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INVESTIGATION INTO THE TEST VARIABLES FOUND IN INCLINED PLANE ASTM 3334 AND TAPPI 503 TEST METHODS APPLIED TO WOVEN POLYPROPYLENE FABRIC

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SU-ER JOE

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James W. Goff

James W. Goff, Ph.d.

Major professor

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INVESTIGATION INTO THE TEST VARIABLES FOUND IN INCLINED PLANE ASTM 3334 AND TAPPI 503 TEST METHODS APPLIED TO WOVEN POLYPROPYLENE FABRIC

By

Su-Er Joe

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ABSTRACT

INVESTIGATION INTO THE TEST VARIABLES FOUND IN INCLINED PLANE ASTM 3334 AND TAPPI 503 TEST METHODS APPLIED TO WOVEN POLYPROPYLENE FABRIC

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SU-ER JOE

This paper investigates the test factors involved in friction measurements on woven polypropylene (PP) bag fabrics. The test factors studied include the inclination rate, contact pressure, dwell time, and the usage of foam padding underneath the sled. This study proposed that the lack of acceptable tolerances in test factors associated with the testing method cause the measurement discrepancies.

Single and multiple factor models were utilized. A nonparametric statistical technique, the Kruskal-Wallis H Test, was chosen for analyzing the experimental data. The results obtained showed that, among the four factors tested, only the usage of foam padding had independent effect on the resultant variations. There was little or no effect on friction measurements caused by individually varying the inclination rate, contact pressure, or the dwell time. The interaction of inclination rate and contact pressure had a significant influence on the measurements.

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To my beloved husband, parents and sisters.

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INTRODUCTION

In distribution packaging,sacks are the oldest and most important containers for transporting grain and other small piece solids. With the advent of palletization for filled sack handling, most shipping sacks are stacked on pallets without the benefit of load-locking methods or restraining straps. It has been recognized that the slippage of sacks during shipment and handling causes most troubles.[1]

These problems result in breakage, wasting time, and extra handling expenses, as well as safety concerns for human life. The problems encountered were not in the strength of the sacks, but in their surface anti-skid characteristics. As a result, considerable interest has been generated in the friction measurement of sacks as a routine control to insure adequate skid-resistant performance.[2]

In the sack industry, paper, textile and plastic sacks are the three major categories.[3] The dominant form of paper sack is the multiwall paper sack. Most plastic sacks are low density polyethylene (LDPE) film bags and polyproplene (PP) woven sacks. Up to 1979, paper and textile sack manufacturers encountered both cost competition from the plastic sacks, and the strength requirements needed for effective bulk handling performance. The market for paper and textile sacks declined considerably as a result of the increased substitution of plastic sacks.[4]

According to a 1979 to 1983 UK sack market study, the sales of paper and textile sacks were reduced by 22.91 percent and 52.93 percent respectively. The usage of LDPE heavy duty sacks was also reduced by 18.42 percent. In contrast, the total consumption of PP woven sacks had increased by 25 percent over the same time period. With the decline of paper and textile sacks, many manufacturers in the sack industry have diversified and entered into the production of plastic woven sacks. It is said that the one-trip plastic woven sack is going to be a predominant item in the sack industry.[5]

The typical method for assessing the friction properties of two contacting surfaces is to measure the friction coefficient. Early studies of slip-resistant performance involved the friction measurement of paper and board used in boxes by utilizing the horizontal plane method. But this kind of conventional procedure failed to adequately predict field performance of multiwall paper sacks.[6] Designers voiced the necessity of a more accurate and easily operated friction testing method for sacks.[7] The inclined plane method was then developed from a simulated bag slide angle test to measure the static coefficient of friction for shipping sacks.

In 1967, the inclined plane method was first adopted by the Technical Association of Pulp and Paper Industry as an official standard for testing the friction properties for shipping sack paper.[8] In 1972 and 1973, the inclined plane method was developed for determining the coefficient of friction of corrugated and solid fiberboard. These specifications included TAPPI 815 and ASTM 3248 for measuring the static coefficient of corrugated and solid fiberboard.

With the increasing usage of PP woven sacks, it was assumed by the sack industry that the inclined method for measuring the friction coefficient of paper or fiberboard could be adopted for determining the slip-resistance of plastic woven fabrics. Thus, the TAPPI 503 "Coefficient of Static Friction of Shipping Sack Papers (Inclined Plane Method)" was generally accepted as a standard method for measuring the friction coefficient of plastic woven sacks by the industries and government.[9,10]

In the inclined plane method, when an object is slowly lifted at a constant speed, it is subject to a constant net force,which increases with respect to the friction force. While the friction force exceeds the net force, the object will rest on the original position. Once the net force is greater than the friction force at a certain angle of the incline, the object starts to slide.[11]

In all real cases where sliding between surfaces occurs, the friction forces result in a loss of energy which is dissipated in the form of heat. Thus, friction measuring depends greatly on the angular velocity, mass of the object, and the nature of contacting surfaces among other things.[12]

Few studies have been done on measuring friction for plastic woven fabrics by using the inclined plane method. The adequacy of the generally accepted test for measuring the static coefficient of friction of plastic woven bags is still unknown. According to the preliminary experiments which have been done by the School of Packaging at Michigan State University, there is a high level of variation between laboratories for measuring the friction coefficient of PP woven fabrics. This occurred even when each test was conducted using the same TAPPI 503 testing procedure, but by different testers and operators.

In view of the resultant discrepancies and the importance of slide resistant performance for PP woven sacks, it is imperative to investigate the adequacy of the adopted friction test. Therefore, the purpose of this study is to test for factors in ASTM 3334 and TAPPI 503 which cause variations among laboratory results. Based on a literature review and preliminary experience, this paper proposes that the lack of acceptable tolerances in factors associated with the testing method causes the resulting variations. The major testing factors which will be studied are;

(1) The Inclination Rate.

(2) The Contact Pressure.

(3) Dwell Time For The Contacting Surfaces.

(4) Foam Padding Underneath The Sled.

In addition, this paper evaluates the existing testing procedures to determine their adequacy in determining the frictional properties of plastic woven fabrics.

LITERATURE REVIEW

According to results of sack tests done by the School of Packaging at Michigan State University for Agriculture Stabilization and Conservation Service (ASCS) commodity sacks, slip-resistance is a basic concern for shipping sacks.

The parameter which defines the friction properties of shipping sacks is the friction coefficient for the two contact surfaces. A sack with a high coefficient of friction is expected to resist sliding. A low coefficient indicates potential problems with the sacks slipping off the load.

First, a few words about friction. Consider a block of weight (W) placed on a horizontal surface. In order to move the block, a certain force (F_s) will be required to start the block in motion. Once the block is in motion, a smaller force (F_k) will be needed to maintain an unaccelerated motion. They are expressed mathematically as:

$$F_s = U_s W \text{ .... (1)}$$

and

$$F_k = U_k W \text{ .... (2)}$$

U_s is called the coefficient of static friction, which is the ratio of the force that resists initial motion of the block. U_k is called the coefficient of kinetic friction, which is the ratio of the force once the motion is in progress to the block. Therefore, the problem of determining either the static or the kinetic coefficient of friction involves measuring the weight of the block and the forces required to start and continue motion. In this paper, the static coefficient of friction is of chief interest in measuring the anti-skid performance of PP woven fabrics.

Both static and kinetic friction coefficients can be obtained by either the inclined plane method or the horizontal plane method. The horizontal plane method gives the coefficient of static friction as the force required to overcome friction divided by the weight. Horizontal plane testers are usually large and hard to operate. A more common friction tester uses the inclined plane method, which measures the angle at which slippage begins. The coefficient of static friction is equal to the tangent of this angle.

The first investigations of friction properties for packaging materials were done for paperboard, combined board, and boxes by using the horizontal plane method. When sliding took place, it was observed that there was a series of sticks and slips at certain points on the two contact surfaces. Bowden (1939) interpreted this as being a fundamental property of friction.[13] Others, such as Block (1940) suggested that the problem was due to the nature of the apparatus.[14]

In the beginning of the 1950s, work at The Institute of Paper Chemistry (IPC) was sponsored by several bag companies to study the smoothness properties of paper and paperboard with different friction testers. The friction testers evaluated by IPC were all of the horizontal plane type.

It was found that some instrumentation design factors would affect the static and kinetic coefficients of friction for paper and paperboard. These factors included contact pressure, contact area, and the relative velocity between the surfaces.

After the smoothness testing, the Institute of Paper Chemistry presented five progress reports. In the No. 1 IPC report, dated July 1955, it was revealed that the coefficient of friction is slightly greater for small pressures on large areas than for large pressures on small areas. The kinetic coefficient of friction decreases as the relative velocity increases. It was also proposed that the time of contact between the two surfaces affects the measurements.[15]

In1955, Walter Egan studied the frictional characteristics of plastic films and laminates. In his studies, the inclined plane method and the horizontal plane method were both used to investigate some factors which would affect measurements of the coefficient of friction. Those factors that Egan studied included temperature and humidity as well as contact pressure.[16]

First, Egan compared the friction measurements for various films on both the horizontal and inclined plane methods. The results showed that both methods appeared to have general applicability. Under specified testing procedures, similar results could be obtained.

Secondly, Egan tested various polyethylene films to study the effect of variable factors on friction measurements. In the study of the effect of temperature and humidity, he performed the test at different atmospheric conditions over a temperature range of 70^{o} F. to 94^{o} F. at a constant relative humidity (51%-55%), and over a humidity range of 24% to 81% at a constant temperature (84^{o} F.-89^{o} F.). These temperatures and humidities cover a substantial part of the range which might be encountered in normal testing situations. Results of tests at these various conditions showed that the coefficient of friction of polyethylene films should not be affected under changing atmospheric conditions.

In the study of the effect of contact pressure, Egan used a sled block with a bottom surface of 2 inches width by 4.5 inches length. Contact pressures from 0.04 psi to 0.51 psi were applied. The results showed that no appreciable change in the coefficient of friction of plastic films occurred with the changes of contact pressure.[17]

In 1958, W. W. Appleton studied the friction measurements for multiwall papers by using the horizontal plane method. He found that the relation between the coefficient of friction and the distance traversed changed in an oscillatory manner and in magnitude. The relation of the former part of the test was irregular and fluctuated. The relation of the latter part of the test tended to be more stable. Appleton also proposed that the smoother-finished papers are more subject to irregular behavior in the test. He interpreted this phenomenon as to the increased effect of slight imperfections in the surface of the sample.

In Appleton's studies, the coefficient of static friction for most uncoated papers ranged from 0.55 to 0.85, and their kinetic coefficients are usually within 0.40 to 0.60. Generally, the kinetic friction was from 70% to 80% of the static friction.[18]

In many cases, the static friction was used as the most important criteria to determine the slip-resistant performance of multiwall bags. While measuring the friction coefficient of coated multiwall papers, Appleton found that a relatively light treatment will provide substantial increases for static friction coefficient. When the amount of coating was increased, the static coefficient decreased and the kinetic friction coefficient became greater. Therefore, Appleton proposed that in the development of anti-slip multiwall sacks, the high kinetic friction was primarily responsible for good performance in handling and stacking of filled units.

Up to 1961, the determination of the friction coefficient was still restricted to utilizing the horizontal plane method. Most horizontal plane methods were standardized for determining the friction properties of plastic film,and wax coatings for paper substances. These specifications include the ASTM 1894 "Static and Kinetic Coefficient of Friction of Plastic Film and Sheeting" and ASTM 2534 " Coefficient of Kinetic Friction For Wax Coating".

The testing variables specified in the ASTM 1894, ASTM 2534 and the horizontal plane method used by Appleton for testing multiwall paper are shown in Table 1. From Table 1, one can easily recognize the variances between each technique for testing different materials. In these

Table 1. Comparison of test variables of horizontal plane method in ASTM 1894, ASTM 2534, and IPC friction testing procedures.

