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This study contributed to research of the Agricultural Experiment Station Southern Regional Housing Project S-54 through a second period of field testing.

Field testing was continued on specimens used in an earlier study to determine the subsequent degree of wear of the finishes under three surface conditions: unwaxed, waxed with a solvent-base liquid wax, and waxed with a solvent-base paste wax; degree of gloss; and subjective appearance rating of the finishes under the different surface conditions. Specimens were blocks of quarter sawn, strip red oak flooring, finished with eight wood floor finishes--amino resin, epoxy, polyurethane, vinyl, lacquer, shellac, varnish, penetrating seal, and a factory-finished block. Blocks within each test area were rotated once a week (every five days of testing) and the test areas were rotated every nine weeks according to a three-factor Latin square design so that in time each group received the same exposure to traffic.

A Zeiss Light-Section Microscope was utilized in measuring film thickness and a Gardner Sixty-Degree Angle Glossmeter registered the gloss readings. Appearance of the test blocks was evaluated by an eight member panel.

Data were analyzed by standard analyses of variance and correlations. Results indicated the following conclusions: (1) there was a difference in the wear of the eight types of wood floor finishes tested, (2) there was no difference in the wear of the finishes with

respect to the surface conditions utilized (unwaxed, waxed with a self-polishing liquid wax and waxed with a solvent-base paste wax), (3) significant differences were found in gloss of the eight wood floor finishes after wear, (4) the surface condition had a significant effect on the change in gloss of the finish, (5) there was no relationship between the loss of gloss and the wear of wood floor finishes, (6) evaluation of appearance by individuals does not seem to be an accurate estimate of wear measured in loss of film thickness of wood floor finishes.

Initial wear of film thickness was greater than subsequent wear. Of the finishes tested in the second period polyurethane, epoxy, and vinyl showed the least wear while the greatest wear occurred with lacquer and amino resin.

After wear under all three surface conditions, highest gloss was evidenced on epoxy and polyurethane finishes. The least gloss in all surface conditions appeared on shellac and penetrating seal.

PERFORMANCE FACTORS OF SELECTED WOOD FLOOR FINISHES

by

Nancy Donave Greene

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Approved by

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APPROVAL SHEET

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CHAPTER I

INTRODUCTION

In ancient times when it was first recorded, the application of a coating to wood was done solely for the purpose of preserving and protecting the wood to which it was applied. It has been noted that Noah, to seal and protect his ark, used natural asphalt. Before Noah an extract from a small tree related to the American poison ivy bush was used by the Chinese, while in India, a secretion from an insect was used as a preservative (11). Ancient Egyptian coffins preserved in the British Museum show evidence of the use of some type of transparent finish to preserve wood. These date back several thousand years and indicate that protective finishes have been of interest to mankind for many generations (14).

Virtually no improvement in the primitive materials occurred until the middle of the eighteenth century. Shellac in the form of French varnish, a mixture of linseed oil and natural resins and crude stains made from colored earths and insects' extracts, were used by artisans in Europe and parts of Asia. There was little change in the finishing process until the late nineteenth century when fossil gums from India and Africa were melted down and combined with linseed oil to make the first true varnish (11).

The popularity of wood for floors of dwellings dates back to pioneer days when men used thick, hewed sections of logs smoothed as

much as possible on one face with an adz and laid edge to edge to make puncheon floors. Later in the mid-nineteenth century planing of the wood produced a floor with better appearance but less resistance to wear and staining (14). To protect these floors, oil and linseed oil were used to prevent stains from penetrating into the wood. A glossy finish (varnish-like) was used whenever a transparency was desired. The varnish-type finish became truly adaptable to accelerated production processes in the early 1920's when faster drying gums and resins were introduced. During this time high quality stains were made by mixing aniline dyes and linseed oil.

In 1923 the basic formula for lacquer was discovered by accident when a workman making viscoe nitrocellulose mixed some caustic soda into the material. The mixture was thin enough to be sprayed at higher solids content and when sprayed produced a tougher, thicker film (11).

With the advent of phenol formaldehyde resins some thirty years ago, a new trend in floor sealers and varnishes began. These new synthetic resin varnishes provided a tougher and more resistant film. Improvement in equipment for sanding and preparing wood floors for treatment together with continued improvement in the performance characteristics of these synthetic resin floor sealers and heavy duty floor finishes, have resulted in their general acceptance as the preferred treatment for hardwood floors.

During the past two to three years, two new types of synthetic resins have become available. They are known as "epoxy resins" and

"urethane varnishes" with outstanding characteristics of toughness and resistance to attrition (2). Polyurethane which had a wide range usage in Germany during World War II is one of the new coatings to come to the market. Only in the last few years has it come into use in this country (3). Hunt has stated: "It's been a long trip down the road of time from the asphalt of Noah's ark to the complicated, catalyzed finishes used today" (11).

THE PROBLEM

The purpose of this study was to determine the wear and gloss performance factors of selected wood floor finishes during a second period of 27 weeks of field testing.

Objectives

The objectives of this study were:

1. To compare the film thickness measurements of each floor finish in new and worn conditions
2. To compare the gloss measurements of each finish in new and worn conditions
3. To relate the gloss measurements of wood floor finishes in a worn condition to film thickness measurements
4. To secure the appearance rating of each finish as determined by a rating panel
5. To compare panel rating to film thickness measurements

Importance of the Study

New synthetic floor finishes, highly publicized because of their outstanding toughness and abrasion, have recently been introduced on

the market. An increase in the kinds of floor finishes available coupled with claims of better performance for the newer finishes have made selection of floor finishes more difficult for the consumer. Martens has indicated that hardwood flooring has not lost its competitive status with other flooring materials. He found that it was preferred more often than wall-to-wall carpeting because of its durability, attractiveness, and wearability (18).

In order for hardwood floors to remain attractive, durable, and maintain wearability, a good finish is needed to enhance these characteristics (18). Precise measurements of gloss is of particular interest in the field of protective and decorative coatings for it is an important appearance property of some materials (26).

With the variety of finishes on the market today, the consumer needs information which can assist him in making a satisfying choice of wood floor finishes that will meet his individual need and provide the best results from his purchase.

