BRISTOL, NANCY LUCAS. Laboratory Testing for Wear Performance of Selected Wood Floor Finishes. (1971) Directed by: Dr. Jane H. Crow. Pp. 41

Eight wood floor finishes were applied to quarter-sawn, red oak flooring blocks and, along with a factory finished block, were tested under laboratory conditions to determine the degree of wear of each of the finishes. A loss in film thickness of the finish was considered wear. Test blocks included four replicates each of polyurethane, vinyl, epoxy, amino resin, lacquer, shellac, varnish, penetrating seal, and a prefinished specimen. Blocks were tested on the Simulated Human Wear Producing Machine consisting of a treadmill and cam-operated legs and feet developed by Dr. Henry Bowen and his engineering students of the Biological and Agricultural Engineering Department at North Carolina State University in Raleigh. A Zeiss Light-Section Microscope was used to measure the film thickness of finishes. Four measurements were recorded from predetermined locations and the mean computed for each test specimen of each finish before testing and during testing at one, two, four, five, six, and eight hour intervals. Blocks were rotated on the machine after each measurement period.

Standard analysis of variance was used in determining differences in wear among finishes; differences in wear produced by right and left foot; the difference in wear according to direction of wood grain, and the interaction of these three factors.

This study resulted in the following conclusions: (1) there was a significant difference in wear among the floor finishes tested; in overall performance vinyl wore least and epoxy wore most, (2) the rate of wear produced by the Simulated Human Wear Producing Machine closely approximated the wear produced by a person; however, it is believed that further testing of the machine is necessary before any firm conclusions can be made, (3) subsequent wear did not occur at the same rate as initial wear, (4) wood grain direction did have an effect on the wear of the finishes.

LABORATORY TESTING FOR WEAR PERFORMANCE OF SELECTED WOOD FLOOR FINISHES

by

Nancy Lucas Bristol

A Thesis Submitted to
the Faculty of the Graduate School at
The University of North Carolina at Greensboro
in Partial Fulfillment
of the Requirements for the Degree
Master of Science
in Home Economics

Greensboro
1971

Approved by

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APPROVAL SHEET

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ACKNOWLEDGMENTS

This study could not have been possible without the help of the following people:

Dr. Savannah S. Day, who conceived the idea of the Simulated Human Wear Producing Machine;

Dr. Henry Bowen, who, along with his engineering students from North Carolina State University at Raleigh, designed, built, and maintained the wear machine;

Mrs. Nancy H. Holmes, whose guidance and direction were invaluable throughout this study;

Dr. Jane H. Crow, director, whose assistance and encouragement were greatly appreciated;

Dr. Mildred Johnson and Dr. Anna Joyce Reardon, committee members, who gave freely of their time, understanding and ideas;

Dr. Robert J. Hader from North Carolina State University at Raleigh, whose assistance as statistical adviser was invaluable; and

Mrs. Kathryn Morris, whose comments concerning grammar and style were an important contribution to this paper.

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CHAPTER I

INTRODUCTION

In the past, wood floor finishes were restricted to lacquer, shellac, varnish, and floor sealer. Current research and technology, especially in the field of plastics, have made several new types of wood floor finishes available on the consumer market. A paper presented to the Forest Research Annual Meeting in 1960 stated that floor finishes utilized one of three well-known types of materials: shellac, varnishes and alkyds, or lacquer. Products containing shellac were noted for their quick drying ability, excellent appearance, and relative ease of maintenance. The varnishes and alkyds, which dry by an oxidative-polymerization process, were noted for their durability and relatively long drying time. Lacquer products were noted for their wide acceptance, especially in the refinishing field. Research has expanded on these three materials through two basic approaches. The first approach has been used with all three types of materials and is concerned with improvement of these materials through the use of additives or through chemical modification. The second approach is the development of new materials or the use of new concepts in application and formulation of the product. Research of the latter type falls into two categories: (1) the use of a two-part system and (2) a study of emulsion or water-dilutable clear finishes for wood. Some of these newer coatings which are gaining acceptance are polyurethane, epoxies, and amino-alkyd combinations (5). Knowledge of the wearability of these newer finishes, in relation to the older finishes, is negligible as few tests relevant to wearability and wood floor finishes have been attempted. Most of the finish testing is done at a commercial level, and the data obtained are not available to the consumer.

Wear is an important characteristic to consider when selecting wood floor finishes. General purpose machines have been developed to measure the wear of finishes; however, these machines have proved unsatisfactory as they have been designed on an arbitrary basis with little consideration given to the wear conditions of the flooring materials being tested (10). Studies show that the amount of wear produced is relative to the machine producing the wear. Testing is probably the most significant and controversial area of wear research. A laboratory test utilizing a machine that can simulate the abrasive interaction between foot and floor during walking is needed in order to enable wear research to progress.

The Problem

Objectives. Major purposes of this study were: (1) to determine through laboratory test the wear characteristics of selected wood floor finishes, and (2) to test the Simulated Human Wear Producing Machine.

Importance of the study. Recent studies have shown that hardwood flooring is the most economical among leading types of flooring materials in terms of annual maintenance cost. Hardwood floors have also been found to have the longest life, more than double other floorings (3). The data collected in a study conducted by Martens showed hardwood floors to be the most practical for both single-family and multi-family dwelling units in reference to cost (both yearly and long-term), wear life, maintenance time, and preference over other types of flooring (13).

Wood floor finishes recently introduced on the market have been advertised as having wearing qualities superior to conventional finishes. Such information has complicated the task of families and builders in selecting the best wearing finish to apply to wood floors.

Extension home economists and manufacturers of flooring materials and finishes have indicated that research relative to wearability of wood floor finishes is needed.

