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TECHNICAL REPORT

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DEVELOPMENT OF TECHNIQUES FOR EVALUATING THE FRICTIONAL PROPERTIES OF RUBBER SOLE AND HEEL COMPOUNDS

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and

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CLOTHING & PERSONAL LIFE SUPPORT EQUIPMENT LABORATORY

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DEVELOPMENT OF TECHNIQUES FOR EVALUATING THE FRICTIONAL PROPERTIES OF RUBBER SOLE AND HEEL COMPOUNDS

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Clothing and Personal Life Support Equipment Laboratory
U.S. ARMY NATICK LABORATORIES
Natick, Massachusetts 01760

FOREWORD

The work covered by this report was carried out under U. S. Army Natick Laboratories In-House Laboratory Task 69, Project No. 1T061101A91A, Studies of Techniques for Measuring Friction of Rubber Compounds Under Forces and Speeds Encountered in Walking, initiated in FY 1969. Its purpose was the development of apparatus and test methods suitable for use in evaluating the frictional characteristics of rubber compounds under the speed and loadings normally encountered in walking.

The techniques developed and described in this report provide a means for evaluating the differences in friction of various compounds for sole and heel applications and furnish a tool useful in the development of Army footwear with improved slip resistance.

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ABSTRACT

The divergence in the behavior of rubbery materials from the classical laws of friction requires testing of rubber compounds under speed and loadings likely to be encountered in service. This report describes a friction-measuring device developed at Natick Laboratories for testing rubber compounds under the speed and loading conditions normally encountered in walking.

The apparatus consists of a carriage traveling on an inclined plane and using a rubber specimen as a braking device. Stopping distances are used as a measure of the comparative friction of various rubber samples. Loadings can be controlled by means of a set of removable weights and speed is controlled by the length of incline used. A second device adapted from a commercially available skid tester, originally developed for testing road surfaces, was also evaluated.

The data obtained from testing rubber compounds on various surfaces show: (1) good correlation between the two types of apparatus, thus providing a commercially available device suitable for specification testing; (2) the type and condition of the surface in contact with the rubber has more effect on friction than do basic polymer differences or variations in compound hardness or resilience; and (3) friction of all the rubber compounds tested is extremely low on wet-lubricated surfaces, such as ice.

DEVELOPMENT OF TECHNIQUES FOR EVALUATING THE
FRICTIONAL PROPERTIES OF RUBBER SOLE AND HEEL COMPOUNDS

1. Introduction

Friction is an important property of materials, intuitively known and instinctively used. It affects all movements of contacting surfaces and is defined simply as the resistance to motion between those surfaces. In rubber it is attractive because it is large compared to the friction of metal, plastics, leather, glass and many other commonly used materials. Thus, rubber is often used in applications where slip resistance is required. One of these is the design of sole and heel compounds used on Army combat footwear.

The friction of rubber, however, is not an easily measured characteristic. Many rubber properties are evaluated using test procedures that have been formalized over the years. Friction is an exception. It has often been investigated and from many varying viewpoints, but generally the investigator has used his own apparatus and method. Since the main interest here is in footwear, it was necessary to work out methods and apparatus allied with conditions likely to be encountered by boots and shoes in actual service. Instruments and procedures developed for that purpose are described in this report and the results obtained are evaluated.

2. Problems in Rubber Friction Testing

Perhaps the main reason for the lack of a standard rubber friction test is the fact that rubber does not obey the classical laws of friction. These were originally derived for rigid bodies and state, in part, that the coefficient of friction, i.e., the ratio of moving force to load, is independent of load or speed. This is not true with rubber. Rubber readily deforms under load and the coefficient changes, as it does with changes in velocity. It therefore becomes necessary to test under load and speed conditions likely to be encountered in use.

Also, friction is now considered to be made up of at least two and sometimes three terms or components[1,2,3], an adhesion term, a deformation term, and an abrasion term. The two generally agreed upon are the adhesion and deformation terms. The adhesion component results from the molecular attraction between the materials in the two contacting surfaces; the deformation component results from mechanical interlocking or entanglement of asperities on the surfaces. Lubrication, either wet or dry, between the two surfaces affects both components, but the adhesion is affected much more than the deformation. Under some lubrication conditions the adhesion component may be practically eliminated. Thus, it is also important that any testing should be done against surfaces which closely approximate those likely to be found in service.

Finally, friction may be sliding, rolling, twisting or any combination of these, since it can occur in any type of motion. Again it may be static and dependent on the force required to start motion, or dynamic and dependent on the force necessary to maintain motion once it starts. Controversy exists as to whether static friction in rubber is measurable. As lateral force is applied to a rubber specimen, continuous sidewise deformation occurs and then total movement begins, but the demarcation between the two is not clear. However, since our interest lies in the skidding of a sole or heel, the primary concern is with sliding and dynamic friction.

To summarize these various restrictions and principles, the main objective in this study was the development of apparatus on which rubber specimens could be tested for sliding friction at speeds and loads normally encountered in walking and against surfaces normally walked upon.

3. Development of Test Apparatus

a. Inclined Plane and Carriage Apparatus

A realistic evaluation of the frictional properties of heels would perhaps best be made using test specimens with the configuration and size of a partially worn heel subjected to loads of 150 to 200 pounds. This would require a cumbersome and heavy structure. In the interest of lighter weight and a desire to have an apparatus that could be handled on a bench top, it was decided that a smaller specimen subjected to the same pound-per-square-inch loading would suffice. Various mechanisms were considered for applying the load and providing a means of lateral movement. A wheeled carriage appeared attractive because loading could be varied by adding or removing weights, and speeds regulated by the amount of lateral force applied. Mounting the carriage on an inclined plane was considered to be the simplest means of finding a constant reproducible source of locomotion. The final concept was of a four-wheeled carriage with removable weights and with a specimen holder fixed near the rear wheels. The carriage was to be used in conjunction with an inclined track leading downward and connecting with a horizontal track, with facility for placing various test surfaces between the horizontal tracks. The test specimen would be mounted to contact the test surface, as the carriage reached the horizontal track, raising the rear wheels of the carriage and thus acting as a brake. The stopping distance obtained would give a comparative measure of the frictional properties of various rubber compounds. A schematic of this is shown in Figure 1.

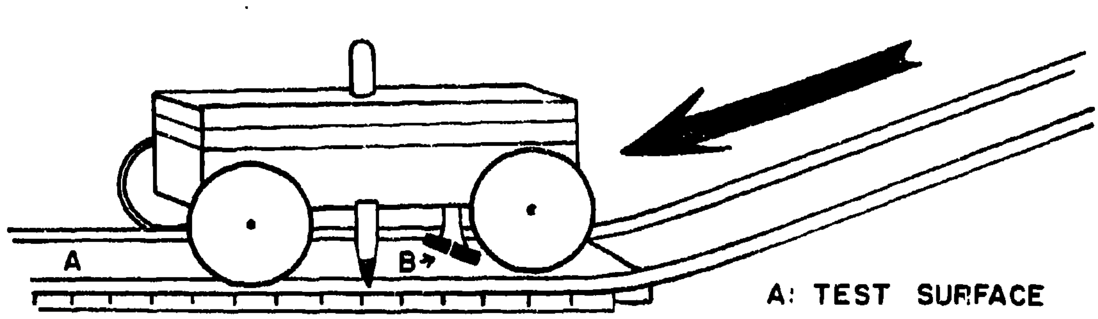

Figure 1. Schematic, Inclined Plane Friction Tester Concept

A means of evaluating this concept was available in a Scott Model IP-4 tensile tester. This machine consists of a three-wheeled carriage on a three-tracked tiltable base. Normally the base and carriage are equipped with sample clamps and the machine is used to provide tensile stress by increasing force as the track tilts. The carriage is equipped with a pen and the base with a chart which moves downward as the base tilts. For test purposes the middle track and middle wheel were removed. The track was replaced by a test surface--either asphalt tile mounted on 3/8-inch thick plywood, a concrete slab, or a tray 1/2-inch deep in which water was frozen by means of dry-ice-cooled methanol circulating through copper tubing within the tray. The middle wheel was replaced with a specimen holder which accommodated a 1-inch square specimen at a contact angle of 15 degrees. Thus, the carriage rested with two wheels on the remaining tracks and the specimen on the test surface. In the test the track was tilted until the carriage moved down the track. A curve recording this movement was drawn by means of the pen and chart. The angles at which the base must be tilted to cause carriage travel were taken as a measure of the comparative friction of the rubber compounds on any one surface. The modified IP-4 tester is shown in Figure 2. A typical curve obtained with it is shown in Figure 3. The results obtained with the modified IP-4 were sufficient to recommend adoption of the inclined plane and carriage concept. Accordingly, the apparatus was built as described below and shown in Figures 4, 5 and 6.