This study also provided additional information for research on floor surfaces being conducted by the School of Home Economics at the University of North Carolina at Greensboro.

DESCRIPTION OF TERMS USED

Conventional Wood Floor Finishes

> Lacquer. The term lacquer is restricted to coatings of which the characteristic ingredient is a solution of nitrocellulose of "pyroxylin" in a combination of ester, ketone and alcohol solvents. . . . Drying of a lacquer film is accomplished through the evaporation of the solvent (27:4).

> Shellac. Shellac is a secretion of the coccus Lacca on the smaller branches of certain members of the fig family found 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 pound cut = 3 pound shellac flakes to 1 gallon alcohol) to make a floor finish (28:5).

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 or 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 (28:5).

Penetrating Seal. A floor seal chemically identified as a linseed oil - modified polyol, moleate, phthalate polyester reduced in aliphatic mineral spirits solvent. It is used as a penetrant for wood substrates to increase abrasion resistance of the wood (27:4).

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 (27:4).

Polyurethane. One of the products formed when an isocyanate reacts with a hydroxy compound. If polyfunctional compounds are used, useful polyurethanes are formed and some of these find application in the surface coating fields. Polyurethane finishes contain polyisocyanates and polyhydroxy compounds and, in some cases, amines which serve as catalysts and cross linking agents (28:6).

Amino Resin. A thermosetting-type resin finish composed of a reaction product of an amino resin and a polyester (28:6).

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 non-volatile resin on the surface; then, the oil

present in the resin oxidizes, changing the resin from a fluid to a solid (28:6).

Prefinished Flooring. Flooring that is completely finished at the factory (21).

Plain Sawn. A sawing process resulting in "U" shaped patterns of annual rings on the surface due to sawing on a tangent to them (1).

Quarter sawn. The process of sawing the log at such an angle that the wood rays appear prominently. The annual rings appear as straight lines (28:4).

CHAPTER II

REVIEW OF LITERATURE

The Forest Products Marketing Laboratory of the United States Forest Service has found that one of the important factors limiting the use of hardwood flooring finishes is the lack of reliable information about the wearability of materials used on wood floors (5). "Bruhn concurred that almost every material producer of wood floor finishes has conducted extensive tests of the wear resistance of their materials" (28:7). These evaluations are not for public use and knowledge, because the tests usually have been conducted on the company's own product. Investigations comparing wearability, gloss and cost of wood floor finishes are even more limited.

This review of literature includes available studies concerned with the wearability of specific wood floor finishes, some of the techniques and instruments used to measure film thickness, and instruments to measure gloss. Characteristics and comparisons of selected wood floor finishes are also included.

STUDIES OF THE WEARABILITY OF WOOD FLOOR FINISHES

A study conducted by Chatham Manufacturing Company compared a urethane finish with other floor finishes, which were not named in the study. Ten foot alley-stretches of flooring were prepared with the different types of finishes. Differences in wear began to show

after four days, and after two months all finishes but the urethane showed definite signs of breaking down. The company, as a result of this test, applied the urethane finish to the 390,000 square feet of wooden floors in the factory. The wood was dressed to the desired smoothness and the first coat of the urethane was brushed on and allowed to dry for eight hours. To give "tooth" for the application of the second coat, the floors were sanded with a fine sand paper. The urethane was hard enough to stand up under heavy traffic without scuffing and was more lustrous, clearer, and freer from lint than any of the finishes tested. The finish was indifferent to oil, bonded well, and gave off no odor (24).

A test conducted by Consumer Research was to determine how a variety of wood floor finishes withstood heavy wear. A section of an oak floor which was subjected to heavy foot traffic in one of the Consumer Research laboratory buildings was machine sanded and divided into equal strips. Four different types of finishes were purchased and applied according to manufacturers' instructions. It was found that varnish was more durable than shellac, but epoxies were more durable than both. Polyurethane was more slip resistant than any of the other finishes used in this study. Penetrating seal had good durability and worn places were easily repaired. Consumer Research reported that most of the finishes used darkened with age (30).

Findings of a twenty-six months study of a urethane finish on hard maple flooring in the productions area of the Brown and Williamson Tobacco Corporation at Petersburg, Virginia, indicated that the finish

had resistance to dirt and chemicals, dried fast under humid conditions, did not darken with age, and had long life. The finish was easily renewed without sanding the floor; the new blended well with the surrounding old finish (24).

In a study conducted by the William Zinsser Company the wear and colorfast qualities of four floor finishes were investigated: penetrating seal, lacquer, oil-modified polyurethane, and an amino resin finish. Seven 22 inch x 22 inch panels of standard oak and maple flooring were finished according to manufacturers' instructions. A narrow 14 foot corridor, leading from the street into the Zinsser Company, was used as the test area, where the panels were subjected to more severe traffic than the usual exposure to wear in the home. Daily, panels were repositioned so as to expose each panel to the same wear conditions. Findings of the test showed that lacquer and penetrating seal did not compare favorably in wear with the amino resin. Even though the wear in the tests was in excess of that in the home, the few months of testing served to represent prolonged wear under similar conditions. The urethane and amino resin finishes wore equally well. The urethane had high gloss, tended to scratch more then the amino resin, and tended to darken (29).

INSTRUMENTS AND TECHNIQUES USED TO MEASURE FILM THICKNESS

Various instruments and techniques have been used to measure the thickness of transparent coatings, both destructively and nondestructively. Numerous magnetic and eddy current instruments are used as

nondestructive techniques among which are the Filmeter and Dermiton. However, functional requirements limit their application to coatings on metallic substrates. Nondestructive techniques have been used to measure coating thickness up to three mils (17). One instrument used for nondestructive film thickness measurements is the Zeiss Light Section Microscope. The instrument does not come in contact with the surface of the material measured; therefore, a large area of the surface can be checked. "Light from an incandescent bulb illuminates a slit diaphragm, whose image is projected through the illuminating objective onto the surface of the sample as a razor thin band of light." This light is observed through an objective lens which has the same power of magnification as the illuminating objective. "A reticle can be shifted within the field of view by turning a micrometer measuring drum, which provides readings in terms of microns." When surfaces that have been coated with transparent films are measured, two lines are visible in the eyepiece because the surface of the film and the surface of the opaque object reflect light. Thickness of the film coating is determined by measuring the distance between the two lines (15).

