SKID RESISTANCE OF WAXED AND UNWAXED SMOOTH FLOOR SURFACES

by

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APPROVAL SHEET

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

For many years it has been recognized that slippery floors are a safety hazard. Researchers have been attempting to measure the antislip properties of smooth surface floors since 1926. In no instance has evidence been presented which rates the available flooring material according to safety values. There is very little information, which is readily available to the consumer, that may be used as a criterion in selecting a safe smooth floor covering. It would be desirable to have available for the consumer a ranking of the flooring materials according to safety values.

I. THE PROBLEM

Statement of the Problem

The objectives of the present study were (1) to determine friction values existing between shoe heel materials and floor covering materials using a friction-testing apparatus, and (2) to suggest implications for the choice of safe floor coverings for use in homes.

The Housing and Management area of the School of Home Economics at The Woman's College has recently acquired a friction testing apparatus for use in a regional housing research project entitled "Testing of Smooth Floor Surfaces and Finishes From the Standpoint of Safety," under the direction of Mrs. Savannah S. Day, project leader. Dr. Henry Bowen of the Department of Agricultural Engineering at North Carolina State College designed the apparatus for testing the friction values. The present study was a pilot study which contributed to the larger study in the following ways: (1) the Bowen friction testing apparatus was tested, using a planned procedure, and (2) a basis for determining the specific experimental design was provided.

Reasons for undertaking the study

It was a previous responsibility of the investigator to select the flooring material for a home for the aged. There was no concrete information found which helped to make a wise choice in selecting the safest, nonskid floor for these elderly people. Most smooth floor covering advertisements emphasize ease of maintenance and attractiveness, with little stress on safety values.

The investigator had previously worked in a hospital operating room and had seen the serious results of falls which necessitated major surgery, followed by excruciating pain and prolonged convalescence. Any research which would contribute to the prevention of falls and human suffering would be worthwhile.

Importance of the study

This study differed from previous studies due to the fact that the friction testing apparatus was tested for the first time. This machine had the advantage of testing several different types of smooth floor coverings at one time, which assisted in making a comparative analysis. In addition, some of the new shoe heel materials which had never been used in skid-resistance testing were tested with the floor coverings.

II. DEFINITIONS OF TERMS USED

Coefficient of static friction: the ratio of the force necessary to start motion to the normal force.

Coefficient of kinetic or dynamic friction: the ratio of the force necessary to maintain motion at a uniform rate to the normal force.

Skidding: to slide without rotating.

Plywood ring: a flat, annular ring of three-eighths inch thick plywood the surface of which was divided into space for 28 test panels.

Test panel: A panel of floor surface material nine inches long, nine inches wide, and one-eighth inch thick, which was cut into the shape of a trapezoid to fit the plywood ring.

CHAPTER II

REVIEW OF THE LITERATURE

A review of the literature revealed that as early as 1926 walkway surface materials were measured for coefficients of friction. Various testing machines have been developed and studies carried out intermittently up until the present. None of the machines has proved entirely satisfactory for testing antislip characteristics of smooth floor coverings and none of the studies has rated the materials tested according to safety values.

THE FIRST STUDY - 1924-1930

When the American Standards Association attempted to formulate a safety code for walkway surfaces in 1924 it was found that available data were inadequate for the satisfactory formulation of the code. As a result of this inadequacy arrangements were made "for a research fellowship at the National Bureau of Standards to conduct an experimental investigation of the frictional resistances of walkway surface materials."[1]

The subsequent research resulted in the development of a process for preparing specimens of walkway surface materials for frictional measurements, a testing machine and methods for measuring coefficients of friction. "Friction measurements under different conditions were made on 148 specimens of walk-way and flooring materials."[2]

In July 1926 a report of this experimental investigation was submitted for review. Due to the incompleteness of the research, the Bureau of Standards conducted an independent follow-up investigation to develop a satisfactory method for measuring the frictional resistances of walkway materials and to obtain the data which would assist in formulating the walkway safety code.[3]

Specimens chosen to afford a study of their coefficients of friction were (a) smooth-faced natural stone products, i.e., slate, marble, and travertine, (b) wood, i. e., maple, larch, and yellow pine flooring, (c) artificial

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[1]R. B. Hunter, "A Method of Measuring Frictional Coefficients of Walk-Way Materials," Bureau of Standards Journal of Research, V (August, 1930), 329.

[2]Ibid., p. 330.

[3]Ibid.

stone products containing hard abrasives in their mixture, (d) compressible manufactured products, i. e., rubber, cork, and linoleum, (e) metal products having ridged or roughened surfaces, and (f) clear metal surfaces.[4]

Coefficients of friction were measured as follows: (a) between clean, dry leather soles and clean, dry walkway materials, (b) between clean, wet leather soles and clean, wet worn walkway materials, (c) between dirty, wet, worn walkway materials and dirty, wet leather soles and dirty, wet rubber soles, (d) between oily, worn walkway materials and oily leather and rubber soles.[5]

The testing machine operated on an "oblique thrust principle corresponding to the thrust on the shoe in walking."[6] It consisted of a right-angled frame carrying a slotted 75 pound weight between two vertical bars that served as guides to the weight. The shoe could be drawn forward by means of a screw and lug. The horizontal component of force increased until the shoe slipped on the

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[4]Ibid.

[5]Ibid., p. 331.

[6]Ibid., p. 333.

surface, letting the weight drop. A graduated scale read the coefficient of friction.[7]

During the testing procedure, it became apparent that some materials became smoother and some became rougher under footwear. It was considered essential that measurements be taken on the worn flooring surfaces.[8]

Results of this follow-up research revealed no rational rating of walkway materials with respect to their safety or antislip values. Hence, the following conclusion was drawn:

> The spread in different determinations of the coefficient of friction of the same material, and the possible error in determining the minimum coefficient needed for safety from the meager data available are too great in comparison with the total range in the coefficients of friction of available materials to admit of a strict rating without introducing inconsistencies.[9]

1947 JOINT RESEARCH PROJECT OF THE NATIONAL SAFETY COUNCIL AND THE NATIONAL BUREAU OF STANDARDS

Nearly twenty years after the first study was completed, a joint research project was undertaken by the

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[7] *Ibid.*, p. 331.

[8] *Ibid.*

[9] *Ibid.*, p. 347.

National Safety Council and the National Bureau of Standards in 1947 for the purpose of developing a suitable instrument and method for measuring slipperiness, and securing data that could be used in the preparation of a code for safe walkway surfaces. The development of a safety code had previously been delayed because an adequate method of measuring slipperiness had not been found. The National Safety Council conducted a statistical survey of accidents from falls, and the National Bureau of Standards engaged in an engineering study of both walkways and footwear materials which were involved in slipping.[10]

Prior to the designing of the testing instrument, a detailed study of the mechanics of walking was conducted. Concealed, slow-motion cameras were used, in order that the people photographed would be walking naturally. These pictures revealed that:

> the leg slows down at the termination of its swing and then appears to vault onto the walkway, the other leg being used as a pole. They also show that the foot is first placed upon the walkway at an angle so that only the rear edge of the heel contacts the walkway surface during the early stages of the retarding phase of a step. The other foot remains in contact with the walkway, thus bearing part of the vertical load until

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[10]Percy A. Sigler, Martin N. Geib, and Thomas H. Boone, "Measurement of the Slipperiness of Walkway Surfaces," Journal of Research of the National Bureau of Standards, XL (May, 1948), 339.

> the heel rocks forward and the foot is fully planted.
>
> . . . .
>
> The horizontal component of the force exerted by the leg on a walkway surface reaches a maximum in the forward direction shortly after the heel makes contact with the walkway, decreases rapidly at first and then slowly as the foot deploys, and rapidly reaches a maximum in the backward direction as the ball of the foot prepares to leave the walkway. These horizontal components are the forces that must be counteracted by friction in order to avoid slipping.[11]

The slipperiness tester was designed by the National Bureau of Standards so that it could be used to test floors in actual service. It was named for its designer, Percy A. Sigler, and called the Sigler Pendulum-Impact Type Slipperiness Tester. The design of the machine was based on the premise that "in the process of ordinary walking, slipping is most likely to occur when the rear edge of the heel contacts the walkway surface."[12]

This portable slipperiness tester is of the pendulum-impact type and is still used to measure the dynamic coefficient of friction of floor surfaces. It can be used

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[11] Ibid., p. 340

[12] Ibid.

wherever a plain level surface has an area large enough to accommodate the instrument. It can also be used as a laboratory instrument for evaluating small test panels but it is not satisfactory for testing rough or corrugated surfaces.[13]

The Sigler Tester operates by means of a pendulum with a heel material which sweeps over the walkway surface that is to be tested. The mechanical heel forms the lower end of the pendulum to which a heel material can be attached to the underside at various angles so that only the rear edge of the test piece makes contact with the flooring material. A spring presses the edge of the test heel against the walkway during the contact.[14]

During the joint research project in 1947 only rubber and leather heels were tested with various flooring materials.[15]

The findings revealed that all the floor and

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[13]"Proposed Method of Test for Measuring the Dynamic Coefficient of Friction of Waxed Floor Surfaces," American Society for Testing Materials Bulletin, No. 196 (February, 1954), p. 21.

[14]Sigler, Geib, and Boone, op. cit., pp. 340-341.

[15]Ibid., p. 343.

walkway surfaces gave relatively high antislip coefficients when tested with the dry rubber heels. Under wet conditions many of the walkway surfaces would be classed as potentially dangerous for rubber or leather footwear. Only two floor materials tested had a coefficient of friction above 0.40 for rubber and leather heels under dry and wet conditions. They were soapstone stair tread with sand rubber finish and metal plate coated with phenolic resin and No. 46 alundum. Poor antislip characteristics (below 0.40) were found when testing leather heels, under both wet and dry conditions, on the following materials: terazzo worn smooth, cement-mortar topping worn smooth, paving brick worn smooth, quarry tile worn smooth, yellow pine, sanded, sealed, burnished, and waxed with water-emulsion-type wax, then polished, white-oak maintained with solvent-type wax, then polished, pressed fiberboard maintained with solvent-type wax, then polished, linoleum with solvent-type wax, linoleum with water-emulsion wax (except one particular brand). Battleship linoleum treated with different types and brands of floor waxes revealed the lowest antislip coefficient under dry conditions testing with a leather heel.[16]

The Sigler machine was used in a rather extensive investigation of untreated and waxed asphalt-tile corridors in a government building in Washington. The tests revealed that two of the asphalt-tile corridors, after being freshly waxed, were slippery when tested with leather heels and a different wax used; and two other corridors were found to be satisfactory. All corridors, when dry, had very good traction with rubber footwear, either waxed or unwaxed. Under dry conditions, waxed asphalt tiles, tested with a rubber heel, showed higher antislip coefficients than those obtained for the untreated tiles. With the leather heel, the opposite was found to be true except when using one particular brand of wax. All corridors were considered dangerous for both rubber and leather heels when wet, and especially so when waxed.[17]

"The results of these tests, considered in relation to slipperiness as actually experienced, indicate that a slippery condition does or does not exist, according to

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[16]Ibid., p. 345.