A carriage equipped with four flanged wheels with roller bearings is mounted on a double track. The flanges of the wheels are 8 inches apart

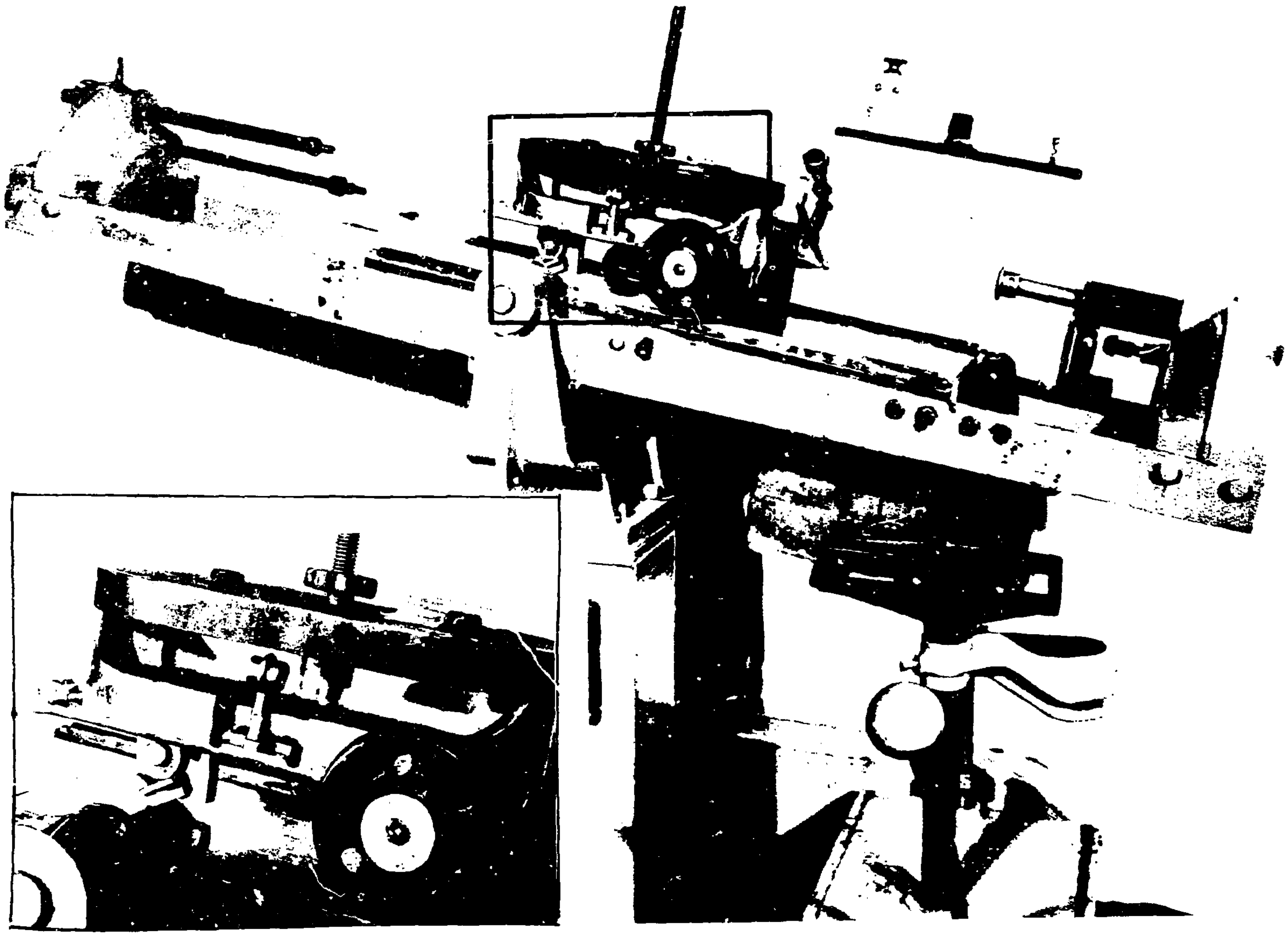

Figure 2. IP-4 Tester, Modified for Friction Testing
(Insert shows closeup of Carriage and Test Specimen)