INSTRUMENTS AND TECHNIQUES USED TO MEASURE GLOSS

The American Standard for Testing and Materials Bulletin on gloss evaluation stated that

> Gloss is the degree to which a surface simulates a perfect mirror in its capacity to reflect incident light. Gloss is the capacity of a surface to reflect light which is responsible for glossy appearance, not the appearance itself. The term glossiness is sometimes used to identify the appearance (13:48).

The visual observer can judge "shininess" or "lustre" of a surface in various ways. He may judge the distinction of the highlights, or the texture or other non-uniformities of the surface. A photoelectric measuring instrument registers a definite optical effect rather than a variety of characteristics. For this reason, visual gloss estimates may disagree with the photoelectric tests (23). Uniformity of the surface of the finishes is very important when considering gloss. Tiny scratches will cause diffuse reflection (12). Gloss to the average person is the property of a surface that gives it a mirror-like or shiny appearance. Gloss is a very complex phenomenon and a difficult property to measure.

Studies by Hunter have indicated that gloss is made up of at least five measurement scales. Since 1936 establishment of five gloss criteria has made it possible to set up successful gloss ranking procedures and to test many different materials. The five types of gloss are as follows:

Specular gloss--perceived at medium viewing angles as the shiness of a surface and the brilliance of its highlights.

Contrast gloss--contrast between specularly reflecting areas and adjacent areas.

Distinctness-of-image-gloss--measure of the distinction and the sharpness of mirror images.

Surface uniformity gloss--uniformity of a surface or the freedom from nonuniformities.

Absence-of-bloom and haze--absence of bloom is an important gloss criterion for high gloss and semi-gloss surfaces on which reflected highlights can be seen. Bloom can be wiped off and haze cannot (7).

There are a number of instruments available for measuring gloss. The one used would depend largely on the individual situation. "Low gloss and flat finishes are measured at high or grazing angles of the incident of light, while glossy finishes are measured at lower angles" (7). For measuring gloss of an average glossy finish, the 60 degree angle is the one most widely used. One common error in measuring gloss, is to measure the gloss of a finish shortly after it has been applied. The film is still wet and contains an appreciable amount of solvent (20). The angular reflection value or gloss is obtained from the film forming component (6). After the solvent has evaporated, the gloss will be lower (20).

The 60 degree angle Gardner Glossmeter is one instrument used to measure gloss. It contains a lamp and lens for projecting light beams on the test surface at its specified angle. The glossmeter has a special lightmeter which measures gloss from a 0-100 scale. The instrument is placed on the desired standard for checking the accuracy of the gloss measurement reading. The glossmeter is then placed on the specimen for a direct scale reading of gloss (10).

CHARACTERISTICS AND COMPARISONS OF SELECTED WOOD FLOOR FINISHES

At one time picking a floor finish was easy, for all one had to choose from were shellac and paint. With the new snythetic finishes which have been introduced on the market and the many conventional finishes available, it is important to know beforehand what one's requirements are and which of the several floor finishes will come closest to meeting them (8).

For a finish to be considered good it should dry fast, have good color and color retention, hardness to scratching, flaking or chipping, chemical and water resistence, and be easy to apply (25). It should seal out dirt and grease, resist stains, be reasonably easy to patch, and should not require excessive care (8). There are two basic types of materials from which to choose: penetrating seals and surface finishes. The latter includes varnishes, shellac, and other synthetic coatings (8).

Hand has stated that gloss is disappearing from residential floors. People are learning that the higher the gloss of the floor the more readily it blemishes (4).

The following section is included to compare characteristics and properties of wood floor finishes, because it is important for an individual to choose a wood floor finish that will meet his particular need.

Shellac

Shellac is a naturally occurring raw material of an animal and is the oldest, cheapest, and fastest drying of all the finishes (8). It has the advantage of easy application. The finish forms a brittle coating which is easily marred and not as durable as some of the newer finishes (24). Shellac dries tack-free in minutes and its fumes are harmless. For best results use shellac that is no more than six months old. The finish should be kept in a tightly scaled glass jar. A four-or-five pound cut that has been diluted with denatured

alcohol, one part to one part, will give the best result. Apply the shellac only on dry days to allow for humidity free drying. Three coats should be used and brushed on at twenty-four hour intervals. The last coat should be allowed to dry a full day (8). Shellac penetrates fairly well and is resistant to dirt (3). Waxing extends the life of shellac and prevents water stains. If the finish is not worn to the bare wood, a light sanding is enough preparation for a new coat of shellac. High quality shellac is as tough as all other finishes (8).

Lacquer

Lacquer is composed of a basic compound of nitrocellulose in a balanced combination of organic solvent (9). It dries by evaporation of the solvent after being applied to the floor; the fast drying solvents in lacquer make it difficult to apply. There is a chance of irregularities and overlapping which are difficult to smooth out if the finish is not applied evenly (8). Some favorable characteristics of lacquer are a hard glossy finish, resistance to water, acid, and dirt, and resistance to impact. It provides a durable finish which does not yellow. The finish can be easily repaired when marred or damaged (24). Lacquer scratches easily in heavy traffic areas, has high flammability and a lingering odor. High solid lacquers are made by combining lacquer with conversion synthesis compounds. The resulting lacquers have improved toughness and chemical resistance (9).

Varnish

Varnish is a durable material that dries by oxidation-polymerization. It is a slow drying surface finish that must be applied in a dust free room. It is more durable than shellac, but the coating is not easily repaired when the finish is worn or damaged (24). Although it is a long wearing material under relatively gently use, it does not resist hard abrasion. It scratches white and should not be used where there is much abuse (4). Varnish holds up much longer under wax, but even when unwaxed it resists water, acid, and alcohol stains. The finish is available in several degrees of gloss, with the high gloss type being more wear resistant (16).

Vinyl

Vinyl is a type of wood finish which has the drying speed of lacquer as well as a few of its disadvantages. The finish dries within fifteen minutes and can be sanded and recoated in two hours. Vinyl is very clear, requires no special thinner and has no offensive odor. Low abrasion resistance is an important limitation for its use (19). Other limitations include low resistance to chemicals and solvents. Several coats of vinyl are needed to build up a high finish because of vinyl's thin film (4).