[17]Ibid., pp. 345-346.

whether the measured coefficient is less or greater than 0.40."[18]

ASTM METHODS FOR TESTING STATIC AND DYNAMIC COEFFICIENT OF FRICTION

In February 1954 the ASTM Bulletin published a report of the Committee D-21 on Wax Polishes and Related Materials which gave methods for determining the static and dynamic coefficient of friction on waxed floor surfaces under controlled laboratory conditions.[19]

The Sigler Pendulum-Impact Type Slipperiness Tester was proposed for measuring the dynamic coefficient of friction of waxed floor surfaces. The method suggested that the test heel be a piece of leather 1½ inches square and ¼ inch thick, conforming to Federal Specification KK-L-261c. Only the rear edge of the heel should come into contact with the test surface. The heel edge should be rounded slightly by light sanding with dry carborundum paper. To prevent too great an area of contact with the

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[18] Ibid., p. 346.

[19] "Evaluating the Slip Resistance of Floor Waxes; The Significance of Friction Measurements," American Society for Testing Materials Bulletin, No. 232 (September, 1958), p. 32.

test panel, a new heel should be prepared after repeated determinations.[20]

The test panels should be not less than 6 by 6 inches and mounted on a rigid base of 5/8-inch plywood to prevent buckling. "With a correctly adjusted machine and heel, these panels should have a coefficient of friction between 0.4 and 0.5."[21]

The Committee D-21 proposed the use of the James Machine, sometimes referred to as the Underwriters' type slip tester, for measuring the static coefficient of friction of waxed floor surfaces. This testing machine is not suitable for use on wet, rough, or corrugated surfaces. The shoe used in the testing should be faced with sole leather and sanded to a smooth flat surface with No. 400-A carborundum paper. The flooring panels should be not less than 6 by 6 inches and mounted on a rigid base to prevent buckling. "With a correctly adjusted machine and shoe, these panels should have a coefficient of friction between

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[20]"Proposed Method of Test for Measuring the Dynamic Coefficient of Friction of Waxed Floor Surfaces," American Society for Testing Materials Bulletin, No. 196 (February, 1954), p. 21.

[21]Ibid., pp. 21-22.

0.9 and 1.0."[22]

In preparation for the test, the panel should be flooded with the wax to be tested and placed in a vertical position.

After 10 minutes the bead should be wiped off at the bottom of the panel and the panel allowed to dry in this vertical position for two hours at 75 ± 2.5 F. and 50 ± 4 percent relative humidity. A second coat should be applied in the same manner but dried in the reverse direction for from 18 to 24 hours. The panel is then ready for testing.[23]

The shoe leather should be prepared for the test by placing a sheet of 400-A wet or dry carborundum paper on the laboratory bench and sanding the shoe. All dust should be removed. The testing should be conducted in a room maintaining the same temperature and humidity as the room in which the panel preparation is performed.[24]

The coefficient of friction is not a characteristic

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[22] Ibid., p. 20.

[23] "Proposed Method of Test for Measuring the Static Coefficient of Friction of Waxed Floor Surfaces," American Society for Testing Materials Bulletin, No. 196 (February, 1954), p. 20.

[24] Ibid., p. 21.

of one material when testing with the James Machine.

> It must always be measured as a resultant of three different materials, the shoe used, the wax, and the substrate. The flooring material itself makes a tremendous difference in overall slip resistance. Waxes completely safe on one type of flooring may be hazardous on another. For that reason, correlation between foot tests on the floor and readings on the machine should not be expected unless the three materials are identical. No correlation can be expected between field tests results with neolite and rubber soled shoes when compared with the readings obtained with an experimental leather sole on the James Machine.[25]

The American Society for Testing Materials is very definite in stating that both of these methods of tests are of a low order of precision. "Numerical differences in the second digit may not be significant, particularly where numerical results are high."[26]

1956 DURA SLIP RESISTANCE TEST

The Dura Slip Resistance Tester became available in the United States about 1956. It is a testing machine operating on the same principle as the James Machine for evaluating the static coefficient of friction of treated

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[25]"Evaluating the Slip Resistance of Floor Waxes; The Significance of Friction Measurements," American Society for Testing Materials Bulletin, No. 232 (September, 1958), p. 32.

[26]Ibid.

and untreated surfaces. In addition, it offers the advantage of portability and automatic operation. It can be operated at different powerstat settings to control the forward speed of the heel assembly.[27]

Due to the flexibility of the Dura Tester, it was evaluated and compared with the James Machine. The preparation consisted of coating the flooring surfaces with two applications of floor polish. The polishes selected represented a typical household type floor polish and a typical maintenance type floor wax. The test surfaces were allowed to dry for two hours in a vertical position, at 77 degrees F. and 50 percent relative humidity. The second coat was applied and dried overnight in the reverse direction.

The findings revealed that this machine measures static coefficients of friction in the range of 0.088 to 1.000. The comparative evaluation revealed that the Dura Tester obtained results which were within acceptable limits of precision for waxed and unwaxed surfaces and compared

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[27]Bernard Berkeley and James D. Burns, "Floor Wax Slip Testing Statistical Analysis of Dura vs. James Coefficient of Friction Measurements," Soap and Chemical Specialties, XXXIII, No. 4 (April, 1957), p. 77.

favorably with results obtained by using the James Machine.[28]

STUDIES TESTING HOSPITAL FLOOR SLIPPERINESS

In December 1958, the Hospital Bureau Research News reported a simple wax test for measuring slipperiness of floors. With a spring scale attached to a ten-pound canvas bag full of lead shot, the bag is pulled across the floor. If it takes less than a three-pound pull to drag the bag over the floor, the floor is too slippery. If it takes five pounds or more to pull the bag, the floor is considered safe.[29]

In 1959 a number of tests were conducted on hospital operating room floors. Among these was one for nonskid characteristics. Using the Sigler Slipperiness Tester, "Tests of relative slipperiness of the conductive flooring samples were made with leather and rubber heels under both wet and dry conditions."[30] The highest antislip coefficients were found to be between dry rubber heels and ceramic tile, latex terazzo, linoleum, rubber tile, and

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[28] Ibid., p. 79.

[29] "Simple Slip Test for Wax," Bureau Research News, (December, 1958), p. 3.

[30] Thomas H. Boone, and others, Conductive Flooring for Hospital Operating Rooms (Reprinted from Journal of Research of the National Bureau of Standards, LXIII (October-December, 1959), (March, 1960), 11.

vinyl tile.

In California, in addition to the Sigler Pendulum-Impact Slipperiness Tester there is a second instrument being used to test the slipperiness of floors in hospitals. Due to the complicated operating procedure and the expensiveness of the Sigler instrument, a number of hospitals developed a machine which is more simple to use. The surface which contacts the floor consists of a leather strip fastened to the underside of the machine. The leather strip simulates a leather shoe. A surface approximately 2 x 4 inches comes in contact with the floor. A ballast box directly over the leather strip is weighted with 19 lbs. 8 oz. of lead shot. Four small wheels aid the locomotion and a large clock like meter registers the friction values. The meter of the portable machine may be evaluated with the Sigler Test Meter and the hospitals can test the coefficient of friction of the floors.[31]

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[31]California Hospital Association, "Sample of Acceptable Hospital Floor Tester," Floor Safety Program, Appendix A., p. 1.

1960 NORWEGIAN BUILDING RESEARCH INSTITUTE STUDY

Dr. R. Schjodt, a research engineer at the Norwegian Building Research Institute, conducted a rather thorough study testing the human reaction to hardness of floor coverings. Electromyographic tests were used for analyzing muscle coordination when walking on various floor coverings. Indentation tests were carried out on the various materials to register the resistance to penetration. The agreement between the electromyograph and indentation tests was excellent, with the exception of the results for rubber. To clear up this point, the friction coefficients of the materials were measured. This was carried out by pulling a weighted sole along the floor. Special test floors were used which were tilted so that the friction angle could be measured directly. It was found that rubber behaves differently from other materials. For rubber, the kinetic coefficient is higher, but for other materials, the static friction coefficient is higher.[32]

The results indicate that the friction coefficient

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[32] R. Schjodt, "Measurements of Human Reaction to Hardness of Floor Covering," American Society for Testing Materials, Bulletin No. 247 (July, 1960), p. 56.

for a floor material, tested for kinetic friction, should be not less than 0.20, and not more than 0.40 for leather soles.[33]

MICHIGAN STUDY COMPLETED IN 1960

A comprehensive study was begun in 1957 at the Agricultural Engineering Department of Michigan State University. It consisted of investigations and personal interviews with victims of 100 home stairway accidents. The case histories of the victims were very informative and showed that slipping was responsible for more than twice as many falls as any other cause. The first approach to the problem of trying to reduce these accidents caused by slipping was to determine the coefficients of friction of the tread covering materials. The project was directed toward "establishing quantitative measurements of the slipperiness characteristics of tread covering materials with various combinations of shoe sole materials."[34]

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[33]Ibid., p. 35.

[34]Agricultural Engineering Department of Michigan State University, "The Cause and Nature of Stairway Falls," Michigan Contributing Project Report for 1959, p. 1. (Mimeographed.)

Tread coverings tested were linoleums, rugs, wood finishes, abrasive materials, rubber mats, marble and bare wood. Shoe sole materials tested were neoprenes, crepes, leathers, and travelites.[35]

It was found that repeated testing of the materials caused the coefficient of friction to become reduced, the reduction varying with various combinations of materials and shoe soles.[36]

Due to the extensiveness of this problem, further research was carried out on various types of tread surfaces on stairways which had caused slipping.[37] Results of this investigation showed that:

> The abrasive strip had the highest overall average coefficient of friction of the six materials studied. This material showed no difference in its slipping characteristics after being used.
>
> The varnish, rubber mat, paint and wood were grouped together with values of .66, .65, .62, and .61, respectively. Linoleum had the smallest frictional value with .56. This was 19 points less than the coefficient of friction for the abrasive strip.

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[35] Ibid.

[36] Ibid.

[37] Merle L. Esmay, "Home Stairway Safety Research Results." (East Lansing: Agricultural Engineering Department of Michigan State University, 1961), p. 8. (Mimeographed.)