Test Factor	ASTM 1894 Static and Kinetic Coefficient of Friction of Plastic Film and Sheeting (1961)	ASTM 2534 Coefficient of Kinetic Friction of Wax Coating (1966)	IPC Friction Test-Static and Kinetic Coefficient of Friction for Board
Sliding Velocity	0.1 ± 0.02 in/sec	0.98 ± 0.02 in/sec	1.56 in/sec
Contact Pressure	12.5 ± 2.5 psi	0.13 psi	0.53 psi
Dwell Time	---	---	---
Foam Padding	12.5 ± 2.5 psi compress 25 %	---	---
Sliding Distance	5 in.	6 in.	Just slide
Test Specimens	5	3	---
Result Recording	1st slide	1 st slide	1st slide

specifications utilizing the horizontal plane method, each specimen is tested once. Only the first slide will be recorded.

From 1961 to 1963, joint efforts were carried out in studying the friction properties of paper sacks to improve the natural slip-resistance of certain multiwall paper grades. When this development work first began, it was found that the horizontal procedures and techniques for measuring surface friction of paper resulted in poor reproducibility. The conventional procedures of conducting single slides failed to adequately predict the field slip-resistant performance of multiwall paper sacks.

A testing program was carried out by R. W. Bolling (1963) to improve testing methods and techniques for the friction measurement of multiwall paper, and to obtain better correlation of controlled frictionmeasuring with actual field performance.[19] This testing program involved studies of the effects of repeated slides, dust on the test material, and relative orientation of the contact surfaces to the paper being tested. He also compared the horizontal plane method with two other simulated bag tests to develop a better testing procedure.

Bolling found that for very rough or embossed surfaces, changes in orientation of the specimens relative to machine direction axis causes variations in the results. For smooth paper surfaces, the orientation changes will not result in significant variation. Sliding two rough surfaces with cross direction to cross direction obtains the highest skid resistance in all orientation arrangements.

In the study of repeated slides, the static coefficient measurements dropped off quite drastically after the first slide, and leveled off at the fourth or fifth slide to a gradual slope. The kinetic coefficient of friction was less variable than the static coefficient of friction, with very little difference in variability between the first and subsequent slides.

Bolling evaluated the effect of handling by using pressure and hand contact. The results showed that the pressure exertion, scuffing, and hand contact will cause false test results. When these influences occurred, the slip-resistance of shipping sack paper was drastically decreased.

The results obtained from the study of the effect of print and dust revealed that print will drastically reduce the skid resistance of bags. On the contrary, the addition of cement dust acted as a very effective nonskid additive in returning the skid resistance to a level almost equal to the unprinted cement dusted level. The cement dust on the bag surfaces improved the slip resistance of the coarse, rough finish grades of paper. The cement dust had little or no effect on the regular finish grades, and drastically lowered the slip resistance of the smooth, hard finish grades of paper.

Acknowledging that the conventional single slide method failed to predict field anti-skid performance, Bolling compared the horizontal plane method with two simulated bag skid tests to determine how well the horizontal plane method would correlate with actual bag skid performance. One of the simulated methods was a homemade bag slide angle device for measuring the static coefficient of friction. The other device was a pendulum impact tester normally used for measuring the impact resistance of corrugated boxes.

In order to simulate field conditions, the filled test sacks and test specimens were dusted with cement prior to testing. The paper surfaces in contact were oriented machine direction to cross direction. The orientation of the machine and cross directions was intended to simulate the crossing pattern of bags during palletizing. Only unprinted sacks and paper were tested. Tests were conducted on several grades of papers.

The results showed that only the bag

slideangle test was directly comparable with the horizontal plane method. The static coefficient of friction obtained from the slide angle tester was considerably lower than those obtained from the horizontal plane method but follow generally the same rate of deterioration with repeated slides.

In the impact test, the distance the bag slides after impact included a measure of the combined resistance of static and kinetic friction forces. The results obtained from the bag impact test can not be directly related to static or kinetic friction independently.

In 1963, a round-robin test was carried out under the direction of the Shipping Sack Testing Committee and the Technical Association of the Pulp and Paper Industry, to correlate the data collected by three different groups of testers in ten laboratories. The three groups of testers included 9 homemade and 2 different commercially available devices. The homemade devices were the inclined plane testers and horizontal testers.

The results of the round robin test showed that there exists significant result variations between laboratory-to-laboratory and tester-to-tester. H. C. Martin (1963) proposed that the measurement discrepancy was from instrument variance as well as operator variance within the friction testers. He also proposed that the contact pressure was not a major factor contributing to the high level of variance.

Based on the studies done by Bolling, Martin and The Institute of Paper Chemistry, the TAPPI 503 "Coefficient of Static Friction of Shipping Sack Paper" was prepared by the Paper Shipping Sack Testing Committee in 1967. This method was written specifically for an inclined plane apparatus.

Later studies have indicated significant variability in the slide angles obtained from the first to subsequent slides. The TAPPI 503 considered the first slide as a preconditioning slide, and the third slide was recorded. In the inclined friction test, the orientation of machine to cross direction was chosen to simulate the cross-locking of bags during palletizing. Other factors such as inclined speed, contact pressure, and dwell time were specified in the TAPPI 503 method.

There are some inclined plane methods derived from TAPPI 503, and used for measuring the coefficient of static friction of corrugated and solid fiberboard by using the inclined plane method. These specifications include TAPPI 815 (1972) and ASTM D-3248 (1973).

In 1974, the American Society For Testing And

Materials published ASTM D-3334, "Standard Method of Testing Fabrics Woven From Polyolefin Monofilment". In ASTM D 3334, the testing method for measuring the coefficient of static friction on woven polyolefin fabric is directly derived from the TAPPI 503. Therefore, the inclined plane method, which was first developed for measuring the friction properties of shipping sacks paper, was standardized for determining the slip-resistant performance of plastic woven bags. The testing variables consisting of TAPPI 503, TAPPI 815, ASTM 3248 and ASTM 3334 are compared in Table 2.

In TAPPI 503 testing procedures, there are three test variables which have wide tolerances. One test variable concerns the inclination rate. The inclination rate is 1.5 $\pm$ 0.5 degree/second. This indicates that the friction measurements will not be changed significantly when changing the inclination rate from 1 degree/second to 2 degree/second. The difference between the maximum and minimum, inclination rate is 100 percent of the slowest inclined speed.

The second testing variable which has a wide tolerance is the weight of the sled. In the TAPPI 503 standard, the contact pressure will be varied from 0.24 psi to 0.16 psi with a bottom area of 14 square inches. Therefore, the weight of the sled varied from 2.24 pounds

Table 2. Comparison of test variables of inclined plane method in TAPPI 503, Tappi 815, ASTM 3248, and ASTM 3334 friction testing procedures.

Test Factor	TAPPI 503 Coefficient of Static Friction of Shipping Sack Paper (1967)	TAPPI 815 Coefficient of Static Friction of Corrugated and Solid Fiberboard (1972)	ASTM 3248 Coefficient of Static Friction of Corrugated and Solid Fiberboard (1973)	ASTM 3334 Coefficient of Static Friction of Woven Polyolefin Fabric (1974)
Inclination rate	1.5 ± 0.5 degree/sec	1.5 ± 0.5 degree/sec	1.5 ± 0.5 degree/sec	1.5 ± 0.5 degree/sec
Contact Pressure	0.2 ± 0.04 psi	0.2 ± 0.1 psi	0.2 ± 0.1 psi	0.2 psi
Dwell Time	30 ± 5 sec	---	---	30±3 sec
Foam Padding	12.5 ± 2.5 psi compress 25 %	---	---	---
Test Specimens	5	5	5	3
Result Record	3rd slide	3rd slide	3rd slide	3rd slide

to 3.36 pounds. The difference between the heaviest and lightest weight of the sled will be 50 percent of the lightest sled weight.

The third testing variable which has large tolerance is dwell time. In the standard procedure, the dwell time can be changed from 25 seconds to 35 seconds.

The fourth testing variable concerned is the application of foam padding. As an alternative to clamping, the bottom surface of the sled may be covered with foam padding of the same dimensions as the sled. In the TAPPI 503, the foam should have a smooth surface, and require 12.5 $\pm$ 2.5 psi pressure to compress it 25%.

Foam padding on the sled is believed to more closely simulate the non-rigid contact normally found between shipping sacks. In addition, it compensates for any small deviations in flatness of the plane or sled, and reduces the likelihood of the hard edge of the sled from influencing the results.[20]

MATERIALS AND METHODS

(1) MATERIALS AND SAMPLE PREPARATION

All the materials are supplied by the Poly Sac Inc.,Houston, Texas: uncoated, unprinted, and 23" wide PP circular woven fabrics packed as a bale of tubular unsewn sacks. These tubular sack fabrics consist of 9 picks/inch in both warp and weft direction. Upon arrival at the School of Packaging, the bale of circular woven fabrics were immediately placed in a laboratory with TAPPI standard condition of $73.0 \pm 3.5\ ^{o}$ F. and $50 \pm 2\%$ R.H.

Because the quality variability of this roll of woven fabrics is unknown, it is doubtful whether the samples taken from the outer part of a roll of tubular woven fabrics will represent also the inner part of the roll. In order to eliminate the quality variability, all specimens were cut before the test began and then distributed to each group of test units on a statistical random basis.

Specimens were taken from the belly of the tubular woven sacks. The cutting pattern is shown in Figure 1.

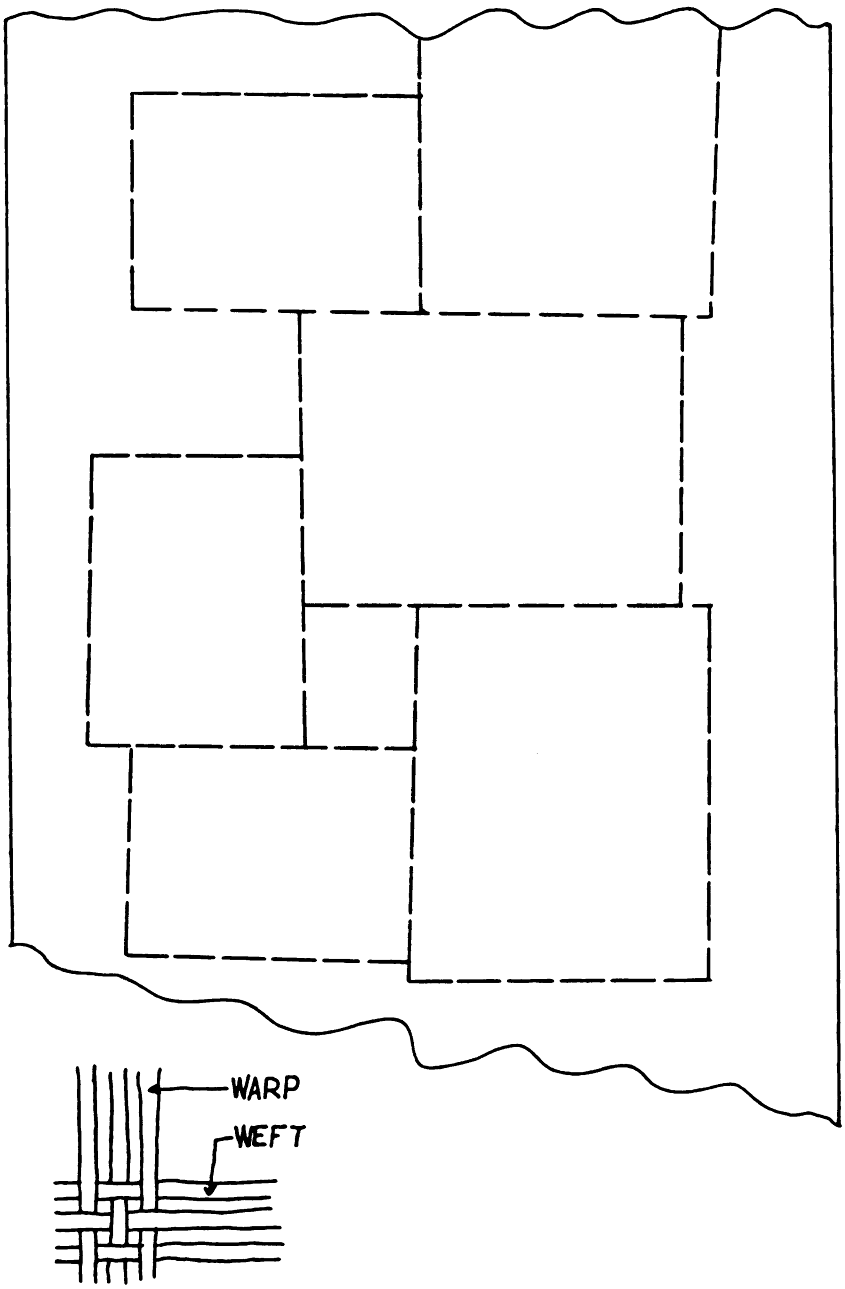


Figure 1 Cutting pattern of tubular woven PP fabrics

Only the outside surfaces of the woven fabric was tested. Each specimen consisted of two sheets. One of the two sheets was cut as 5" by 8" to be affixed to the sled and will extend beyond the side edge of the sled. The other test sheet was cut 6" by 10" to be affixed to the surface of the inclined plane and to be large enough to cover the working surface of the plane.