Polyurethane

Polyurethane finishes are the newest additions to the organic coatings family (3). The polyurethanes, in comparison with the conventional finishes that have been used for many years, provide

great improvements in chemical resistance. A swelling of the finish is noticed when strong solvents such as esters and ketones come in contact with the finish. It will resist caustic substances and dilute acids, but concentrated acids will attack the film.

Polyurethanes have a higher vapor transmission rate than most conventional clear finishes. An outstanding characteristic of polyurethane is its adhesion to untreated wood. The finish is of such excellent build that it precludes the need for fillers, even on open grain wood. Polyurethanes have excellent hardness and toughness, but are difficult to handle because of solvent odors and short pot life (16).

The polyurethane finishes tend to yellow more in direct light than many of the conventional finishes (16). Due to this unfavorable characteristic, research involving ultraviolet light absorbers has resulted in great improvements in color stability of the polyurethane finish (25).

Compared to the conventional types of clear coatings, polyurethane coatings are the most expensive as a result of the cost of the raw materials from which it is made and the manufacturing processes necessary (16). Producers of polyurethane finishes are seeking methods to develop specific coating formulas for all types of woods (25).

Epoxy

Epoxy, though chemically different, displays some of the physical qualities of polyurethane. The epoxies are hard coatings, but generally not as hard as the polyurethanes.

Panelists at a Paint and Wallpaper Association of America Workshop entitled "The New Coatings" maintained that the oil-modified epoxies are not much superior to conventional finishes, but the two component epoxies do have many desirable qualities. The epoxy coatings require caution in use, particularly with the second coat, for it must be applied within a time limit to avoid lifting. Neslage stated that the adhesion of epoxies was better than that of the polyurethane coatings, but not as good as conventional oleo-resinous varnish (19).

Epoxies are not as clear as the urethane varnishes, but are less likely to darken with age when used indoors. Both epoxy and urethane are available in high gloss and semi-gloss finishes. The new finishes are quick drying in two to four hours. For full curing the last coat needs from seven to fifteen days. Only if the solvents contained in the finish evaporate completely, can the finish cure properly and attain maximum hardness. Good ventilation is required for applying the epoxies. The solvent vapor, being heavier than air, will remain suspended over the surface if the air is still. This can cause a sticky film to form and the finish to remain soft and susceptible to peeling and rapid wear (19).

Amino Resin

The two part amino resin finish has been rated by Hand as second in wearability to the urethane coatings. The resin is made up of a base varnish and separate chemical hardner. The amino resin finish has a pot life of six months after hardner has been added. It

dries dust free in fifteen minutes. Amino resin is resistant to chemicals, is clear, and will not darken with age. Two coats will outwear practically all conventional floor varnishes and lacquers (4).

Penetrating Seal

Penetrating seal is usually a thin varnish made with a slow-drying oil or with specially controlled drying properties that allow them to work down well into the wood fibers of hardwood floors, locking the fibers together. The appearance of the penetrating seal is a modest gloss instead of a mirror shine. After the finish has penetrated the wood, it cannot chip or flake off and scratching and marring are negligible (8). If worn places do occur, they can be easily repaired (24). Most of the sealers are resistant to water and moisture, alkalies, heat, and alcohol. With a wax application of high-grade paste or solvent-base liquid wax, the floor finish is almost indestructable (24).

Prefinished Flooring

Prefinished flooring is available in many styles, colors, and types. Hand reported that it is less expensive than floors finished on the job and nearly as economical as refinishing jobs (4).

In a study by Spencer, eight wood floor finishes and one prefinished flooring specimen were tested in three surface conditions in a test floor for 27 weeks. The prefinished flooring showed the greatest mean percentage of wear under all three surface conditions (28).

CHAPTER III

PROCEDURE FOR TESTING

This study was a continuation of a previous one; therefore, procedure for testing and data collection were identical to those reported by Spencer (28). A review of these follows.

SELECTION AND PREPARATION OF TEST PANELS

Blocks of 9 inch x 9 inch red oak, quarter sawn, tongue and groove strip flooring, 25/32 inch by 2¼ inches, select grade were obtained for this study upon recommendation from the School of Forestry at North Carolina State University, as stated by Spencer (28).

A wide belt sanding process was used to sand each test sample uniformly before the finishes were applied. The wood test panels were conditioned in a room with constant temperatures of 70° F$\pm 2^{\circ}$ and humidity of $40\% \pm 2\%$.

Prefinished flooring blocks with identical specifications as the unfinished blocks were also purchased for the study.

SELECTION AND APPLICATION OF SPECIFIC WOOD FLOOR FINISHES

The eight types of finishes selected for testing were varnish, shellac, lacquer, penetrating seal, epoxy, polyurethane, vinyl, and amino resin. One finish of each type was selected for testing. It was recommended that the selection of finishes be based on solids

content; therefore, within each finish type, the finish having the highest solids content was chosen.

The finishes were randomly assigned to the test panels and then applied according to manufacturers' directions. The test panels prepared for a previous study were used in this study.

SELECTION, APPLICATION AND REMOVAL OF WOOD FLOOR WAXES

Selection of Waxes

A solvent-base paste wax and a self-polishing solvent-base liquid wax were used in this study. One brand of each type was selected from the local market. The basis for selection of each brand was its high volume of sales reported by retail personnel.

Application and Removal of Waxes

The procedure used for applying liquid floor wax was that recommended in the ASTM Designation D1436-56T. The area of each test panel was determined to be 81 square inches. The volume of wax needed was 2 ml. for 81 square inches. The required amount of liquid was pipetted onto the test panel. The wax was distributed over the test surface with a two inch strip of cheesecloth pad weighing 0.60 gram. A ground glass stoppered weighing bottle containing the used cheesecloth was weighed on a 100-gram scale. The weight of the bottle and used wax applicator were calculated and recorded for each test specimen. According to ASTM specifications the bottle and used applicator could not vary more than 0.15 gram for any finish. If there was a weight variation of more than 0.15 gram recorded for any bottle

and applicator, the floor wax was stripped from that particular test panel and the panel rewaxed.

