THE PERFORMANCE OF FOUR TYPES OF DURABLE PRESS FINISHES ON COTTON WORK TROUSERS

A DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR

THE DEGREE OF DOCTOR OF PHILOSOPHY IN TEXTILES

IN THE GRADUATE SCHOOL OF THE

TEXAS WOMAN'S UNIVERSITY

COLLEGE OF

NUTRITION, TEXTILES, AND HUMAN DEVELOPMENT

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MAY, 1976

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May, 1976

We hereby recommend that the dissertation prepared under our supervision by Christine Calvert entitled "The Performance of Four Types of Durable Press Finishes on Cotton Work Trousers"

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ACKNOWLEDGMENTS

The author wishes to express her sincere appreciation for the assistance and interest shown by the following persons during the course of this study:

To Dr. Esther Broome, Coordinator of Textile Research, who served as director of the study and gave continued encouragement and excellent guidance throughout the study;

To Dr. Bethel Caster, Dr. Clarice Garrett, and Dr. Harold Simpson for their excellent guidance in their respective fields of study and for serving as members of the author's doctoral committee;

To Dr. Ralph Pyke, who served on the author's doctoral committee;

To Mr. Edgar Sprinkle for his guidance in the statistical analysis;

To Cotton Incorporated for providing the experimental garments and the assistantship which made the study possible;

To Eloise Jackson, Ora Jackson, Martin Cudd, and other members of the textile research staff for their assistance in the evaluation and collection of the data;

To Frances Willis for her friendship and moral support which was so freely given;

To Carole Normile for her proficiency in typing the manuscript; and

To the author's father, Mr. E. M. Calvert, and to Phillip and Montie for their expressions of love and encouragement throughout the graduate study.

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INTRODUCTION

Cotton for years was "king" of the textile industry, but the advent of the synthetic fibers brought a major competitor to cotton's economic position. In an effort to curtail the synthetic erosion, cotton manufacturers sought the solution to their problem through the use of durable press finishes.

By definition, durable press is a process which bestows properties of shape-retention throughout the life of the fabric or garment. Some of the features of durable press include a smooth surface appearance, sharp creases, and flat seams, all without the need of ironing. True durable press is accomplished through the process of crosslinking a chemical reactant with the cellulose molecule.

Many problems were encountered in early attempts to perfect a durable press finish for an all-cotton garment. Production problems included the offensive odor produced by the crosslinking agents; spontaneous curing; yellowing of white fabric; and loss in fabric strength.

The problem of odor was solved by a thorough afterwash and by the development of new crosslinking agents. The use of different chemical substances prevented spontaneous curing, and the carbamate finishes have prevented the yellowing of white fabrics.

One of the early approaches to the improvement of fabric strength was the blending of cotton with a synthetic fiber. The most popular combination was cotton and polyester. The major contributions of the polyester were toughness, resilience, and crease resistance; whereas, the cotton reduced problems of static electricity, moisture absorption, and loss of hand. Other endeavors to improve wear life were through yarn and fabric structure.

Numerous processing techniques also have been developed in an effort to improve the durability of durable press garments. Techniques of commercial value include surface impregnation, radiation cure, wet fixation, steam cure, dry-room temperature slow cure, mild cure, poly-set, preferential crosslinking, and the vapor phase process. This latter process has shown less loss of strength, and has the advantage of no baking at high temperatures. The vapor phase process also is resistant to chlorine, and provides a much lower add-on than other processes.

Objectives

This study was undertaken to obtain additional information concerning the wear life relationship of garments treated by the vapor phase treatment, by the pad-dry-cure finish, and by a proprietary finish. The following specific objectives were chosen to provide this information: (a) to evaluate the relative performance of four types of durable press treatments with regard to appearance retention values, and (b) to measure the comparative strength values of the trousers after specified laundering and wear-laundering periods.

CHAPTER I

REVIEW OF LITERATURE

Cotton possesses many desirable characteristics but lacks the easy-care performance which is expected by today's consumer. Durable press processing has attempted to satisfy this consumer demand by providing garments that will retain a smooth attractive appearance during wear and will return to their original smooth surface and shape after laundering. This chapter reports pertinent research studies which were instrumental in the development of technology for durable press treatments.

The resin treatment of cellulosic materials to obtain a muss resistant finish came to fruition in the late 1920's. Steel (64) credited Tootal-Broadhurst and Lee with receiving the initial patent for this development. This patent

> . . . was based on the hypothesis that introducing synthetic resins-forming materials into cotton fiber to swell it permanently would produce liveness and resilience in the same way that water, distending a canvas hose pipe, can change it from an empty, flat, lifeless ribbon to a lively and elastic structure.

The first resins used were simple methylol ureas and methylated methylol ureas. Fabrics thus finished were referred to as wash-wear. These finishes imparted a flat memory to cotton, but creases and pleats had a tendency to disappear during laundering.

The basis for most durable press processing involves a cellulosic fiber and a crosslinking agent. In order to understand the crosslinking of cellulose, it is necessary to consider the chemistry of crosslinking, a chemical reaction which occurs deep in the fiber structure and imposes physical restraints on the microstructural units in the fiber.

Rowland (57) (58) described the crosslinking concept as follows:

> The cotton fiber is a complex, well ordered unit which is generated during the growth cycle of the cotton plant in the form of a long, hollow tube . . . each fiber is composed of a multitude of microstructural units which are packed in close proximity and which are microfibrils . . . These microfibrils are composed from cellulose molecules which, in turn, consist of more than 3,000 D-glucopyranosyl units joined together into a linear chain.
>
> The hydroxyl groups in cotton cellulose, upon which we depend for the crosslinking reactions and for the development of performance properties, are buried in a catacomb-like labyrinth in the cotton fiber. Only a fraction of these potential sites for chemical reactions are actually accessible to the reagent in commercial finishing operations. Moreover, there are two different types of hydroxyl groups in the fibers of cotton cellulose; i.e., secondary hydroxyls at carbon atoms 2 and 3, and primary hydroxyls at carbon atom 6 of each D-glucopyranosyl unit. These three hydroxyl groups react at different rates and the linkages developed exhibit different stabilities. The science of the crosslinking of cotton fibers then appears to reduce to the selection of the appropriate chemical reagent, control of the penetration of the reagent into the fiber to the accessible hydroxyl groups, and control of the

reactions with specific hydroxyl groups to develop the desired physical performance characteristics.

Kopacz and Perkins (31) explained the chemical reaction of crosslinking in a similar manner stating that reactions at specific hydroxyl groups, in specific locations, and between specific microstructural units, depend on the chemical nature and size of the reagent, the swelling power of the medium, the rate of diffusion, and the rate of the reaction. The hypothesis accepted today by most chemists is that crosslinking builds up molecular bridges from one cellulose chain to another by establishing covalent chemical bonds between the individual fiber molecules.