In order to simulate the cross-locking patterns of sacks during palletizing, the orientations of the top and bottom sheets in each specimen are chosen to be warp direction to weft direction. As long as the warp directions of the two specimen sheets are perpendicular to each other, it does not matter which one is parallel to the inclined plane. The woven sack manufacturing is described in Appendix A.

(2) TESTING APPARATUS

There is a wide variety of friction testers designed in accordance with the TAPPI 503 standard -- The Inclined Plane Method. Costs for commercial TAPPI slide angle testing apparatus range from $1,500 to $4,000. This high cost has prompted bag makers to build the friction testers themselves.

There are two types of homemade inclined plane testers commonly used in the sack industry. One is driven by motor, the other is operated by hand. The typical problem experienced in homemade motor driven inclined plane testers is finding a power source that will provide a rate of inclination as slow as 1.5 $\pm$ 0.5 degree/second. The difficulty encountered by homemade hand-operated inclined plane testers is finding a lifting action that will be smooth and constant.

In order to solve these problems, the power source used in the inclined plane testers must be variable in the low speed range. In addition, power must have sufficient torque to provide a constant rate of inclination overcoming all the associated friction of the testing apparatus.

Therefore, the apparatus used in this study is an inclined plane device attached to an MTS crosshead mechanism, which is utilized as the power source to lift the inclined plane. The MTS T-5000 tensile tester consists of electronic servo-controlled DC motors. This completely eliminates mechanical screw changing. By changing the range of crosshead speed the tension will be able to provide a variable speed and constant torque for each speed setting. The assembly of the inclined plane apparatus and the MTS T-5000 tensile tester is shown at Figure 2.

The inclined plane device consists of a rigid

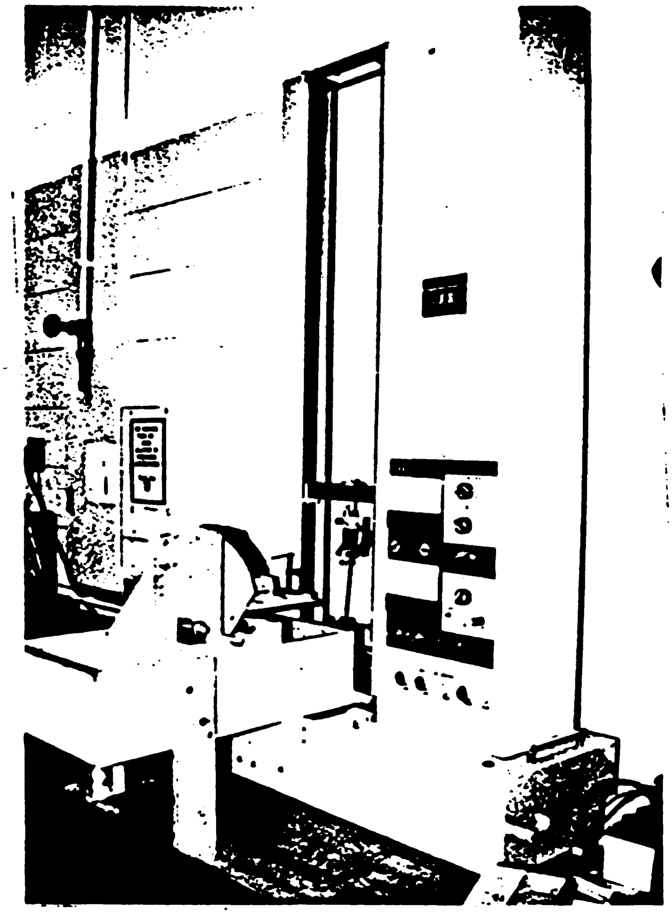
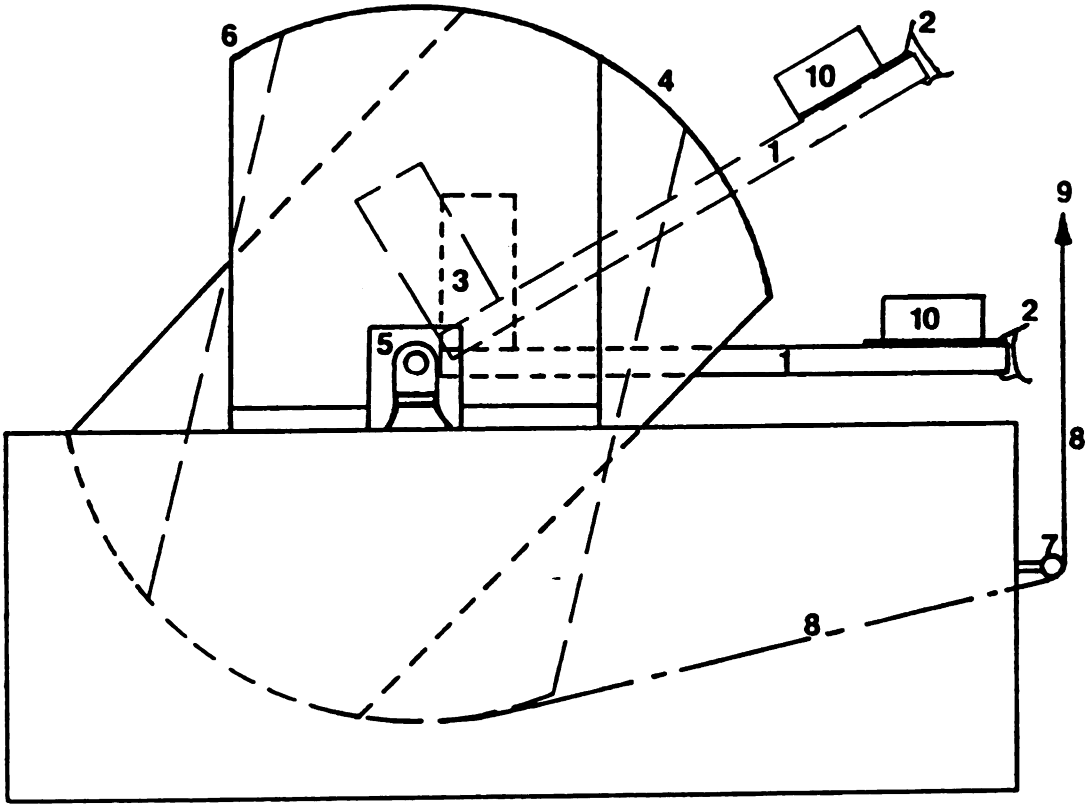


Figure 2 Assembly of inclined plane device and MTS T 5000 tensile tester

plane made of plywood measuring 6" by 12.5" attached to a portion of a wheel. A clamp is provided at the upper end of the plane to hold the bottom sheet on the plane. A bumper stop and hinge were also utilized at the lower end of the plane. The schematic of the inclined plane device is shown in Figure 3.

The portion of a wheel consists of an arc which is a 60 degree segment of a circle with a 14.75" radius. It is rotatably fixed at its midpoint to the hinge of the lower end of the plane. There is another non-rotatable counter mount with a mark lined up at 0 degree of the segment of the wheel portion when the plane is laid horizontally. While the inclined plane is tilted, the angle of slide can be read from the angular displacement between the reading on the wheel portion and the mark on the counter mount. The plane can be lifted at variable rates of inclination by changing the crosshead speed of the tensile tester.

In this study, three pieces of aluminum blocks were prepared for the sled. They all had same flat surface but different thicknesses and weights. One of them was 3" x 4" x 1.5" and weighed 2.25 lbs. The other two were 3" x 4" x 0.375" and weighed 0.55 lbs each. When the 2.25 lb block was used, the sled provided a pressure of 0.16071 psi. When one 0.55 lb block was attached onto the 0.25 lb



1. Inclined Plane
2. Clamp
3. Bumper
4. Portion of Wheel
5. Hinge
6. Counter Mount
7. Pulley
8. Strap
9. MTS T 5000 Tensile Tester
10. Aluminum Block

Figure 3 Schematic of the inclined plane device block, a pressure of 0.2 psi was exerted. When two 0.55 lb blocks and the 2.25 lb block were used, a pressure of 0.2394 psi was obtained.

A stopwatch accurate to one hundredth of a second was used as the timing device. A clip was also used on the top of the sled to clamp the leading edge of the top sheet. As an alternative to clamping, a foam was prepared to be attached under the bottom surface of the sled. As required in the TAPPI standard, the foam padding used in this study was Evalite, which had the same contact dimensions as the sled and would compress 25% when a pressure of 12.5 ± 0.5 psi is applied.

(3) TESTING PROCEDURES

Specimens were preconditioned and test was conducted in accordance with ASTM D 1776 "Conditioning Textiles and Textile Products for Testing." The testing procedures for measuring the friction properties are in accordance with the TAPPI T 503 om-84 "Coefficient of Static Friction of Shipping Sack Papers (Inclined Plane Method)".

Before each slide, the inclined plane was levelled that it is horizontal when the arc indicates zero. The bottom sheet of the specimen was mounted on the plane with its outside surface upward. The top sheet of the specimen was attached to the sled with its outside surface downward.

Without exerting undue pressure, the sheet-affixed sled was placed on top of the bottom sheet. The length of the sled should be parallel to the length of the plane. When the contacting surfaces of the two sheets were placed so that their warp directions at right angles. A period of dwell time was allowed for the surfaces in contact. The plane was slowly elevated until the sled starts to slip. Then, the plane was returned to a level position.

The sled and attached specimen were carefully placed on the assembly in its original starting position with the plane in its horizontal position. The test was repeated for a total of three slides. The angular displacement of slide was recorded in degrees to the nearest 0.5 degree at the moment the sled started to slip. Only the angular displacement of the third reading was used in data analyzing.

(4) PILOT STUDY

Because the quality variability and the anti-skid properties of uncoated PP woven fabrics were unknown, a pilot study was first conducted to obtain some basic idea about the slip-resistant performance of the woven fabrics being tested. This preliminary experiment included the studies of the effect of repeated slides, inclination rate, contact pressure, dwell time, and foam padding on friction measuring. The findings from this pilot study were used to determine the experimental models and statistical analysis techniques used in this paper.

The results for the repeated slides showed that the relation between slide angles and repeated slides changed in an oscillatory manner. The relation changed markedly and slide angles dropped off drastically after the first slide. This difference of angles between each slide diminished after the second slide.