This study is part of a larger project entitled "Wearability of Wood Floor Finishes" sponsored by the North Carolina Agricultural Experiment Station.

Definitions of Terms Used

Wood floor finish. A coating or sealer applied to bare or raw wood surface for the purpose of protecting and preserving the natural appearance of the wood. The term finish is not synonymous to the term wax or polish in this study.

Conventional Wood Floor Finishes.

Shellac. Shellac is a secretion of the coccus Lacca on the smaller branches of certain members of the fig family in India and neighboring countries. The secretion is gathered, purified, and dried in flake form. Shellac producers "cut" these flakes with alcohol in various proportions (2 pound cut = 2 pounds of shellac to 1 gallon alcohol; 3 pounds cut = 3 pounds shellac flakes to 1 gallon alcohol) to make the floor finish (22:5).

Varnish. A broad term used to describe a clear (no pigment) coating comprised principally of resins, oils, plasticizers and solvents. When spread upon a surface in a thin film, varnish dries by the evaporation of its volatile constituents, by the oxidation and chemical reaction of other constituents, or partly by evaporation and partly by oxidation and chemical reaction to a continuous protective coating which may be either highly lustrous or practically devoid of luster (22:5).

Lacquer. The term Lacquer is restricted to coatings of which the characteristic ingredient is a solution of nitrocellulose or "pyroxylin" in a combination of ester, ketone and alcohol solvents. ...Drying of a lacquer film is accomplished through the evaporation of the solvent (19:4).

Penetrating seal. A floor seal chemically identified as a linseed oil - modified polyol, moleats, phthalate polyester reduced in an aliphatic mineral spirits solvent. It is used as a penetrant for wood substrates to increase abrasion resistance of the wood (19:4).

Newer Wood Floor Finishes.

Epoxy. Epoxies are a class of resins derived from the interaction of epichlorohydrin and bisphenol. These resins are thermosetting when cured in the presence of catalysts and yield hard, tough, adherent films with good abrasion, water and alkali resistance. Combined with vegetable oil fatty acids, they yield esters which are useful in the manufacture of highly resistant, industrial finishes (19:4).

Polyurethane. One of the products formed when an isocyanate reacts with a hydroxy compound. If poly-functional compounds are used, useful polymers are formed and some of these find application in the surface coating field. Polyurethane finishes contain polyisocyanates and polyhydroxy compounds and, in some cases, amines which serve as catalysts and cross linking agents (22:6).

Amino resin. A thermosetting—type resin finish, composed of a reaction product of an amino resin and a polyester (25).

Vinyl. As a chemical term, "vinyl" refers to a chemical radical composed of two carbon atoms joined by unsaturated bonds capable of combining with two other atoms or similar radicals. When the word "vinyl" is used in connection with synthetic resins, it refers to polymerized vinyl-toluene or polymerized vinyl chloride plus vinyl acetate.

The resin dries in two steps. First, the solvent evaporates leaving the nonvolatile resin on the surface; then the oil present in the resin oxidizes, changing the resin from a fluid to a solid (22:6).

Quarter-sawn. Lumber which is cut so that the face of the board is perpendicular to the annual growth rings.

Wear. "...the unwanted removal of solid material from rubbing surfaces" (6:119).

CHAPTER II

REVIEW OF LITERATURE

Published studies related to wear of wood floor finishes are limited. Scherrer stated:

> It would appear that any manufacturer testing his material against competitive samples is reluctant to publish any of these results. Possibly, certain advertisements may list some tests of one material against other types or brands (20).

Martens agreed with Scherrer by stating:

> There is definitely a lack of reliable information pertaining to this subject area. Many of the finish manufacturers, as well as flooring manufacturers, have data on wearability of their particular products but these are generally found to be conflicting. Each firm has proven that its particular product is better than all others and consequently none of the data are very useful for research purposes (15).

This review of literature includes available studies concerned with wear of specific wood floor finishes, the forces applied to the floor by the foot during walking, and machines and techniques used to produce wear on wood floor finishes.

Studies of Wear of Wood Floor Finishes

In the late 1930's the Home Economics Research Department of the Rhode Island Agricultural Experiment Station conducted two practical studies and one laboratory study of accelerated wear on floor finishes. The first practical study concerned a series of stairsteps receiving constant use. Alternate steps were of oak and pine with a pair of steps, one oak and one pine, finished with one of seven test finishes. The wear and maintenance requirements of the seven finishes were checked over a two-year period. Results from the study showed that penetrating seal maintained the best appearance over the two-year period for oak floors. The shellac and four types of varnish showed wear more readily and had to be cleaned more frequently than the two penetrating seals (11).

The other practical study involved a worn, hard pine library floor. One-half of the floor was divided into four sections and completely refinished with four different brands of penetrating seal. These four sections were then waxed with an application of liquid wax. The other half of the floor was left unfinished and only cleaned and waxed with a good self-polishing, water-emulsion wax. By the end of the two-year period, the unfinished half of the floor showed greater wear than the finished half. Of the four types of penetrating seal used on the finished half of the floor, one finish soiled more readily than the other three. The evaluation of wear of all the tests included in the Rhode Island studies was based only on visual appearance (11).

The accelerated wear tests at Rhode Island State College were centered around a wear testing machine adapted for this study. Members of the Engineering School of Rhode Island State College designed and constructed the machine, which worked on the "rotating disk" principle. The specimen being tested was placed on a rotating disk which came in contact with a revolving arm carrying the abrasive. The abradant would strike the surface of the revolving specimen and skid a short distance before being lifted from the surface of the specimen. This would produce an action similar to that of walking on a floor surface. No definite results were reported on this study (11).