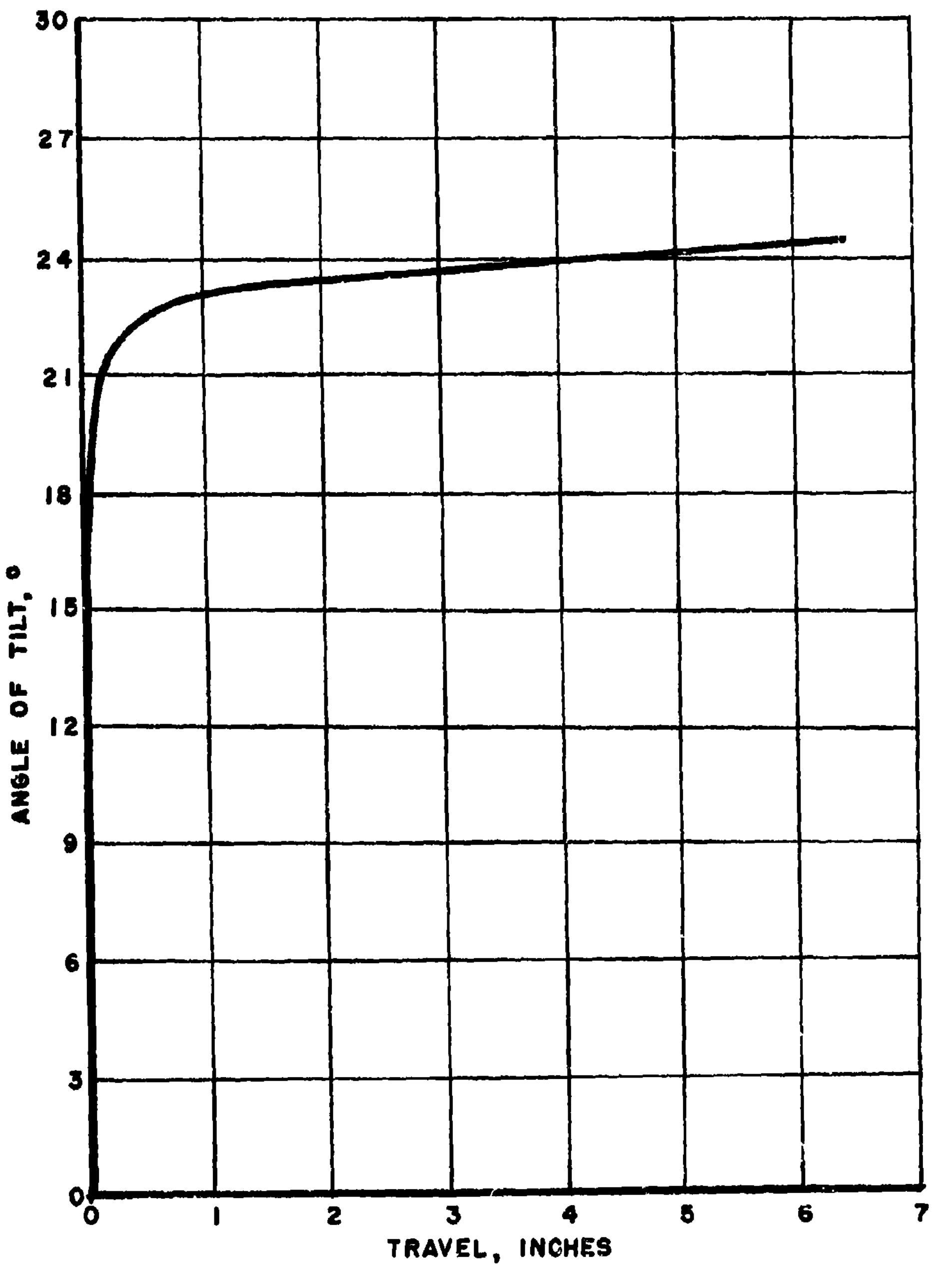

Figure 3. Typical Curve, Modified IP-4 Tester

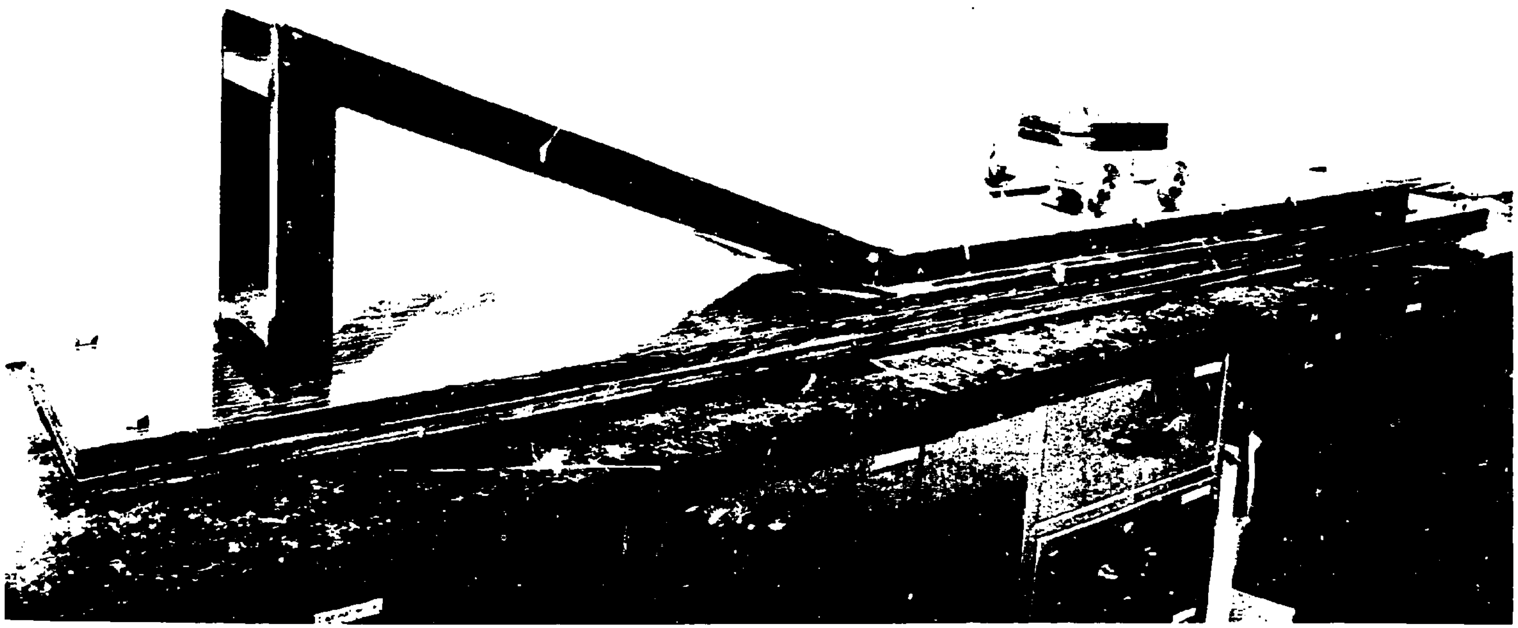

Figure 4. Rolling Carriage Tester and Track

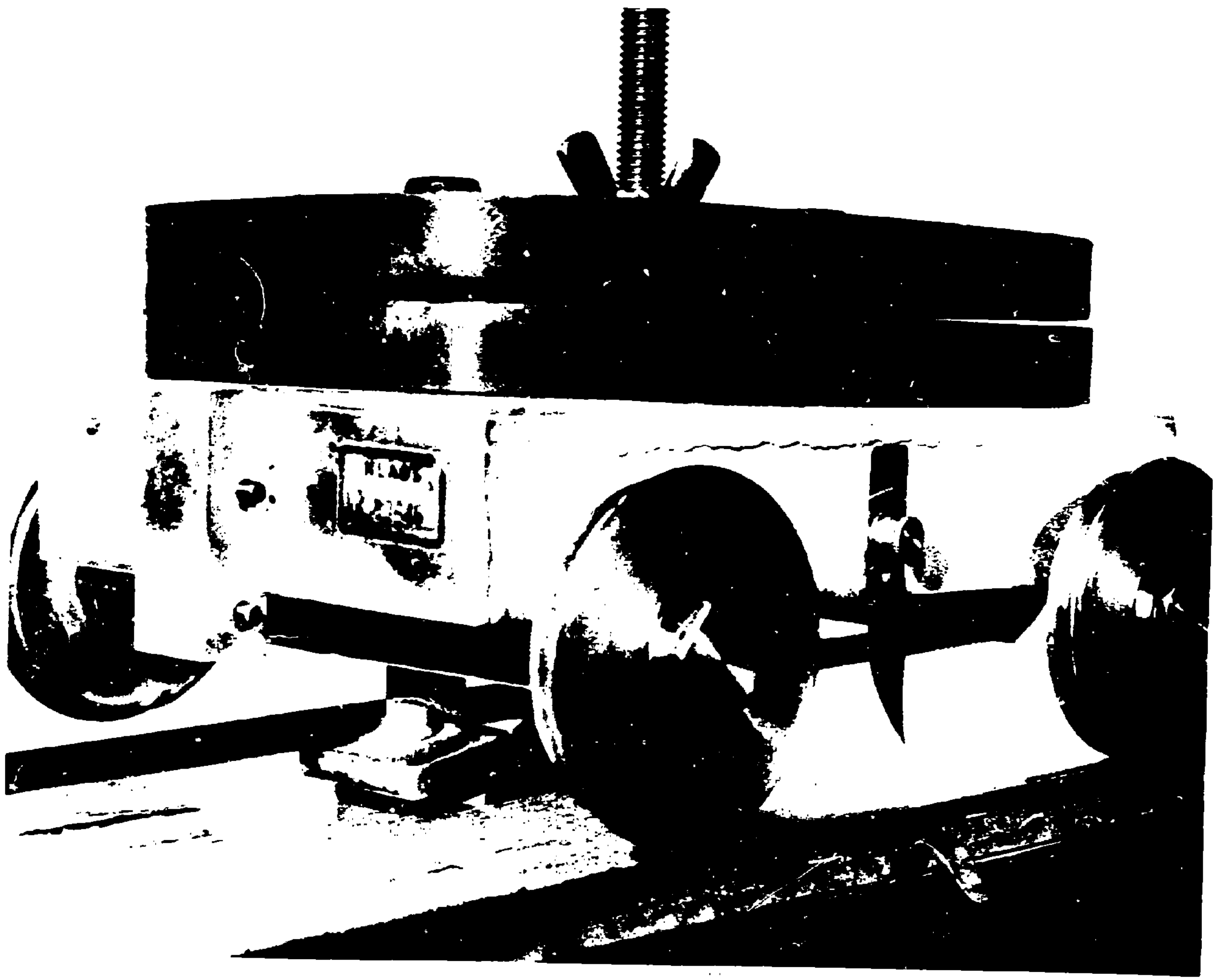

Figure 5. Rolling Carriage Tester and Track, Closeup

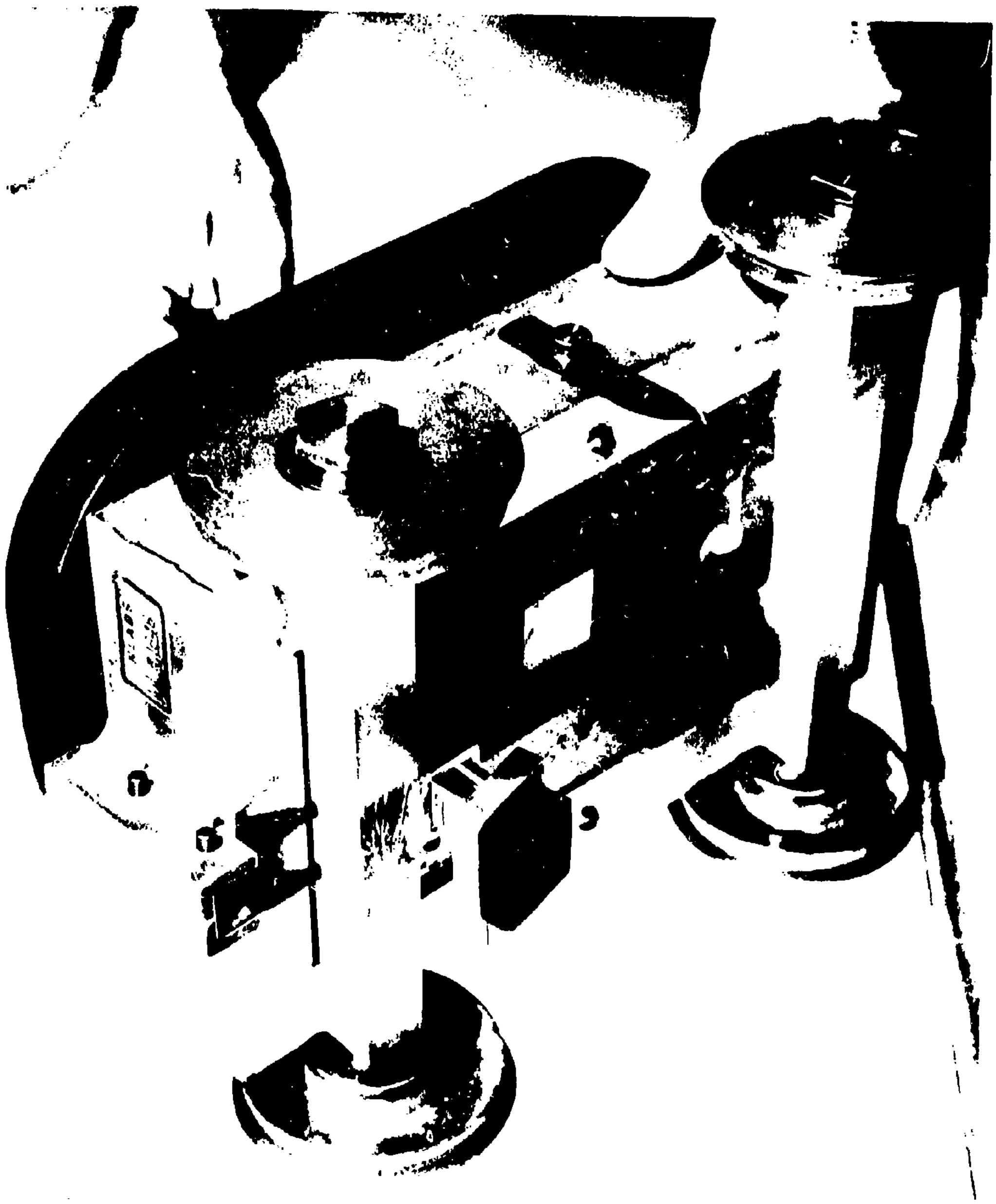

Figure 6. Carriage Showing Specimen Clamp

as are the centers of the track. A specimen holder is positioned beneath the carriage so that specimen contact area is between the rear wheels. The weight of the empty carriage is 10 pounds, giving a load on the specimen of 5.3 pounds. Weights can be added to the carriage to increase the total weight to 100 pounds and the sample loading to 53 pounds.

Calibrated speeds of the carriage were obtained by releasing the carriage, without a specimen, at various points on the section of track inclined at 20 degrees. A micro-switch connected to a millisecond timer was affixed to the carriage half-way between the front and rear wheels and was activated by a contact along the first 6 inches of horizontal track. Thus, the average speed of the specimen clamp in approximately 3 inches of travel both before and after the contact point can be found. Positions on the inclined plane for speeds of 2.5 and 4 miles per hour were thus determined. These speeds were chosen because the speed of walking is generally accepted as 3 to 4 miles per hour. A pointer fastened to the side of the carriage is used in conjunction with a moveable scale fastened to the side of horizontal track, and capable of being zeroed on the sample contact point (See Fig. 5). This provides a simple means of measuring the stopping distance of the carriage when the friction of the rubber specimen on the test surface is high enough to stop it on the horizontal track, and permits easy comparison of the friction of various rubber compounds. When the test surface used has a friction too low to cause stopping of the carriage on the horizontal track, the microswitch and millisecond timer are used to determine speed in the last 12 inches of travel (from 33 inches to 45 inches), and the speeds thus obtained are taken as friction ratings of the various rubber compounds.

Test specimens are flanged, 1-inch square, molded rubber pieces conforming to the size and shape required in ASTM Test Method D1630.[4] The flanges permit easy mounting in the specimen holder shown in Figure 6. Shims are used beneath the specimens, when needed, to insure tight fit. The angle of mounting is 15 degrees and the contact area is approximately 0.18 square inch depending on the loading and hardness of the specimen. A loading of 30 pounds on the carriage results in 16 pounds on the specimen which is equivalent to 88 pounds per square inch on the sample. This correlates with a man's average heel contact area of 1.70 square inches and an average weight of 150 pounds, giving a similar loading of 88 pounds per square inch. Heel contact area was found by having various individuals place a foot on black paper, while maintaining their heel at a normal contact angle. They then placed their weight on the heel, while still maintaining it at that angle. The area of the print thus made was determined by tracing the outline of the print onto paper gridded in 0.1-inch squares.