The effect of repeated slides on friction measurements of PP woven fabrics corresponded with that of shipping sack paper. Therefore, the recording of the third slide specified in TAPPI 503 can be well adopted for determining the frictional properties of PP woven sacks. This concept is also fortified by the belief that shipping sacks in the distribution environment will encounter multiple handling. Thus, the first two slides were considered as preconditioning slides and only the third slide was recorded.

According to the TAPPI 503 slide angle test, the friction measuring should be conducted at an inclination rate of 1.5 $\pm$ 0.5 degree/second with a contact pressure of

0.2 ± 0.04 psi, and for a dwell period of 30 ± 5 seconds. Thus, in the study of the effect of testing variance, tests were made to identify the variance of four test factors. They were inclination rate, contact pressure, dwell time and foam padding. Each factor consisted of two sub-levels. One was its maximum allowance. The other was the minimum allowance specified in TAPPI standard.

Tests of the effect of inclination rate were made at 1 degree/second and 2 degree/second. The effect of contact pressure was tested on 0.24 psi and 0.16 psi. The contact area was held constant (3" x 4") while the weight of sled was varied. Test of the effect of dwell time on the friction measurements was determined by using 25 seconds and 35 seconds. The effect of foam padding was identified by comparing the results obtained by attaching a piece of foam under the bottom surface of the sled with those obtained without foam padding. Based on the Central Limit Theorem[21], sixteen specimens were selected for each test treatment.

Results of the pilot investigations showed that the variance of inclination rate, contact pressure and dwell time have little or no effect on the friction measurements of PP woven fabrics. The usage of foam padding was found to affect the friction measuring. There is difference between results obtained by using sled with foam and those obtained by using sled without foam. However, this difference was not very significant. In view of this, it is necessary to increase the sample size used in each test treatment to make the analysis more effective.

(5) EXPERIMENTAL ANALYSIS MODELS

Two analytical models were employed. One was the single factor analysis. The other was the multiple factor analysis. The purpose for studying the single factor model was to identify the independent effect of testing factors on friction measuremets. The purpose for studying the multiple factor model was to determine whether the multiple test variance will cause the resulting variations.

In the single factor analysis model, friction measuring was tested as a function of inclination rate, contact pressure, dwell time and foam padding. Each single factor study consisted of two sub levels. They were the maximum and minimum allowance of test factors specified in the TAPPI 503 standard. The experimental methods designed for single factor analysis is shown in Table 3. Eight test treatments were selected. Twenty five pairs of specimens were tested for each treatment.

Since the friction force is a form of loss of energy, the coefficient of friction depends on the angular

Table 3. Design of experimental treatments for single factor model.

Test Variance	Treatment No.	Test Factor			
		Incli-nation Rate	Contact Pressure	Dwell Time	Foam Padding
Inclination Rate	1	1^{o}/sec	0.2 psi	30 sec	No
	2	2^{o}/sec	0.2 psi	30 sec	No
Contact Pressure	3	1.5^{o}/sec	0.16 psi	30 sec	No
	4	1.5^{o}/sec	0.24 psi	30 sec	No
Dwell Time	5	1.5^{o}/sec	0.2 psi	25 sec	No
	6	1.5^{o}/sec	0.2 psi	35 sec	No
Foam Padding	7	1.5^{o}/sec	0.2 psi	30 sec	Yes
	8	1.5^{o}/sec	0.2 psi	30 sec	No

velocity and the nature of contacting surfaces. Therefore, in the multiple factor analysis, inclination rate and contact pressure are of chief interest to be studied in this paper. The experimental design for multiple factor analysis is shown in Table 4. Four treatments were selected from a combination of the maximum and minimum allowances of inclination rate and contact pressure.

(6) **STATISTICAL ANALYSIS TECHNIQUE**

Based on the results obtained from the pilot study, the probability distribution of the friction measurements is not constant and may be decidedly non-normal. It might be very flat, peaked or strongly skewed to one side of the distribution.

The static coefficient of friction, which is the maximum slip resistance to the initial sliding, involves the measurements of extreme values. Therefore, the normal distribution analytical techniques, which are not suitable for analyzing extreme values, are not adequate to analyze the friction measurements.

Nonparametric statistical technique, the Kruskal-Wallis H Test, is employed to analyze the effect of two contrast variances for each test factor on friction measuring. This analytical technique is utilized by

Table 4. Design of experimental treatments for multiple factor model.

Treatment	Test Variance			
No.	Inclination Rate	Contact Pressure	Dwell Time	Foam Padding
1	1^{o}/sec	0.16 psi	30 sec	No
2	1^{o}/sec	0.24 psi	30 sec	No
3	2^{o}/sec	0.16 psi	30 sec	No
4	2^{o}/sec	0.24 psi	30 sec	No

ordering the experimental data according to their relative magnitudes rather than their actual numerical values. The Kruskal-Wallis H Test is described in Appendix B.

Investigations will focus on the precision of the TAPPI 503 and ASTM 3334 standard for measuring the static coefficient of friction for PP woven fabrics. Therefore, the discussions will be based on the distribution of friction measurements and the concentration of the distribution shapes. The more concentrated the distribution is, the more precise results will be obtained, and the less result variations will occur.

RESULTS AND DISCUSSIONS

A. SINGLE FACTOR MODEL

In the single factor analysis, only the usage of foam padding has significant effect on friction measurements of PP woven fabrics. Twenty five pairs of speciments were tested in each treatment. The effect of each testing factor studied in single factor analysis is discussed as follows.

(1) Inclination Rate

The effect of inclination rate on the friction measurements for PP woven fabrics is determined. Tests were made at two inclination rate settings. One was at 1 degree/second, the other was at 2 degrees/second by using 0.2 psi contact pressure and 30 seconds dwell period. It was found that the inclination rate has no significant influence on friction measuring for woven PP fabrics.

Table 5 shows the third slide angles obtained. The probability distribution of these results is shown in Figure 4. The friction measurements obtained at 1 degree/second ranged from 22.0 degrees to 32.5 degrees.

Table 5. Friction measurements of PP woven fabrics at test variables: 1^{o} /sec and 2^{o}/sec.

Specimen No.	Friction Measurements at 1^{o} /sec (degrees)	Rank	Friction Measurements at 2^{o} /sec (degrees)	Rank
1	24.5	17	27.5	39
2	23.0	4.5	32.0	48
3	30.0	45	29.0	41.5
4	29.5	43.5	25.5	28.5
5	25.5	22.5	27.0	37
6	25.5	28.5	25.0	22.5
7	23.0	4.5	23.5	8
8	26.5	33.5	25.0	22.5
9	24.5	17	23.0	4.5
10	25.5	28.5	34.0	50
11	32.5	49	27.0	37
12	24.5	17	29.5	43.5
13	26.5	33.5	24.0	12.5
14	25.0	22.5	25.5	28.5
15	31.0	47	25.0	22.5
16	23.5	8	27.0	37
17	23.0	4.5	28.5	40
18	29.0	41.5	24.0	12.5
19	24.0	12.5	24.0	12.5
20	24.0	12.5	30.5	46
21	23.5	8	25.0	22.5
22	22.0	1	25.0	22.5
23	25.0	22.5	22.5	2
24	24.0	12.5	26.5	33.5
25	26.0	31	26.5	33.5
Rank Sums		567.5		707.5
H Value	1.73793			

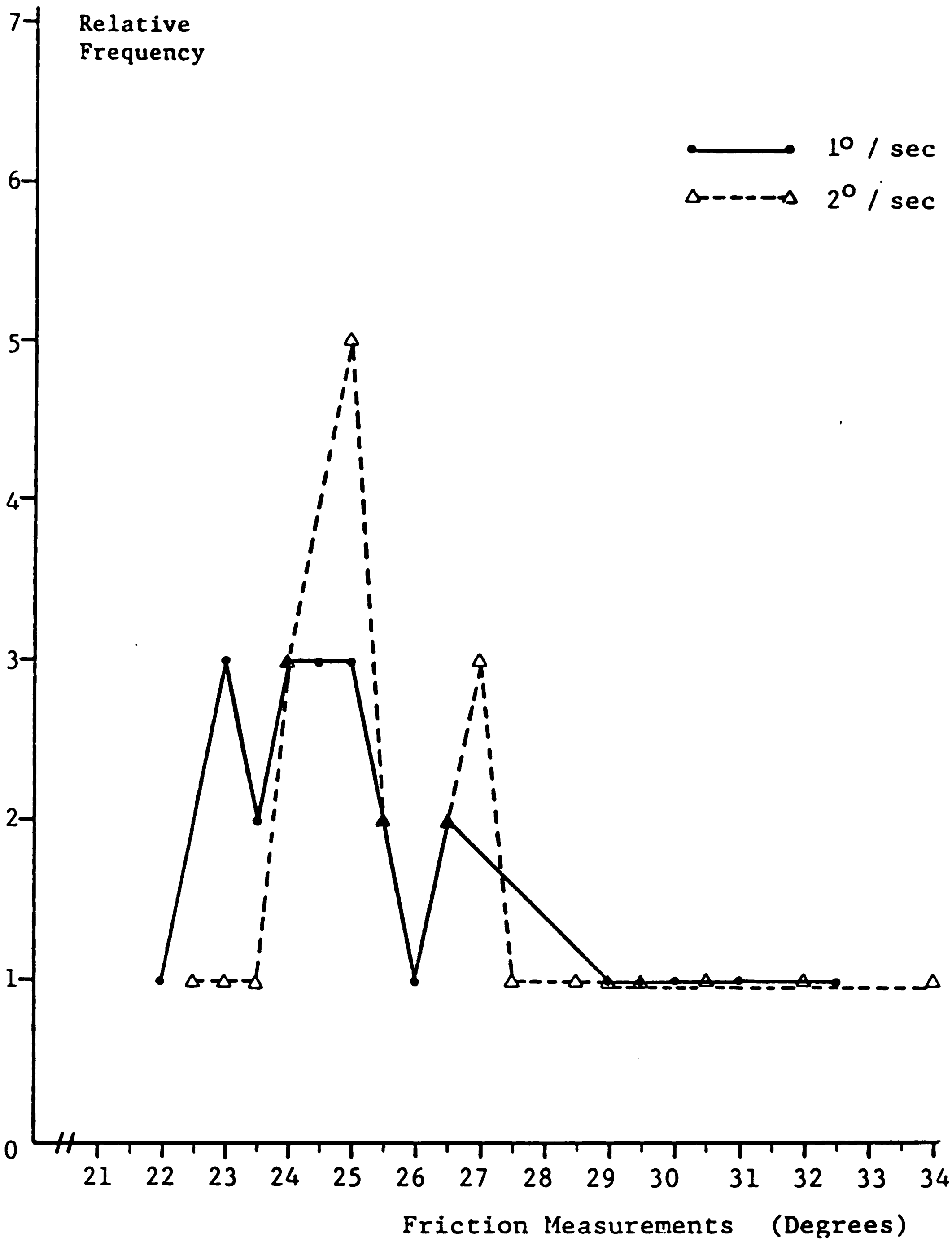


Figure 4 Distributions of friction measurements at 1°/sec and 2°/sec inclined speed

The results obtained at 2 degrees/second varied from 23.0 degrees to 34.0 degrees. It can be seen from the Figure 4 that the distribution shapes of these two treatments are both fairly wide and inconsistent. This indicates that the variance of inclination rate may cause variable friction measurements to an appreciable extent. However, by using the nonparametric statistical analysis, the variance of inclination rate has no significant effect on the friction measuring.

In Figure 4, the distribution of friction measurements obtained at 1 degree/second is quite flat. The distribution shape plotted for the 2 degree/second one is relatively peaked. In view of the shape discrepancy, it is not quite adequate to conclude that the inclination rate specified in TAPPI standard is suitable for measuring the anti-skid properties of PP woven bags. Therefore, in order to detect the real difference between these two treatments, it is necessary to increase the statistics power by increasing the number of the sample size.