> It will be noted . . . that the coefficient of friction decreased by 0.14 for varnish as it became worn. Wood and paint decreased slightly with use and linoleum and rubber mat increased some.[38]

Shoe sole materials studied were ripple, neoprene, neolite, crepe, Goodrich, and leather. Tests were performed on the new sole and on the worn sole. "The ripple sole performed with a considerably higher friction value than any of the other materials.[39] Listed in order are ripple 1.02, neoprene .67, neolite .63, crepe .59, and Goodrich .55. There was a .35 drop from ripple to neoprene and a .04 difference in a descending order thereafter. "Leather soles performed most poorly of those tested with a coefficient of friction much less than half that of the ripple sole."[40]

Wear improved and raised the coefficient of friction of all the sole materials except crepe. Probably this was due to the fact that new soles, except crepe, have a smooth, hard finish.

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[38] Ibid.

[39] Ibid., p. 10.

[40] Ibid.

Professor Esmay stated, in December 1960, at the annual meeting of the American Society of Agricultural Engineers, that the conclusion from this extensive study revealed that:

> The abrasive strip and the rubber mat showed the best frictional properties of the materials studied. The coefficient of friction for these two tread materials was higher than the other tread materials for most all of the sole materials studied. For these two treads there was little difference between the new and used materials. Wood, varnish, and paint generally showed a decrease in the coefficient of friction with use, while linoleum increased with use.[41]

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[41] Larry J. Segerlind and Merle L. Esmay, "An Analysis of the Frictional Characteristics of Stairway Tread Covering Materials," (paper No. 60-914 presented at the annual meeting of the American Society of Agricultural Engineers, December 6, 1960).

SUMMARY

A review of the literature has revealed that several research studies have been conducted to determine the antislip characteristics of floor coverings. The outstanding ones were: The 1926 American Standards Association Study, followed by the 1929 National Bureau of Standards Study, the 1948 Joint Research Project of the National Safety Council and the National Bureau of Standards, the ASTM Methods for Testing Static and Dynamic Coefficient of Friction, the 1957 Dura Slip Resistance Test, the studies testing hospital floor slipperiness, the 1960 Norwegian Building Research Institute Study, and the Michigan Study, completed in 1960.

The results have been informative and interesting. However, there is no list to be found which rates the materials on the market today that will be a guide in selecting the safest floor coverings for private homes, commercial buildings or institutions.

CHAPTER III

EXPERIMENTAL PROCEDURE

This is a pilot study to a state project contributing to the Southern Regional Housing Research Project S-8. The experimental procedures are based on both the procedures given in previous studies of skid resistance and those used in the preliminary testing of the friction testing machine.

This chapter presents a description of the friction testing machine, the procedure for preparing for the tests, the testing procedure, and the method of data analysis.

I. DESCRIPTION OF THE TESTING APPARATUS

The testing apparatus used in this study was designed and constructed by Dr. Henry Bowen of the Department of Agricultural Engineering at North Carolina State College. The design of the machine was based on the premise that, in the process of walking, slipping is most likely to occur when the floor surface is first contacted by the heel.

The laboratory machine consists chiefly of a movable circular table, a controllable speed electric motor, and a mechanical recorder. Figure 1 shows the testing machine. The movable circular table is approximately seven feet in diameter. Attached to the circular table is a 3/8 inch thick plywood ring on which test materials may be mounted. The rings are interchangable; therefore, not permanently attached. The circular table rotates underneath a shoe heel which is attached to a platform to which weights may be applied. Figure 2 shows the platform with a shoe heel attached. When the circular table is rotated, the mechanical recorder continuously charts the force of friction on record rolls. Figure 3 shows the mechanical recorder. The apparatus is capable of measuring both kinetic and static friction. One of the basic assumptions of this study was that the measurements recorded by the friction testing apparatus are accurate.

II. SELECTION OF TEST MATERIALS

Selection of floor surface materials

Nine different types of resilient floor covering

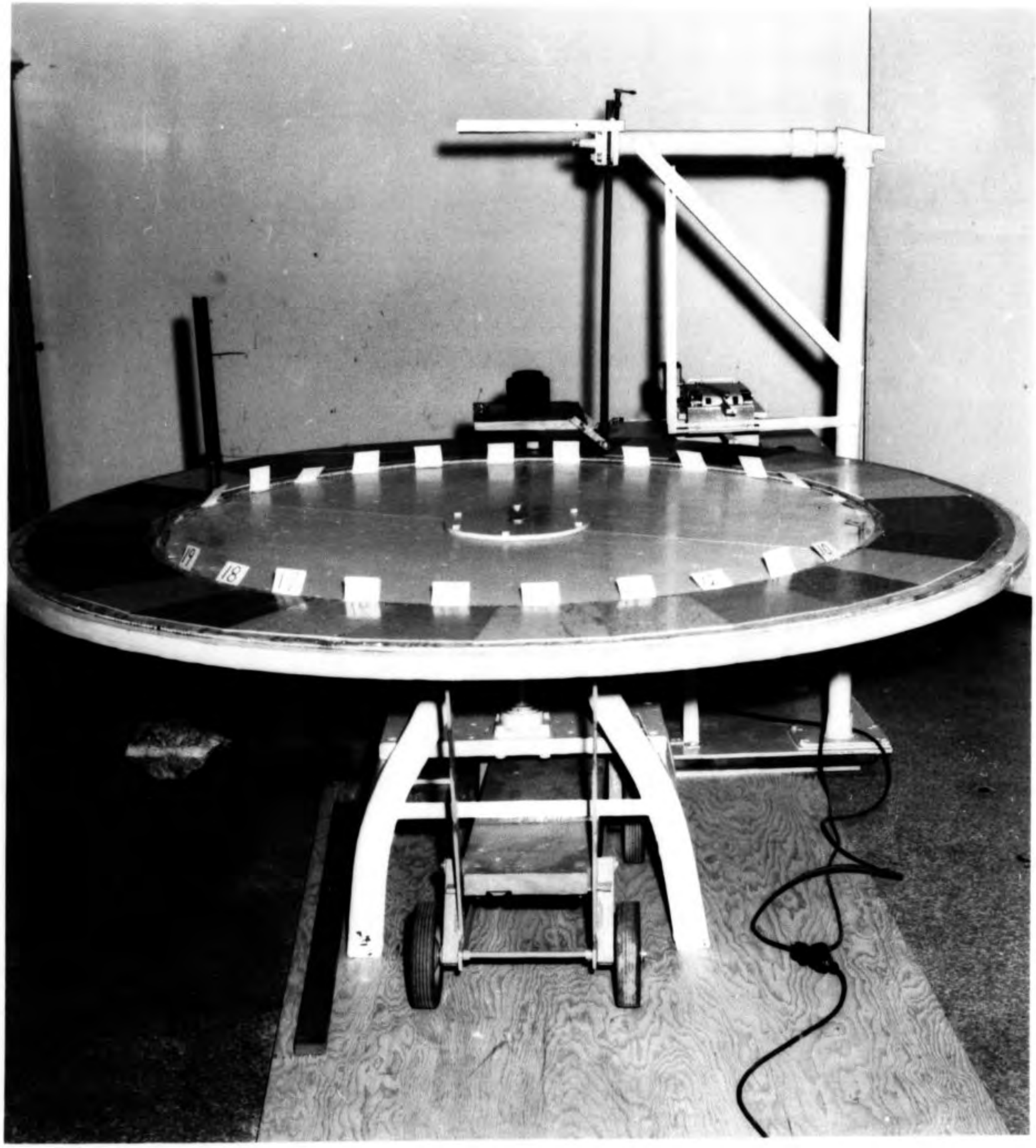

Figure 1. The friction testing apparatus.

Figure 2. Weighted platform with shoe heel attached.

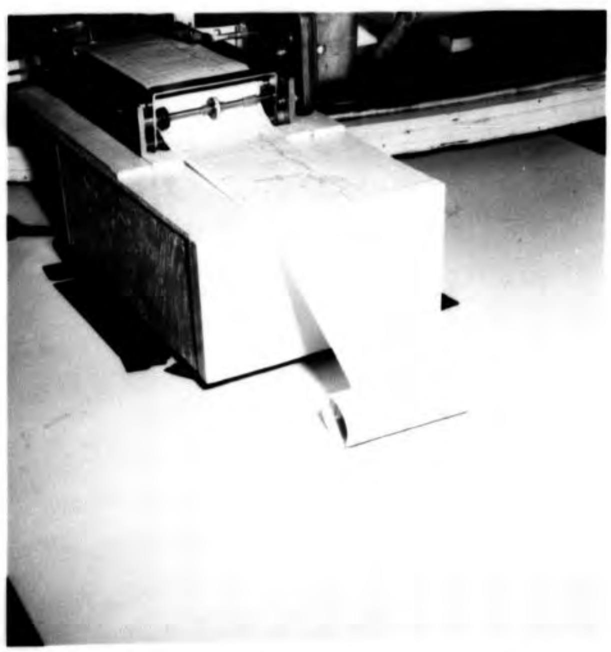

Figure 3. The mechanical recorder with record roll set in position.

materials were selected for testing. For each type of material to be tested six samples were obtained, three samples from each of two manufacturers, providing a total of fifty-four test samples. All the materials selected met the requirements of federal specifications. Table I lists the floor materials selected, the manufacturers, and the federal specification numbers. The materials were either purchased on the open market or contributed by the manufacturer.

Description of floor surface materials selected: The terminology employed by the floor covering industry as to type and composition of resilient smooth floor surface materials will be used in the present study. In 1958, at a conference conducted by the Building Research Institute these flooring materials were described as follows:

Asphalt Tile	"Composed through full thickness of asphaltic or resinous binder with asbestos or other fibers, fillers, and pigments formed under pressure while hot.
Vinyl-Asbestos Tile	"Composed through full thickness of vinyl resins, plasticizers, pigments, fillers and asbestos fibers formed under pressure while hot.