The previous discussion has explained the crosslinking process that occurs prior to any alteration of the fiber structure. Sloan and associates (62) conducted a study to determine the effects of crosslinking the less accessible sites on the physical properties of cotton print cloth and sateen fabrics.

The introductory fabric processing included blocking the readily accessible OH groups with a low level partial acetylation treatment, partial deacetylation, and a second crosslinking treatment. This procedure was applied to plain and mercerized fabrics, with and without a presoaking treatment. The fabrics were tested after each treatment for breaking strength, tearing strength, flex and flat abrasion resistance, and wrinkle recovery.

The technique of partial acetylation prior to crosslinking generally resulted in improved breaking and tearing strength, better abrasion resistance, some loss in dry wrinkle recovery, and poor wet recovery. These observations indicated that less degradation occurred when less accessible sites were crosslinked.

The tests after partial deacetylation showed strength values and wet wrinkle recovery to be better, but further losses of dry wrinkle recovery were recorded. A second crosslinking restored most of the dry wrinkle recovery but caused a decrease in strength and abrasion resistance. The mercerized fabrics had a significant increase in wet wrinkle recovery for both fabrics but showed a decrease in dry wrinkle recovery for the print cloth. Presoaking before partial acetylation lowered the nitrogen content after crosslinking and also produced higher breaking, tearing, and abrasion resistance values than were found in the fabrics which were not presoaked.

Sloan and associates (62) explained that the low wet wrinkle recovery of the non-mercerized fabrics after partial acetylation and crosslinking was perhaps due to the fact that the acetyl groups were located in the regions where crosslinking normally takes place for the impartation of wet wrinkle recovery.

Rowland (57) studied the length of crosslinks in cotton cellulose which had been modified with DMEU. The conclusions reached were that the average linkage was 1.5 reagent units long, and that the value was based on the formaldehyde and nitrogen content of the cellulose. The average linkage of oxymethylene linkage in CH_2O-modified cotton indicated that the average linkage involved as many as 2.5 units of formaldehyde.

The potential mechanical and chemical possibilities for all-cotton durable press fabrics were suggested in 1964 by Koret of California. Koret, a manufacturer of women's wear, cultivated a strong market demand for truly durable shaped garments by developing facilities and techniques.

According to Nirenberg (46), Koret was granted U.S. Patent No. 2,974,432 for its post-cure process, and the Koratron Company was established to market and license the process. The first application of the finish was on men's and boys' pants which were introduced to the consumer by Levi Straus and McCampbell Graniteville Company. When these first durable press garments appeared on the market, consumer acceptance was tremendous, and claims reported in the April 1966 Textile Recorder (48) stated that no less than 170 million pairs of Koratron-treated trousers were sold in the United States during 1965.

The Koratron Company contributed its knowledge and experience to the textile industry and developed machinery for deferred cure processing. This new process required the finisher to be more cautious in the application of the chemicals because the final curing would occur later and would be beyond his control. It became necessary for the finisher to consider possible difficulties of odor development, premature catalysis, objectionable hand, excess resin concentration, and fabric embrittlement resulting in loss of fabric strength, and in abrasion resistance. Consumer dissatisfaction with yellowing of white fabrics caused by chlorine retention also was a problem that needed a solution.

Turner (68) evaluated the performance of Koratron delayed-cured work trousers. The study revealed low durability ratings due to the effects of the crosslinking reactant and high curing temperatures on the cotton fabric.

An editorial written for the <u>Textile World</u> magazine (21) reported that in 1967 Sterling Pile Fabrics produced the first commercially acceptable durable press finish for all-cotton corduroy by the conventional pad-dry-cure processing. The finish was applied to give a relatively low add-on rate of 4 to 5 percent. The resin was padded onto the fabric, dried, and at this point either cured or left dormant, depending upon the end-use of the fabric.

Results obtained from laboratory testing indicated that the treated cotton corduroy fabric lost in tensile, tear, and abrasion resistance. This loss, according to the manufacturer, was within the range of average durable press results. Other data on the same fabric revealed that the crease recovery angle increased 37.8 percent; that the wash-and-wear rating was 4.8; and that crease retention received a rating of 4.0. These last two ratings were above today's acceptable ratings of 3.5, but they were obtained at the expense of the wear-life of the fabric.

One of the first attempts to overcome strength losses resulting from durable press processing was the use of synthetic fibers, the most popular ones being polyester and nylon. In reviewing the early efforts used in developing a satisfactory blended fabric for durable press processing, Alexander (3) pointed out that fiber manufacturers were reluctant to recommend the use of resins for the cotton portions. They felt that the loss of abrasion resistance would be offset by the improvements in wash-and-wear ratings. The Koratron development reversed this position, and active support was given to the resin treatment of cotton in blended fabrics of polyester-cotton for use in deferred curing. In this process the sensitized cloth was dormant; and chemical reaction on the cotton fiber took place only during pressing and curing, leaving the synthetic fiber unaffected.

Numerous studies have been conducted in the Texas Woman's University Textile Research Laboratory to determine the performance of all-cotton fabrics when compared with various blend levels of polyester or nylon and cotton. Studies by Roch (55), Roemhildt (56), and Turner (68) all support the premise that synthetic fibers give added strength and durable press properties to cotton fabrics.

Among other studies related to the end-use performance of blended durable press garments was another study by Hearne and Broome (25) conducted in the research laboratory at the Texas Woman's University. The researchers undertook the study as a means of comparing the performance of durable press finished fabrics with wash-and-wear fabrics. The experimental garments, 36 pairs of girl's slacks, were constructed from blends of 50/50 cotton-Fortrel and 35/65 cotton-Dacron.

Eighteen pairs of the slacks were treated with 3 different types of permanent press finishes. The remaining 18 pairs of identical slacks were given a wash-and-wear treatment. After each 8-hour wear period, the slacks were laundered and tumble dried.

The results revealed that the slacks made of permanent press treated fabrics surpassed those made of the wash-and-wear treated fabrics in appearance values, in the retention of creases, and in seam smoothness. Progressive shrinkage was noted in both types of experimental slacks, but no statistically significant differences were established, warpwise or fillingwise. Tests for durability demonstrated the superior performance of the wash-and-wear finished fabrics over the permanent press fabrics.

Ball (7) evaluated the appearance of all-cotton and cotton-polyester blended trousers which were worn both by white and blue collar workers. She found that the type of wear had no effect on smoothness rankings, and that there was no significant difference between trouser finishes with regard to soiling. The 100 percent cotton Koratron treated trousers, however, ranked first in crease sharpness followed by the 50/50 cotton-polyester blend which also was finished with a delayed cure treatment.

Other researchers have pursued the importance of all-cotton durable press treatments through the study of fabric and yarn structure to enhance end-use performance. Kopacz and Perkins (31) determined that fabric structure performed an important function in determining the performance of fabrics during successive launderings. The selected experimental fabrics, summer suitings, were woven from untreated all-cotton Pima S-2 yarns.