The same procedure was followed to apply the paste wax to the panels except for the volume of wax used. Over each test panel there was distributed an amount of paste wax comparable by weight to the liquid wax. The wax was allowed to dry and was then buffed twice with an electric floor polisher.

The test panels were cleaned with a solution of one part detergent and one part ammonia to six parts of water, applied with a sponge. The floor materials were scrubbed, rinsed and thoroughly dried.

FIELD TESTING PROCEDURES

According to manufacturers' recommendations, eight types of wood floor finishes were applied to the flooring blocks. These blocks and one type of identical prefinished strip oak flooring were tested. Each of the eight finishes were applied to three of the flooring blocks. Of the three blocks with identical finish, one received no wax, one received solvent-base paste wax, and one received self-polishing liquid wax. The test floor was installed in a corridor in the School of Home Economics at The University of North Carolina at Greensboro, where it was exposed to foot traffic.

The floor was divided into three separate test areas which consisted of specimens in the three surface conditions: unwaxed, waxed with a solvent-base paste wax, and waxed with a solvent-base

liquid wax. The test areas were separated by four rows of identical unwaxed flooring blocks (not included in the study) to eliminate any wax carry over. In each test area there were three blocks representing three replicates of each finish surface condition. A randomized block design was used to determine the position of the test specimen within the test area. The individual blocks were also randomized for their initial positions in the replicate groups. The individual test specimens were rotated once a week so that each was in each position in the test floor for an equal amount of time and had the same opportunity to be exposed to the same amount of foot traffic. At the end of each complete rotation cycle of nine weeks the test areas were rotated according to a three factor Latin square design (Appendix A).

Each day the test floor was vacuumed and each week it was dry-mopped with a dust mop treated with a transparent, non-staining aromatic chemical. Every nine weeks the waxed specimens were stripped and rewaxed while the unwaxed blocks were damp mopped.

A daily count of the number of people who had walked on the test floor was taken by a wall-mounted photoelectric counter.

DATA COLLECTION AND ANALYSIS

Subjective Evaluation

An eight member rating panel consisting of men and women from The University of North Carolina at Greensboro participated in a subjective evaluation of the floor finishes. The panel was asked to rate the test floor specimens with the finishes in a worn condition at

the end of each nine week rotation period.

Test specimens from each of the three replicates representing each surface condition were arranged on a dull white counter surface above which a flourescent wall bracket provided even lighting. Control groups (blocks which were finished identically to the test blocks but not subjected to wear) for each set of the test blocks were arranged in corresponding order to the experimental blocks. The panel was asked to rate the test specimen with the control specimen using the following scale (Appendix B):

1. No noticeable change from control
2. Slight change from control
3. Moderate change from control
4. Very marked change from control
5. Complete change from control

The panel considered such factors as gloss, surface marking, and change of color in rating each finish. The individuals were allowed to lift and tilt, touch and view the panels from any angle to determine any change from the control.

Objective Evaluation

Film thickness measurements of each finished test panel were taken at eight random locations after 27 weeks wear. This was the second 27 week period of wear for the specimens. The sixty degree angle Zeiss Light-section Microscope was utilized to obtain the film thickness readings.

A Gardner Sixty Glossmeter was utilized to obtain the gloss readings at nine week intervals in ten random locations, five in a crosswise direction and five in a lengthwise direction of wood grain

on each test block. By means of observation, it was determined that the blocks needed to be rewaxed every nine weeks. A mean for each test specimen was computed for each set of readings.

Statistical Analysis

Standard analysis of variance and correlations were used in analyzing data with assistance and advice from the Department of Experimental Statistics, North Carolina State University. The analyses of subjective and objective data were computed on an IBM 360 computer according to the following models:

Subjective Evaluation	Source of Variation	Degrees of Freedom
	Surface condition	2
	Finishes	8
	Surface condition x finish	16

Objective Evaluation	Source of Variation	Degrees of Freedom
	Surface condition	2
	Group x surface condition	6
	Finishes	8
	Surface condition x finish	16
	Group x finish x surface condition	48

The statistical analysis included an evaluation of three factors for each of the eight wood floor finishes and the prefinished samples:

1. The differences among the surface conditions (unwaxed, waxed with a self-polishing liquid wax, and waxed with a paste wax)
2. The differences among finishes
3. The interaction of surface conditions and finishes in regard to film thickness, gloss and panel ratings

Hypotheses Tested

The hypotheses tested in the study were:

1. There is no positive correlation between the actual wear of the wood floor finishes as determined by the light-section microscope and the order in which the finishes are ranked by individuals.

2. There is no difference in the gloss measurements of the finishes in new and worn conditions.

3. There is no positive correlation between the gloss of wood floor finishes in a worn condition and objective wear measurements of the floor finishes.

CHAPTER IV

ANALYSIS OF DATA AND RESULTS

Analysis of field test data for the wear of eight floor finishes applied to quarter sawn, red oak flooring blocks is presented in this chapter. Gloss and panel evaluation data are also presented in this chapter. Data analyses are presented under five headings: film thickness, gloss, correlation of film thickness and gloss, appearance rating, correlation of film thickness and panel rating. Basic data may be found in Appendix C, Tables 10 and 11.

FILM THICKNESS

Analysis of variance for the second period and for the total testing period showed no significant difference among surface conditions with respect to wear of the finishes (Tables 1 and 2). Therefore, findings will be reported without regard for surface conditions.