(2) Contact Pressure

Contact pressure from 0.16 psi to 0.24 psi was used for these tests. The contact area was held constant (3.5" x 4" = 14 inches square) while the weight of the loading sled was varied. The friction measurements obtained at 0.16 psi and 0.24 psi are shown in Table 6. Figure 5

Table 6. Friction measurements of PP woven fabrics at test variables: 0.16 psi and 0.24 psi.

Specimen No.	Friction Measurements at 0.16 psi (degrees)	Rank	Friction Measurements at 0.24 psi (degrees)	Rank
1	25.0	25	25.0	25
2	25.0	25	28.0	44.5
3	27.5	42.5	25.0	25
4	25.0	25	24.5	15.5
5	28.0	44.5	27.5	42.5
6	30.0	49.5	27.0	41.0
7	24.5	15.5	25.0	25
8	24.5	15.5	25.5	32.5
9	30.0	49.5	23.0	4
10	23.0	4	25.5	32.5
11	26.5	40	23.0	4
12	25.0	25	25.0	25
13	25.0	25	28.5	47
14	23.0	4	23.5	8
15	24.5	15.5	26.0	37
16	23.5	8	24.5	15.5
17	25.0	25	25.5	25
18	23.5	8	28.5	47
19	26.0	37	25.5	37
20	26.0	37	24.5	15.5
21	28.5	47	24.5	15.5
22	25.5	32.5	24.0	10.5
23	26.0	37	23.0	4
24	24.5	15.5	21.5	1
25	26.0	37	24.0	10.5
Rank Sums		689.5		585.5
H Value	1.01798			

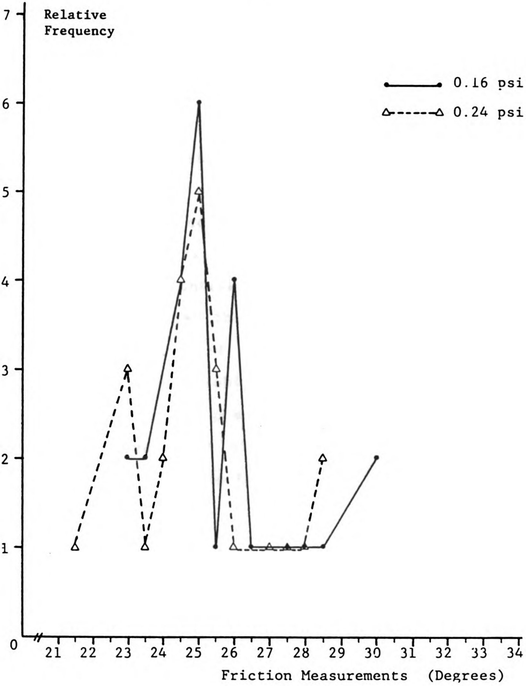


Figure 5 Distributions of friction measurements at 0.16 psi and 0.24 psi contact pressure

shows the plots of friction measurements versus relative frequencies of these two treatments.

There is a conflict between Bolling (1963) and Martin (1963) on the effect of contact pressure for determining the anti-skid properties of multiwall paper. Bolling reported that the pressure of exertion will cause false test results and decrease the slip resistance of multiwall paper. Martin proposed that contact pressure is not a major factor contributing to the result variations. Egan (1955) found that the contact pressure would only affect the coefficient of friction for plastic films and laminates to an appreciable extent. In the single factor studies, when contact pressure varied from 0.16 psi to 0.24 psi, the variance of contact pressure causes no significant difference on the friction measurements of PP woven fabrics.

Table 6 and Figure 5 show the results and distributions obtained at 0.16 psi and 0.24 psi. In Figure 5, the friction measurements obtained by applying 0.16 psi varied from 23.0 degrees to 30.0 degrees. The results obtained by exerting 0.24 psi ranged from 21.5 degrees to 28.5 degrees. The distributions of these two treatments are consistent with each other and concentrate on the same range of measurements.

Most of the friction measurements obtained with 0.16

psi are slightly higher than those obtained with 0.24 psi. This may be related to the general idea that light contact pressure tends to give higher coefficient of friction than the heavy contact pressure. However, it can not be concluded that the smaller pressure will result in higher coefficient of friction. The experimental data reveals that within the range of 0.2 $\pm$ 0.04 psi the variance of contact pressure is not a significant factor to influence the friction measuring for PP woven fabrics.

(3) Dwell Time

To study the effect of dwell time, the weight was allowed to initially rest on the specimen for 25 seconds and 35 seconds. The results obtained are shown in Table 7 and the friction measurements versus relative frequencies are plotted in Figure 6. .

It can be seen from Figure 6 that the distribution shapes of these two treatments have a certain degree of consistency. Both of them are concentrated on the same range of friction measurements. This indicates that no matter which dwell time was utilized, 25 seconds or 35 seconds, the results will be only varied to a certain appreciable extent.

Using Kruskal-Wallis H Test, it can be concluded that the variance of dwell time has no significant effect

Table 7. Friction measurementsof PP woven fabrics at test variables: 25 seconds and 35 seconds.

Specimen No.	Friction Measurements at 25 seconds (degrees)	Rank	Friction Measurements at 35 seconds (degrees)	Rank
1	23.5	6.5	22.5	1.5
2	24.5	16	23.5	3.5
3	27.0	44	23.0	3.5
4	23.5	6.5	26.5	39.5
5	24.0	11	24.0	11
6	25.0	24	23.5	6.5
7	25.5	31.5	23.5	6.5
8	24.0	11	25.0	24
9	24.5	16	26	35.5
10	24.5	16	25.0	24
11	22.5	1.5	24.5	16
12	26.0	35.5	26.5	39.5
13	24.5	16	25.5	31.5
14	26.0	35.5	27	44
15	25.0	24	26.0	35.5
16	30.5	49	25.0	24
17	27.0	44	28.5	48
18	27.0	44	32.5	50
19	26.5	39.5	25.0	24
20	25.0	24	25.5	31.5
21	28.0	47	27.0	44
22	26.5	39.5	25.0	24
23	25.0	24	25.0	24
24	24.0	11	25.5	31.5
25	25.0	24	24.0	11
Rank Sums		641		634
H Value	0.00461			

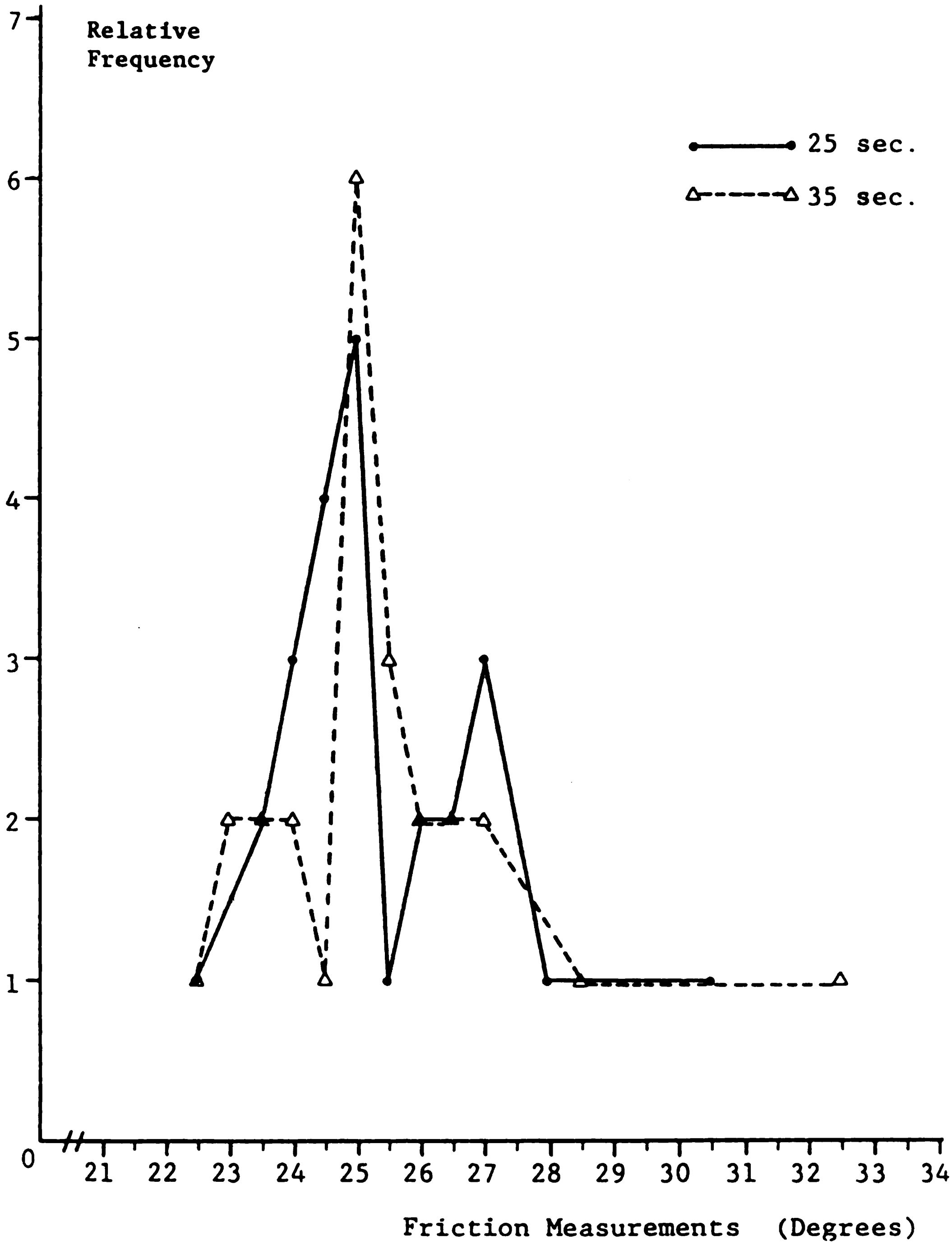


Figure 6 Distributions of friction measurements at 25 sec. and 35 sec. dwell time

on friction measuring for PP woven fabrics at 0.05 significance level.

(4) Foam padding

Tests were conducted with two sub-levels. One treatment consisted of a foam padding attached on the bottom surface of the sled. The other used no foam treatment on the aluminum sled. Table 8 and Figure 7 show the friction measurements and result distributions of these two treatments. It is found that the usage of foam padding has significant effect on friction measuring for PP woven fabrics.

The friction measurements of with foam treatment ranged from 21.0 degrees to 28.0 degrees. The friction measurements obtained from no foam treatment varied from 24.0 degrees to 35.0 degrees. In Figure 7, the width of the distribution for with foam treatment is relatively narrow and has two peaks. The distribution shape for no foam treatment is fairly wide and concentrated on one side of the distribution. Using Kruskal-Wallis nonparametric analysis, the two groups of friction measurements obtained by these two treatments are different at 0.025 significance level.

As mentioned above, the distribution shape of the treatment without foam is fairly wide. This variance may be caused by the irregularities of the contacting

Table 8. Friction measurements of PP woven fabrics at test variables: with foam and no foam padding on sled.

Specimen No.	Friction Measurements with foam (degrees)	Rank	Friction Measurements without foam (degrees)	Rank
1	24.5	11.5	25.5	21.5
2	25.5	21.5	26.0	28
3	25.0	15.5	26.0	28
4	24.0	7	25.5	21.5
5	24.5	11.5	26.5	32.5
6	27.5	41.5	24.0	7
7	27.5	41.5	27.5	41.5
8	27.5	41.5	34.0	49
9	26.5	32.5	26.0	28
10	25.5	21.5	26.0	28
11	24.5	11.5	26.5	32.5
12	27.5	41.5	31.5	47.5
13	24.0	7	27.0	36.5
14	27.5	41.5	25.5	21.5
15	25.0	15.5	25.0	15.5
16	22.5	2.5	31.5	47.5
17	23.0	4	26.5	32.5
18	25.5	21.5	35.5	50
19	27.5	36.5	25.5	21.5
20	28.0	45.5	28.0	45.5
21	24.0	7	26.0	28
22	21.0	1	27.0	36.5
23	24.0	7	25.5	21.5
24	22.5	2.5	24.5	11.5
25	25.0	15.5	27.0	36.6
Rank Sums		505.5		769.5

H Value: 6.41011 $X_{0.025} < H < X_{0.010}$

The two groups are significant different at 0.025 significance level.