Sward and Hart conducted a study of practical testing of floor finishes also in the late 1930's. Eleven clear finishes and one pigmented finish were applied to blocks placed in the corridor of the laboratory. A path three blocks wide by fourteen blocks long was formed and subjected to wear. The locations of the blocks were rotated every two weeks for a six month period. Examination of the blocks at the end of the test period revealed that penetrating seal wore less than the other finishes. The shellac, lacquer, and varnish wore approximately the same (23).

The Chatham Manufacturing Company began testing floor finishes in the late 1950's. Under the direction of Hart, several different types of finishes were applied to ten foot stretches of a main traffic alley. After several days, differences began to show; after two months, all but the urethane finish showed definite signs of breaking down. Because of the results of this test, Chatham Manufacturing Company applied urethane finish to its nine acres of wood floors with the expectation that the finish would last one and one-half years in heavily traveled areas (7).

The Brown and Williamson Tobacco Corporation's plant at Petersburg, Virginia, conducted tests for twenty-six months on 312,000 square feet of hard maple flooring. During the testing period a change was made from a high quality lacquer floor finish to a new oil-free urethane finish. The tests showed that the urethane finish produced the following results:

> (1) about $2\frac{1}{2}$ to 4 times longer life under severe traffic than was possible before; (2) greatly improved dirt and chemical resistance (hard, resilient surface offered little chance for soilage adhesion); (3) better retention of attractive "new wood" appearance. No noticeable oxidation or darkening with age; (4) very fast drying under humid conditions (Moisture actually acts as a catalyst and speeds curing, which is exactly the opposite of conventional finishes); (5) substantial cost-saving (per square foot per year) due to long life of urethane coating before renewal is needed; less time needed for sweeping or cleaning, etc; (6) relatively easy finish renewal without sanding. Material blends well with surrounding finish (16:128).

In 1962 the William Zinsser Company compared the wear and color-fast qualities of four finishes: lacquer, penetrating seal, oil-modified polyurethane, and amino resin. The finishes were applied according to the manufacturer's instructions to 22 in. by 22 in. blocks of standard oak or maple flooring. The test blocks were installed in a well-traveled fourteen-foot corridor in the Zinsser factory. The blocks were rotated daily in order to insure maximum wear on each block. After exposure to wear for 120 days, the lacquer and penetrating seal could not compare with the amino resin for wear. Although the wear on the blocks greatly exceeded wear exposure of finishes in the home, tests did serve to compress prolonged wear in the home into a few months in the factory. The amino resin and the urethane finish wore equally well. However, because of its gloss, the urethane tended to show scratches more. It also darkened because of its oil content (24).

In 1967 Spencer conducted a study of wood floor finishes at the University of North Carolina at Greensboro under the sponsorship of the North Carolina Agricultural Experiment Station. Blocks of quarter-sawn, strip red oak flooring, finished with eight different wood floor finishes and a factory-finished block, were field tested to determine the degree of wear of the finishes. Three surface conditions were used: unwaxed, waxed with a solvent base liquid wax, and waxed with a solvent base paste wax. Three replicates of each finish were used with one control for each replicate. The finish thickness on each block was measured with a light-section microscope. The blocks were then placed in a random block design in a busy hallway. Blocks were rotated each week, and the test areas were rotated every nine weeks in a modified Latin square design to ensure equal wear. The finish thickness was measured again at the end of each wear period. Results indicated the following for the applied finishes: lacquer showed the lowest mean percentage of wear under all surface conditions, while shellac and epoxy showed the highest mean percentage of wear (22). Spencer concluded that:

> (1) under all surface conditions, lacquer generally had the longest projected wear life and epoxy the shortest; (2) self-polishing, solvent base liquid wax, solvent base paste wax, or no wax could be used with the same results in wear; (3) generally, amino resin showed the fewest scratches, mars, and the least affinity for soil; lacquer and vinyl were the least desirable in appearance; (4) the appearance of the wood floor finishes waxed with a solvent base paste wax was more desirable than that of the same finishes in an unwaxed condition but less desirable than those waxed with a self-polishing solvent base liquid wax (22:49).

After 54 weeks of additional testing, lacquer showed the greatest wear, while polyurethane and epoxy had the least wear. There was no significant difference in wear with respect to surface conditions (8).

In 1967, Consumer Bulletin reported a wear study of finishes. Four different finishes were applied to a floor in one of the Consumer Bulletin laboratories. The floor was sanded and divided into numbered strips. After two years of wear, differences in the finishes were apparent. Based on the results of this study, Consumer Bulletin recommended the polyurethane varnish and lacquer finishes. Alkyd varnish was classified as intermediate, while interior varnish and clear sealer were not recommended (26).

Few studies related to wear of wood floor finishes have incorporated adequate means of measuring the wear produced on the finishes. Many studies have used only visual appearance of the finishes to measure wear. Others have measured the amount of abrasive used to produce a certain amount of wear on a finish. Another method used to assess wear is to measure the thickness of the test specimen both before and after wear. None of these methods are satisfactory for accurate measurement of film thickness of the finish.

Laboratory Accelerated Methods Used to Produce Wear on Floor Finishes

Abrasion methods. Salomon stated in 1957 that machines producing wear had been, to that date, frequently hybrids, producing figures of no physical significance and of little practical value (17). Lea surmised that:

> General-purpose machines for the measurement of abrasion resistance have proved unsuitable for assessing the resistance of flooring materials to wear by foot traffic. This is evidently

attributable to the complexity of the interaction between floot and floor during walking, and to the existence of a number of mechanisms of wear which probably depend upon the materials involved (12).