b. Pendulum Apparatus

Since the inclined plane and carriage apparatus described in "a" above is specialized, and since it might be desirable to have a readily obtainable instrument for use in specification work, tests were also run using a commercially available, portable, skid-resistance tester. The intent was to determine if agreement existed between the two instruments and methods. The portable skid-resistance tester is described in detail in an article by Giles, Sabey and Cardew.[5] As shown in Figure 7, it consists essentially of a standard rubber slider, spring mounted on the end of a pendulum, a scale, and a pointer which travels with the initial swing of the pendulum and indicates its highest point of travel. In operation, the pointer is aligned with the pendulum arm in a horizontal position. The pendulum arm is released, carrying the pointer with it. At the bottom of the swing, the slider contacts the test surface for a travel of 5 inches. The angle of contact is 20 degrees and the speed at the time of slider contact is 9 feet per second, or about 6 miles per hour. The height of the pendulum swing after contact is determined by means of the pointer, which remains at the maximum point of swing, and a scale marked in skid-resistance units. These units decrease with increasing height of swing from 150 to 0.

The instrument was originally designed for the evaluation of road surfaces, but has been adopted by many people for testing rubber specimens on various surfaces. When thus used, the slider (which is a 3-inch wide block of 55 durometer rubber bonded to a metal plate) is replaced with test pieces of rubber, also usually bonded to a metal plate. To eliminate the bonding procedure, the slider on the portable skid-resistance tester used in this work was replaced by a specimen clamp similar to the one used on the inclined plane carriage previously described. Thus, the same 1-inch square specimens can be used on either instrument.

The test surfaces used with the inclined plane and carriage apparatus were also used with the pendulum apparatus.

4. Materials

Thirty-two natural and synthetic rubber compounds were mixed and included all commercially available elastomers generally used in sole and heel manufacture. The type and amounts of filler materials used were varied to obtain a range of hardness and resilience values. The formulas are listed in Tables I-A through I-E, and polymer type, hardness[6] and resilience values[7] are given in Table II.

The asphalt tile test surface was made from commercial flooring tile adhered to 3/4-inch thick plywood. The concrete test slab was approximately 1-inch thick and was cast from "Sakrete" sand mix.

5. Results and Discussion

a. The test compounds were first checked for frictional properties by determining their slip angles using the modified Scott Model IP-4 machine. This was done by placing the test specimen in the specimen clamp and inclining the machine at standard speed (30 degrees in 20 seconds) until the carriage moved down the incline. The angle at which specimen