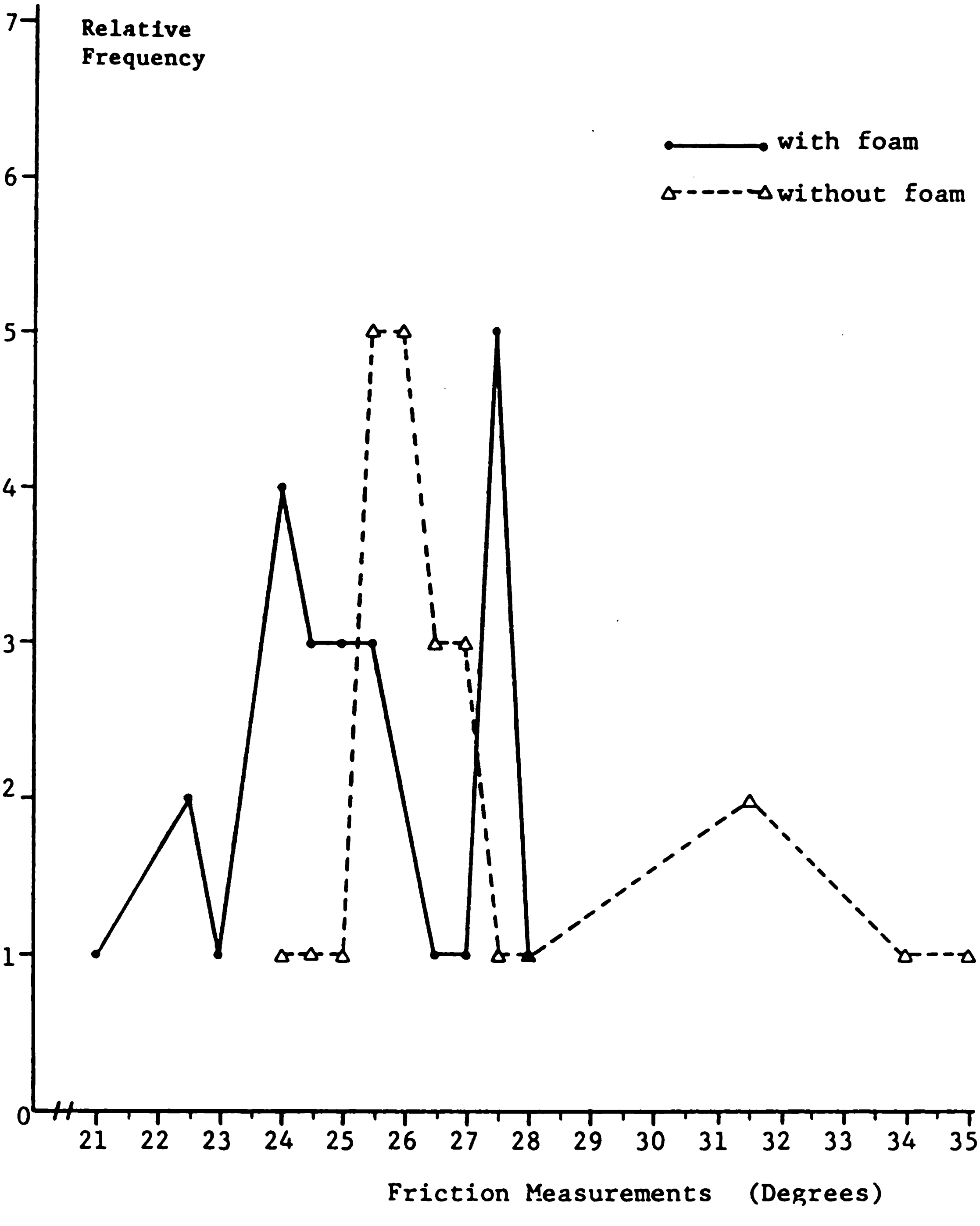


Figure 7 Distributions of friction measurements with foam and without foam padding

surfaces on PP woven fabrics. When the foam-wrapped sled rests on the bottom specimen sheet, contact between small protrusions and depressions will provide some effort to shift the surfaces relative to each other. The effort will be greater the more intimate the contact surfaces.

In the tests made without foam padding, the contacting surfaces between two sheets are not totally intimate. There are some impending areas to make some protrusions on the surfaces of the two sheets hooked together. Thus, a force which is against the friction force is provided. On the contrary, when tests were made by using foam padding, the intimate areas between two contacting surfaces will be increased. The irregularities of the surfaces are pressed by the foam and a lower friction force is obtained.

B. MULTIPLE FACTORS ANALYSIS

The study of multiple factors analysis intends to explore the interactive effect of inclination rate and contact pressure on friction measurements of PP woven fabrics. Table 4 presents the treatment levels and combinations of testing factors used in this model. Table 9 exhibits the friction measurements obtained.

In Table 10 are shown the selective pairwise comparisons and their significance. The distributions of

Table 9. Friction measurements of PP woven fabrics by using multiple test variables.

Specimen No.	Friction Measurements (degrees) 1°/sec 0.16psi	1°/sec 0.24 psi	2°/sec 0.16 psi	2°/sec 0.24 psi
1	25.5	28.0	27.0	25.5
2	24.0	23.5	25.5	25.5
3	25.0	27.0	27.0	27.0
4	23.5	25.0	24.5	24.5
5	22.5	23.0	25.0	26.0
6	23.0	24.5	25.0	26.5
7	23.5	25.0	25.0	26.0
8	24.0	26.0	27.0	25.5
9	24.0	24.5	25.0	24.0
10	25.0	27.5	28.5	28.5
11	23.5	26.5	28.0	24.0
12	27.0	25.5	23.5	24.0
13	21.5	27.0	24.5	25.0
14	27.5	25.5	24.5	24.0
15	23.5	23.5	23.5	25.0
16	27.0	26.5	27.5	26.5
17	22.5	25.5	21.5	27.0
18	24.5	25.0	22.5	25.0
19	23.0	25.0	25.0	32.5
20	32.0	27.5	31.0	26.0
21	26.0	25.0	25.0	23.0
22	26.0	27.5	26.0	26.0
23	24.5	27.5	25.0	32.5
24	27.0	27.5	29.0	24.5
25	22.5	27.5	24.5	28.5

Table 10. The selective pairwise comparisons of friction measurements for PP woven fabrics at multiple test variables.

Pairwise	H Value	Effect of Multiple Test Variance
T1 - T2	2.08950	NS
T3 - T4	0.35021	NS
T1 - T3	3.39765	S
T2 - T4	1.44715	NS
T1 - T4	5.78861	S*
T2 - T3	1.99153	NS

T : Treatment No. in multiple factors model

S : Significant, significance level at 0.10

S* : Significant, significance level at 0.025

NS : Not significant

friction measurements for each pairwise comparison are plotted in Figure 8 through 13. With regard to the significance between the effect of inclination rate and contact pressure on fiction measuring of PP woven fabrics the following were observed.

The variance of contact pressure has no significant effect on friction measuring at each same inclination rate setting. The variance of inclination rate has slightly effect (at 0.10 significance level) on friction measurements when a contact pressure of 0.16 psi was used. However, the variance of inclination rate has no significant effect on results when a contact pressure of 0.24 psi was used. It was also found that a 0.025 significant difference appeared when tests were made at 1 degree/second with 0.16 psi contact pressure, while the results showed no difference when tests were made at 2 degrees/second with 0.24 psi contact pressure.

Focusing on the interactive effect of the variances between inclination rate and contact pressure, the friction measurements are subject to the variance of inclination rate when tests were made at low contact pressure. This can be found from Table 10 by comparing the significance of T1-T2 with that of T2-T4. The difference of friction measurements will be amplified between tests made at slow inclined speed with low contact

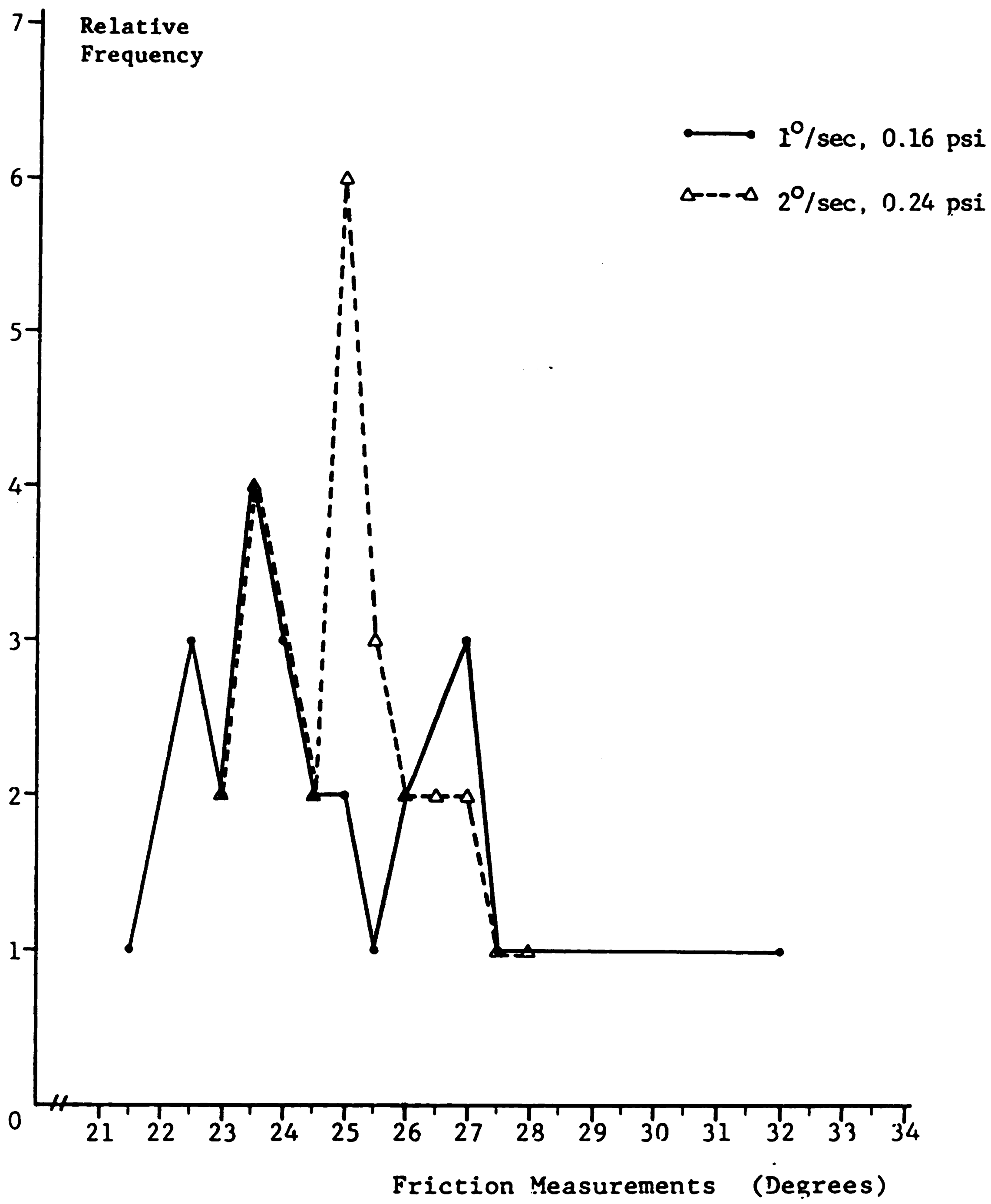


Figure 8 Distributions of friction measurements at 1^{o}/sec, 0.16 pai and 1^{o}/sec, 0.24 psi