TABLE I

FLOOR SURFACE MATERIALS SELECTED, THE MANUFACTURER AND FEDERAL SPECIFICATION NUMBER

Floor surface materials	Manufacturer	Federal specification number
Asphalt	Armstrong Cork Co. Flintkote Co.	SST-306b
Greaseproof asphalt	Kentile, Inc. Flintkote Co.	SS-T-307 (GSA-FSS)
Vinyl asbestos	Flintkote Co. Kentile, Inc.	L-T-00345 (COM NBS)
Solid vinyl opaque	Robbins Floor Products, Inc. Kentile, Inc.	LF-00450
Solid vinyl translucent	Amtico Flooring Div., American Biltrite Rubber Co. The General Tire and Rubber Co.	LF-00450
Rubber	Kentile, Inc. B. F. Goodrich Co.	ZZ T-301b
Battleship linoleum	Armstrong Cork Co. Congoleum-Nairn, Inc.	LLL-L-351b
Plain cork	Kentile, Inc. Armstrong Cork Co.	LLL-T-431b
Vinyl cork	Armstrong Cork Co. Dodge Cork Co.	LLL-T-431b

Vinyl (Homogeneous) Tile	"Composed through full thickness of vinyl resin, plasticizers, pigments and fillers formed under pressure while hot.
Rubber Sheet & Tile	"Composed through full thickness of vulcanized rubber compound binder with reinforcing fibers, pigments and fillers.
Linoleum Sheet & Tile	"Composed of oxidized linseed oil, fossil and other oxidized oleoresinous binder mixed with ground cork, wood flour, mineral fillers and pigments and pressed on burlap or saturated felt backing.
Cork Tile	"Composed through full thickness of compressed granulated cork bonded with a heat processed resinous binder."[42]
Vinyl Cork	"Composed of large particles of natural cork. These particles of virgin cork are fused together with vinyl binders and the tile is permanently sealed in with clear vinyl."[43]

Selection of heel size and materials

For this study, one heel size, a woman's cuban heel, was selected for two reasons: (1) by using one heel size,

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[42]Building Research Institute, Installation and Maintenance of Resilient Smooth-Surface Flooring (National Research Council, Publication 597. Washington, D. C.: 1958), p. 81.

[43]Armstrong Technical Data 1962-63 for Interior Designers (Lancaster, Pennsylvania: 1962), p. 140.

1¼ square inches, the area of contact between the heel and the floor surface material could be controlled and (2) "Nearly nine tenths of the people reported as fatally injured in falls on the same level are 65 years of age and older."[44] The majority of these fatalities occur among older women, many of whom wear cuban heels.

The heel materials chosen for testing with the floor coverings were leather, hard rubber, nylon, Neolite, rubber crepe, Adiprene, and Neoprene-cord. The first five listed were the only ones available from the local suppliers. Adiprene and Neoprene-cord were secured directly from the manufacturer.

Description of heel materials:

Nylon: "A generic title for a group of compounds called polyamides, substances which contain in their chains, besides carbon and hydrogen clusters, the amide group occurring at regular intervals."[45]

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[44]Metropolitan Life Insurance Company,"Falls a Major Cause of Death," Statistical Bulletin, XL (April, 1959), p. 8.

[45]B. H. Wiel and Victor J. Anhorn, Plastic Horizons (Lancaster: Jaques-Cattell Press, 1944), p. 113.

Neoprene: "A polymer of chloroprene, which is 2:chloro-1: 3 butadiene. One of the first commercial synthetic rubbers which was developed by DuPont in 1931."[46]

Adiprene: "Liquid urethane polymers which may be cast as solid elastomers or sponges."[47]

Rubber: "A substance that is obtained from the latex of many tropical plants, characterized by its elasticity...prepared by coagulating the latex, collecting the sticky coagulum, and either milling into rough sheets of crepe rubber or rolling into smooth or ribbed sheets and drying."[48]

Leather: "The hide or skin of an animal, tanned, tawed, or otherwise dressed for use."[49]

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[46] J. T. Marsh, An Introduction to Textile Finishing (New York: John Wiley & Sons, Inc., 1951), p. 453.

[47] R. J. Athey, J. G. Dipinto and J. S. Rugg, Adiprene L A Liquid Urethane Elastomer, Elastomer Chemicals Department, E. I. Du Pont de Nemours S. Company, Inc., Development Products Report No. 10 (Wilmington: E. I. Du Pont de Nemours S. Company, 1958), p. 4.

[48] Webster's Third New International Dictionary (Springfield: G. & C. Merriam Co. 1961), p. 1287.

[49] Ibid., p. 1983.

Neolite: "is the trade name for a rubber resin composition material manufactured and sold by the Goodyear Tire & Rubber Company...Neolite and comparable products are composed of various blends of natural and synthetic rubbers, the most important synthetic being styrene butadiene (SBR), Hycar and Neoprene."[50]

III. PREPARATION FOR TESTING

Randomization and placement of test panels

A table of random numbers was used for randomizing the test panels which were arranged on two plywood rings. The panels were nine inches long, nine inches wide, and one-eighth inch thick, and were cut into the shape of a trapezoid to fit the circular ring. The test panels were numbered 1 through 54. The first twenty-seven numbers drawn from the table of random numbers were placed on plywood ring No. 1 and the second twenty-seven numbers drawn were placed on plywood ring No. 2. Since a ring held a possible twenty-eight test panels, an additional panel of asphalt-asbestos was used to fill the vacant space

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[50] Letter from J. S. Roney, Sales Engineer, The B. F. Goodrich Company dated April 11, 1962.

on each ring. The data resulting from these panels were not used in the experimental analyses.

The test panels were cemented into position with Welwood Permaset Glue. Each of the test panels was numbered on the ring for identification. One of the basic assumptions of this study was that the small test panels of floor surface materials used in the laboratory tests are like the floor surfaces installed in homes.

Preparation of heel surfaces

The cuban heels, mounted on wooden blocks, were fitted by a shoe repairman with a top lift of the seven different heel materials. Fourteen heels were prepared in duplicate pairs with a top-lift of each material. For identification, one set of seven heels was labeled A and the duplicate set B.

Each wooden block with the heel attached was weighed and a uniform weight established either by adding or reducing the weight of the block. Each heel was sanded with No. 400 wet or dry carborundum paper until any design or roughness was eliminated and the entire heel surface was level.

The order for testing the seven heel materials was established by a randomized drawing.

Preparation of the testing assembly

The plywood ring with the mounted test panels of floor material was attached to the surface of the circular table. The wooden block with the cuban heel attached was fastened to the weight platform with winged nut screws. The heel was lowered into position on the floor covering material so that the entire heel surface was in direct contact with the floor surface material. The recorder cable was attached to the load beam and a record roll set in position.

IV. TESTING PROCEDURE

For this particular experiment only kinetic friction measurements were obtained for various combinations of floor coverings and shoe heel materials. All measurements were obtained at room temperature of $74^{\circ} \pm 2^{\circ}$ F with no control of humidity. Three series of tests were run on the two rings containing the test panels of floor materials. Force of friction measurements were first recorded for the new materials using the seven different types of heel materials. The same series of tests were repeated with the same floor materials, worn and then waxed.

Testing new floor panels

All of the test panels were cleaned with a mild soap and water solution, followed by clear rinse water, after which the panels were thoroughly dried before initiation of tests. The general testing procedure which was followed is listed in steps 1 through 10.

1. Before each test, the floor covering material and the top-lift of the heel were wiped off with a clean, soft cloth to remove any possible dust particles which might have an affect on the friction measurements.
2. The heel was raised approximately 1/16 inch off the floor material by attaching a wire with a small rod over the extended bar above the heel platform.
3. The recorder pin was adjusted so that it rested on line 0 of the record roll. A calibration of the recorder was taken to establish a method by which the recorder readings could be accurately converted into

pounds of frictional force. With the mechanical recorder registering the readings, one pound weights were added singly until a number, ranging from 13-17 pounds, was reached. The weights were removed one at a time, as the readings were recorded by the mechanical recorder.

4. The heel was then lowered into position so that the entire heel surface was in direct contact with the floor surface on the testing apparatus.
5. A vertical load of 15 pounds was placed on the weight platform directly above the center of the heel to be tested. This amount of weight was selected since preliminary tests had indicated that the 1/2 inch load beam on the testing machine would support a 15 pound vertical load on the materials to be tested.
6. The heel was pre-positioned on the panel preceding panel No. 1.
7. The testing machine and the recorder switches

were turned on simultaneously. As the heel reached the center of each test panel, one person read the test panel number which was recorded by a second person on the record roll at the point on the graph corresponding to the frictional force measurement for the particular test panel.

8. The table was rotated to complete three revolutions, giving three readings for each of the twenty-eight test panels.
9. After the three revolutions, a second calibration was made to verify the accuracy of the recorder.
10. After the testing of each type of heel material, the table assembly was moved. This was done to decrease the radial distance of the testing surface so that each type of heel material came in contact with a different portion of the floor material.

Testing worn floor panels

After tests were run on the new floor covering materials they were worn by an accelerated method. The floor surface was sanded with No. 400-A carborundum paper as suggested by the American Society for Testing Materials.[51] The carborundum paper was attached to a block of wood which was fastened onto the weight platform in the same manner as the test heels were fastened. The floor covering materials revolved 21 times under the sanding block loaded with a five pound weight. New carborundum paper was applied after every 4¼ revolutions. After this preparation, general testing procedures 1 through 10 as previously described were followed.

Testing waxed floor panels

In this series of tests a water-emulsion type wax was used. This type of wax was selected for two reasons: (1) it was recommended for general use on more of the floor materials to be tested than any other type of wax. (2) it accounts for approximately 4/5 of the total sales of floor waxes.[52] Two basic assumptions of this study,

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[51]"Proposed Method of Test for Measuring the Dynamic Coefficient of Friction of Waxed Floor Surfaces," American Society for Testing Materials Bulletin, No. 196 (February, 1954), p. 21

[52]Walter J. Hackett and Cyril Kimball, "Waxing Enhances Floors," Soap and Chemical Specialties (August, 1960), p. 77.

with reference to wax, were that uniformity exists among lots in the same wax brand and that the results obtained from applying wax to the test panels in the laboratory are relevant to the results obtained from applying wax to floor surfaces in homes. A mohair applicator was employed for distributing the wax uniformly, as suggested by a study sponsored by the Chemical Specialties Manufacturers Association.[53] The floor covering materials were coated with two applications of the water emulsion wax. After application of the first coat, the floor covering materials were allowed to dry overnight. The second coat was then applied in the reverse direction and allowed to dry approximately 48 hours. After this preparation, general testing procedures 1 through 10 as previously described were followed.

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[53] Ibid., p. 78.

V. METHOD OF DATA ANALYSIS

The testing program was carefully designed so that a sound statistical analysis of the results would be possible. Insofar as possible, all factors affecting results were controlled, either experimentally or statistically.

The three conditions of the floor surface materials-new, worn, and waxed - were analyzed as three separate experiments. The following four hypotheses were tested under the three separate conditions as three separate experiments.

1. There is no difference among the means of the force of friction measurements for the nine types of floor surface materials.

2. There is no difference among the means of the force of friction measurements for the seven types of shoe heel materials.