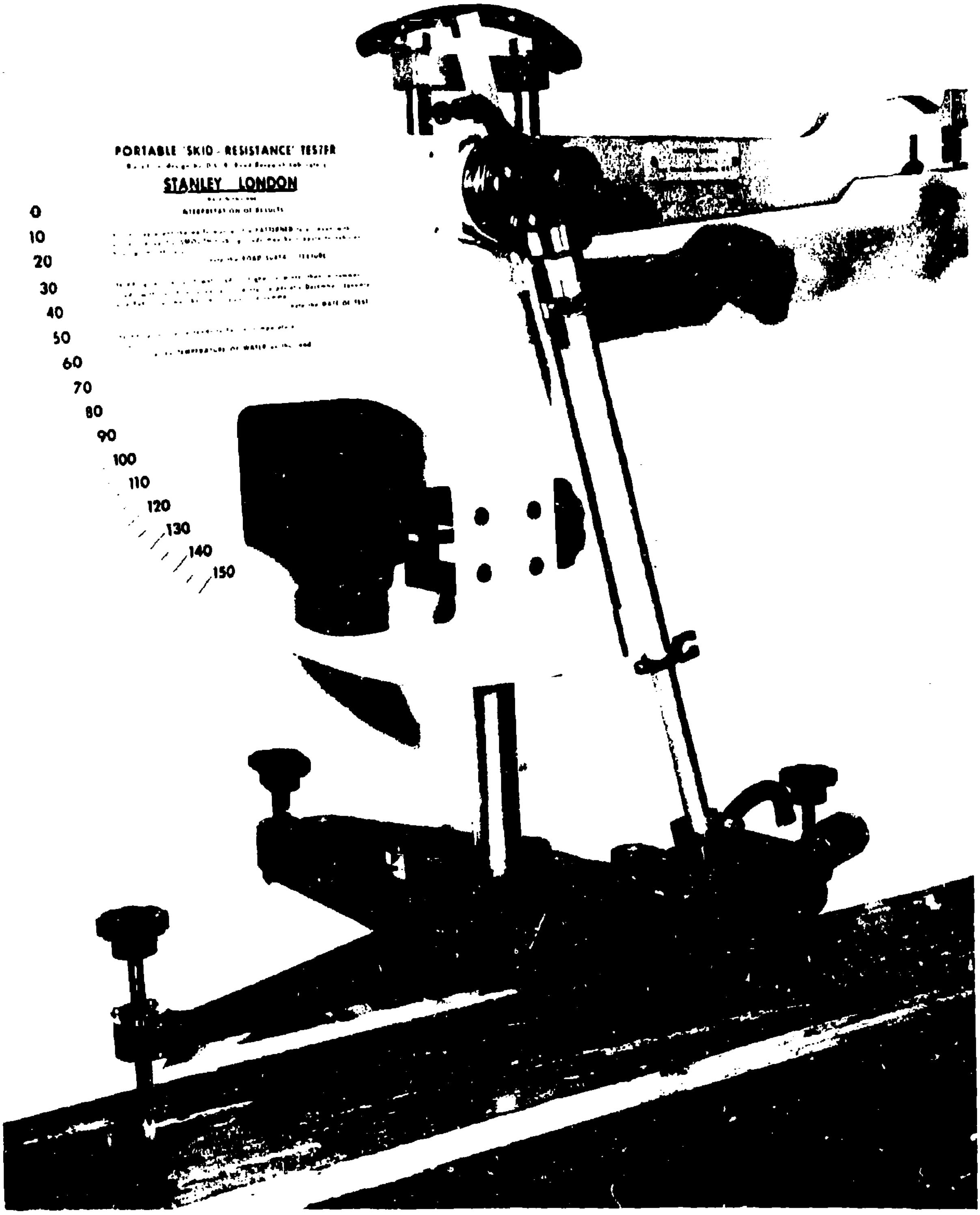

Figure 7. Portable Skid-Resistance Tester

movement began was read from the chart. The values obtained are given in Table III. Typical curve and the point of beginning movement are shown in Figure 3. Slip angles measured on waxed asphalt tile ranged from 14.7 degrees for compound 21 to 22.8 degrees for compound 7. The slip angles were plotted against hardness and resilience properties of the compounds, but no direct relationship was apparent. However, there was a general tendency for softer stocks to have higher friction. Slip angles measured on concrete were 2 to 9 degrees lower than those measured on the waxed asphalt tile. The only exception to this was compound 21, an SBR compound containing 50 parts of a high styrene resin in which the relationship was reversed. However, there was no relationship apparent between the slip angle and either hardness, resilience or polymer type. The slip angles determined on wet ice were extremely low and those determined on ice at 0°F were only moderately higher than those on wet ice.

If the machine was stopped before reaching the previously determined slip angle and held for a period of time, some movement down the incline took place, even at considerably lower angles. This is illustrated by Figure 8 where the specimen has a normal slip angle of 17 degrees but shows one inch travel down the incline at 12 degrees over a period of 21.5 minutes. This demonstrates the difficulty in separating static friction in rubber from dynamic, and shows frictional movement over prolonged periods of time.

b. Thirty-two test specimens were checked for skid distance with the rolling-carriage, inclined plane apparatus at various speeds and under various loadings, using waxed asphalt tile as the sliding surface. Skid distances of the specimens are included in Table II.This apparatus was found to consistently give reproducible results with these various compounds with values varying by no more than 1/2 to 1-inch between runs.

Twelve compounds were selected for more extensive tests at an incline speed of 4 miles per hour and a carriage weight of 30 pounds on asphalt tile and concrete under different wet and dry conditions. These results are listed in Table IV and show skid distances on unwaxed, waxed, and dusted asphalt tile, * and undusted concrete and dusted concrete. Differences in friction of the specimens undergoing wet lubricated sliding (wet asphalt tile) could be shown only by the difference in speeds of the carriage at the end of the track (between 33 and 45 inches) as all compounds traveled the entire 45 inches of track without stopping.

A study of the data in Table IV reveals the following:

(1) The skid resistance of the test compounds on unwaxed and waxed asphalt tile show no marked differences with one exception: a 95

* Dust consisted of a mixture of whiting (ground calcium carbonate), talc, clay and carbon black