Since original film thickness varied greatly among the finishes tested, film loss in microns was converted into percentage loss. When film thickness loss in both microns and percent were ranked from least to greatest, little consistency was found between the two. Finishes were then grouped according to whether they appeared among the top three ranks of least or greatest loss in thickness. Results are reported on this basis. Often, finishes appearing among those

TABLE 1

Analysis of Variance of Second Period Film Thickness

Variance Source	Degrees of Freedom	Sum of Squares	Mean Squares	F Value
Corrected Total	71	668.279794	9.412391	
Surface condition	2	7.757220	3.878610	0.411777
Group x surface condition	6	56.515143	9.419191	
Finish	7	234.014379	33.430626	5.700465*
Surface condition x finishes	14	123.682335	8.834452	1.506418
Finish x group x surface condition	42	246.310716	5.864541	

*Significant at .05 level

TABLE 2

Analysis of Variance of Film Thickness for Total Study

Variance Source	Degrees of Freedom	Sum of Squares	Mean Squares	F Value
Corrected Total	80	1097.544916	13.719311	
Surface condition	2	3.188420	1.594210	0.143989
Group x surface condition	6	66.430163	11.071694	
Finish	8	689.183994	86.147999	16.865730*
Surface condition x finishes	16	93.565907	5.847869	1.144880
Finish x Group x surface condition	48	245.176432	5.107842	

*Significant at .05 level

showing least wear according to loss of thickness in microns also appeared among those evidencing greatest wear according to percentage loss thickness, and vice versa.

Second Period

In the second testing period, the finishes evidencing the least wear in both microns and percentage were polyurethane, epoxy, and vinyl, in that order. Finishes evidencing greatest wear in microns and percentage were amino resin and lacquer. There was no uniformity in microns and percent loss for any other finishes ranked in the upper three positions of least and greatest loss in film thickness (Table 3).

Total Study

In the total field study only vinyl appeared among the three finishes ranked for least film thickness change in both microns and percent. The same results were reported in the second phase of study for this finish. The greatest loss of film thickness both in microns and percent was shown by shellac, only. No patterning appeared in rank order of wear in either microns or percent between the first and second period studies. However, initial wear (first period) was greater in both microns and percent than in subsequent wear (second period). Similarities in results of the second period and the total study were that vinyl showed least wear in both microns and percent, while varnish evidenced greatest wear in microns and penetrating seal, in percent (Table 3).

GLOSS MEASUREMENTS

There was a significant F ratio between gloss change and the wood floor finishes and in these finishes under three surface conditions

TABLE 3

Finishes Among Top Three Ranks of Least and Greatest Surface Loss
(by Microns and Percent)

	Second Period				Total Field Study			
	Least Wear		Greatest Wear		Least Wear		Greatest Wear	
	Microns	Percent	Microns	Percent	Microns	Percent	Microns	Percent
Amino Resin			X	X	X			X
Epoxy	X	X						
Polyurethane	X	X				X		
Vinyl	X	X			X	X		
Lacquer			X	X			X	
Shellac							X	X
Varnish			X			X	X	
Penetrating Seal				X	X			X

in the first and second periods and at the end of the total testing (Table 4).

In comparing gloss among the finishes under all three conditions high gloss was retained by epoxy and polyurethane. Greatest gloss loss under all conditions occurred with shellac and penetrating seal (Table 5).

CORRELATION OF FILM THICKNESS AND GLOSS

No significant relationship was evident between change in gloss and change in film thickness (Table 6).

APPEARANCE RATING

In the second period of study the subjective rating of the appearance of the finishes by a panel of judges indicated significant differences among the finishes but not under different surface conditions. The same was true for the total study (Table 7). Even though there was no significant difference among the surface conditions as rated by the panel, it is interesting to note that the panel preferred the appearance of liquid self-polishing wax at each interval.

Amino resin, penetrating seal and polyurethane were rated as having the least change in appearance at the end of the second test period while epoxy, shellac, and varnish were rated as having the greatest appearance change. This was consistent in the first period and total study only for amino resin, penetrating seal, and varnish (Table 8).

TABLE 4

Analysis of Variance for Gloss Change

Variance Source	F Values		
	Period I	Period II	Total Study
Corrected Total			
Surface condition	281.43435*	1.191542	383.630576*
Surface condition x groups			
Finishes	11.84687*	9.279681*	17.779124*
Finishes x Surface condition	15.86486*	8.708548*	20.254237*
Groups x finishes x surface condition			

*Significant at .05 level

TABLE 5

Rank Order of Gloss Readings at End of Second Period
(from low to high gloss)

Finishes	Unwaxed	Waxed Liquid	Waxed Paste
Newer Finishes			
Amino Resin	5	5	6
Epoxy	8	6	8
Polyurethane	7	8	7
Vinyl	4	1	5
Conventional Finishes			
Lacquer	6	4	3
Shellac	1	2	2
Varnish	3	7	4
Penetrating Seal	2	3	1

TABLE 6

Correlation of Changes in Film Thickness and Gloss

Change	Correlation Coefficient
First Period	0.0525
Second Period	0.0659
Total Study	0.1058

TABLE 7

Analysis of Variance for Panel Ratings

	F Value		
Variance Source	Period I	Period II	Total Study
Corrected Total			
Surface condition	.887011	1.872387	3.942514
Finish	1.463022	6.907968*	7.097908*
Surface condition x finishes			

*Significant at .05 level

TABLE 8

Panel Mean Appearance Ratings* and Rank

Finishes	Period I		Period II		Total Study	
	Rating	Rank	Rating	Rank	Rating	Rank
Amino resin	2.33	1	2.87	1	2.60	1
Epoxy	2.57	2	4.27	8	3.42	4
Polyurethane	3.30	5	3.47	3	3.38	3
Vinyl	3.93	8	3.50	4	3.71	8
Lacquer	3.63	7	3.70	5	3.66	6
Shellac	3.10	4	3.83	7	3.46	5
Varnish	3.60	6	3.77	6	3.68	7
Penetrating seal	3.07	3	3.27	2	3.17	2

*The lower the rating the better the appearance

CORRELATION OF FILM THICKNESS AND PANEL RATING OF APPEARANCE

Correlation coefficients for film thickness change and panel appearance ratings appear in Table 9. No significant correlation occurred at any interval between panel evaluation and wear of the finishes.

TABLE 9

Correlation of Change in Film Thickness and Panel Appearance Rating

Change	Correlation Coefficient
First Period	-0.1737
Second Period	-0.0405
Total Study	0.3428

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

SUMMARY

With the increase of wood floor finishes on the market and claims of better performance, selection of finishes has become more difficult for the consumer. Organizations and the American consumer have expressed a need for reliable information on the performance factors of wood floor finishes to aid them in making a satisfying choice that would meet each individual need.