3. There is no interaction among the floor surface materials and the shoe heel materials.

4. There is no difference between the means of the force of friction measurements of samples from the respective pairs of manufacturers of the same type of floor material.

In this study, the primary interest was in testing the skid resistance of various smooth floor surfaces; however, it was recognized that there might be a difference in skid resistance among various heel materials and an interaction between the floor materials and heel materials. Therefore each experiment was planned as a two factor experiment with seven categories of one factor and nine categories of the other factor and with twelve measurements in each cell.

Since the six samples of each type of floor material were supplied by two manufacturers, but not the same two manufacturers for all floor materials, variations between manufacturers had to be treated as part of the within cell variation.

Hence, the following analysis of variance model was used:

Source of variation		Degrees of freedom
Among heel materials		6
Among floor materials		8
Heel material x floor material interaction		48
Within cells		693
Between manufacturers	63	
Within sub-cells	630	
Total		755

It was decided that if the interaction mean square was significantly greater than the mean square within cells that interaction mean square would be used as the error mean square for testing significance of the main effects. It was further decided that if these main effects were significant the various coefficients of kinetic friction would be computed and the materials ranked accordingly.

Coefficient of kinetic friction, an experimental constant, was used in this study in order (1) to compare the frictional properties of the nine floor materials and of the seven shoe heel materials, (2) to compare the same pair of materials under the three varying conditions of their surfaces of contact, and (3) to calculate the maximum frictional force corresponding to any normal load. From the frictional force recorded by the mechanical recorder and the vertical force - the weight applied to the shoe heel - the coefficient of kinetic friction was calculated. The following formula was used: Coefficient of kinetic friction = (force to slide heel on surface) ÷ (total weight pressing heel surface to floor surface).

A comparison was then made of new, worn, and waxed floor material with each type of heel material.

Results based on the analyses of the experiments may be found in the following chapter.

CHAPTER IV

EXPERIMENTAL RESULTS

Testing the skid resistance of new, worn, and waxed smooth floor surfaces comprised three laboratory experiments of 84 tests, resulting in 2,352 measurements which were analyzed.

This chapter presents an analysis of variance and results of coefficient of friction measurements of new, worn, and waxed smooth floor surface materials. A comparison of the new, worn, and waxed materials is presented at the conclusion of the chapter.

I. NEW FLOOR SURFACE MATERIALS

Analysis of variance

An analysis of variance of skid resistance of the new floor surface materials is shown in Table II. All main effects and the interaction between main effects were significant beyond the .1 per cent level of significance.

Among the seven heel materials the F ratio of 225.17 was significant at the .1 per cent level. This significant

TABLE II

ANALYSIS OF VARIANCE OF SKID RESISTANCE
OF
NEW FLOOR SURFACE MATERIALS

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Among heel materials	6	9352.98	1558.83	225.17*
Among floor materials	8	713.40	89.18	12.88*
Heel material x floor material interaction	48	332.31	6.92	2.28*
Within cells	693	2100.45	3.03	
Between manufacturers	63	500.89	7.95	3.13*
Within subcells	630	1599.56	2.54	
Total	755	12499.14		

*Significant beyond the .1 per cent level.

value of F indicated that some shoe heel materials have greater skid resistance than others. These findings, indicating a significant difference among the seven heel materials led to rejecting the original null hypothesis.

Among the nine new floor materials the F ratio of 12.88 was significant at the .1 per cent level. This significant value of F indicated that some new smooth floor surface materials have greater skid resistance than others. These findings, indicating a significant difference among the nine new, smooth floor surface materials led to rejecting the original null hypothesis.

The heel material x floor material interaction revealed that the F ratio of 2.28 was significant at the .1 per cent level of significance. This significant value of F indicated that the interaction of new floor materials tested with shoe heel materials produces effects that can not be explained by adding the main effects. These findings, indicating a significant interaction between the heel materials and the floor materials, led to rejecting the original null hypothesis.

The within cells, between manufacturers, revealed that the F ratio of 3.13 was significant at the .1 per cent level.

This value of F indicated that the samples of the same material from two different manufacturers were significantly different and led to rejecting the original null hypothesis.

Coefficient of friction measurements

The coefficient of friction measurements between the new floor surface materials and the seven shoe heel materials are shown in Table III. The table also shows the average coefficient of friction for the floor materials from each of the two manufacturers of each type of floor material. In addition, the overall average coefficient of friction is shown for each type of floor material and heel material.

The coefficients of friction for all types of new floor material were lowest with the leather heel and highest with Neoprene cord. The differences among the coefficients of friction for heel materials were considerably greater than the differences among floor surface materials. However, for both types of materials the differences were highly significant. The nine types of floor materials tested with the seven types of heel materials may be ranked in terms of overall average coefficient of friction in ascending order as follows: linoleum, vinyl asbestos, greaseproof asphalt, vinyl cork, solid vinyl opaque, asphalt, plain cork, solid

TABLE III

COEFFICIENT OF FRICTION MEASUREMENTS BETWEEN NEW FLOOR SURFACE MATERIALS AND SHOE HEEL MATERIALS

Type of floor surface materials	Mfr. No.	Type of shoe heel material: Leather	Adi-prene	Nylon	Neo-lite	Hard rubber	Rubber crepe	Neoprene-cord	Overall average for floor material	
		(Average coefficient of friction)								
Linoleum	1	.199	.315	.365	.508	.578	.741	.868	.510	.533
	2	.243	.331	.427	.539	.632	.780	.942	.555	
Vinyl asbestos	1	.246	.367	.461	.595	.656	.808	.870	.572	.595
	2	.221	.385	.498	.613	.763	.846	1.000	.618	
Greaseproof asphalt	1	.224	.471	.561	.673	.760	.891	1.051	.662	.622
	2	.235	.492	.436	.578	.655	.756	.930	.583	
Vinyl cork	1	.210	.333	.456	.590	.669	.829	1.007	.585	.632
	2	.262	.679	.548	.629	.723	.835	1.085	.680	
Solid vinyl opaque	1	.313	.484	.541	.627	.731	.897	1.167	.680	.656
	2	.271	.366	.541	.647	.739	.836	1.031	.633	
Asphalt	1	.260	.523	.517	.679	.751	.899	1.026	.665	.657
	2	.271	.510	.490	.686	.683	.883	1.021	.649	
Plain cork	1	.359	.377	.425	.563	.650	.842	.963	.597	.658
	2	.579	.625	.545	.638	.724	.914	1.015	.720	
Solid vinyl translucent	1	.316	.444	.618	.794	.756	1.026	1.098	.722	.672
	2	.267	.341	.449	.632	.709	.848	1.110	.622	
Rubber	1	.408	.591	.680	.856	.897	1.011	1.197	.806	.789
	2	.307	.582	.615	.833	.865	.975	1.229	.772	
Overall average for heel material		.288	.456	.509	.649	.719	.867	1.034		

vinyl translucent, and rubber.

Linoleum: The new linoleum had the lowest coefficient of friction of any of the new smooth floor materials tested. The coefficient of friction for linoleum ranged from .217 with leather heels to .905 with Neoprene cord and resulted in an overall average of .533 for all heels tested. Between the two manufacturers of this material there was a difference of .045 in average coefficient of friction obtained from their six samples.

Vinyl asbestos: The coefficient of friction for vinyl asbestos ranged from .234 with leather heels to .935 with Neoprene cord and resulted in an overall average of .595 for all heels tested. Between the two manufacturers of this material there was a difference of .046.

Greaseproof asphalt: The coefficient of friction for greaseproof asphalt ranged from .230 with leather heels to .991 with Neoprene cord and resulted in an overall average of .622 for all heels tested. Between the two manufacturers of this material there was a difference of .079.

Vinyl cork: The coefficient of friction for vinyl cork ranged from .236 with leather heels to 1.046 with Neoprene cord and resulted in an overall average of .632

for all heels tested. Between the two manufacturers of this material there was a difference of .095.

Solid vinyl opaque: The coefficient of friction for solid vinyl opaque ranged from .292 with leather heels to 1.099 with Neoprene cord and resulted in an overall average of .656 for all heels tested. Between the two manufacturers of this material there was a difference of .047.

Asphalt: The coefficient of friction for asphalt ranged from .266 with leather heels to 1.024 with Neoprene cord and resulted in an overall average of .657 for all heels tested. Between the two manufacturers of this material there was a difference of .016.

Plain cork: The coefficient of friction for plain cork ranged from .469 with leather heels to .989 with Neoprene cord and resulted in an overall average of .658 for all heels tested. Between the two manufacturers of this material there was a difference of .123.

Solid vinyl translucent: The coefficient of friction for solid vinyl translucent ranged from .292 with leather heels to 1.104 with Neoprene cord and resulted in an overall average of .672 for all heels tested.

Between the two manufacturers of this material there was a difference of .10.

<u>Rubber</u>: The new rubber floor surface material had the highest coefficient of friction of any of the new smooth floor surface materials tested. The coefficient of friction for rubber ranged from .358 with leather heels to 1.213 with Neoprene cord and resulted in an overall average of .789 for all heels tested. Between the two manufacturers of this material there was a difference of .034.

Among the nine floor materials tested, the overall average coefficient of friction ranged from .533 for linoleum (lowest) to .789 for rubber (highest), a range of .256. The floor surface materials tested with leather, Adiprene, and nylon heels tended to be below the overall average. The floor surface materials tested with heel materials containing either synthetic or natural rubber (Neolite, hard rubber, rubber crepe, and Neoprene cord) tended to be above the overall average.

II. WORN FLOOR SURFACE MATERIALS

Analysis of variance

An analysis of variance of skid resistance of the worn floor surface materials is shown in Table IV. All main effects and the interaction between main effects were significant beyond the .1 per cent level of significance.

Among the seven heel materials the F ratio of 229.90 was significant at the .1 per cent level. This significant value of F indicated that some shoe heel materials have greater skid resistance than others. These findings, indicating a significant difference among the seven heel materials, led to rejecting the original null hypothesis.

Among the nine worn floor materials the F ratio of 5.95 was significant at the .1 per cent level. This significant value of F indicated that some worn smooth floor surface materials have greater skid resistance than others. These findings, indicating a significant difference among the nine worn smooth floor surface materials led to rejecting the original null hypothesis.

TABLE IV

ANALYSIS OF VARIANCE OF SKID RESISTANCE
OF
WORN FLOOR SURFACE MATERIALS

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Among heel materials	6	4913.45	818.91	229.90*
Among floor materials	8	169.55	21.19	5.95*
Heel material x floor material interaction	48	170.98	3.56	2.44*
Within cells	693	1012.27	1.46	
Between manufacturers	63	353.08	5.60	5.36*
Within subcells	630	659.19	1.05	
Total	755	6266.25		

*Significant beyond the .1 per cent level.