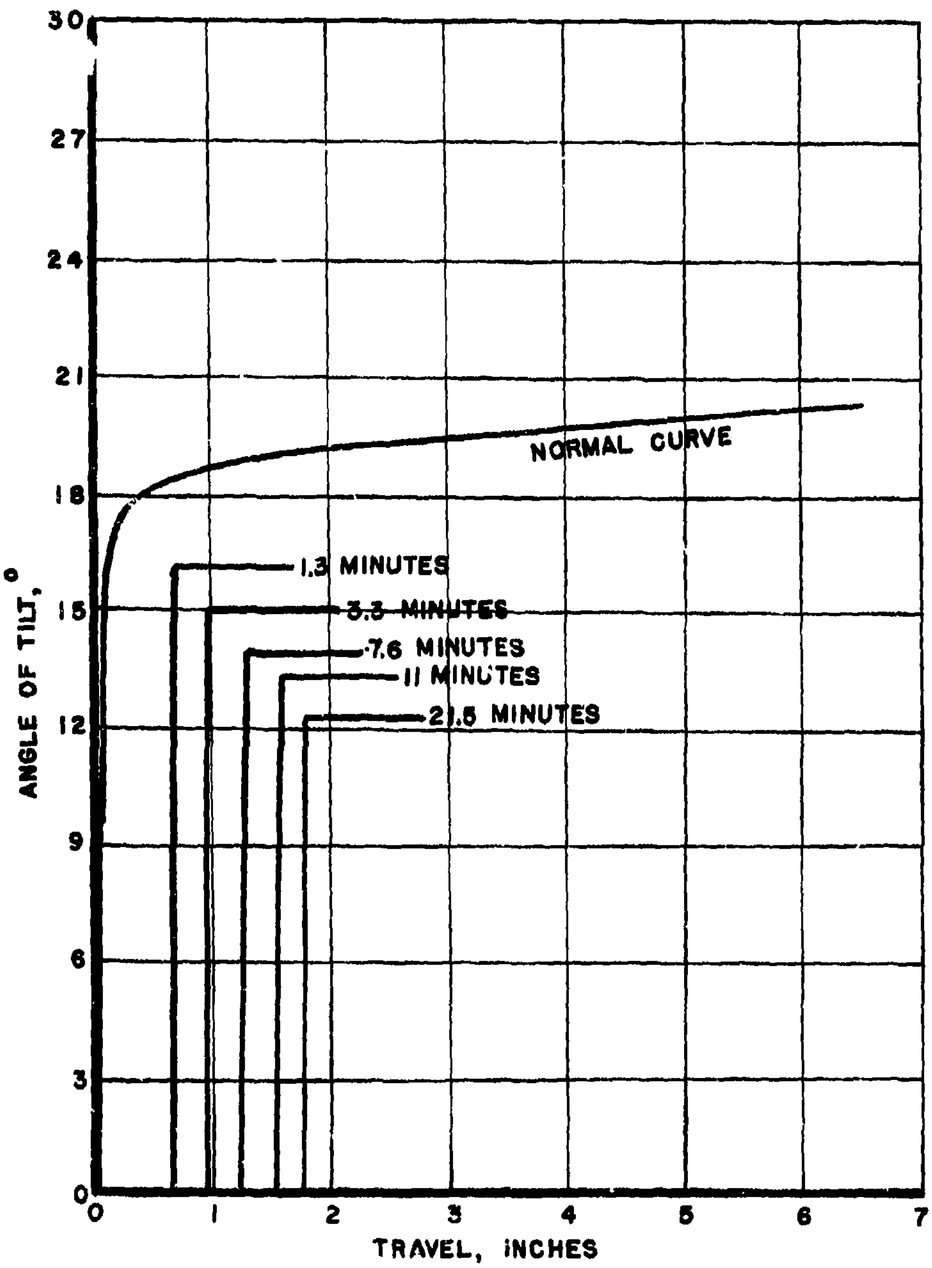

Figure 8. Time for 1-inch Travel at Various Angles of Tilt - IP-4 Tester

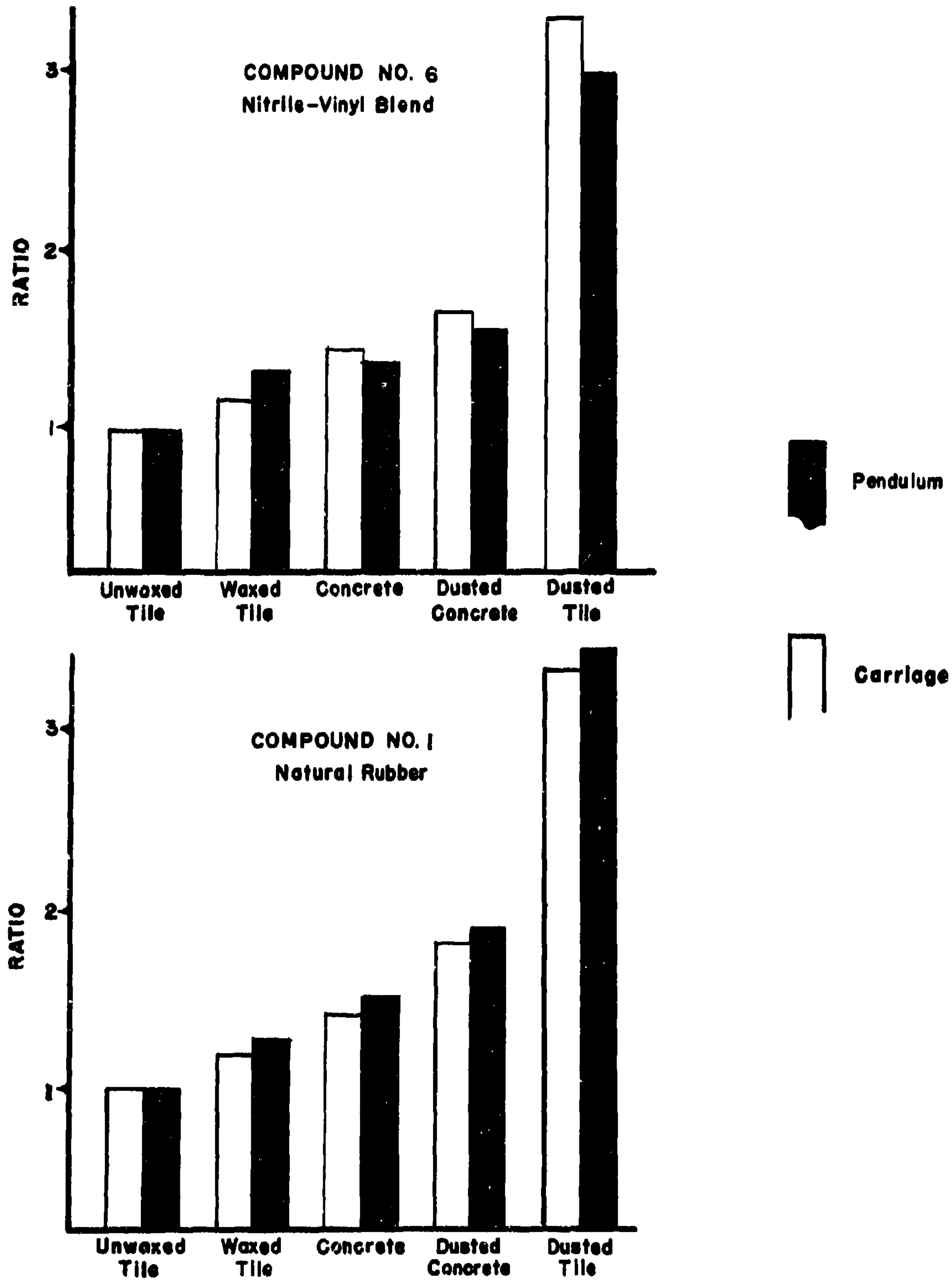

Figure 9. Comparative Friction Values - Carriage and Pendulum
(Ratios Related to Value on Unwaxed Tile = 1)

hardness SBR stock (No. 21) containing a large amount of high-styrene resin. The skid distance of this compound was 25.7 inches on waxed tile while that of the other compounds was 13 to 16 inches.

(2) As with the modified IP-4 tester, the skid resistance on concrete was lower than on waxed or unwaxed tile, again with the exception of sample No. 21. While this may be counter to what one intuitively believes about the two surfaces, it would appear, since there is more contact between the rubber and the smooth tile than between rubber and rough concrete, that on clean-dry surfaces the adhesion term contributes more to rubber friction than does the deformation term. Dusting the surfaces reverses the relationship and causes higher friction on concrete, and can be explained by the dust layer interfering with the adhesion mechanism and diminishing its effect. Since floors and walks are not dust and dirt free, this is in accord with experience and our intuitive knowledge that concrete is more slip-resistant than waxed asphalt tile.

(3) In tests involving lubricated sliding on a smooth surface (wet asphalt tile) the skid resistance of all test compounds was extremely poor. After 45 inches of sliding, the test carriage lost less than 20 percent of its initial speed, regardless of the test specimen used.

c. The 12 test compounds selected were also tested on the pendulum machine using the same test surfaces. Test results are listed in Table V as skid indices of the compounds. These indices increase as friction increases; however, comparatively speaking, the values closely parallel those obtained with the carriage-inclined plane instrument. Test compounds on unwaxed tile have the highest index (75 to 115). The compounds on wet waxed asphalt tile have a low range of 4 to 8 units. The low friction on wet tile conforms with the findings of Bevilacqua and Percarpio; [1] that on a flat surface not only is lubricated friction low, but differences in friction for different rubber specimens are small; that the hard surface must have a characteristic peak-to-valley roughness to produce differences in wet friction with different rubber specimens; and that high friction without abrasive damage can not occur on wet surfaces.

The correlation between the two test methods is illustrated in Figure 9, which shows the relative friction values of two randomly selected test compounds on the various surfaces. The values plotted are ratios of carriage results obtained at 4 mph under 30-pound load, and pendulum results obtained on various surfaces, results obtained with the carriage and pendulum on unwaxed asphalt tile (e.g., skid distances of 12.8 inches, 14 inches, 18.2 inches, 21.8 inches and 43 inches on different surfaces are in the ratio of 1 : 1.09 : 1.42 : 1.70 : 3.36). Carriage values are direct ratios and pendulum values are reciprocals of the ratios. A further demonstration of the correlation between the two methods is found in the fact that the carriage values in Table IV are generally related to the pendulum values in Table V according to the formula:

$$\text{carriage value} = \frac{13.8}{\text{pendulum value}} \times 100$$

This formula was obtained after noting that results of dividing pendulum value reciprocals into carriage values centered around 1400. The calculation was carried out on all the values in Tables IV and V and an average value of 1377 obtained. The formula thus derived was used with the pendulum values in Table V to calculate carriage values. The results obtained from the calculation are listed in Table VI along with the values obtained from actual test. There is close agreement between the two sets of figures in many cases and a good approximation in the rest, showing a better correlation between the two methods than might have been expected.

One item worthy of note is the behavior of specimen No. 21. This hard rubber material (Shore Duro, 99) showed low frictional characteristics on tile and waxed tile as evidenced by high skid distances and low pendulum skid-resistance units. However, when the surfaces were coated with either a wet or dry lubricant (water or dust), the material generally showed better friction than the other samples (Tables III, IV and V). While the differences are not outstanding, they may be an indication that on some surfaces a very high hardness gives the best slip resistance.

6. Conclusions

a. A test apparatus which uses a rubber specimen as the braking mechanism for a rolling carriage has been developed and found suitable for testing the frictional properties of rubber heel and sole compounds at various speeds and loadings.

b. A commercial apparatus, The Portable Skid-Resistance Tester, with minor modifications, was found to give results that correlate with those of the rolling carriage device.

c. Test compounds showed that no rubber or commercially available synthetic polymer tested to date has outstandingly superior skid resistance.