> Three facts were apparent: (1) weave type influences fabric wear to a considerable degree, (2) fabrics made from heavy yarns outwear those made from lighter yarns, and (3) fabrics made from single yarns outperformed those made from equivalent ply yarns. The plain woven fabrics exhibited the greatest wear, followed by sateens, the 63° steep twills, and the 45° regular twill.

The data from home laundering procedures showed that fabric wear performance was closely associated with the freedom of yarn movement within the fabric structure and with the amount of yarn exposure to the wear-causing forces. The best performance was displayed by the 45° twills which combined freedom of yarn movement with a balanced exposure of the warp and filling yarns.

These same properties for all-cotton durable press fabrics were studied. A statistical analysis of the data for repeated launderings of test trouser cuffs confirmed similar relationships previously observed and indicated the following new relationships: ". . . there appears to be a geometric relationship between fabric performance as measured by the number of laundering cycles required to produce fabric failure in the test cuffs and the fabric filling thread count."

Denyes (16) related fabric structure to the tensile properties of woven fabrics in a study of polyester and cotton blends. Data from this study of Kodel IV, regular polyester, and untreated cotton blends indicated very high correlations between spun yarn strength and fabric ravelled-strip strength when blend curves were compared. Denyes pointed out, however, that grab and tear tests were more complex. In the grab test, breaking strength was influenced by the yarns directly between the jaws in addition to those outside the jaws. Denyes explained the relationship which existed as follows:

> The amount of reinforcement is dependent upon the mobility of the yarns within the structure of the fabric and is determined by such factors as weave, tightness of construction, finish applied to the fabric, and particularly by the elongation of the yarns within the fabric. The greater the mobility of yarns within a fabric or the elongation of yarns, the more reinforcement that will be achieved from these ends outside of the width of the jaws.

Tear strength values were extremely low when there were little mobility and elongation of the yarns within the fabric. The use of elastic fabrics to overcome these losses was found to significantly increase the resultant tear strength.

Warfield and Fickle (71) designed a study to determine the fabric breakdown mechanisms involved when boys' jeans were actually worn for selected periods of time.

Attempts were then made to correlate these data with those reported when similar fabrics were abraded by laboratory instruments.

The jean fabrics were 100 percent Sanforized cotton without a crease resistant finish and a 75/25 blend of polyester-cotton with a durable press finish. The pattern in both types of fabric disarray increased warpwise with increasing wear. In the filling direction it increased to a point, then decreased, and increased again with longer wear. After 30 wearings yarn thinning and yarn separation leading to breaks were noted. The degree of scuffing was found to increase with each wear period. The trousers which received no wear showed scuffing in the hem areas after 45 launderings. The cotton jeans showed fibrillation which was most extensive in the knee areas, while the polyester/cotton jeans had some fused polyester fiber ends. Although both types showed damage, the extent varied, and specimens from the leg area showed the least damage. Laundering alone caused extensive damage to the hem area. The knees received more damage than did the inner leg or hem areas. Abrasion and stressing plus abrasion by laboratory instruments on the 50/50 polyester/cotton blend produced much the same type of damage as that observed in the knee area of the cotton jeans worn for the selected time periods.

Research in the development of satisfactory finishes for all-cotton fabrics has been continuous. Textile technologists have attempted to eliminate the limitations of durable press treatments through improved variations in processing techniques and the application of new chemical reagents.

Several general approaches to the improvement of abrasion resistance and added wear-life were proposed by Hartis (24). These methods included slack mercerization, wet-fixation, polymer coatings, use of polymers, and preferential crosslinking. Approaches from other researchers have been related to radiation curing, grafting, low or mild temperature cure, and vapor phase processing.

One of the most effective techniques is the wet-fixation process which involves the fixation of a polymer former and a crosslinker to the cotton fabric under aqueous, acidic conditions. The major advantages of the wet-fixation process over the conventional process are less odor, smooth drying, less loss of tear strength and flex abrasion.

The major steps for the wet-fixation process as outlined by Leonard (33) are as follows:

> (1) Pad fabric through the reagent bath at a pH of about 2; (2) Heat padded fabric at 82° C for 15 minutes in a closed system to retain water; (3) Neutralize, wash, and dry; (4) Pad on catalyst and softeners; (5) Dry and treat as durable-press fabric.

Through evaluations of variations of the wet-fixation process Leonard found that the room-temperature process had the advantage of lower reagent requirements than did the standard wet-fixation. Cotton fabrics so treated showed an increase in conditioned wrinkle recovery, good wet wrinkle recovery, and little or no change in abrasion resistance or tearing strength. The other variation evaluated was moist fixation, in the presence of an inert additive. This process produced a highly wrinkle and abrasion resistant cotton fabric.

Hollies (26) has summarized evidence which has aided in understanding the wet-fixation process and has served as a basis for improved durable press systems. The wet-fixation process described occurs in essentially two stages. The first stage consists of the wetting and swelling of the fibers, and the second involves the diffusion and the fixation of the resin. The main departure in wet-fixation processing from conventional methods occurs in the third step. During this step the resin-impregnated fabrics are held in the moist state for 15 minutes at 180^0 Centigrade, which allows for resin deposition in the fiber.

The altered mechanical properties of wet-fixed cotton trouser cuffs showed that the presence of the resin polymer provided improved strength and resilience over the conventional method. Apparently polymer-building and crosslinking resins aided in providing a stronger substrate for crosslinking and yet provided sufficient high wrinkle resistance.

An exploratory study undertaken by Bertoniere and his colleagues (9) sought to obtain a clearer concept of the reactions which take place and the structural changes of the fiber which occur during the fixation step. The study was limited to a single combination of reagents (DMDHEU and a catalyst--magnesium chloride), a single pad-bath concentration, and a limited range of fixation and curing conditions.

Results of the investigation revealed that resins were deposited on the fiber surface as well as in the internal pore of the fiber. The resin deposition developed greater internal pore volume and surface than was found in the untreated cotton. Only part of the increased internal pore volume and surface was lost during curing, so that the final product was characterized by larger internal volume and more accessible surfaces than were produced by a pad-dry-cure process.

Bertoniere et al. (10) also studied the effects of cotton fabrics treated with methylolated melamines and a crosslinking agent of DMDHEU. The fabrics were given different periods of wet-fixation at a temperature of 25^{o}C. Polymer add-on showed continuity of increasing with added time in fixation. This rate of increase was equally affected by the particular melamine reagent being used. The tri-methylolmelamine had a much faster add-on rate than did the hexamethylolmelamines. The two melamines also showed a greater decrease in CH_2O/N ratio as the fixation time increased.

The durable press ratings for the fabrics finished with hexamethylolmelamine-DMDHEU were not acceptable, with duration of time having little or no effect. Trimethylolmelamine-DMDHEU ratings decreased drastically when the time of fixation exceeded six hours. The shorter times (2, 4, and 6 hours) were acceptable, but the durable press ratings were poorer than those provided by hexamethylolmelamines.