The heel material x floor material interaction revealed that the F ratio of 2.44 was significant at the 1 per cent level of significance. This significant value of F indicated that the interaction of worn floor materials tested with shoe heel materials produces effects that cannot be explained by adding the main effects. These findings, indicating a significant interaction between the heel materials and the floor materials, led to rejecting the original null hypothesis.

The within cells, between manufacturers, revealed that the F ratio of 5.36 was significant at the .1 per cent level. This value of F indicated that the samples of the same type of floor material from two different manufacturers were significantly different and led to rejecting the original null hypothesis.

Coefficient of friction measurements

The coefficient of friction measurements between the worn floor surface materials and the seven shoe heel materials are shown in Table V. The table also shows the average coefficient of friction for the floor materials from each of the two manufacturers of each type of floor material. In addition, the overall average

TABLE V

COEFFICIENT OF FRICTION MEASUREMENTS BETWEEN WORN FLOOR SURFACE MATERIALS AND SHOE HEEL MATERIALS

Type of floor surface materials	Mfr. No.	Type of shoe heel material: Leather	Nylon	Adiprene	Rubber	Neolite	Rubber crepe	Neoprene-cord	Overall average for floor material	
Linoleum	1	.238	.311	.333	.500	.584	.592	.698	.465	.475
	2	.230	.292	.369	.528	.543	.662	.775	.486	
Vinyl asbestos	1	.248	.326	.405	.577	.606	.648	.720	.504	.515
	2	.235	.359	.401	.583	.653	.647	.808	.527	
Vinyl cork	1	.232	.357	.407	.572	.604	.600	.754	.504	.516
	2	.244	.347	.368	.578	.551	.707	.897	.527	
Greaseproof asphalt	1	.235	.375	.386	.615	.644	.671	.849	.539	.531
	2	.257	.364	.360	.589	.584	.677	.828	.523	
Solid vinyl translucent	1	.286	.382	.475	.635	.583	.687	.824	.553	.534
	2	.238	.358	.438	.582	.574	.621	.796	.515	
Solid vinyl opaque	1	.286	.353	.466	.584	.645	.663	.895	.556	.540
	2	.263	.378	.374	.586	.642	.601	.819	.523	
Asphalt	1	.260	.353	.437	.647	.660	.690	.801	.550	.542
	2	.254	.387	.431	.580	.675	.649	.772	.535	
Plain cork	1	.284	.354	.374	.504	.490	.558	.669	.462	.577
	2	.633	.561	.628	.655	.662	.820	.889	.692	
Rubber	1	.298	.438	.517	.659	.733	.639	.879	.595	.587
	2	.303	.423	.479	.650	.623	.593	.888	.580	
Overall average for heel material		.279	.373	.425	.590	.614	.657	.809		

coefficient of friction is shown for each type of floor material and heel material.

The coefficients of friction for all types of worn floor material were lowest with the leather heel and highest with Neoprene cord. The differences among the coefficients of friction for heel materials were considerably greater than the differences among floor surface materials. However, for both types of materials the differences were highly significant. The nine types of floor materials tested with the seven types of heel materials may be ranked in terms of overall average coefficient of friction in ascending order as follows: linoleum, vinyl asbestos, vinyl cork, greaseproof asphalt, solid vinyl translucent, solid vinyl opaque, asphalt, plain cork and rubber.

Linoleum: The worn linoleum had the lowest coefficient of friction of any of the worn smooth floor surface materials tested. The coefficient of friction for linoleum ranged from .234 with leather heels to .737 with Neoprene cord and resulted in an overall average of .475 for all heels tested. Between the two manufacturers of this material there was a difference of .021 in average coefficient of friction obtained from their six samples.

Vinyl asbestos: The coefficient of friction for vinyl asbestos ranged from .242 with leather heels to .764 with Neoprene cord and resulted in an overall average of .515 for all heels tested. Between the two manufacturers of this material there was a difference of .023.

Vinyl cork: The coefficient of friction for vinyl cork ranged from .238 with leather heels to .826 with Neoprene cord and resulted in an overall average of .516 for all heels tested. Between the two manufacturers of this material there was a difference of .023.

Greaseproof asphalt: The coefficient of friction for greaseproof asphalt ranged from .246 with leather heels to .839 with Neoprene cord and resulted in an overall average of .531 for all heels tested. Between the two manufacturers of this material there was a difference of .016.

Solid vinyl translucent: The coefficient of friction for solid vinyl translucent ranged from .262 with leather heels to .810 with Neoprene cord and resulted in an overall average of .534 for all heels tested. Between the two manufacturers of this material there was a difference of .038.

Solid vinyl opaque: The coefficient of friction for solid vinyl opaque ranged from .275 with leather heels to

.857 with Neoprene-cord and resulted in an overall average of .540 for all heels tested. Between the two manufacturers of this material there was a difference of .033.

Asphalt: The coefficient of friction for asphalt ranged from .257 with leather heels to .787 with Neoprene-cord and resulted in an overall average of .542 for all heels tested. Between the two manufacturers of this material there was a difference of .015.

Plain cork: The coefficient of friction for plain cork ranged from .458 with leather heels to .779 with Neoprene-cord and resulted in an overall average of .577 for all heels tested. Between the two manufacturers of this material there was a difference of .230.

Rubber: The worn rubber floor surface material had the highest coefficient of friction of any of the worn smooth floor surface materials tested. The coefficient of friction for rubber ranged from .301 with leather heels to .884 with Neoprene-cord and resulted in an overall average of .587 for all heels tested. Between the two manufacturers of this material there was a difference of .015.

Among the nine floor materials tested, the average overall coefficient of friction ranged from .475 for linoleum (lowest) to .587 for rubber (highest), a range of .112. The floor surface materials tested with leather, nylon and Adiprene heels tended to be below the overall average. The floor surface materials tested with heel materials containing either synthetic or natural rubber (Neolite, hard rubber, rubber crepe, and Neoprene cord) tended to be above the overall average.

III. WAXED FLOOR SURFACE MATERIALS

Analysis of variance

An analysis of variance of skid resistance of the waxed floor surface materials is shown in Table VI. The main effects and the interaction between main effects were significant beyond the .1 per cent level of significance among heel materials and among waxed floor materials.

Among the seven heel materials the F ratio of 173.34 was significant at the .1 per cent level. This significant value of F indicated that some shoe heel materials have greater skid resistance than others. These findings, indicating a significant difference among the seven heel materials led to rejecting the original null hypothesis.

TABLE VI

ANALYSIS OF VARIANCE OF SKID RESISTANCE
OF
WAXED FLOOR SURFACE MATERIALS

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Among heel materials	6	2079.01	346.50	173.34*
Among floor materials	8	200.37	25.05	12.53*
Heel material x floor material interaction	48	95.99	2.00	1.89**
Within cells	693	734.07	1.06	
Between manufacturers	63	88.81	1.41	1.38***
Within subcells	630	645.26	1.02	
Total	755	3109.44		

*Significant beyond the .1 per cent level.

**Significant beyond the .5 per cent level.

***Significant beyond the 5 per cent level.

Among the nine waxed floor materials the F ratio of 12.53 was significant at the .1 per cent level. This significant value of F indicated that some waxed smooth floor surface materials have greater skid resistance than others. These findings, indicating a significant difference among the nine waxed smooth floor surface materials led to rejecting the original null hypothesis.

The heel material x floor material interaction revealed that the F ratio of 1.89 was significant at the .5 per cent level of significance. This significant value of F indicated that the interaction of waxed floor materials tested with shoe heel materials produces effects that cannot be explained by adding the main effects. These findings, indicating a significant interaction between the heel materials and the waxed floor materials, led to rejecting the original null hypothesis.

The within cells, between manufacturers, revealed that the F ratio of 1.38 was significant at the 5 per cent level. This value of F indicated that the samples of the same material, waxed, from two different manufacturers were probably significantly different and led to rejecting the original null hypothesis.

Coefficient of friction measurements

The coefficient of friction measurements between the waxed floor surface materials and the seven shoe heel materials are shown in Table VII. The table also shows the average coefficient of friction for the floor materials from each of the two manufacturers of each type of floor material. In addition, the overall average coefficient of friction is shown for each type of floor material and heel material.

The coefficients of friction for all types of waxed floor material were lowest with the leather heel and highest with Neoprene-cord. The differences among the coefficients of friction for heel materials were considerably greater than the differences among floor surface materials. However, for both types of materials the differences were highly significant. The nine types of floor materials tested with the seven types of heel materials may be ranked in terms of overall average coefficient of friction in ascending order as follows: linoleum, vinyl asbestos, greaseproof asphalt, vinyl cork, asphalt, solid vinyl translucent, solid vinyl opaque, plain cork and rubber.

TABLE VII

COEFFICIENT OF FRICTION MEASUREMENTS BETWEEN WAXED FLOOR SURFACE MATERIALS AND SHOE HEEL MATERIALS

Type of floor surface materials	Mfr. No.	Type of shoe heel material							Overall average for floor material	
		Leather	Nylon	Adi-prene	Rubber	Neo-lite	Rubber crepe	Neoprene-cord		
Linoleum	1	.254	.282	.320	.377	.324	.439	.627	.375	.397
	2	.301	.352	.404	.396	.362	.513	.595	.418	
Vinyl asbestos	1	.277	.345	.361	.414	.375	.474	.604	.407	.405
	2	.312	.318	.385	.402	.377	.479	.538	.402	
Vinyl cork	1	.273	.291	.355	.418	.369	.488	.693	.412	.425
	2	.319	.336	.431	.392	.389	.542	.661	.438	
Greaseproof asphalt	1	.279	.297	.383	.370	.393	.498	.609	.404	.414
	2	.306	.343	.400	.426	.395	.512	.586	.424	
Solid vinyl translucent	1	.243	.301	.392	.483	.460	.519	.751	.450	.445
	2	.292	.293	.398	.485	.409	.503	.696	.439	
Solid vinyl opaque	1	.345	.383	.506	.479	.479	.603	.807	.515	.483
	2	.303	.311	.458	.448	.449	.547	.636	.450	
Asphalt	1	.291	.373	.428	.443	.429	.521	.635	.446	.431
	2	.298	.349	.379	.430	.382	.490	.584	.416	
Plain cork	1	.259	.329	.371	.398	.392	.467	.701	.417	.433
	2	.345	.359	.395	.415	.394	.528	.710	.449	
Rubber	1	.355	.422	.547	.501	.483	.540	.733	.512	.508
	2	.337	.422	.528	.497	.441	.595	.709	.504	
Overall average for heel material		.299	.339	.413	.432	.406	.514	.660		

<u>Linoleum</u>: The waxed linoleum had the lowest coefficient of friction of any of the waxed smooth floor materials tested. The coefficient of friction for linoleum ranged from .278 with leather heels to .611 with Neoprene-cord and resulted in an overall average of .397 for all heels tested. Between the two manufacturers of this material there was a difference of .043 in average coefficient of friction obtained from their six samples.