As early as 1878 abrasion machines were used for testing flooring materials. These early machines as well as many later machines were built on a "rotating disk" principle. The specimen being tested was placed on a rotating disk or cylinder which came in contact with a fixed abrasive; the abrasive was placed on a rotating disk or cylinder which came in contact with a fixed specimen; or both specimen and abrasive rotated simultaneously. In each case, the abrasive came in contact with the surface of the specimen (9).

Another large group of machines featured a rectilinear motion between the specimen and the abrasive. The specimens move in a vertical direction while the abrasive presses against the specimens and moves in an opposing vertical direction (9).

Some machines use a cam to produce reciprocating movement and therefore enable the speed of the specimen to change relative to the abrasive. These machines are divided into two groups: (1) those with the specimen resting on the abrasive and (2) those with the abrasive resting on the specimen (9).

A fourth type of abrasion machine is the type using the "falling sand method." This consists of an abrasive falling through a cylinder onto the test specimen. The abrasion resistance is measured by the amount of abrasive required to wear the specimen (2).

Still another technique used to abrade a floor finish is the "air-blast" abrader. This type of machine forces the abrasive through a nozzle by a stream of air and blows it onto the test specimen (1).

One final method employed to abrade specimens is that of a rotating drum containing pieces of abrasive. The specimens to be tested line the inside of the drum. When the drum is rotated, the abrasive falls onto the specimens (9).

Simulated walking methods. There have been few machines designed specifically to simulate the wearing of a floor finish by foot traffic. Harper, Warlow, and Clark have stated that: "for testing flooring materials, the more promising approach seems to be to develop a machine to simulate service conditions and to accelerate the test by applying the abrasive forces more frequently than in actual use" (10).

One of the first machines designed to simulate floor traffic was the Stuttgart machine developed by Egner in 1932. This was a reciprocating machine with a shoe shod with emery cloth. As the table with the specimens mounted on it moved back and forth, the shoe, which rested on the table, rocked back and forth much like a walking foot (9).

Chaplin and Armstrong developed a machine with two important features--impact and rubbing. The specimen reciprocates beneath a 30 pound metal "stamper" and an abrasive pad (9).

The Swedish Forest Products Research Laboratory developed a machine similar to that of Chaplin and Armstrong. This machine substituted two loaded rotating cylinders for the "stamper" and abrader of the Chaplin-Armstrong Machine (9).

Several other machines have been developed to produce wear by the use of a "foot." The specimens on these machines rotate or reciprocate under a leather shod "foot" (9).

Walking has been simulated by two machines designed to wear carpets. In the first machine, "heels" were pounded into a pile carpet under a pressure of 30 pounds per square inch. The heel, with a loose piece of emery cloth attached behind it, is moved across the carpet until the carpet is "beyond service fitness" (9). The second machine utilizes a stamping "foot" which is leather covered and hammered with emery. The "stamping foot" is driven forward and downward with decreasing velocity as the sample rotates. The degree of wear is determined by the decrease in the height of the pile (9).

There are at least two machines of the walking wheel type. The machine designed by the National Bureau of Standards consists of a wheel covered with eight leather covered blocks. The wheel, which produces a bumping-slipping motion much like that produced by walking, rotates on a track covered with 20 flooring specimens. The Forest Products Research Institute uses a walking-wheel to test wood specimens. The specimens are mounted on the wheel which turns on its axis as it rolls on a track. This wheel also produces a bumping-slipping motion much like the National Bureau of Standards' wheel (9).

Forces Exerted on the Floor by the Foot in Walking

In order to understand more readily the principle of wear, one must review the effect of the foot in walking. In 1933 Schwartz, Heath, and Wright agreed to the premise that because no two people walk alike the possibility of determining a normal gait is doubtful (18). Results of tests conducted by Morton showed the weight distribution of an average gait to be as follows:

> As body weight is superimposed, the bones of the foot gravitate into firm apposition with a tightening of the plantar ligaments, until the arched framework becomes rigid and relatively non-yielding to further pressure. Body weight is now transmitted to the ground through the various bony channels of the foot, posteriorly represented by the heel and anteriorly by the five metatarsal bones (14:107).

In a study of the mechanics of walking conducted by the National Bureau of Standards, body movement was observed through the use of concealed slow-motion cameras. These pictures revealed that:

> ...the leg slows down at the termination of its swing and then appears to vault onto the walkway, with 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 the heel rocks forward and the foot is fully planted (21:45).

Morton found that the estimated distribution of body weight in stance through the feet of an individual weighing 120 pounds would be:

To each foot....................60 pounds divided as follows:
To the heel.....................30 pounds
To metatarsal I (two points of contact, of 5 pounds each).........................10 pounds
To each lateral metatarsal II-V, (5 pounds each)...
................................20 pounds (14:109).

In 1961 Harper, Warlow, and Clarke, in an effort to determine contact pressure of the foot, found that there is no turning of the foot about its vertical axis; the motion is that of rolling about a horizontal axis (10).

The pressure, initially high, falls to a fairly constant value while the foot is flat and rises again as the toe pushes off (10). When examining horizontal forces, the researchers found that the force rises to a peak in the direction of walking as the body accelerates forward, but it falls when the trunk is directly over the foot and rises again in a backward direction as muscle action accelerates the body forward again (10). The three also observed that for most subjects the lateral component of the horizontal force is minute; when it occurs, it is usually directed outward from the foot and arises from the effort to keep the center of gravity of the trunk over the point of support (10).