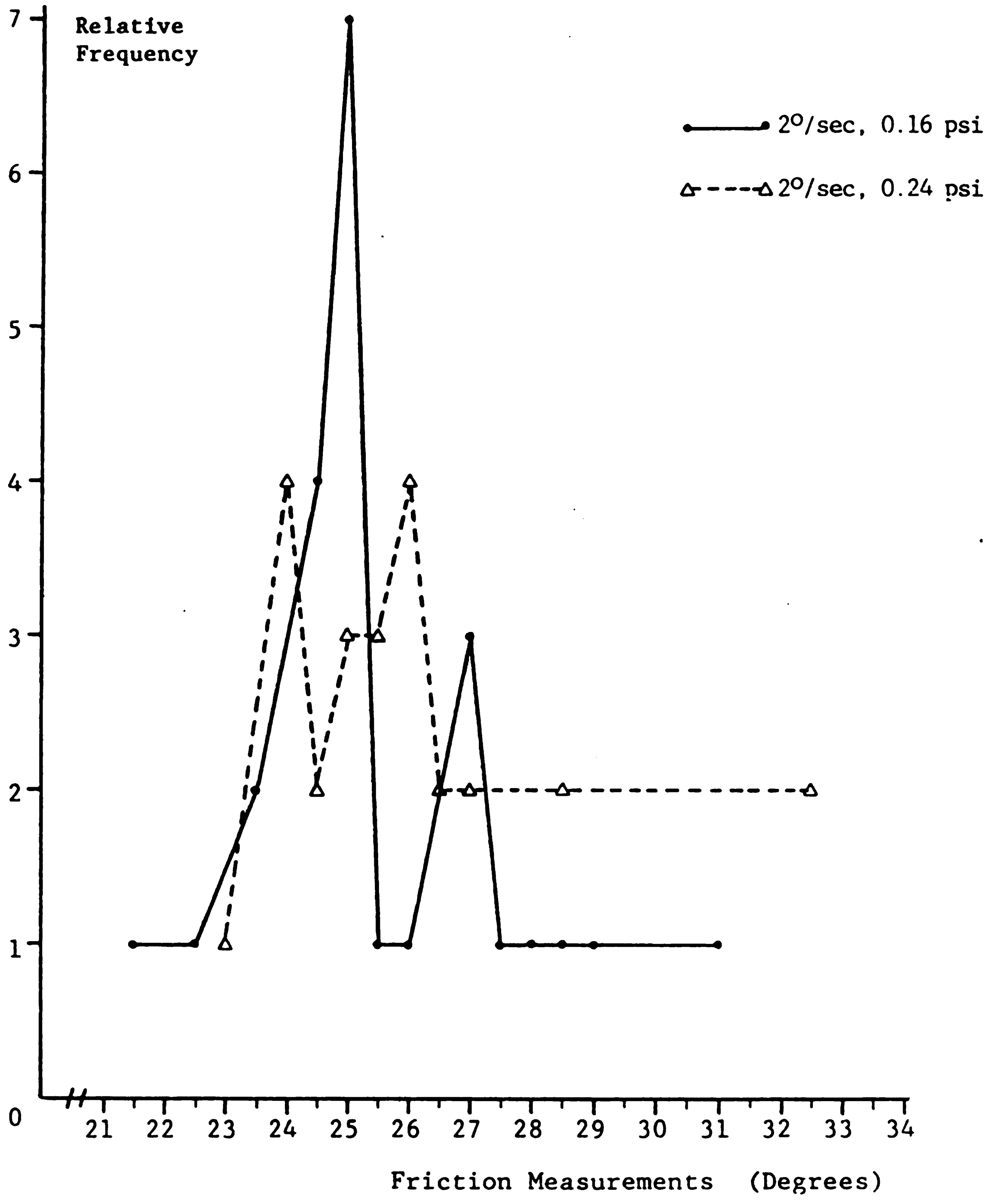


Figure 9 Distributions of friction measurements at 2^{o}/sec, 0.16 psi and 2^{o}/sec, 0.24 psi

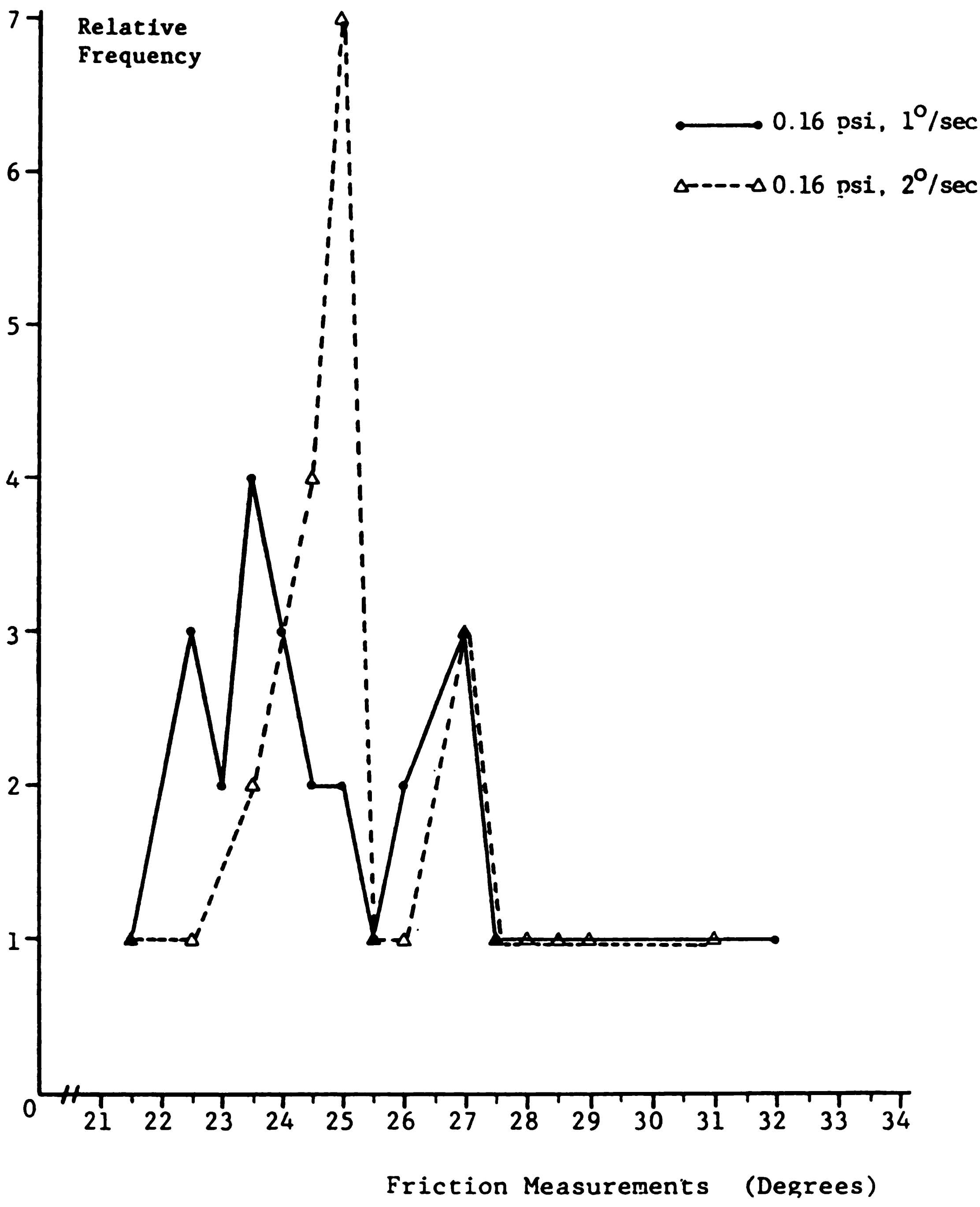


Figure 10 Distributions of friction measurements at 0.16 psi, 1°/sec and 0.16 psi, 2°/sec

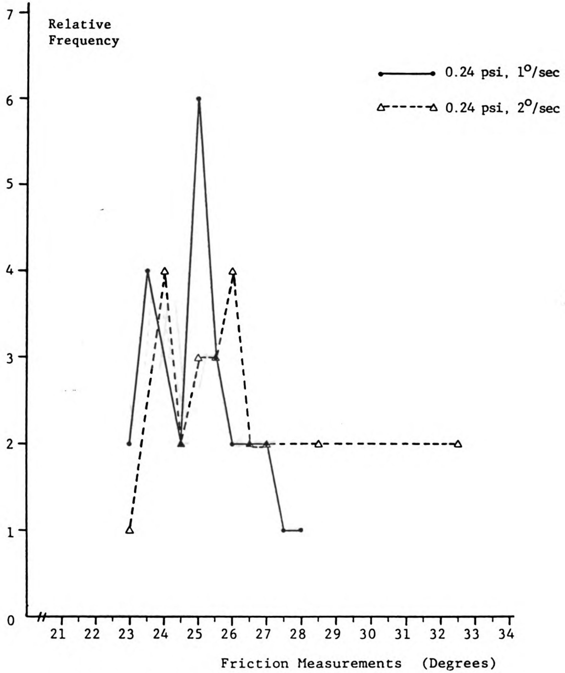


Figure 11 Distributions of friction measurements at 0.24 psi, 1°/sec and 0.24 psi, 2°/sec

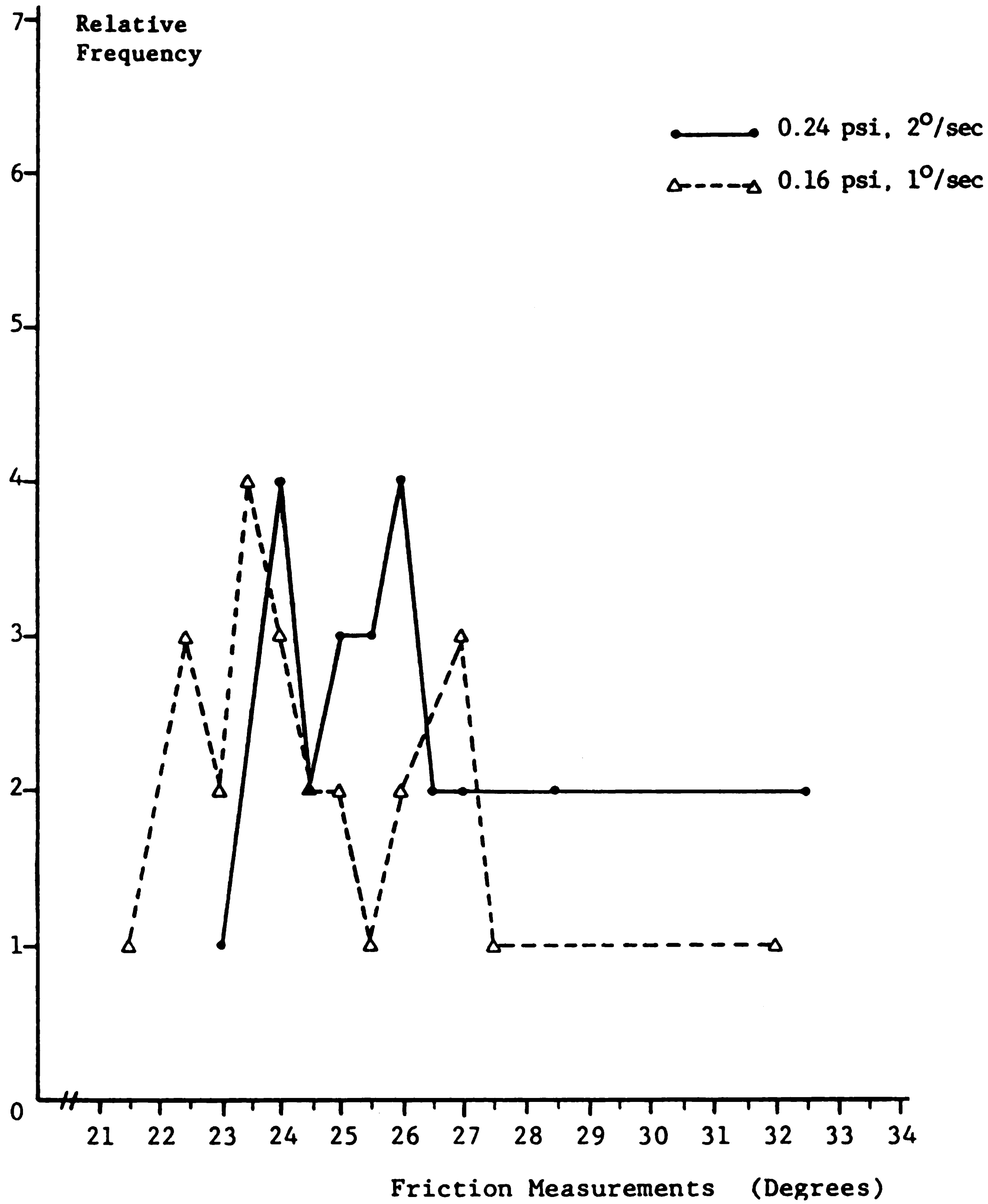


Figure 12 Distributions of friction measurements at 0.24 psi, 2^{o}/sec and 0.16 psi, 1^{o}/sec