<u>Vinyl asbestos</u>: The coefficient of friction for vinyl asbestos ranged from .295 with leather heels to .571 with Neoprene-cord and resulted in an overall average of .405 for all heels tested. Between the two manufacturers of this material there was a difference of .005.

<u>Greaseproof asphalt</u>: The coefficient of friction for greaseproof asphalt ranged from .293 with leather heels to .598 with Neoprene-cord and resulted in an overall average of .414 for all heels tested. Between the two manufacturers of this material there was a difference of .020.

<u>Vinyl cork</u>: The coefficient of friction for vinyl cork ranged from .296 with leather heels to .677 with Neoprene-cord and resulted in an overall average of .425 for all heels tested. Between the two manufacturers of this

material there was a difference of .026.

Asphalt: The coefficient of friction for asphalt ranged from .295 with leather heels to .610 with Neoprene-cord and resulted in an overall average of .431 for all heels tested. Between the two manufacturers of this material there was a difference of .030.

Plain cork: The coefficient of friction for plain cork ranged from .302 with leather heels to .706 with Neoprene-cord and resulted in an overall average of .433 for all heels tested. Between the two manufacturers of this material there was a difference of .032.

Solid vinyl translucent: The coefficient of friction for solid vinyl translucent ranged from .268 with leather heels to .724 with Neoprene-cord and resulted in an overall average of .445 for all heels tested. Between the two manufacturers of this material there was a difference of .011.

Solid vinyl opaque: The coefficient of friction for solid vinyl opaque ranged from .324 with leather heels to .722 with Neoprene-cord and resulted in an overall average of .483 for all heels tested. Between the two manufacturers of this material there was a difference of .065.

Rubber: The waxed rubber floor surface material had the highest coefficient of friction of any of the waxed smooth floor surface materials tested. The coefficient of friction for rubber ranged from .346 with leather heels to .721 with Neoprene-cord and resulted in an overall average of .508 for all heels tested. Between the two manufacturers of this material there was a difference of .008.

Among the nine waxed floor materials tested, the overall average coefficient of friction ranged from .397 for linoleum (lowest) to .508 for rubber (highest), a range of .111. The floor surface materials tested with leather, nylon and Adiprene heels tended to be below the overall average. The waxed floor surface materials tested with heel materials containing either synthetic or natural rubber (Neolite, hard rubber, rubber crepe, and Neoprene-cord) tended to be above the overall average.

IV. COMPARISON OF NEW, WORN, AND WAXED SMOOTH FLOOR SURFACE MATERIALS

A comparison between the coefficient of friction measurements of new, worn and waxed floor surface materials with each of the seven types of shoe heel materials is presented.

Leather heels

A comparison between the coefficient of friction measurements of new, worn and waxed floor surface materials and leather heels is shown in Table VIII.

Linoleum, greaseproof asphalt, vinyl asbestos and vinyl cork, when tested with a leather heel, had higher coefficients of friction as worn material than as new material. However, when these worn materials were waxed the coefficients of friction were greater than when the materials were either in the new or worn condition.

Asphalt, solid vinyl translucent, solid vinyl opaque, and rubber, when tested with a leather heel, had lower coefficients of friction in the worn condition than in either the new or the waxed condition. Plain cork did not fall into either of these patterns, but had the highest coefficient of friction when new and the lowest when waxed.

Adiprene heels

A comparison between the coefficient of friction measurements of new, worn, and waxed floor surface materials and Adiprene heels is shown in Table IX.

Greaseproof asphalt, vinyl cork, asphalt, solid

TABLE VIII

COEFFICIENT OF FRICTION MEASUREMENTS OF NEW, WORN AND WAXED FLOOR SURFACE MATERIALS WITH LEATHER HEELS

Type of floor surface materials	Condition of floor materials		
	New	Worn	Waxed
	(Coefficient of friction - leather heels)		
Linoleum	.217	.234	.278
Greaseproof asphalt	.230	.246	.293
Vinyl asbestos	.234	.241	.295
Vinyl cork	.236	.238	.296
Asphalt	.266	.257	.265
Solid vinyl translucent	.292	.262	.268
Solid vinyl opaque	.292	.275	.324
Rubber	.358	.301	.346
Plain cork	.469	.459	.302

TABLE IX

COEFFICIENT OF FRICTION MEASUREMENTS OF NEW, WORN AND WAXED FLOOR SURFACE MATERIALS WITH ADIPRENE HEELS

Type of floor surface materials	Condition of floor materials		
	New	Worn	Waxed
	(Coefficient of friction - Adiprene heels)		
Linoleum	.323	.351	.362
Vinyl asbestos	.376	.403	.373
Solid vinyl translucent	.393	.457	.395
Solid vinyl opaque	.425	.420	.482
Greaseproof asphalt	.482	.373	.392
Plain cork	.501	.501	.383
Vinyl cork	.506	.388	.393
Asphalt	.517	.434	.404
Rubber	.587	.498	.538

vinyl opaque, and rubber, when tested with Adiprene heels showed lower coefficients of friction in the worn condition than in the new. All of these floor materials except solid vinyl opaque showed a lower coefficient of friction when waxed. In contrast, linoleum, vinyl asbestos, and solid vinyl translucent had higher coefficients of friction in the worn than in the new condition; however, vinyl asbestos showed a lower coefficient of friction when waxed. Again, plain cork had the lowest coefficient of friction when waxed.

Nylon heels

A comparison between the coefficient of friction measurements of new, worn, and waxed floor surface materials and nylon heels is shown in Table X.

All of the new floor materials compared with worn and waxed materials had the highest coefficients of friction when tested with nylon heels. The waxed materials, except linoleum, showed the lowest coefficients of friction. Linoleum showed the lowest coefficient in the worn condition.

Neolite, hard rubber, rubber crepe, Neoprene-cord heels

In general, the pattern was consistant for heel

TABLE X

COEFFICIENT OF FRICTION MEASUREMENTS OF NEW, WORN AND WAXED FLOOR SURFACE MATERIALS WITH NYLON HEELS

Type of floor surface materials	Condition of floor materials		
	New	Worn	Waxed
	(Coefficient of friction -	Nylon heels)	
Linoleum	.396	.302	.317
Vinyl asbestos	.480	.343	.332
Plain cork	.485	.458	.344
Greaseproof asphalt	.499	.370	.320
Vinyl cork	.502	.352	.314
Asphalt	.504	.370	.361
Solid vinyl translucent	.534	.370	.297
Solid vinyl opaque	.541	.366	.347
Rubber	.648	.431	.422

materials containing natural and synthetic rubber, with the new material having the highest coefficients of friction and the waxed materials the lowest (Tables XI, XII, XIII, and XIV). The one exception was Neolite which showed higher coefficients of friction with linoleum, vinyl asbestos, and solid vinyl opaque in the worn condition.

TABLE XI

COEFFICIENT OF FRICTION MEASUREMENTS OF NEW, WORN AND WAXED FLOOR SURFACE MATERIALS WITH NEOLITE HEELS

Type of floor surface materials	Condition of floor materials		
	New	Worn	Waxed
	(Coefficient of friction - Neolite heels)		
Linoleum	.524	.564	.343
Plain cork	.601	.576	.393
Vinyl asbestos	.604	.630	.376
Vinyl cork	.610	.578	.379
Greaseproof asphalt	.626	.614	.394
Solid vinyl opaque	.637	.644	.464
Asphalt	.683	.618	.406
Solid vinyl translucent	.713	.579	.435
Rubber	.845	.678	.462

TABLE XII

COEFFICIENT OF FRICTION MEASUREMENTS OF NEW, WORN AND WAXED FLOOR SURFACE MATERIALS WITH HARD RUBBER HEELS

Type of floor surface materials	Condition of floor materials		
	New	Worn	Waxed
	(Coefficient of friction - hard rubber heels)		
Linoleum	.605	.514	.387
Plain cork	.687	.580	.407
Vinyl cork	.696	.575	.405
Greaseproof asphalt	.708	.602	.398
Vinyl asbestos	.710	.580	.408
Asphalt	.717	.614	.437
Solid vinyl translucent	.733	.609	.484
Solid vinyl opaque	.735	.585	.464
Rubber	.881	.655	.499

TABLE XIII

COEFFICIENT OF FRICTION MEASUREMENTS OF NEW, WORN AND WAXED FLOOR SURFACE MATERIALS WITH RUBBER CREPE HEELS

Type of floor surface materials	Condition of floor materials		
	New	Worn	Waxed
	(Coefficient of friction - rubber crepe heels)		
Linoleum	.761	.627	.476
Greaseproof asphalt	.824	.674	.505
Vinyl asbestos	.827	.648	.477
Vinyl cork	.832	.654	.515
Solid vinyl opaque	.867	.632	.575
Plain cork	.878	.689	.498
Asphalt	.886	.670	.506
Solid vinyl translucent	.937	.654	.511
Rubber	.993	.616	.568

TABLE XIV

COEFFICIENT OF FRICTION MEASUREMENTS OF NEW, WORN AND WAXED FLOOR SURFACE MATERIALS WITH NEOPRENE-CORD HEELS

Type of floor surface materials	Condition of floor materials		
	New	Worn	Waxed
	(Coefficient of friction - Neoprene-cord heels)		
Linoleum	.905	.737	.611
Vinyl asbestos	.935	.764	.571
Plain cork	.989	.779	.706
Greaseproof asphalt	.991	.839	.598
Asphalt	1.024	.787	.610
Vinyl cork	1.046	.826	.677
Solid vinyl opaque	1.099	.857	.722
Solid vinyl translucent	1.104	.810	.724
Rubber	1.213	.884	.721

V. DISCUSSION OF RESULTS IN RELATION TO CONCLUSION FROM NATIONAL BUREAU OF STANDARDS TESTS

At present, there are no generally accepted coefficient of friction standards for the various types of floor materials or finishes. However, previous skid resistance tests, described in the May, 1948 Journal of Research of the National Bureau of Standards concluded that the results of their tests, "considered in relation to slipperiness as actually experienced, indicate that a slippery condition does or does not exist, according to whether the measured coefficient is less or greater than 0.4."[54]

In the present study the overall average coefficients of friction for all the floor materials (based on tests including all seven different heel materials) in the three conditions resulted in measurements above 0.4, except for waxed linoleum. However, when the coefficients of friction of the floor materials were considered in relation to the individual types of shoe heel materials this was not always the case. Table XV shows the floor materials tested

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[54] Percy A. Sigler, Martin N. Geib, and Thomas H. Boone, "Measurement of the Slipperiness of Walkway Surfaces," Journal of Research of the National Bureau of Standards, XL (May, 1948), 346.