CHAPTER III

EXPERIMENTAL PROCEDURE

This chapter includes a discussion of the following:

The Simulated Human Wear Producing Machine

Selection and preparation of test panels

Selection and application of specific wood floor finishes

Film thickness measurement

Laboratory testing procedure

Data analysis

The Simulated Human Wear Producing Machine

The Simulated Human Wear Producing Machine was designed and built by Dr. Henry Bowen and his engineering students of the Biological and Agricultural Engineering Department at North Carolina State University, Raleigh, North Carolina. In order to develop specifications for the machine, Dr. Bowen worked in conjunction with Dr. Savannah S. Day (formerly of the University of North Carolina at Greensboro), Mrs. Nancy Holmes of the School of Home Economics, the University of North Carolina--Greensboro, and Dr. Robert Hader of the Experimental Statistics Department, North Carolina State University, Raleigh.

Dr. Bowen produced a machine that simulates the wear produced by a human being walking on wood floor finishes in an environment that holds as many variables constant as possible. The purposes of the machine were to reduce the variables affecting wear on wood floor finishes and to establish a convenient standard for testing wood floor finishes.

The machine consists of two main parts: the treadmill and the cam-operated legs and feet (Figures 1 and 2). Twenty-four 92 in. by 60 in. pans are mounted on the treadmill. These pans may hold 9 in. by 60 in. carpet strips or 9 in. by 9 in. tile or wood parquet blocks. A total of one hundred ninety-two 9 in. by 9 in. blocks may be mounted on the treadmill. The pans are mounted on two 18 foot conveyor chains which revolve about four 17 in. diameter sprockets driven by a 3/4 horsepower electric motor.

High speed movies of a man walking on a treadmill enabled Dr. Bowen to use the resulting time--angular displacement curves to develop four positive return cams and the cam follower system. The simulation of human walking is achieved through the use of cams which are driven by a system of sprockets, chains, and speed reducers.

The frame of the machine was designed so that it could be adapted to the step length, the weight, and foot pressure distribution of either a man or woman. From 0 to 300 pounds pressure may be applied to the blocks on the conveyor belt. The weight is regulated by either adding weight to the pelvic region of the machine or by removing weight through the use of an air cylinder and air tank. The wooden foot of the machine have the shape of a human foot. They are fitted with size 10 D/B men's shoes, right and left, which have

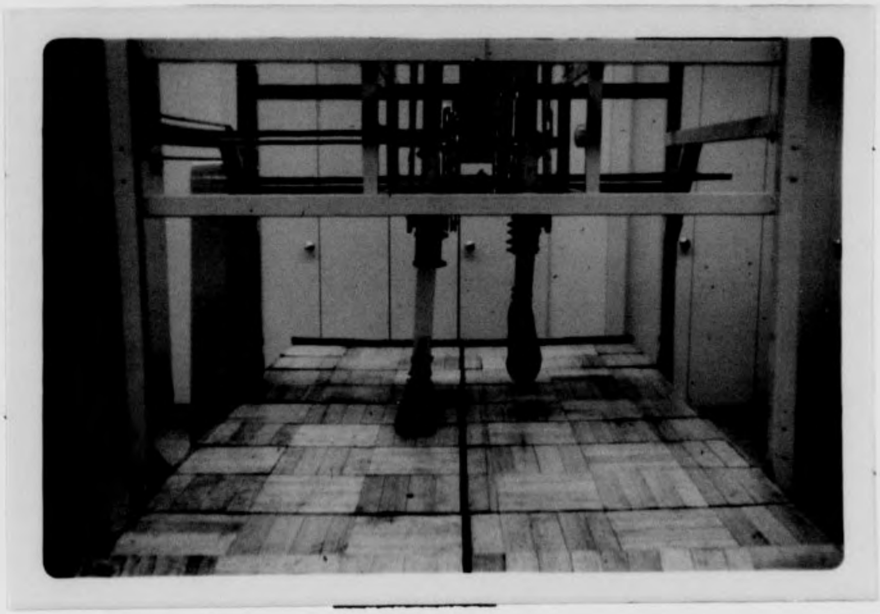

FIGURE 1

The Simulated Human Wear Producing Machine

FIGURE 2

Dr. Henry Bowen with the Simulated Human Wear Producing Machine leather soles and rubber heels. In adapting these wooden feet to human foot manipulation, Dr. Bowen used "transverse joints at the ball of the foot and at the ankles with adjustable distribution on ball of the foot and heel in the mid-range of the weight carrying portion of the step" (4:2). The machine was designed originally to walk in either a straight line or a random movement across the test blocks, but to date has been adjusted to walk only in a straight line. Speed of the treadmill may be varied from one to three miles per hour. Testing on the floor finishes was conducted at a three mile per hour rate.

Selection and Preparation of Test Panels

The test panels were selected and prepared in the same manner as prescribed by Spencer (22). The School of Forestry at North Carolina State University at Raleigh recommended the use of blocks of red oak, 9 in. by 9 in. quarter-sawn, tongue-and-grooved strip flooring, 25/32 in. by 2¼ in., select grade. Although plain-sawn flooring is more commonly used, quarter-sawn flooring was recommended because of its equal distribution of summer and winter growth. Prefinished test blocks of the same type and size as the other test blocks were also used in this study. A wide belt sanding process was used on the test blocks before applying the finish to insure surface uniformity of the specimens.

Selection and Application of Wood Floor Finishes

The procedure for the selection and application of the wood floor finishes followed by Spencer (22) was also followed in this study. Wood floor finishes were selected on the basis of their solids content as recommended by the School of Forestry staff at North Carolina State University at Raleigh and also on their availability on the local market. The eight finishes selected for testing were a gloss varnish, shellac, lacquer, penetrating seal, epoxy, polyurethane, vinyl, and amino resin (22). The finishes were applied in accordance with the directions furnished by the manufacturers. Four replicates of the eight floor finishes and prefinished block were tested. A total of 36 blocks were tested.