7. Recommendations

It is recommended that additional work be undertaken to study the frictional properties of various rubber compounds; and to study the effect of additive materials such as cork and cotton flock, and the effect of patterned or textured surfaces on the frictional properties of rubber compounds.

8. References

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TABLE I-A

NATURAL RUBBER TEST COMPOUNDS

Compound Ingredients	Compound Number 1	13	16	17	18	23
Pale Crepe	100	100	100	100	100	100
Zinc Oxide	5	5	5	200	100	5
Stearic Acid	3	1	2	2	2	3
Reogen	- -	2	2	- -	- -	2
Diethylene Glycol	1	- -	- -	- -	- -	- -
MPC Black	3	3	3	3	3	3
Hi-Sil 233	30	- -	- -	- -	- -	- -
Hard Clay	- -	100	75	- -	- -	150
Silene EF	- -	25	- -	- -	- -	40
Talc	- -	- -	75	- -	--	- -
Altax	0.8	1.5	1.5	1.5	1.5	1.5
D.O.T.G.	1.2	- -	- -	- -	- -	- -
Methyl Tuads	- -	0.15	0.15	0.15	0.15	0.15
Agerite Powder	1	1	1	1	1	1
Sulfur	2	3.25	2.75	2.75	2.75	[illegible]
Cure, Min/°F	20/290	20/290	20/290	20/290	20/290	20/290

TABLE I-B

SBR AND NITRILE TEST COMPOUNDS

Compound Ingredients	Compound Number 2	14	15	19	20	21	5	26
SBR-1500	100	100	80	90	100	100	--	--
Goodrite 50	--	--	20	10	--	50	--	--
Hycar 1001	--	--	--	--	--	--	100	100
Zinc Oxide	5	3	3	3	5	5	5	5
Stearic Acid	1	1	1	1	1	1.6	1	1
Diethylene Glycol	4	--	--	--	--	--	--	--
Cumar MH	5	5	10	7.5	--	--	--	5
Circo Lt. oil	--	2.5	5	3.5	5	9	--	--
TP-90 plasticizer	--	--	--	--	--	--	10	5
Sunproof	--	1	1	1	--	--	1	--
FT Black	--	--	--	--	30	--	--	--
MPC Black	3	3	3	3	--	0.5	3	3
Hi Sil 233	30	--	--	--	--	65	35	--
Hard Clay	--	100	90	95	--	--	--	--
Silene EF	--	30	40	35	--	--	--	75
Altax	1.2	1.5	1.6	1.6	1.5	1.54	1.5	1.5
Methyl Zimate	--	0.4	0.4	0.4	0.4	--	--	--
Methyl Tuads	0.25	--	--	--	--	0.73	--	0.5

TABLE I-B
SBR AND NITRILE TEST COMPOUNDS (Cont'd)

Wingstay 100	- -	- -	- -	- -	- -	1.5	1	1
Titanium Dioxide	- -	- -	- -	- -	- -	4.25	- -	- -
Yellow Oxide	- -	- -	- -	- -	- -	2.00	- -	- -
Red Oxide	- -	- -	- -	- -	- -	0.60	- -	- -
Sulfur	3	2.75	2.1	2.4	2.75	1.97	1.5	1.5
Cure, Min/°F	20/300	20/300	20/300	20/300	20/300	8/320	20/310	20/310

TABLE I-C

NEOPRENE AND HYPALON TEST COMPOUNDS

Compound Ingredients	Compound Number 3	22	24	4	25
Neoprene W	100	100	100	- -	- -
Hypalon 40	- -	- -	- -	100	100
Zinc Oxide	5	5	5	- -	- -
Stearic Acid	0.5	2	- -	2	2
XLC Magnesia	4	4	0.5	5	5
Circo Lt. oil	12	6	20	20	15
Sunproof	3	- -	- -	- -	- -
Cumar MH	- -	- -	7	- -	- -
Hi Sil 233	32	- -	40	40	50
Hard Clay	- -	40	- -	- -	- -
Silene EF	- -	- -	30	- -	- -
MPC Black	3	45	- -	3	1
SRF Black	- -	25	0.5	- -	- -
2 MT	0.5	0.5	- -	- -	- -
Neozone D	2	1.5	2	- -	- -
Diethyl Thiourea	- -	- -	2	- -	- -
D.O.T.G.	- -	- -	1.5	- -	- -
Altax	- -	- -	0.5	- -	- -
Pentaerythritol	- -	- -	- -	5	5
Butyl Oleate	- -	- -	- -	20	15
Polyethylene glycol	- -	- -	- -	2	2
Tetrone A	- -	- -	- -	2	2
Cure, Min/°F	25/307	10/320	15/310	8/345	8/345

TABLE I-D

TEST COMPOUNDS OF VARIOUS RUBBER

Compound Ingredients	11	29	6	27	7	8	28
			Compound Number				
EPDM	100	- -	- -	- -	- -	- -	- -
Paracril Ozo	- -	- -	100	100	- --	- -	- -
Adiprene C	- -	- -	- -	- -	100	- -	---
Butyl 235	- -	- -	- -	- -	- -	100	100
Stearic acid	1	1	1.5	1	1	2	2
Zinc oxide	5	5	3	3	- -	5	5
Plastogen	10	10	- -	- -	- -	- -	- -
Anco Lt. oil	30	30	- -	- -	- -	- -	- -
Paraffin Wax	2	2	- -	- -	- -	- -	- -
Turgum S	- -	- -	3	- -	- -	- -	- -
Methlyn 100	- -	- -	20	15	- -	- -	- -
Wax	- -	- -	1	- -	- -	- -	- -
Flexol TOF	- -	- -	- -	- -	3	- -	- -
Hard Clay	150	150	- -	90	- -	- -	- -
HMF Black	3	3	3	5	3	3	3
Hi Sil 233	- -	20	30	- -	18	40	60
Captax	1.5	1.5	2.5	- -	2	1	1
Methyl Tuads	.75	.75	0.5	- -	- -	1.5	1.5
Methyl Zimate	2.4	2.4	- -	- -	- -	- -	- -
DPG	- -	- -	0.5	0.25	-.-	- -	- -
Unads	- -	- -	- -	0.25	- -	- -	- -
Altax	- -	- -	- -	1	3	- -	- -

TABLE I-D (Cont'd)
TEST COMPOUNDS OF VARIOUS RUBBER

RCD 2098	--	--	--	--	0.35	--	--
Cadmium Stearate	--	--	--	--	0.5	--	--
Wingstay 100	1.5	1.5	1	1	--	--	--
Sulfur	2	2	1.5	1.5	1.5	1.25	1.25
Cure, Min/°F	20/300	20/300	15/310	15/310	15/310	40/320	40/320

TABLE I-E

TEST COMPOUNDS - POLYBUTADIENE AND POLYISOPRENE

Compound Ingredients	Compound Number 31	32
Polybutadiene	100	- -
Polyisoprene	- -	100
Stearic Acid	1	3
Zinc Oxide	5	5
Process Oil	30	5
Red Oxide	3	3
Hard Clay	75	- -
Silene EF	35	- -
Hi Sil 233	- -	25
Titanium Dioxide	39	- -
Diethylene Glycol	2	- -
Polyethylene Glycol	- -	[illegible]
Captax	.75	- -
Altax	1	- -
D.O.T.G.	.35	--
Santocure	- -	1.3
Sulfur	2	2.5
Cure, Min/°F	10/290	20/297

TABLE II

TEST COMPOUNDS - HARDNESS AND RESILIENCE PROPERTIES

Compound Number	Shore A Hardness	Bashore Resilience	Skid Distance on Waxed Tile (inches)
	Natural Rubber		
1	61	51	13.2
13	56	48	14.5
16	61	43	15.9
17	63	56	13.6
18	50	75	13.7
23	76	35	19.8
	Styrene-Butadiene Rubber		
2	58	40	13.5
14	68	26	15.6
15	94	16	24.5
19	80	23	20.1
20	46	55	17.2
21	99	30	23.4
	Ethylene-Propylene-Diene Monomer Rubber		
9	58	47	15.9
10	51	57	13.2
11	56	38	15.4
12	60	50	13.0
29	67	36	17.5

TABLE II (Cont'd)