Data on strength and abrasion resistance for hexamethylolmelamine treatments were considerably superior to those for trimethylolmelamines. These ratings were believed due to the slower reactions of the former, which allowed greater diffusion of the reagent into the fiber, yarn, and fabric.

Hollies and Getchell (27) conducted research for imparting durable press properties to cotton by depositing the resin inside the wet, swollen cotton fiber. The researchers felt that the use of two resin components was the key to good strength properties, high levels of resistance to wrinkling, and crease retention. One of the components, a polymer builder, acted as a swelling agent. The second component was primarily a crosslinking reagent which enhanced wet recovery and, when catalyzed and dried, imparted high dry wrinkle recovery to the fabric. The suggested add-on amounts of 8 to 15 percent of dry resin were needed for durable press performance.

Laboratory tests on a twill fabric resulted in filling breaking strength retention values of 60 percent, dry wrinkle recovery values of 300 degrees and wash-and-wear ratings of 5. The treated fabrics were made into simulated trouser cuffs and subjected to 20 laundering cycles. The wet-fixed cuffs showed no wear; whereas, all of the pad-dry-cured cuffs failed, on the average, at the sixth laundering cycle. Similar results were obtained in relation to other abrasion tests. These abrasion studies indicated that the wet fixation process was a real improvement over the pad-dry-cure process.

Edge abrasion resistance of durable press cotton fabrics treated with polymer additives such as a trepolymer of ethylene vinyl acetate and methacrylol chloride was reported by Harper et al. (2) at the Sixth U.S.D.A. Utilization Conference. When the fabrics so treated were tested in a flat state using the Stoll flex abrasion and the Accelerotor abrasion procedures, resistance increased, but when durable press cuffs were subjected to the same treatment the abrasion resistance decreased because of a sharp increase in fabric stiffness. Another polymer which failed to show abrasion improvement in cuffs was nylon-8, but the polymer did give substantial improvement in wet wrinkle recovery. Other polymer additives which were found by Harper and associates to increase wrinkle recovery were polyurethane and polyether. The use of these additives permitted significantly lower concentrations of cross-linking agents.

Research done by Smith (63) has shown that improved abrasion resistance in durable press fabrics can be achieved through the use of polymeric additives. The two found most effective, as reported by Smith, were high-density polyethylene and polyurethanes, which were added in amounts of approximately 5 percent. There was some change in fabric hand, due to the high level of additives, which made the fabric unsuitable for some garment usages.

Lofton et al. (34) conducted a study in an effort to develop improved all-cotton fabrics for use in durable press garments through the application of polymers to cotton yarn prior to weaving. Previous research conducted with yarns treated with polyurethane and polyacrylate created a polymer build-up on loom parts, thus becoming detrimental to productive weaving. Two approaches were used to minimize the polymer accumulation. In one approach warp sizing was applied with a 1-bath mixture of a durable (2 to 6 percent solid) and a temporary (2 to 4 percent solid) polymer. In the second approach low concentrations (3 percent solid) of crosslinking reactants and catalysts were added to the size bath.

The results showed that fabrics woven from warp yarns sized with 8 percent polyurethane had strength retention values of 82 percent warpwise and 71 percent fillingwise after a pad-dry-cure treatment with a 15 percent solution of Permafresh 183k. The polyurethane treated warps also resulted in fabrics with much better crease recovery angles which showed the contribution of the polymer.

The warp yarns produced very distinctive characteristics when the crosslinking resins and catalysts were included in the polymer size bath. In this method temporary polymers such as polyvinyl alcohol and carboxymethylcellulose were converted to durable polymers. The resulting fabrics had good durable press properties after being crosslinked with only 2 percent solid additional resin add-on. The addition of 1 percent carboxymethylcellulose to the crosslinking bath produced strength retention values of 95 percent warpwise and 82 percent fillingwise, and flex abrasion values of 2.0 to 4.5 times greater than untreated fabrics.

Investigations also were made by Lofton (34) to determine the most effective percentage of polyurethane needed in the size bath to produce the highest physical property values and the greatest resistance to abrasion. Results revealed that the fabrics woven with warp sized with 8 percent solids of polyurethane had the greatest improvement in all physical properties.

Preferential crosslinking was employed as another method in improving all-cotton durable press products. The technique involved either coating the back, center, or face of the fabric with a crosslinking agent.

Reeves et al. (52) delineated two methods for preferentially crosslinking cotton fabrics. The basis for one method employed the back coating technique, while the other depended on catalyst inactivation. In the coating process a viscous solution containing the crosslinking agent, catalyst, and auxiliary finishing agents was applied to the fabric. Before the crosslinking agents could penetrate through to the other side, the fabrics were dried. Once dried, to about 7 to 10 percent moisture, the reagent remained essentially in the same locations. The fabrics then were cured, or the curing was delayed until garment construction was completed.

In the catalyst inactivated process the fabrics were padded through a conventional resin formulation, and then either or both sides of the fabric were treated with a catalyst inactivator. Immediately after padding, the inactivator either was applied to the wet fabric or delayed until the fabric had dried. For gaseous inactivators such as NH_3, good results were obtained by treating the wet fabric.

Fabrics treated by the back coating, catalyst inactivator, and conventionally pad-dry-cured methods received a rating of 5 for wash-wear and crease retention after 20 launderings. The preferentially crosslinked fabrics showed improvements in flex abrasion ranging from 4 to 20-fold better than did the pad-dry-cured fabrics. Improvements in flat abrasion were 1.5 to 3-fold better. When compared with the non-crosslinked control fabrics, the preferentially crosslinked fabrics displayed better abrasion resistance, but elongation, breaking, and tearing strengths were lower than for the control fabrics. The explanation for the lower ratings was thought to be due to softening effects of absorbed detergents which were used to wash the treated fabrics.

Small holes appeared in the conventionally cured cuffs during 6 to 10 wash-tumble dry cycles. The back coating and catalyst inactivation developed small holes during 12 to 20 laundering cycles.

In these experiments it was noted that the preferential crosslinked fabrics lost color due to the lack of crosslinking in the fibers located in the face of the fabric which led to the production of considerable loose fiber ends. In order to overcome this problem,the processes were modified to produce improved abrasion resistance without fading problems.

In the accelerated testing of trouser cuffs,one broken warp yarn was noted at the center seam after 17 wash-tumble dry cycles. No holes were observed at the tips after 20 cycles. The pad-dry-cuffs developed holes in 6 to 10 cycles. The face coated fabrics had excellent color retention, but a white line developed at the crease. Overall service life of the preferential treated cuffs was over twice that of the conventional resin treated 100 percent cottons.

Similar results were obtained by Cooper and associates (15). In an attempt to improve the wear life of resin treated cotton, the research team combined the techniques of preferential crosslinking with slack mercerization. The fabric weaves varied from a plain to a pile. These fabrics were resin treated either by back-coating with a crosslinking agent or by catalyst inactivators on the face of the fabric.