Film Thickness Measurements

Four film thickness measurements were taken at specific locations within the wear path on each of the test blocks and an average film thickness was computed. Specific locations were chosen to insure that the machine walked over that area of each block. These locations were an estimated centimeter from the needle hole filled with a drop of ink. A Zeiss Light-Section Microscope was utilized in measuring film thickness.

Following is the procedure used for measuring the film thickness of the wood floor finishes:

1. The workpiece (specimen) was placed on the stage of the microscope in a flat position.

2. The coarse and fine focus knobs (black knob, coarse; silver knob, fine) were adjusted until the small green line (brighter line) was distinctly near the center of the field.

3. With the outer knob of the micrometer drum, the zero (0) was set on the nearest whole number of the stationary section of the drum. By using the inner micrometer drum knob (lowest part of the drum), the black horizontal line was set to the starting point of the measure. (The starting point is the visual average of the valleys and peaks at the bottom of the "fuzzy" green line.)

"Fuzzy" green line (porosity of wood)	WWWWWWWWWWWWWW	
	$\updownarrow$	Film thickness
Bright green line (top of film coating)	______________	

4. The outer drum was moved counter clockwise to the left until the black line seen through the microscope, was aligned with the center of the thin bright green line. (1 rotation of the micrometer equals 50 microns at 400 X)

<u>Laboratory Testing Procedure</u>

Tests were conducted in a temperature ($70^{\circ} \pm 2^{\circ}$ F.) and humidity (40% $\pm$ 2%) controlled laboratory.

The number of variables affecting the wear of the finishes was reduced as much as laboratory conditions permitted in order to establish a convenient standard for testing wood floor finishes using the Simulated Human Wear Producing Machine. The wood flooring blocks were of the same type wood and cut to the same size in order to insure the sameness of wood texture. The finish thickness of each block was measured in the same manner (see page 21) and by the same measuring device, the Zeiss Light Section Microscope.

A table of random numbers was used to assign the blocks to a test position. The blocks were then installed on the machine treadmill in the two center tracks. Test blocks were placed only in the first 18 of the 24 positions on each track; the remaining six positions were filled with dummy blocks.

The weight applied to the mounted blocks on the Simulated Human Wear Producing Machine was kept at a constant 165 pounds to approximate the average weight of men.

Test measurements were compared with the measurements from Spencer's and Greene's field tests of wear on wood floor finishes. The test showed that four hours of time approximated 27 weeks of field tests and eight hours approximated 54 weeks of field tests.

Film thickness measurements were recorded on the test specimens for each finish at one, two, four, five, six, and eight hours. The blocks were rotated after each measurement period. The blocks were rotated as to track and position on each track according to the table of random numbers. The shoes on the machine were changed after the fourth-hour measurements.

Data Analysis

Standard analysis of variance was used in analyzing the data. These analyses were computed according to the following model:

Source of Variation	Degrees of Freedom
Finish	8
Direction	1
Finish/Direction	8
Foot	1
Finish/Foot	8
Direction/Foot	1
Finish/Direction/Foot	8

The statistical analysis included an evaluation of the following four factors of wear for each of the eight wood floor finishes and of the prefinished specimens:

The differences among finishes

The differences between right and left foot

The differences in direction of wood grain

The interaction of finishes, direction, and foot

CHAPTER IV

FINDINGS

Results of laboratory tests of selected wood floor finishes are presented in this chapter.

Laboratory Test Results

There was a significant F ratio for degree of wear among floor finishes as reported in TABLE I. The direction in which the blocks were placed upon the treadmill was found to be significant for both the four hour and eight hour test periods.

Data showed that after four hours of wear epoxy had the greatest loss of film thickness, 19.46 microns, while vinyl and shellac had the smallest losses, 6.03 microns and 6.94 microns, respectively (TABLE II). Penetrating seal had the greatest percentage loss of film thickness (29%) and vinyl the least (19%).

After eight hours wear, epoxy again had the greatest loss in microns (30.35) and vinyl had the least (11.68 microns). Penetrating seal had the greatest loss of finish according to percent (55%) and vinyl the least (26%).

All finishes except polyurethane and shellac wore less during the second four hours than during the first four hours.

As the prefinished specimen was treated with a penetrating-type finish, it was concluded that measurement of film thickness was

TABLE I

Analysis of Variance for Laboratory Wear of Film Thickness

Variance source	Degrees of freedom	F value				
		Four hours wear	Eight hours wear	Original minus four hours	Original minus eight hours	Four hours minus eight hours
Corrected total	35					
Finish	8	19.07*	30.45*	n.s.	6.03*	n.s.
Direction	1	n.s.	n.s.	5.49**	5.32**	n.s.
Finish/Direction	8	n.s.	n.s.	n.s.	n.s.	n.s.
Foot	1	n.s.	n.s.	n.s.	n.s.	n.s.
Finish/Foot	8	n.s.	n.s.	n.s.	n.s.	n.s.
Direction/Foot	1	n.s.	n.s.	n.s.	n.s.	n.s.
Finish/Direction/ Foot	8	n.s.	n.s.	n.s.	n.s.	n.s.