TABLE XV

FLOOR MATERIALS TESTED WITH HEEL MATERIALS RESULTING IN COEFFICIENT OF FRICTION MEASUREMENTS ABOVE 0.4

Type of floor surface material	Condition of floor material	Type of shoe heel material						
		Leather	Adi-prene	Nylon	Hard rubber	Neo-lite	Rubber crepe	Neoprene-cord
Linoleum	New				X	X	X	X
	Worn				X	X	X	X
	Waxed						X	X
Vinyl asbestos	New			X	X	X	X	X
	Worn		X		X	X	X	X
	Waxed				X		X	X
Vinyl cork	New		X	X	X	X	X	X
	Worn				X	X	X	X
	Waxed				X		X	X
Greaseproof asphalt	New		X	X	X	X	X	X
	Worn				X	X	X	X
	Waxed						X	X
Solid vinyl translucent	New			X	X	X	X	X
	Worn		X		X	X	X	X
	Waxed		X		X	X	X	X
Solid vinyl opaque	New		X	X	X	X	X	X
	Worn		X		X	X	X	X
	Waxed				X	X	X	X
Asphalt	New		X	X	X	X	X	X
	Worn		X		X	X	X	X
	Waxed		X		X	X	X	X
Plain cork	New		X	X	X	X	X	X
	Worn	X	X	X	X	X	X	X
	Waxed				X	X	X	X
Rubber	New		X	X	X	X	X	X
	Worn		X	X	X	X	X	X
	Waxed		X	X	X	X	X	X

with individual heel materials resulting in coefficient of friction measurements above 0.4.

The coefficients of friction for all the new floor surfaces tested with leather heels were below 0.4. When tested with Adiprene heels, the coefficients of friction for three of the new floor materials--linoleum, vinyl asbestos and solid vinyl translucent--were less than 0.4. When tested with a nylon heel only the coefficient of friction for linoleum was below 0.4. The coefficients of friction for all the new floor surface materials tested with Neolite, hard rubber, rubber crepe, and Neoprene-cord were above 0.4

The coefficients of friction for all worn floor surfaces tested with leather heels were below 0.4 except plain cork; with nylon heels all except two were below, plain cork and rubber. When tested with Adiprene heels, the coefficient of friction for linoleum, vinyl cork and greaseproof asphalt in the worn condition were below 0.4. As with the new material, the coefficients of friction for all the worn floor surface materials tested with Neolite, hard rubber, rubber crepe, and Neoprene-cord were above 0.4.

The coefficients of friction for all waxed floor surfaces tested with leather heels were below 0.4; with nylon heels, all except rubber were below, and with Adiprene heels all except solid vinyl opaque, asphalt, and rubber. When tested with hard rubber heels, the coefficient of friction for linoleum and greaseproof asphalt were below 0.4; with Neolite, the following waxed floor materials were below 0.4: linoleum, vinyl asbestos, vinyl cork, and greaseproof asphalt. The coefficients of friction for all the waxed floor surface materials tested with rubber crepe and Neoprene-cord were above 0.4.

CHAPTER V

SUMMARY, IMPLICATIONS AND RECOMMENDATIONS

I. SUMMARY

This investigation was a pilot study to a state project entitled "Testing of Smooth Floor Surfaces and Finishes from the Standpoint of Safety." The state project contributes to the Southern Regional Housing Research Project S-8.

The purposes of the present study were: (1) to determine the friction values existing between shoe heel materials and floor covering materials using a friction-testing apparatus, and (2) to suggest implications for the choice of safe floor coverings for use in homes.

The testing apparatus was designed and constructed by Dr. Henry Bowen of the Department of Agricultural Engineering at North Carolina State College. The design of the machine was based on the premise that, in the process of walking, slipping is most likely to occur when the floor surface is first contacted by the heel.

The laboratory machine consists chiefly of a movable circular table, a controllable speed electric motor, and a mechanical recorder. The testing machine had the advantage of testing several different types of smooth floor surfaces at one time, and assisted in making a comparative analysis.

The machine is capable of measuring static and kinetic friction, however, only kinetic friction was measured in this study.

Nine smooth surface floor materials were tested: asphalt, greaseproof asphalt, vinyl asbestos, solid vinyl opaque, solid vinyl translucent, rubber, linoleum, plain cork and vinyl cork. For each type of material six samples were obtained, three samples from each of two manufacturers, providing a total of 54 test samples. All of the floor materials tested met the requirements of federal specifications.

Seven shoe heel materials were tested: leather, nylon, Adiprene, hard rubber, rubber crepe, Neolite, and Neoprene-cord. One heel size, a woman's Cuban heel, was used in the tests. By using one heel size, 1¼ square inches, the area of contact between the heel and the floor surface material was the same for all tests.

The 54 test samples were cut into the shape of a trapezoid and mounted on plywood rings which were in turn attached to the circular table. The table rotated underneath the shoe heel, mounted on a wooden block, which was attached to a platform to which weights were applied. Placement of the test panels on the two plywood rings and the order of testing heel materials were determined by randomization.

Three series of tests were run on the two plywood rings containing the test panels of floor materials. Force of friction measurements were first recorded for the new materials with the seven different types of heel materials. The same series of tests were repeated with the same floor materials, worn, and then waxed. The table assembly was moved after each test to decrease the radial distance of the testing surface and to provide a different portion of flooring material.

An accelerated wear method using carborundum paper was used to prepare the worn materials. Water-emulsion wax was used to prepare the waxed test panels. The same general testing procedures were followed in obtaining the measurements for new, worn, and waxed floor materials.

This investigation of the skid resistance of new, worn, and waxed smooth floor surfaces comprised three laboratory experiments of 84 tests, resulting in 2,352 measurements which were analyzed. The experiments were designed so that the results could be analyzed statistically for determining significant differences.

An analysis of variance of skid resistance of the floor surface materials in the new, worn, and waxed conditions revealed the main effects to be significant beyond the 1 per cent level of significance among heel materials and among floor materials in each of the three conditions. These findings led to rejecting the original null hypotheses (1) that there is no difference among the means of the force of friction measurements for the nine types of floor surface materials, and (2) there is no difference among the means of the force of friction measurements for the seven types of shoe heel materials.

An analysis of variance revealed that the interaction between floor materials x heel materials was significant at the 1 per cent level of significance for the floor materials in the new and worn conditions and significant at the 5 per cent level of significance in the waxed condition. These findings led to rejecting the original null hypothesis that there is no interaction among the floor surface materials and the shoe heel materials.

The within cells, between flooring samples of two manufacturers, was significant at the .1 per cent level for the new and worn conditions of the floor material and significant at the 5 per cent level for the waxed condition. This indicated that the samples of the same type of material from two manufacturers were significantly different and led to rejecting the original null hypothesis that there is no difference between the means of the force of friction measurements of samples from the respective pairs of manufacturers of the same type of floor material. Since it was found that there was a significant difference among floor materials and heel materials, coefficients of kinetic friction were computed for the nine floor materials with the seven heel materials tested.

The coefficients of friction for all types of floor materials in the new, worn and waxed conditions were lowest with the leather heel and highest with Neoprene cord. The difference among the coefficients of friction for heel materials was considerably greater than the differences among floor surface materials. However, for both heel and floor materials the difference in coefficients of friction were highly significant

The nine types of floor materials tested in the new condition with the seven types of heel materials may be ranked in terms of overall average coefficient of friction in ascending order as follows: linoleum, vinyl asbestos, greaseproof asphalt, vinyl cork, solid vinyl opaque, asphalt, plain cork, solid vinyl translucent, and rubber They may be ranked as follows for worn material: linoleum, vinyl asbestos, vinyl cork, greaseproof asphalt, solid vinyl translucent, solid vinyl opaque, asphalt, plain cork, and rubber They may be ranked as follows for waxed materials: linoleum, vinyl asbestos, greaseproof asphalt, vinyl cork, asphalt, plain cork, solid vinyl translucent, solid vinyl opaque, and rubber

The floor surface materials in all three conditions tested with leather, Adiprene and nylon heels tended to be below the overall average coefficient The floor materials tested with heel materials containing either synthetic or natural rubber (Neolite, hard rubber, rubber crepe, and Neoprene cord) tended to be above the overall average

The coefficients of friction were consistently higher for the new floor materials tested with nylon heels and with the heel materials containing natural and synthetic rubber and consistently lower for the waxed floor materials tested with the same heels.

II. IMPLICATIONS

In drawing implications from this study consideration was given to the stated limitations of the investigation which included the testing of nine resilient floor surface materials in new, worn, and waxed (water emulsion wax) conditions with seven different shoe heel materials of one size. Therefore, the results of this study suggest the following implications:

1. Clean and dry resilient floor covering materials have a high coefficient of friction with rubber crepe and Neoprene-cord shoe heels.
2. Linoleum, when tested with leather and Adiprene heels has a higher coefficient of friction when waxed than when new or unwaxed.
3. Of the resilient floor materials, linoleum when dry - either new, worn, or waxed - provides the greatest resistance to slipping.
4. In general, the coefficients of friction of resilient floor coverings decrease with wear and moreover with the application of

water emulsion wax.

5. There is a significant difference in the coefficient of friction of the same types of floor materials from different manufacturers.

6. The coefficients of friction for different types of resilient floor surface materials and for different types of heel materials differ substantially one from another. Certainly, both factors should be considered. However, the greatest difference exists among types of heel materials which suggests that more attention should be given to the selection of the material for shoe heels.

7. The friction testing machine is a valuable apparatus for initially assessing the skid resistance of floor surface and heel materials for comparative analysis. Further experiments with the machine will add even more enlightenment to its use potential.

III. RECOMMENDATIONS

1. That further investigations be made to rank smooth floor surfaces according to safety by conducting tests under controlled wet, oily and soiled conditions of the floor materials and with the use of different types of wax.

2. That investigations be made to correlate the gloss values of floor surface materials with coefficient of friction measurements.

3. That investigations include a broader sampling of available floor surface materials including those that do not meet federal specifications.

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