Physical testing showed resistance to flex abrasion to be 5 to 13 times that of conventional pad-dry-cured fabrics, and flat abrasion also was improved. Data from fabrics which were pretreated by slack mercerization with complete, partial, and no restretching gave an indication that partial restretching should improve abrasion resistance. This improvement in abrasion resistance, however, could be offset by variations in the crosslinking technique.

Simulated pant cuffs which were laundered for 20 cycles showed that the preferentially crosslinked fabrics had wash-wear appearance ratings equal to conventionally treated fabrics and a small, but definite improvement, in wear resistance.

At the Fifteenth Chemical Finishing Conference held in November 1966, Rutherford (45) reported on ionizing radiation as the final step in a delayed cure durable press process. The chemical reactant used in this work was methyol acrylamide. The chemical was reacted monofunctionally with cotton by a pad-dry-cure process using acid catalysis. All unreacted chemicals were removed by an afterwash before garments were made and crosslinked at room temperature with the beta rays. The advantages of radiation curing, according to Rutherford, stem from the fact that it can be done at room temperature; it eliminates dye migration and damage of thermally-sensitive garment accessories; the irradiator can be stopped and started again in minutes as required by production schedules; the irradiation room may be entered immediately after the curing process; and the fabric contains no residual chemicals when made into a garment. The disadvantage is that radiation curing is limited to free-radical or ionic chain reactions, and a new class of chemicals will be required before the process can become widespread.

The fabrics that were treated with methylol acrylamide showed a lack of chlorine resistance;and, after irradiation, they yellowed slightly on standing or heating. They, however, did exhibit remarkably good storage properties, and the creases ironed into the treated cotton fabric could be removed at any time prior to irradiation.

The results of radiation modifications of cotton have been presented in 2 parts by Nasr (41) (42). Part I concerned the crosslinking of cotton by means of multifunctional monomers, to improve the crease recovery performance. The effects of a delayed heat cure also were studied.

The monomers were prepared and placed in quickfit bottles, and fabric specimens then were immersed in the solution. The bottles were stoppered and placed in the center of the gamma cell to be irradiated to the required dose. Results showed that the 2 multifunctional monomers, hexahydro-1,3,5-triacrylol-5-triazine and N-methylol acrylamide, successfully crosslinked cotton cellulose when irradiated with gamma rays from a Co-60 source. The crease recovery angle of the single monomer treated fabric, dry and wet, showed improvements of 50 and 56 percent, respectively.

In mixed monomer systems, irradiation followed by delayed curing and chemical catalysis gave the treated fabrics an easy-care finish with 72 and 70 percent improvement in dry and wet crease recovery properties, respectively. At the same time the fabrics retained their tensile strength which was in contrast to the behavior of conventionally finished fabrics.

Part II of Nasr's (42) work dealt with the catalytic effect of grafted acids in crosslinking reactions as substitutes for conventional inorganic ones. The 2 substitutes were a monocarboxylic-(acrylic) acid [AAC, CH_2 = CHOOH] and a dicarboxylic-(maleic) acid [mal AC, $\begin{matrix} CHOOH \\ \| \\ CHOOH \end{matrix}$]. These were radiated-grafted on cellulose singly and/or mixed.

The procedure was the same as described in Part I of Nasr's report. A significant improvement was noted in wet and dry wrinkle recovery angles for mono- and dicarboxylic acids when used singly or combined. The limited loss of tensile strength (0 to 10 percent) showed the potential of radiation grafting as a method for improving the wrinkle resistance performance of cotton fabrics.

The possibility that grafting could improve the strength retention of crosslinked cotton was investigated further by Prahl, Tovey, and Underwood (51), at Bjorksten Research Laboratories. The grafting techniques used by these investigators were vapor phase and liquid phase. Following the grafting procedure the fabrics were crosslinked with Permafresh 183, a methylol imidazolidone resin. An electric iron with a "cotton setting" was used to set creases, after which the fabrics were oven-cured at 160° Centigrade for 70 minutes.

Results of the study confirmed that grafting increases the elongation and decreases the tensile strength of cotton print cloth. Further studies were conducted using ethyl acetate grafts because these showed a substantial increase in elongation without a decrease in tensile strength. Results with an 18 percent graft showed that warp elongation nearly doubled and filling elongation increased 60 percent, which was accomplished by only a small decrease in filling tensile strength. The results also showed the grafted fabric to have improved abrasion resistance as well as improved wrinkle resistance. The most effective grafts were those based on diethylaminoethyl acrylate or ethyl acrylate. These grafts were able to overcome most of the loss in abrasion resistance incurred by conventional crosslinking treatments.

At the Sixth USDA Utilization Conference Gagliardi and Jutras (2) reported on findings from the vapor phase grafting of cotton with acrylic monomers, chlorosilanes, perfluoroacrylates, and ethylene oxide. The acrylic monomers produced improved wet and dry wrinkle resistance and increased abrasion resistance. When these grafted cottons were reacted further with crosslinking agents by pad-dry-cure or vapor phase processing the abrasion resistance and wrinkle resistance continued to improve. These same observations were made when ethylene oxide and chlorosilane grafts were used.

The belief that strength loss is associated with the formation of crosslinks and not with catalytic hydrolysis, and the results of research with sublimation drying of paper prompted Cashen (12) to conduct a study of chemical cure and resin fixation by sublimation drying on cotton print cloth. The basic steps of fixation used by Cashen included the following: padding the fabric and drying to a desired water content; quick freezing in a Dry Ice-acetone bath; placing the frozen fabric in a vacuum vessel; and drying by sublimation under vacuum.

The findings demonstrated that with the proper adjustments of conditions, catalyst concentration, initial moisture, and time of lyophilization, a smooth dry cotton fabric could be prepared with high levels of conditioned and wet wrinkle recovery. The fabrics also showed improved strength and abrasion resistance.

Reinhardt and Cashen (53) studied the mild-cure durable press finish and described the process as one which impregnated the fabric with an aqueous solution containing a cellulose crosslinker and a strong acid catalyst. Strong Lewis acids were used by these investigators as the catalyst, and dimethylol methyl carbamate was used as the crosslinker. Among the acids used were aluminum chloride, aluminum nitrate, aluminum sulfate, aluminum potassium sulfate, and stannic chloride.

Results of testing after treatments showed improved wrinkle recovery properties for all treated fabrics. The selected Lewis acids used were suitable for use in the mild-cure (100° Centigrade) finishing of cotton, but were less effective than the strong mineral acids at lower temperatures.

Verburg, Parikh, and Vail (70) studied the Steam Set process and described it as a combination of a melamine-containing resin and crosslinking agent fixed or deposited in wet, swollen cotton under mild acidic conditions. The sensitized fabrics were found to be suitable either for immediate or for delayed curing.