*Significant at .01 level

**Significant at .05 level

n.s. - not significant

TABLE II

Loss of Film Thicknesses by Finishes (in Microns and Percentage)

Finishes	Original film thickness	After 4 hours wear		After 8 hours wear		Difference (8-4 hours)	
NEWER FINISHES		microns	percent	microns	percent	microns	percent
Polyurethane	63.4750	8.7438	14%	22.4656	35%	13.7218	22%
Vinyl	44.5812	6.0313	14	11.6844	26	5.6531	13
Amino Resin	38.6500	9.8156	25	16.2219	42	6.4063	17
Epoxy	74.5625	19.4594	26	30.3531	41	10.8937	15
CONVENTIONAL FINISHES							
Lacquer	66.8812	12.4531	19	19.9438	30	7.4907	11
Shellac	45.8812	6.9406	15	17.5281	38	10.5875	23
Varnish	66.4375	12.4563	19	24.6406	37	12.1843	18
Penetrating Seal	41.1000	11.9250	29	22.5406	55	10.6156	26
*PREFINISHED	16.3562	7.6937	47	12.9250	79	5.2312	32

*Excluded from remaining Tables.

not an adequate test for this finish and thus was eliminated from further comparison to other finishes.

Finishes were ranked from low to high as indicated by micron loss and percentage loss from the original film thickness (TABLE III). There was no identical rank ordering of finishes in both micron and percentage loss. However, vinyl appeared in the position of least wear in each of the test periods, both by micron and percent.

Finishes were then grouped according to incidence in any of the top three positions of least and most wear (TABLE IV). Considering both four and eight hour test periods, both by micron and percentage loss, vinyl appeared in each of the four least wear situations. Shellac and polyurethane appeared in three of the four situations. Therefore, vinyl, shellac, and polyurethane were identified as finishes evidencing the best wear performance of those tested. Epoxy appeared in each of the four situations of greatest wear; penetrating seal appeared in three of these four. Therefore, epoxy and penetrating seal were identified as finishes evidencing the poorest wear performance.

TABLE III

Rank Ordering of Loss in Film Thickness From Low to High (in microns and percent)

Rank	Four hour test		Eight hour test	
	microns	percent	microns	percent
1	vinyl 6.0313	vinyl 14%	vinyl 11.6844	vinyl 26%
2	shellac 6.9406	polyurethane 14%	amino resin 16.2219	lacquer 30%
3	polyurethane 8.7438	shellac 15%	shellac 17.5281	polyurethane 35%
4	amino resin 9.8156	varnish 19%	lacquer 19.9438	varnish 37%
5	pentrating seal 11.9250	lacquer 19%	polyurethane 22.4656	shellac 38%
6	lacquer 12.4531	amino resin 25%	penetrating seal 22.5406	epoxy 41%
7	varnish 12.4563	epoxy 26%	varnish 24.6406	amino resin 42%
8	epoxy 19.4594	penetrating seal 29%	epoxy 30.3531	penetrating seal 55%

TABLE IV

Finishes Among Top Three Ranks of Least and Greatest Surface Loss
(by microns and percent)

Finish	Surface Thickness Loss							
	Least Surface Loss				Greatest Surface Loss			
	microns		percent		microns		percent	
	four hours	eight hours	four hours	eight hours	four hours	eight hours	four hours	eight hours
Polyurethane	X		X	X				
Vinyl	X	X	X	X				
Amino resin		X					X	X
Epoxy					X	X	X	X
Lacquer				X	X			
Shellac	X	X	X					
Varnish					X	X		
Penetrating seal						X	X	X

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

This study is a part of a larger project entitled "Wearability of Wood Floor Finishes" sponsored by the North Carolina Agricultural Experiment Station.

Objectives of this study were:

1. To determine through laboratory tests the wear characteristics of selected wood floor finishes.

2. To test the Simulated Human Wear Producing Machine.

Blocks of red oak, 9 inch by 9 inch quarter-sawn, tongue-and-grooved strip flooring, 25/32 inch by 2-¼ inch, select grade were used as test panels. A wide belt sanding process was used on the test blocks before applying the finish to insure surface uniformity of the specimens. Wood floor finishes were selected on the basis of solids content--the greater the solids content, the more acceptable the finish.

Four test replicates were prepared with each of the eight floor finishes: a gloss varnish, shellac, lacquer, penetrating seal, epoxy, polyurethane, vinyl, and amino resin. Four replicates of a prefinished specimen were also included. A Zeiss Light-Section Microscope was used to measure the film thickness at predetermined locations on each specimen. Measurements were taken before testing and at intervals of one, two, four, five, six, and eight hours. The four and eight hour intervals are reported here since the tests indicated they approximated test periods of the field studies of these finishes. A mean film thickness was then computed for each block for use in data analysis.

The Simulated Human Wear Producing Machine developed by Dr. Henry Bowen and his engineering students in the Biological and Agricultural Engineering Department at North Carolina State University, Raleigh, was used to simulate human walking. It consists of two main parts: the treadmill for mounted specimens and the cam-operated legs and feet. Test blocks were placed in the first 18 of the 24 positions in each of the center tracks of the treadmill; the remaining positions were filled with dummy blocks. Blocks were rotated after each measurement interval. The shoes on the machine were changed after the fourth hour of testing.

Standard analysis of variance was used in an evaluation of the effect on wear of the following four factors for each of the eight wood floor finishes and of the prefinished specimens:

The differences among finishes

The differences between right and left foot

The differences in direction of wood grain

The interaction of finishes, wood grain direction, and foot

The statistical analysis of data showed a significant $\underline{F}$ ratio for degree of wear among each of the wood floor finishes. The wood grain direction was also found to be significant. This indicated that there is a significant difference in wear resistance among wood floor finishes. Of the finishes tested, vinyl had the lowest overall amount of wear followed by shellac and polyurethane. Epoxy showed the greatest amount of wear in microns. Penetrating seal maintained the greatest overall mean percentage of wear followed by amino resin. Vinyl had the smallest mean percentage of wear.

The rate of wear produced by the Simulated Human Wear Producing Machine closely approximated the wear produced by a person. However, it is believed that further testing of the machine is necessary before any firm conclusions can be made.