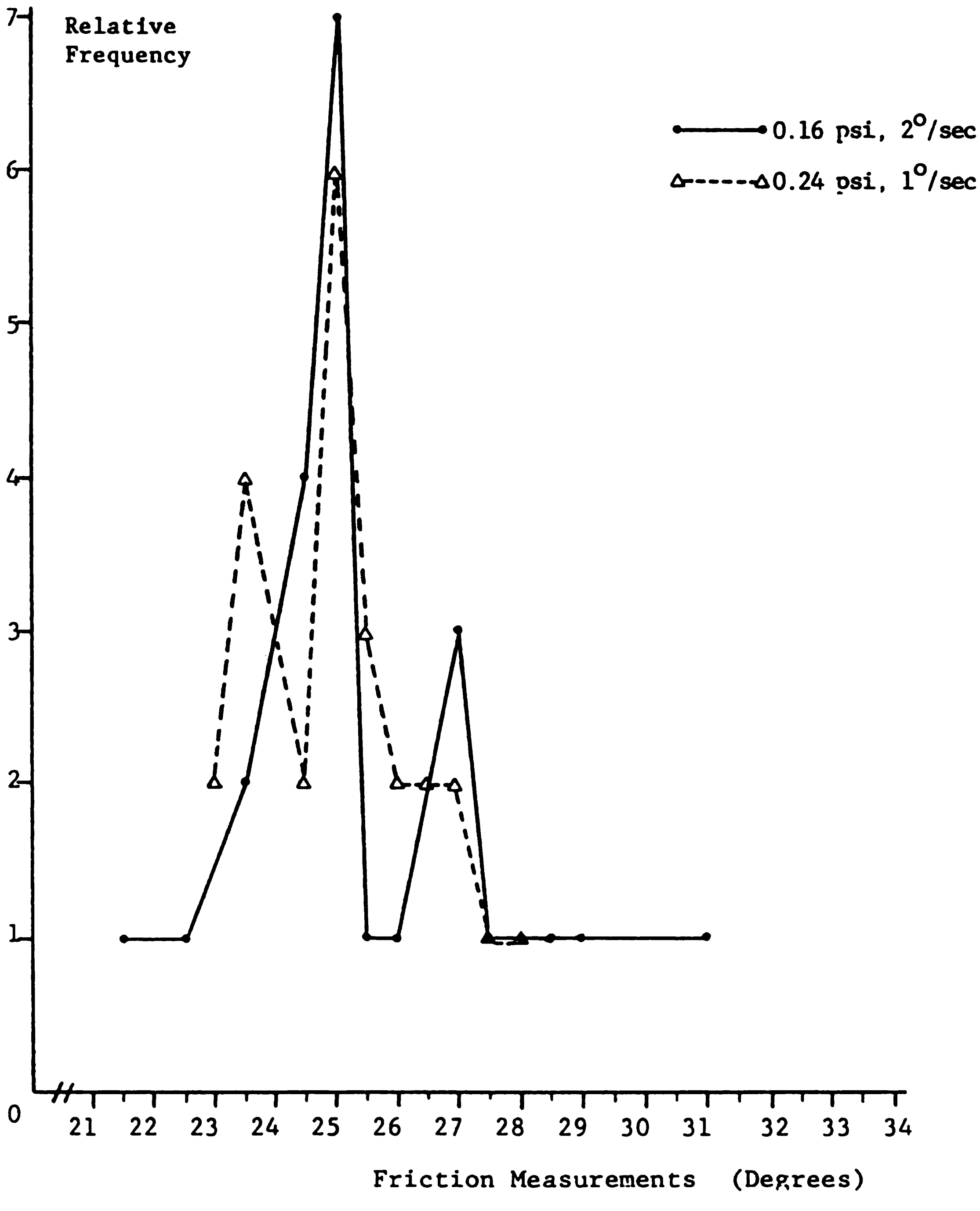


Figure 13 Distributions of friction measurements at 0.16 psi, 2^{o}/sec and 0.24 psi, 1^{o}/sec

pressure and at fast inclined speed with high contact pressure (T1-T4).

In terms of rotational kinematics, the static coefficient of friction depends greatly on the angular speed as well as the nature of contacting surfaces when the inclined plane method is used. Theoretically, the mass of the loading object will not affect the friction measurements. This concept is coincident with results obtained in this study. Results appeared that the inclination rate has more impact on friction measuring than the contact pressure. However, this does not mean that the contact pressure has no influence on friction measurements for PP woven fabrics. Further study for the effect of contact pressure on friction measurements of PP woven fabrics is needed.

Comparing the significance of T1-T4 versus that of T2-T3, we can conclude that the variances of inclined speed and contact pressure do have interactive effect on friction measurements at 0.025 significance level.

CONCLUSIONS

Of all the factors included in this study, the usage of foam padding has significant effect on friction measuring for PP woven fabrics. Other testing factors such as inclination rate, contact pressure and dwell time have no independent effect on friction measuring for PP woven fabrics. However, the inclination rate and contact pressure do have interactive effect on friction measurements. This may imply that using the inclination rate of 1.5 ± 0.5 degree/second with contact pressure of 0.2 ± 0.04 psi is not an adequate testing processure and will cause result variations.

From the multiple factors analysis, the results obtained agree with the concept of rotational kinematics. The friction measurements depends more on the inclination rate than on the mass of the object. The more the inclination rate changed the more result discrepancies will be obtained. Besides, this phenomenon will be more significant when tests are made on rougher surfaces. This means that the rougher the contacting surfaces the friction measuring will be more sensitive to the variance of inclination rate. Since the surfaces of PP woven fabrics are rougher than those of shipping sack paper. Therefore, the variation of inclination rate results in greater differences for friction measurements on PP woven fabrics.

It also should be noticed that the distribution of friction measurements on PP woven fabrics is not normal. Therefore, two statistical procedures are proposed. One is the specimen sampling. The other is the analysis technique. Since there exists wide quality variation of the PP woven fabrics. It is necessary to increase the statistics power to detect the real difference between treatments by increasing the number of the sample size.

Based on the investigations observed from the results, the friction measurements of PP woven fabrics is not normal distributed. Those measurements represent the extreme values to determine the static coefficient of frictionand the anti-skid properties of PP woven sacks. Therefore, it is not a suitable approach to analyze the friction measurements of two treatments by using tranditional t of F tests. Nonparametric statistical technique should be utilized.

APPENDICES

APPENDIX A

Woven Sack Manufacturing

Any form of natural or synthetic fiber can be woven into fabric and converted into sacks. Natural fibers such as jute and cotton have been the dominant materials of woven sacks for a long period. Until late 1960s, the plastic woven sack manufacturing originated in Asia, and in the late 1960's was quickly taken up in the UK.

Most woven plastic sacks produced in the UK are made mainly from polypropylene (PP) tapes. The PP resin is first turned into film by extrusion casting techniques. While still in the web, the film is slit into narrow widths and then highly stretched by a drawing process orienting the film in the longitudinal direction. The individual tape being used in the weaving process is called thread or yarn.

Each piece of woven fabric consists of two orientations. One is weft direction, the other is warp direction. Weft direction is the orientation where the yarns run across the width of the fabric. The orientation where the yarns run along the length of the fabric is called warp direction.

Usually the woven fabrics can be converted into sacks by either flat weaving or circular weaving of the yarns. In conventional flat loom weaving, the weft yarns are carried backward and forward by the shuttle across the width of the fabric, over and under the warp yarns. The edge of the fabric where the weft yarn turns back on itself will therefore not unravel. This creates a selvage edge. In order to convert the flat woven fabrics into sacks, the fabrics have to be sewn both at bottom and at the sides.

In circular loom weaving, the warp yarns still run along the length of the fabric, but the weft yarns are carried around the girth of the tube by a rotating shuttle. Therefore, the circular woven sacks are constructed in tubular shape and have no selvage.

APPENDIX B

Nonparametric Statistical Analysis : Kruskal-Wallis H test

It is quite unlikely that the friction measurements would follow a normal distribution. Prior experiments have shown that a population of friction measurements for PP woven fabrics often possess distributions that are skewed to one side. Consequently, the normality assumption that is required for the t test is not valid in comparing friction measurements.

Therefore, the nonparametric statistical methods are needed which require fewer or less stringent assumptions concerning the nature of the probability distribution. The nonparametric counterparts of the t and F tests compare the probability distributions of the sampled populations, rather than specific parameters of these populations (such as the means or variances).

In this paper, the Kruskal-Wallis H test was employed to compare the probability distributions for friction measurements made at two test variables. First, the sample observations were ranked as though they were all drawn from the same populations. The measurements from both samples were pooled and ranked from the smallest (a rank of 1) to the largest. When several observations were equal, a tie occurs. Each tied observation was assigned the average of ranks that these observations would have received. The results of this ranking process are illustrated in Table 5, 6, 7, and 8.

If the two populations are identical, the ranks would be expected to be randomly mixed between the two samples. On the other hand, if one population tends to have larger measurements than the other, the larger ranks would be expected to be mostly in one sample and the smaller ranks mostly in the other. When the sample sizes are equal, the greater the difference in the rank sums, the greater will be the weight of evidence to indicate a difference between the probability distributions for populations.

Based on the same concept of rank statistics, the Kruskal-Wallis H test for comparing k probability distributions which is summarized as follows.

H_o : The k probability distributions are identical

H_a : At least two of the k probability distributions differ in location

Test statistic: $$H = \frac{12}{n\,(n+1)} \bar{Z} \frac{R_j}{n_j} - 3\,(n+1)$$

where

H_o = Null hypothesis

H_a = Alternative hypothesis

n_j = Number of measurements in sample

R_j = Rank sum for sample

n = Total sample size

Assumptions:

1. The k samples are random and independent.
2. There are five or more measurements in each sample.
3. The observations can be ranked.

Rejection region: $H > X^2_\alpha$ with (k-1) degrees of freedom.

To determine how large H must be before we reject the null hypothesis, we have to consult the critical values of X^2 (chi square), such that $P(X^2 > X^2_\alpha) = \alpha$. This means that when the H value is larger than X^2_α, we conclude that at least two populations are different. The significance level is α. In the X^2 distribution, when degrees of freedom is equal to 1, ${X^2}_{0.100}$ is 2.70554, ${X^2}_{0.050}$ is 3.84146, and ${X^2}_{0.025}$ is 5.02389.

ENDNOTES

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