A review of literature revealed limited exploration in this field. Of the studies reviewed, most were conducted by manufacturers of wood floor finishes on their own products.

This comparative study of the performance factors of wood floor finishes is the second part of a two-year study which is part of a larger project entitled, "Wearability and Relative Cost of Wood Floor Finishes," which contributes to the Southern Regional Housing Project S-54.

Objectives of this study were:

1. To compare the film thickness measurements of each floor finish in new and worn conditions
2. To compare gloss measurements of each finish in new and worn conditions
3. To relate gloss measurements of wood floor finishes in a worn condition to film thickness measurements

4. To secure an appearance rating for each finish as determined by a rating panel

5. To compare panel rating to film thickness measurements

Blocks of 9 inch x 9 inch, quarter sawn, red oak strip flooring in the standard pattern were used as test blocks for eight wood floor finishes: varnish, shellac, lacquer, epoxy, penetrating seal, vinyl, amino resin, and polyurethane. One finish of each type was chosen based on high solids content. One prefinished flooring sample was also tested but not utilized in analysis of data due to its surface film thickness being considered unsuitable for the comparative study.

Ten flooring blocks were finished with each of the eight floor finishes, nine for testing and one for control. Of the nine blocks tested, three received no wax, three received solvent-base paste wax, and three received solvent-base liquid wax. The prefinished blocks were waxed accordingly. Eight film thickness measurements were taken, in microns, with a Zeiss Light-Section Microscope at random locations on each of the test blocks before the specimens were installed in a test floor where they were subjected to foot traffic and at the end of six rotation periods. An average thickness was computed for the eight measurements for each of the test blocks.

Ten gloss readings were taken with a Gardner sixty degree angle glossmeter at random locations in lengthwise and crosswise directions with the wax in a new condition and at the end of each nine week rotation period. A mean was computed for each block.

The test floor, consisting of three separate test areas, contained finished specimens in three surface conditions: unwaxed, waxed

with a self-polishing solvent-base liquid wax, and waxed with a solvent-base paste wax. Each test area contained three replicates of each finish. A randomized block design was used to determine the position of the test specimens within the test area. Once a week each test panel was rotated so that each specimen occupied each position in the block for an equal amount of time. At the completion of each block rotation, the test areas were rotated according to a three factor Latin square design. Consequently, each group received the same exposure to traffic.

Standard analyses of variance and correlations were used to analyze the data. Statistical analyses included an evaluation of three factors for each of the eight wood floor finishes and the pre-finished samples:

1. The differences among the surface conditions-unwaxed, waxed with a self-polishing solvent-base liquid wax, and waxed with a solvent-base paste wax
2. The differences among finishes
3. The interaction of surface conditions and finishes in regard to film thickness, gloss, and panel ratings

Film Thickness

Measurements of film thickness taken before testing, after 27 weeks of wear, and after 54 weeks of testing were compared. Loss in thickness was considered to be wear. Analysis of variance for film thickness showed no significant difference among surface conditions in the second period of study nor over the total testing period. In the second period of testing, findings showed epoxy, polyurethane, and vinyl

finishes to have the least wear. Amino resin and lacquer showed the greatest wear. During the total study the least wear was with the vinyl finish; the greatest wear occurred with shellac.

Gloss Measurements

Analysis of data showed a significant difference between gloss and floor finishes in the three surface conditions. Therefore, the null hypothesis that there is no difference in the gloss measurement of finishes in new and worn conditions was rejected.

At the end of the total study shellac and penetrating seal showed the greatest gloss change (loss) under all surface conditions. Highest gloss was retained by epoxy and polyurethane.

Correlation of Film Thickness and Gloss

There were no significant relationships between gloss and film thickness; therefore, the null hypothesis that there is no positive correlation between the gloss of wood floor finishes in a worn condition and objective wear measurements of the floor finishes was retained.

Appearance Rating

Analysis of variance showed no significant difference in the panel rating of finishes or surface conditions in the first year of study; however, there was a significant difference in the panel rating of finishes in the second year and in the total study.

The least change in appearance at the end of the second test period occurred for amino resin, penetrating seal, and polyurethane

while epoxy, shellac, and varnish were rated as having the greatest appearance change. This was consistent in the first period and total study only for amino resin, penetrating seal, and varnish.

Correlation of Film Thickness and Rating

No significant correlation existed between the film thickness and the panel ratings for finishes at any stage of the study. The null hypothesis that there is no positive correlation between the actual wear of the wood floor finishes as determined by the light-section microscope and the order in which the finishes are ranked by individuals was accepted.

CONCLUSIONS

Conclusions drawn as a result of this study follow:

1. There was a difference in the wear of the eight types of wood floor finishes field tested. After 54 weeks of wear under all surface conditions, shellac showed the greatest wear, while vinyl evidenced the least wear.

2. There was no difference in the wear of the finishes with respect to the surface conditions utilized (unwaxed, waxed with a self-polishing liquid wax, and waxed with a solvent-base paste wax).

3. Significant differences were found in gloss of eight wood floor finishes after wear.

4. The surface condition had a significant effect on degree of gloss of the finish.

5. There was no relationship between amount of gloss and wear of wood floor finishes.

6. Evaluation of appearance by individuals does not seem to be an accurate estimate of wear of wood floor finishes.

RECOMMENDATIONS FOR FURTHER STUDY

The following recommendations are made as a result of this study:

1. Test several types of wood flooring with wood floor finishes used in this study.
2. Conduct a study of the performance of wood floor finishes in everyday home conditions with exposure to dirt, oil, grit, paint, etcetera.
3. In further study have a greater variety of people (i.e., sex, age) as a source of wear to make the study more conducive to home situations.
4. Compare the results of the field study with a laboratory study using the same procedure and materials.