Steam setting produced fabrics with a greater retention of tearing, breaking, and bursting strength and higher flex abrasion resistance values than were produced by the pad-dry-cure process. Overcuring of steam set fabrics, however, reduced strength and abrasion properties to the level of overcured pad-dry-cure fabrics. The researchers also noted that the amount of resin fixation was determined by the type of resin used, by the steaming time, and by the pH of the pad bath.

Steam-cure processing to improve wrinkle resistance properties for cotton fabrics also were studied by Parikh, Frick, and Iwata (47). To demonstrate actual in-service life, simulated durable press trouser cuffs were treated by a steam-cure process and by a conventional process. After 25 launderings the trouser cuffs were compared with respect to smoothness and fabric damage. The steam-cured trouser cuffs showed improvements in smoothness and resistance to laundering abrasion on the creases, but only small improvements in overall resistance to damage in laundering were found. The greater stiffness of steam-cured fabrics apparently caused an additional susceptibility to wear in laundering.

A new approach to the crosslinking of cotton was investigated by Kullman and Reinhardt (32) at the United States Department of Agriculture Southern Regional Research Laboratories. The researchers held the opinion that cotton fabrics impregnated with a suitable finishing agent and catalyst and then exposed to an unheated dehydrating atmosphere would become wrinkle resistant. The theory underlying this opinion was that the crosslinking reaction would occur with deswelling slowed sufficiently to allow better distribution of crosslinks and thus result in the achievement of high conditioned and wet wrinkle recovery.

The effects of time in the dehydration curing process upon fabric properties were determined. During the first 4 hours there was little change in conditioned wrinkle recovery angles, but there was a continuous increase in wet wrinkle recovery angles. At the end of 8 hours both conditioned and wet recovery values began to level off supporting the hypothesis that initial recovery occurs while the fiber is still considerably swollen. As moisture was removed, there was an increase in the concentration of the catalyst and in the reaction rate. A modification of the dehydration chamber was made to permit air to be circulated within the closed chamber. More rapid drying produced lower levels of wrinkle resistance, with little difference between wet and conditioned wrinkle recovery angles.

Another approach to dehydration curing included the continuous passage of unheated, dry air into the chamber. This increased evaporation and accelerated the reaction. Fabrics were cured in 1.5 to 2 hours with excellent resistance to chlorine damage.

Accelerated dehydration curing techniques also were investigated using 50/50 polyester and cotton. Wet and conditioned wrinkle recovery angles were substantially improved in the blended fabric, but the durable press performance was not outstanding.

A procedure considered for the application of crosslinking resins to fabrics was the Poly-set process. Kopacz and Perkins (31) and Leonard (33) described the process as a two-step treatment accomplished by the deposition of N-methylol crosslinking agents within the cotton by the use of a weak acid polymerization catalyst. Curing conditions of about 3 minutes with a temperature of 160° Centigrade were found to give desirable results. A strong latent acid catalyst was used by the investigators to initiate crosslinking of the formed polymer and the cellulosic molecule. The effective curing time was 5 minutes at 160° Centigrade. This process was found to be suitable for pre- and post-curing operations.

The breaking and tearing strengths were greater for the Poly-set fabrics than for the fabrics treated conventionally. The greatest improvements were in abrasion resistance which was several times that of the conventionally processed fabrics. The physical and chemical data indicated that the high degree of wrinkle recovery and the durable press properties were obtained through polymer deposition in the fiber and through fewer covalent crosslinks than were present when fabrics were processed by the conventional method. The reduced number of covalent crosslinks was believed to account for the greater strength and elongation of the treated fibers.

Fiberset, a new method of curing crosslinking agents by solvent vapor, was developed by Cashen, Reinhardt, and Reid (13). The crosslinking was accomplished by means of a one or a two-step process. In the one-step method the fabric was impregnated with an aqueous solution containing a cellulose reactive melamine prepolymer and an N-methylol crosslinking agent. The water content of the swollen fabric was adjusted, followed by polymerization and crosslinking in the vapors of a relatively low chlorinated hydrocarbon.

In the two-step method the crosslinking agents were fixed in the vapors of a boiling chlorinated hydrocarbon and then oven cured to affect crosslinking of the cellulose. This method permitted creasing of garments before the final curing step.

Cashen, Reinhardt, and Reid (13) conducted studies on cotton fabrics and polyester-cotton khaki twill trousers which had been treated by the Fiberset process. Both methods of polymer fixation produced fabrics with a high wet and conditioned wrinkle resistance, with excellent crease setting properties, and with good abrasion resistance.

Marsh (38) and the American Fabrics magazine (67) reviewed a mechanical process known as "M-S" for micro-stretch. The M-S process made possible a reduction in the percentage of manmade components in fabrics or in some end-uses, to dispense with the manmade component completely.

In the micro-stretch process the stretch was evenly applied to the filling yarns. This increased the strength of the cloth by 30 to 40 percent, and at the same time the fabric width was increased by 5 to 15 percent. Test results showed that strength losses of durable press cotton can be cut in half or more by the M-S process.

The objective of a study conducted by Franklin, Madacsi, and Rowland (18) (19) was to provide durable press cotton fabrics which could be formed permanently into desirable shapes by conventional hand ironing or by hot-head pressing. Selected catalysts were used to reduce the curing time required to form sharp, permanent creases in fully cured durable press cotton fabrics.

In this study, latent acid salts (activating catalysts) were used with carboxylic acid which were co-valently bonded to cotton print and khaki cloth containing DMDHEU crosslinks. Results showed that the pre-activated fabrics, when pressed with a hand iron for 15 seconds at 160° to 200° Centigrade, produced sharp, durable creases with ratings of 4.0 to 5.0 after five launderings. High crease recovery angles also were produced, yet precautions were necessary to avoid overcuring the fabric for the catalytic mixture was very active.

In the post-activated process the original cure was easily controlled and the addition of the activated catalyst had little effect on the resistance, strength, or stability of the fabric. The creasability was retained during storage. Sharp, permanent creases resulted when the fabric was ironed at 145° to 160° Centigrade for 15 seconds, and there was little strength loss due to the creasing process.

A new concept for reducing wrinkles and seam puckering was announced in a recent issue of the Daily News Record (44) by the Sanforized Company. The fabric finishing system was described as a finish which can substantially reduce wrinkle and seam puckering in tumble-dried cellulosic fabrics such as heavy cotton denim, chambray, corduroy, and sheeting. The finish is based on the use of liquid ammonia and is not regarded as a durable press finish. However, it does produce garments with a substantially reduced amount of shrinkage which do not require ironing.