Conclusions

The following conclusions were drawn as a result of this study:

1. Of the eight floor finishes tested there was a significant difference in amount of wear. In overall performance vinyl wore least; epoxy wore most.
2. The rate of wear produced by the Simulated Human Wear Producing Machine closely approximated the wear produced by a person. However, it is believed that further testing of the machine is necessary before any firm conclusions can be made.
3. Subsequent wear did not occur at the same rate as initial wear.
4. Wood grain direction did have an effect on the wear of the finishes.

Recommendations

The following recommendations for further study are made with respect to the results of this investigation:

1. The study should be continued until the wear life of each finish is calculated.
2. The study should include more replicates and more measurements of each finish for more valid results.
3. Each finish should be tested on the machine with average weights and foot sizes of men, women, and children.
4. The legs of the machine should be made of metal instead of wood in order to reduce the wear and slippage of parts of the machine.
5. The machine should be made to walk randomly over the surface of the treadmill to decrease the possibility of a "path" being formed on the test specimens.
6. A comparative study should be made of field and laboratory test with film thickness readings at the same magnification.
7. The machine should be used to test other forms of flooring materials.

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APPENDIX

APPENDIX

Mean Film Thickness Measurements in Microns

Finishes	Original Thickness	After 4 hours wear	After 8 hours wear	Original minus 4 hours wear	Original minus 8 hours wear	8-4 hours
NEWER FINISHES						
Polyurethane						
Right Foot Direction-						
crosswise	54.1250	51.4250	38.6250	2.7000	15.5000	12.8000
lengthwise	60.9000	49.7000	36.4875	11.2000	24.4125	13.2125
Left Foot Direction-						
crosswise	59.7250	60.1500	43.3625	-0.4250	16.3625	16.7875
lengthwise	79.1500	57.6500	45.5625	21.5000	33.5875	12.0875
Penetrating Seal						
Right Foot Direction-						
crosswise	33.1250	27.5500	22.2000	5.5750	10.9250	5.3500
lengthwise	41.6500	29.5750	9.0500	12.0750	32.6000	20.5250
Left Foot Direction-						
crosswise	39.4500	29.8500	19.1750	9.6000	20.2750	10.6750
lengthwise	41.6500	29.5750	9.0500	12.0750	32.6000	20.5250
Vinyl						
Right Foot Direction-						
crosswise	44.6750	33.4250	29.1125	11.2500	15.5625	4.3125
lengthwise	38.9000	39.5875	31.5625	-0.6875	7.3375	8.0250
Left Foot Direction-						
crosswise	45.7750	41.6375	31.7875	4.1375	13.9875	9.8500
lengthwise	48.9750	39.5500	39.1250	9.4250	9.8500	0.4250

APPENDIX (Continued)

Finishes	Original Thickness	After 4 hours wear	After 8 hours wear	Original minus 4 hours wear	Original minus 8 hours wear	8-4 hours
Amino Resin						
Right Foot Direction-						
crosswise	40.1750	28.1125	22.1625	12.0625	18.0125	5.9500
lengthwise	38.9000	25.6500	19.3875	13.2500	19.5125	6.2625
Left Foot Direction-						
crosswise	34.6500	30.1750	20.0375	4.4750	14.6125	10.1375
lengthwise	40.8750	31.4000	28.1250	9.4750	12.7500	3.2750
Epoxy						
Right Foot Direction-						
crosswise	77.3000	64.3625	46.1875	12.9375	31.1125	18.1750
lengthwise	78.0250	51.8000	40.7500	26.2250	37.2750	11.0500
Left Foot Direction-						
crosswise	76.0500	51.8500	44.8125	24.2000	31.2375	7.0375
lengthwise	66.8750	52.4000	45.0875	14.4750	21.7875	7.3125
CONVENTIONAL FINISHES						
Lacquer						
Right Foot Direction-						
crosswise	59.5500	53.4375	41.2625	6.1125	18.2875	12.1750
lengthwise	69.9500	50.2250	45.2750	19.7250	24.6750	4.9500
Left Foot Direction-						
crosswise	62.6500	61.1000	50.5250	1.5500	12.1250	10.9500
lengthwise	75.3750	52.9500	50.6875	22.4250	24.6875	2.2625
Shellac						
Right Foot Direction-						
crosswise	41.8000	35.9875	25.0375	5.8125	16.7625	10.9500
lengthwise	45.0750	39.8625	29.7375	5.2125	15.3375	10.1250
Left Foot Direction-						
crosswise	40.6000	30.5250	19.2750	10.0750	21.3250	11.2500
lengthwise	56.0500	49.3875	39.3625	6.6625	16.6875	10.0250

APPENDIX (Continued)

Finishes	Original Thickness	After 4 hours wear	After 8 hours wear	Original minus 4 hours wear	Original minus 8 hours wear	8-4 hours
Varnish						
Right Foot Direction-						
crosswise	74.3500	65.3250	50.4750	9.0250	23.8750	14.8500
lengthwise	61.5250	46.2875	33.4375	15.2375	28.0875	12.8500
Left Foot Direction-						
crosswise	57.7250	42.9125	37.1875	14.8125	20.5375	5.7250
lengthwise	72.1500	61.4000	46.0875	10.7500	26.0625	15.3125
PREFINISHES						
Prefinished						
Right Foot Direction-						
crosswise	16.7000	7.1000	3.5250	9.6000	13.1750	3.5750
lengthwise	17.2500	9.2750	5.9625	7.9750	11.2875	3.3125
Left Foot Direction-						
crosswise	15.6500	11.4625	4.2375	4.1875	11.4125	7.2250
lengthwise	15.8250	6.8125	0.0000	4.1875	11.4125	7.2250