TEST COMPOUNDS - HARDNESS AND RESILIENCE PROPERTIES

Compound Number	Shore A Hardness	Bashore Resilience	Skid Distance on Waxed Tile (inches)
	Neoprene Rubber		
3	50	47	12.5
22	83	28	21.0
24	62	36	13.8
	Hypalon Rubber		
4	65	43	13.9
25	80	35	15.5
	Nitrile Rubber		
5	58	23	14.3
26	75	10	20.9
	Nitrile-Vinyl Rubber		
6	56	20	14.0
27	68	12	18.6
	Butyl Rubber		
8	55	12	13.7
28	71	15	18.0
	Urethane Rubber		
7	55	45	15.4
	Polybutadiene Rubber		
31	60	52	13.2
	Polyisoprene Rubber		
33	62	49	12.8

TABLE III

SLIP ANGLE VALUES USING MODIFIED IP-4 MACHINE

Compound Number	Polymer	Slip Angle (degrees) on: Waxed Asphalt Tile	Concrete	Wet Ice	0°F Ice
1	Natural Rubber	20.4	13.8	- -	- --
18	Natural Rubber	21.9	13.2	2.7	9.0
2	SBR	19.5	14.1	1.8	6.0
20	SBR	18.9	13.8	- -	- -
21	SBR	14.7	17.1	- -	- -
11	EPDM	18.6	13.5	3.3	11.4
3	Neoprene	21.3	14.1	2.1	7.5
24	Neoprene	18.9	15.0	- -	- -
4	Hypalon	19.5	14.7	1.8	7.5
25	Hypalon	19.5	16.2	- -	- -
5	Nitrile	20.1	15.0	3.6	4.5
6	Nitrile-Vinyl	21.6	14.4	3.3	3.0
7	Urethane	22.8	14.4	1.5	4.2
8	Butyl	18.6	14.4	- -	- -

TABLE IV

SKID DISTANCE - 30 LB. CARRIAGE - 4-MPH

Compound Number	Polymer	Skid Distance - Inches: Unwaxed Asphalt Tile	Waxed Asphalt Tile	Dusted Waxed Asphalt Tile	Concrete	Dusted Concrete	Speed at Track End Wet Asphalt Tile
1	Natural Rubber	12.8	14.0	43.0	18.2	21.8	3.50 MPH
2	SBR	13.6	13.7	42.0	18.4	21.4	3.61 "
5	Nitrile	13.5	15.7	39.	18.4	21.0	3.67 "
6	Nitrile-Vinyl	12.9	14.9	42.0	18.5	21.0	3.70 "
8	Butyl	13.8	15.6	42.0	16.3	19.5	3.55 "
12	EPDM	12.9	13.6	40.5	19.4	22.2	3.44 "
18	Natural Rubber	14.3	13.8	43.0	19.5	22.3	3.72 "
21	SBR	18.8	25.7	29.	20.6	21.8	3.29 "
24	Neoprene	13.4	13.8	38.3	17.0	20.5	3.72 "
25	Hypalon	3.8	15.9	39.0	19.9	22.0	3.25 "
31	Poly-butadiene	13.9	15.5	43.5	19.8	21.8	3.69 "
33	Poly-isoprene	12.6	13.9	44.0	17.3	20.8	3.29 "

TABLE V

SKID INDEX - PENDULUM MACHINE

Compound Number	Polymer	Skid Index: Unwaxed Asphalt Tile	Waxed Asphalt Tile	Dusted Waxed Asphalt Tile	Wet Waxed Asphalt Tile	Concrete	Dusted Concrete
1	Natural Rubber	114	89	33	7	75	64
2	SBR	108	88	35	5	75	67
5	Nitrile	105	76	36	6	75	70
6	Nitrile-Vinyl	104	78	35	6	75	67
8	Butyl	98	86	35	8	77	73
12	EPDM	104	86	32	8	70	62
18	Natural Rubber	118	102	34	5	67	64
21	SBR	75	51	48	8	65	67
24	Neoprene	104	90	35	4	78	72
25	Hypalon	94	72	36	7	75	67
31	Poly-butadiene	94	86	34	5	68	65
33	Poly-isoprene	115	97	33	7	73	66

TABLE VI

COMPARISON OF OBSERVED AND CALCULATED CARRIAGE SKID DISTANCES

Compound	Polymer	Unwaxed Tile		Waxed Tile		Dusted Tile		Concrete		Dusted Concrete	
No.		Obtained	Calc.	Obt'd.	Calc.	Obt'd.	Calc.	Obt'd.	Calc.	Obt'd.	Calc.
1	Natural Rubber	12.8	12.1	14.0	15.5	43	42	18.2	18.4	21.8	21.6
2	SBR	13.6	12.8	13.7	15.7	42	39	18.4	18.4	21.4	20.6
5	Nitrile	13.5	13.1	15.7	18.2	39	38	18.4	18.4	21.0	19.7
6	Nitrile-Vinyl	12.9	13.3	14.9	17.7	42	39	18.5	18.4	21.0	20.6
8	Butyl	13.8	14.0	15.6	16.0	42	39	16.3	17.9	19.5	18.9
12	EPDM	12.9	13.3	13.6	16.0	41	43	19.4	19.7	22.2	22.3
18	Natural Rubber	14.3	11.7	13.8	13.5	43	41	19.5	20.6	22.3	21.6
21	SBR	18.8	18.4	25.7	27.1	29	29	20.6	21.2	21.8	20.6
24	Neoprene	13.4	13.3	13.8	15.3	38	39	17	17.7	20.5	19.2
25	Hypalon	13.8	14.8	15.9	17.2	39	38	19.9	18.4	22.0	20.6
31	Poly-butadiene	13.9	14.8	15.5	16.0	44	41	19.8	20.3	21.8	21.2
33	Poly-isoprene	12.6	12.0	13.9	14.1	44	42	17.3	18.9	20.8	20.9

* Obt'd (obtained)

APPENDIX A

COMPOUNDING MATERIALS

Trade Name (Material)	Identification
Agerite Powder	Phenyl-B-Napthylamine
Altax	Benzothiazyl disulfide
Captax	2-Mercaptobenzothiazole
Circo Light Oil	Naphthenic type oil
Cumar MH	Coumarone-indene resin, medium grade
Goodrite 50	High styrene resin
Hi Sil 233	Hydrated silica
Hycar 1001	Butadiene-acrylonitrile rubber
Hypalon 40	Chlorosulphonated polyethylene
Methlyn 100	Methylated tall oil ester
Methyl Tuads	Tetramethylthiuram disulfide
Methyl Zimate	Zinc dimethyldithiocarbamate
2 MT	2-Mercaptothiazoline
Neoprene W	Polychloroprene
Paracril Ozo	Nitrile-polyvinylchloride resin blend
Reogen	Oil soluble sulfonic acid
Santocure	N-cyclohexyl-2-benzothiazole sulfenamid
Silene EF	Calcium silicate
Sunproof	Mixture of selected waxes
Tetrone A	Dipentamethylene thiuram tetrasulfide
TP-90	A high molecular weight polyether

APPENDIX A (Cont'd)

COMPOUNDING MATERIALS

Trade Name (Materials)	Identification
Turgum S	Terprene resin acid blend
Unads	Tetramethylthiuram monosulfide
Wingstay 100	Mixture of diaryl-p-phenylene diamines

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13. ABSTRACT

The divergence in the behavior of rubbery materials from the classical laws of friction requires testing of rubber compounds under speed and loadings likely to be encountered in service. This report describes a friction-measuring device developed at NLABS for testing rubber compounds under the speed and loading conditions normally encountered in walking.

The apparatus consists of a carriage traveling on an inclined plane and using a rubber specimen as a braking device. Stopping distances are used as a measure of the comparative friction of various rubber samples. Loadings can be controlled by means of a set of removable weights and speed is controlled by the length of inclined used. A second device adapted from a commercially available skid tester originally developed for testing road surfaces was also evaluated.

The data obtained from testing rubber compounds on various surfaces show: (1) good correlation between the two types of apparatus, thus providing a commercially available device suitable for specification testing; (2) the type and condition of the surface in contact with the rubber has more effect on friction than do differences in polymer type, hardness or resilience; and (3) friction of all the rubber compounds tested is extremely low on wet-lubricated surfaces, such as ice.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Tests	8					
Test equipment	8					
Elastomers	9		7			
Sliding friction	8,9		6			
Footwear	4		4			
Heels (footwear)	4		4			
Soles (footwear)	4		4			
Army	4		4			
Requirements	4		4			
Velocity	5		6			
Loads (forces)	5		6			

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