Since 1964 there has been increased interest in the reaction of cellulose with a crosslinker and/or a catalyst from a vapor phase treatment rather than from the normal aqueous impregnation. This interest has resulted from evidence that vapor phase processing provides a better relationship between strength retention and performance on 100 percent cotton fabrics than does the aqueous impregnation process. Two basic approaches to vapor phase finishing have been practiced. The application of modifiers, lubricants, and similar materials may be applied in an aqueous padding solution prior to the vapor phase curing with the crosslinker and catalyst, or the crosslinker may first be padded on followed by the vapor phase curing to complete the molecular crosslinking. Goldstein (22) described the latter technique as one in which cyclic ethylene urea is padded into the fabric before it is dried and then cured by exposure to formaldehyde vapors and a volatile catalyst. The first reaction takes place between the CH_2O with the ethylene urea, and this new compound then reacts with the cotton fiber. The vapor phase treatment may be applied as a pre- or a post-cured technique.

During 1965 the Gagliardi Research Corporation (69) announced their VP-3 Process for producing permanent press in 100 percent cotton garments. The VP-3 processing involves several steps. Untreated cotton garments are placed in a closed oven or chamber. The garments are then exposed to vaporous crosslinking agents and catalysts which are introduced into the chamber by air or nitrogen stream.

The developers of this new process gave the following advantages over other techniques being used to provide durable press properties:

1) Complete freedom to operate outside of restrictive patents now covering pre-cure, partial-cure, two-step cure, and delayed cure resin treating systems.

2) Ability to use low cost, truly permanent and completely chlorine proof volatile cellulose crosslinking chemicals for both 100 percent white cotton fabrics and for dyed and printed fabrics.

3) Since the vapor phase crosslinking is done under very mild conditions (room temperature to 120°C) and in the presence of moisture or non-reactive swelling agents, the permanent press cotton garments so produced have higher tensile strength, tear strength and abrasion resistance than those produced in the resin based high temperature curing systems.

4) No problem of fabric storage stability between the finishing plant operation and the making of garments, since the cotton is either not treated at all in the finishing plant or is only treated with non-reactive softeners, polymers, water repellents, stiffening agents, etc., and the main reaction is done later on the garments in the vapor phase oven.

5) Low cost of the process, since simple chemicals are used and also there are low power requirements because of the low temperatures employed.

Vapor phase reactions and reactor designs for special use were considered by Gagliardi, Jutras, and Shippee (20). The researchers studied the different chemical modifications for the vapor phase treatment provided by alkylation, esterification, crosslinking, resin or polymer formation, and grafting. In laboratory experiments cotton fabrics were pretreated with a crosslinking agent either of urea, ethylene urea, bis hydroxymonourein or a carbamate. The fabrics then were exposed to vapors of Methyl Formcel and formic acid. Each of these treatments resulted in very high wet and dry crease recovery values, improved fabric strength, and high flex abrasion resistance.

A finishing process for crosslinking cotton fabrics based on the vapor phase treatment with formaldehyde and sulfur dioxide was studied by Wilson, Gamarra, and Swidler (73). Their goal was to develop an acceptable vapor phase process which would provide improvements in abrasion resistance, appearance ratings, and would produce a longer laundering life than conventional durable press fabrics.

The experimental fabrics were cotton print cloth and twill fabrics which were padded with various latex polymers and Permafresh 183 to approximately 100 percent wet pick-up. The treated fabrics were placed in a reactor for predetermined time periods, after which they were removed, rinsed in hot water, washed in 25 milliliters of Vel detergent, and tumble dried. Ratings from abrasion due to laundering were obtained by attaching a constructed trouser cuff, with ironed creases, to the legs of trousers.

Results from moisture content studies showed that too little moisture gave low wrinkle recovery values, and excessive degradation occurred when there was too much moisture. These results were directly related to the amounts of sulfonic acid catalyst that were formed from formaldehyde, sulfur dioxide, and water. A reaction time of 2 or 3 minutes, using sulfur dioxide as a catalyst, gave good wrinkle-recovery values with less than 50 percent loss in tear strength.

This study included a variety of polymeric additives, especially those known to form a soft film. The exact function of the additive was not clearly understood, but results showed improved flex abrasion and wrinkle recovery values. The cuffs which had been crosslinked with formaldehyde in the presence of additives withstood 5 to 13 wash-dry cycles before showing major damage. Those crosslinked with Permafresh 183 showed major damage before 3 to 4 wash-dry cycles. Resistance to flex abrasion also rated higher for the formaldehyde cuffs than for the Permafresh cuffs. Additive effects on tensile properties resulted in Permafresh fabrics rating higher than formaldehyde treated fabrics, but lower extensibilities resulted, and the work-to-rupture of the two fabrics was almost the same.

Certain amides were affixed to cotton fabrics with a treatment of formaldehyde vapors and no catalyst at 120° Centigrade. These finishes were stable to laundering,and the fabrics were not weakened. When 20 percent zinc nitrate was padded into these fabrics and cured for 5 minutes at 160° Centigrade, wrinkle recovery values increased and excellent permanent creases were obtained thus producing the basis for a delayed-cure process. The two amides that gave the highest wrinkle recovery values after the second cure were urea and ethyleneurea. Although the data on chlorine retention ranged from no retention to moderate retention, the research team felt that further study was needed to determine chlorine retention more precisely.

Campbell and Staples (11) studied the effects of exposing cotton fabrics treated with various nitrogenous compounds and suitable catalyst to formaldehyde vapors. Bleached 80X80 cotton print cloth which was treated with 5.0 percent urea, 5.5 percent formaldehyde, and 2.0 percent catalyst had very low crease recovery ratings. When the specimens were padded with an aqueous solution containing 10 percent urea-catalyst, the results showed an increase in crease recovery angle and less loss of strength. This was especially true when ammonium salts were used.

Since the organic acid catalyst used in the liquid phase process has been known to produce fabrics which have unsatisfactory crease recovery, extremely high strength losses, and frequent yellowing the research team chose to use cyanamide (H_2NCN) in place of amino compounds. These test trials were run with varying percentages of cyanamide and catalyst. The first trials used no cyanamide and 1.0 percent catalyst which resulted in reduced fabric strength while the crease recovery was not improved. The second trial of 5.0 percent cyanamide and no catalyst showed some improvement in crease recovery and a stiffening of the fabric which yellowed when ironed. The third trial contained 5.0 percent cyanamide and 1.0 percent catalyst which received moderately good crease recovery ratings without severe strength losses. The fabric properties included a good hand and whiteness which did not yellow when ironed.

Results also were obtained concerning the catalytic effects of ammonium salts and organic acids in this system. Those that produced improvements in crease recovery and fabric color were the ammonium phosphates, ammonium sulfate and sulfite, and ammonium sulfamate.

Arceneaux et al. (6) investigated the effects of time and temperature, concentration of catalyst, and moisture content on the wrinkle resistance and wash-wear properties of mercerized and non-mercerized cotton fabrics. The cotton cellulose was crosslinked by a treatment with gaseous formaldehyde in the presence of hydrogen chloride as catalyst. At the completion of the curing treatment the cotton samples were removed and soaked in a 2.0 percent sodium carbonate solution followed by an afterwash and tumble drying.