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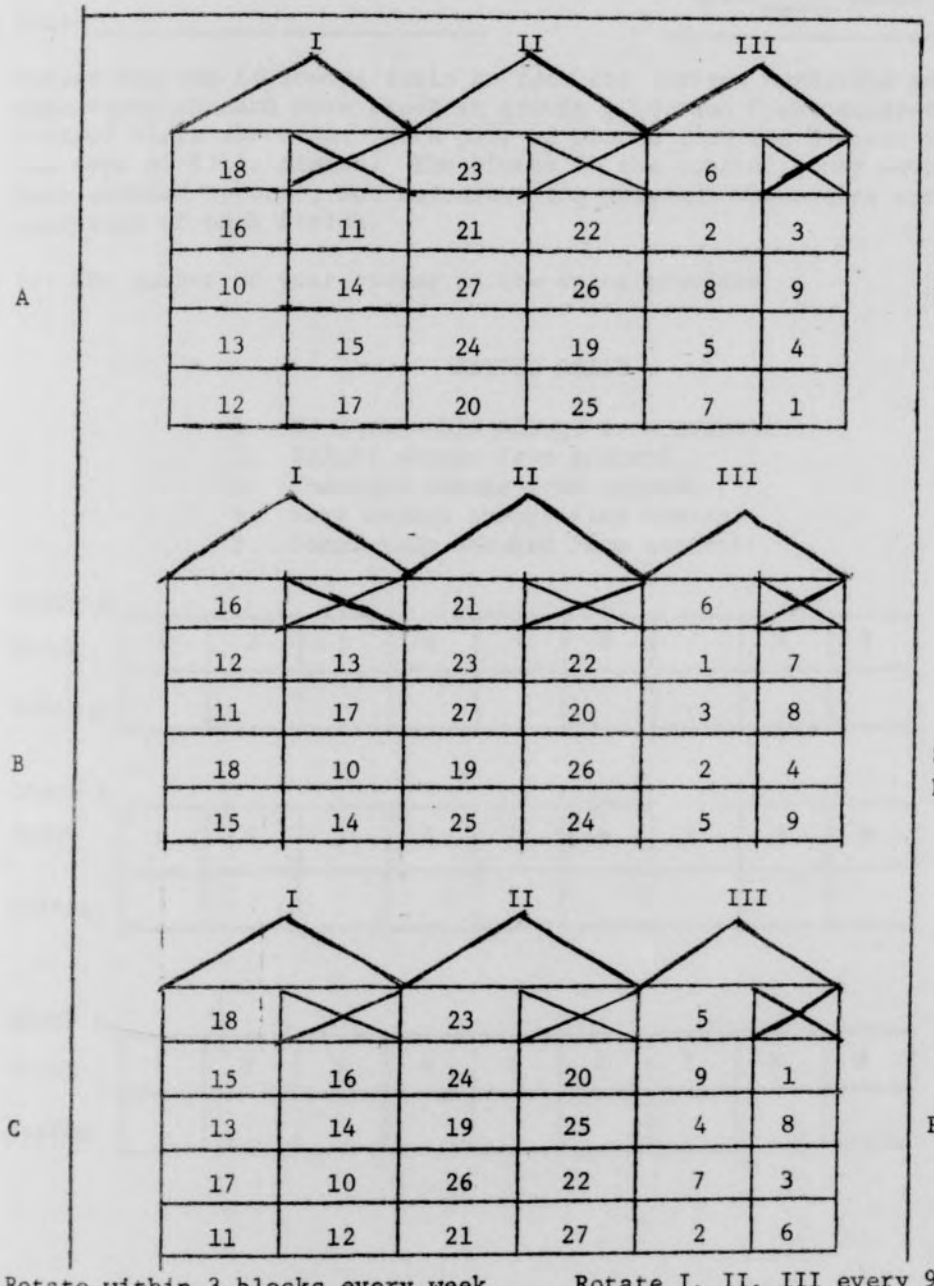
APPENDIXES

Appendix A

Latin Square Design for Field Tests

1st Cycle - 9 Weeks



Appendix B

Panel Rating Scale

Name _____ _____

After_____ weeks

Date _____ _____

Please use the following scale to rate the surface condition and appearance of each worn block in groups A, B, and C as compared to the control block above it. Each pair of blocks (control ± worn) represents one type of floor finish. The blocks in the control group have not been exposed to wear, but represent the original appearance and condition of each finish.

Put the number of your rating in the space provided.

RATING SCALE

1. No noticeable change from control
2. Slight change from control
3. Moderate change from control
4. Very marked change from control
5. Completely changed from control

GROUP A

Block	1	2	3	4	5	6	7	8	9
Rating									

GROUP B

Block	1	2	3	4	5	6	7	8	9
Rating									

GROUP C

Block	1	2	3	4	5	6	7	8	9
Rating									

Appendix C

Summary Tabulations

TABLE 10

Loss of Film Thickness of Finishes for Two Wear Periods and For Total Field Study (in Microns and Percent)

Finishes	Period I (Original - 27 weeks)				Period II (27 weeks - 54 weeks)				Total Study (Original - 54 weeks)			
	Microns	Order	Percent	Order	Microns	Order	Percent	Order	Microns	Order	Percent	Order
Amino resin	9.50	2	39.33	6	4.66	6	19.29	6	14.16	3	58.63	7
Epoxy	12.75	6	44.73	8	2.78	2	9.75	2	15.53	5	54.49	5
Polyurethane	11.61	4	34.53	4	2.64	1	7.85	1	14.26	4	42.41	1
Vinyl	9.78	3	32.58	2	3.57	3	11.87	3	13.35	2	44.45	2
Lacquer	12.85	7	29.54	1	8.68	8	19.95	7	21.53	8	49.49	4
Shellac	12.34	5	43.47	7	4.25	4	14.89	5	16.73	6	58.36	6
Varnish	13.46	8	33.25	3	5.61	7	13.85	4	19.07	7	47.10	3
Penetrating seal	7.00	1	37.13	5	4.42	5	23.44	8	11.42	1	60.55	8

TABLE 11

Mean Gloss Measurements of Worn Finishes Under Three Surface Conditions (Second Period)

Finishes	Unwaxed	Liquid	Paste
NEWER FINISHES			
Amino resin	10.47	38.18	31.75
Epoxy	19.70	42.47	35.03
Polyurethane	15.12	49.22	33.65
Vinyl	10.20	32.88	30.93
CONVENTIONAL FINISHES			
Lacquer	13.23	36.33	26.95
Shellac	6.57	35.27	26.53
Varnish	9.88	45.75	30.18
Penetrating seal	9.67	35.67	24.70