.010 | 0.40 | 0.78 |
| | Dynamic | -0.0003 | 0.013 | 0.33 | 0.94 |
| Paper | Static | 0.0007 | -0.009 | 0.33 | 0.60 |
| | Dynamic | -0.0001 | 0.006 | 0.23 | 0.52 |
| Plastic | Static | -0.00005 | 0.0025 | 0.25 | 0.85 |
| | Dynamic | -0.0003 | 0.013 | 0.21 | 0.99 |
| Rubber | Static | 0.0007 | -0.006 | 0.63 | 0.82 |
| | Dynamic | -0.0013 | 0.043 | 0.56 | 0.90 |

Discussion

These results at low velocity agree with the behaviour of dry engineering materials as noted by Mohsenin (1986) who observed that the friction force decreases as the velocity increases. The increase in dynamic coefficient of friction for apples at higher sliding velocities may be caused by a temperature rise at higher sliding velocitys as noted by Chen and Squire (1971) for oranges. Puchalski and Brusewitz (1996b) found the opposite relationship however, between the coefficient of friction and preloading velocity for watermelon.

These increases in static coefficient of friction for 'McLemore' were different from 'Gala' possibly because of differences in internal structure and surface wax properties which derive from differences in ripening of the fruit (Corey et al., 1988). The effect of sliding velocity on dynamic coefficient of friction of both cultivars was more evident for surfaces of rubber and plastic that may cause higher temperatures.

Table 8. Summary - effect of velocity (preloading for static and sliding for dynamic) on friction coefficient for different friction surfaces m, p, l, r (masonite, paper, plastic, rubber) and cultivars G, M. ('Gala', 'McLemore'). x = highest significant changes

| Characteristic of friction Coefficient | Cult. | Velocity mm/s | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.42 | | | | 0.83 | | | | 1.67 | | | | 4.17 | | | | 8.33 | | | | 16.67 | | | |
| | | m | p | l | r | m | p | l | r | m | p | l | r | m | p | l | r | m | p | l | r | m | p | l | R |
| Lowest value of static | G | | | | | x | x | | x | | | x | | | | | | | | | | | | | |
| | M | | | | | | | x | x | x | x | | | | | | | | | | | | | | |
| Lowest value of dynamic | G | x | x | x | x | | | | | | | | | | | | | | | | | | | | |
| | M | | | | | x | x | x | x | | | | | | | | | | | | | | | | |
| Start in signif. increase of static | G | | | | | | | | | | | | | x | x | | x | | | x | | | | | |
| | M | | | | | | | | | | | | | | | x | x | | x | | | x | | | |
| Start in signif. increase of dynamic | G | | | | | | x | | | x | | x | x | | | | | | | | | | | | |
| | M | | | | | | | | | | | | | x | | x | x | | | x | | | | | |
| Largest changes between cultivars for static | | X | x | x | | x | | | | | | | | x | | x | | | | | x | x | | | |
| Largest changes between cultivars of dynamic | | | | | | | | | | | | | | | x | | | | | | x | x | | | |
| Largest changes with storage of static | G | | | | x | | | | | | | x | x | x | | | | x | | | | x | | | X |
| | M | | | | | | | | | | | | x | | | | | | | | | | | | |
| Largest changes with storage for dynamic | G | | | | | | | | | | | | x | | x | | | x | x | | | x | x | x | x |
| | M | | | | | | | | | | | | | | | | | | | | | | | | |

A summary of the effect of velocity (preloading and sliding) on friction coefficient as affected by friction surfaces is presented in table 8. To obtain characteristics of the friction coefficient one needs to know the velocity and type of friction surface. The results of this study could be used for protecting products against damage or as an indicator of changes between cultivars during storage. Sliding velocity of 4.17 mm/s was the threshold where friction coefficient started to increase significantly depending on friction surface and cultivar. Among the velocities tested, the higher ones (8.33 and 16.67 mm/s) produced the largest differences in static and dynamic coefficients of friction between cultivars against rubber and masonite, respectively. Largest changes in coefficient of friction appeared at 8.33 and 167 mm/s velocities against masonite surface.

## CONCLUSIONS

Velocity is a friction parameter that can damage fruit as a result of sliding of one body against other. This study found that the static and dynamic coefficients of friction increased 30 to 100% with increases in velocity (either preloading and sliding) from 0.42 to 16.62 mm/s. The effect of sliding velocity for both cultivars was more evident on the dynamic coefficient than the effect of preloading velocity on static friction for rubber and plastic. Among velocities, 4.17 mm/s had the largest difference between tested surfaces and cultivars. A second-degree polynomial was the best model to describe the relationship between friction coefficients and velocity.

## REFERENCES


Chen, C. and E.F. Squire. 1971. An evaluation of the coefficient of friction and abrasion damage of oranges on various surfaces. Transactions of the ASAE 14(6): 1092-1094

Chung, J. H. and L.R. Verma. 1989. Determination of friction coefficients of beans and Peanuts. Transactions of the ASAE 32(2):745-750.

Cooper, H.E. 1962. Influence of maturation on the physical and mechanical properties of the apple fruit. M.S. thesis, Pennsylvania State University.

Corey, K.A., D.V.Schlimme, and N.A.Chaney. 1988. Changes in epicuticular wax on watermelon fruits during ripening. HortScience 23(4): 730-731.

Mohsenin, N.N. 1986. Physical Properties of Plant and Animal Materials. Gordon and Breach Science Publishers. New York, NY.

Puchalski, C. and G.H. Brusewitz. 1996a. Techniques for evaluating fruit and vegetable friction and abrasion - a review. Paper No. 96F-043. Eur. Ag. Eng. Madrid.

Puchalski, C. and G.H. Brusewitz. 1996b. Coefficient of friction of watermelon. Transactions of the ASAE 39(2): 589-594

Schaper, L.A. and E.C.Yaeger. 1992. Coefficients of friction of Irish potatoes. Transactions of the ASAE 35(5):1647-1651.

Vis, E. D. Wolf, B.A. Stout and D.H. Dewey. 1969. Experimental evaluation of physical properties of apple fruit pertaining to orientation. Transactions of the ASAE 12(5):673-676, 680.