Test results indicated that the best strength retention was obtained at 20° Centigrade in 1.5 hours with a 3.0 percent catalyst. The moisture regain values were about 1.5 percent higher than those obtained when the pad-dry-cure treatment was used with formaldehyde. In order to produce a given crease recovery angle mercerized fabrics required a higher formaldehyde content than non-mercerized fabrics. The greater range of strength losses incurred by the mercerized fabrics was believed due to the slower rate of reaction. The study showed that gaseous formaldehyde produced cotton fabrics with improved wrinkle resistance and good durability to repeated launderings.

Guthrie (23) published findings on improved wrinkle resistance to cotton fabrics with vapors from HCL-para-formaldehyde. The vapor treatment resulted in improved wrinkle recovery angles, 250° warp plus filling, with about one-seventh the amount of formaldehyde required for other processing. The process also provided crosslinking throughout the fiber, but strength losses were about 40 to 50 percent.

A report on experimental fabrics finished with a vapor phase treatment using the Stanford Research Institute reactor was presented by Swidler, Gamarra, and Jones (66). The reactor used in this research was a cylindrical vessel (42 centimeters in diameter and 57 centimeters high) constructed of aluminum. The walls of the reactor could be heated to 600, 1200, or 2400 watts. It was equipped with two lines, one from a vessel which supplied the formaldehyde gas and another which provided gases such as steam, air, and/or sulfur dioxide when needed.

Fabrics were padded to 65 percent wet pick-up with Rhoplex K-14, K-87, and K-3 and urethane Latex E-502. They were dried at 80^{0} Centigrade, conditioned, and then placed in the reactor for predetermined time periods.

Mock trouser cuffs were used to measure abrasion due to laundering. Evaluations were made after one laundering and tumble drying. Results showed good tumble dry performance, better retention of abrasion resistance, better line dry durable press performance, and better finish durability. Moisture regain, moisture imbibition, and hand were about the same before and after processing.

The American Laundry Industries (ALMI) (17) announced on November 4, 1970, a successful process for producing durable press through the vapor phase treatment. The first reactor, which was described as a fully automatic reactor which could process 15 dozen garments within 22 minutes, was installed at American Uniform Company.

As a result of this process a very high level of fabric smoothness was observed through repeated launderings at high temperatures with souring and bleaching. There was evidence that stain removal was made easier, especially greasy stains, and there were definite improvements in seam appearance, due to the fact that non-resinated fabrics were used in garment construction.

Abrasion resistance as rated by the Accelerotor showed less loss in weight than when other durable press processes were used. The improved abrasion resistance also provided increased color retention. The fabric hand did not have the typical stiffness of the conventional processing, although the ALMI process does allow for a wide range of hand by the use of suitable additives. Moisture regain and absorbency values were higher, which should add to the comfort of garments.

Multi-purpose finishing using the vapor phase process was reported by Conner (14). The research involved the use of silicone treated cotton and formaldehyde which permitted the crosslinking of cotton cellulose to give wrinkle resistance and wash-wear properties without affecting the water repellency characteristics.

Tests showed that the silicone treatment did not prevent the penetration of the formaldehyde vapors. The processed fabrics were unchanged in appearance; wrinkle resistance was improved; hand was soft and supple; breaking and tear strength losses were slightly less than those of scoured samples; and the water repellency characteristics were unaffected.

In a letter to the editors of Textile Chemist and Colorist, Keating, Haydel, and Knoepfler (30) reported on exploratory data provided by a third method of treatment using formaldehyde and sulfur dioxide. Previous experimental methods included a liquid phase as well as a vapor state. In this method no vapor chamber was needed, yet fabric properties comparable to those provided by the liquid phase were obtained. The procedure involved the padding of fabrics with an aqueous solution of formaldehyde and sulfur dioxide followed by drying in a hot air oven. The processed fabrics then were given an afterwash and dyed with a direct dye before they were tested.

Data obtained from print cloth treated with the formalin-sulfur dioxide solution showed that as the sulfur dioxide concentration increased the bound formaldehyde also increased. At the same time the physical properties of breaking strength decreased and the wrinkle recovery angle increased. As the bound formaldehyde content remained constant for a given temperature the wrinkle recovery values increased with increasing drying time, while the breaking strength retention decreased with increased drying time.

Concurrent with the development of advancements in methods of fixation, research also has been undertaken in an effort to determine the most effective crosslinking reagent. The most frequently chosen reagents were the N-methylol compounds. As demands have become more stringent new N-methylol reagents have been developed. The move has been away from those reagents based on urea and melamine to those based on substituted ureas and carbamates.

A recent publication on modified cotton with N-methylol reagents was presented by Rowland and his associates (59). The objectives of their work were to

> . . . obtain data . . . relative to the formation of methylene ether linkages between reagents and cellulose, to the trapping of self-condensed N-methylol reagents residues, and to the formation of oxymethylene cross-linkages.

The experimental cotton fabrics were chemically modified with solutions of pure HMEU, MMEU, and a commercial grade of DMEU, which contained zinc nitrate as a catalyst. After completion of the study analysis confirmed that trapped dimers of HMEU were present within the cotton fibers. Oxymethylene linkages also were noted along with the expected methyleneethylene-urea substitutes.

Berni, Gonzales, and Jung (8) conducted a study to determine the reactions between cotton and selected finishing agents. The research team was especially concerned with the

> . . . influence of structural changes of the cyclic ureas upon physical and chemical properties of cotton fabric reacted at high temperatures of cure in the presence of an active catalyst and upon the kinetics and activation parameters of the cotton cyclic urea reaction.

The experimental materials included dimethylol-ethylene-urea (DMEU), dimethyloldihydroxyethyleneurea (DMDHEU), dihydroxyethyleneurea (DHEU), dimethylolpropylene-urea (DMPU), and dimethyldihydroxyethyleneurea (DMeDHEU). The study showed that the high (160° Centigrade) temperature cure using $Zn(NO_3)_2$ resulted in nitrogen content and wrinkle recovery angles higher for the fabrics treated with DMEU, DHEU, or DMPU. This group also possessed methylol hydroxyls only or methylol and ring hydroxyls.

Lower ratings were recorded for the DHEU and DMeDHEU, and they possessed only ring hydroxyls for reaction.

The nitrogen-to-formaldehyde ratios were approximately equal for the DMPU and DMDHEU, but were higher than the DMEU reaction products. In the lower temperature range of 45° to 85° Centigrade the relative ratio differed with each catalyst, but the order of reactivity was always DMEU, DMPU, DMeDHEU, DHEU, and DMDHEU.

Cotton fabrics which had been modified with methylated methylol-melamine were studied by Jung et al. (28). The fabrics were treated with a solution of Aerotex Resin M-3 (MeMM) and a catalyst, $Zn(NO_3)_2$. Wrinkle recovery properties of the modified cotton fabrics were noted before and after partial hydrolyses with a solution of urea-phosphoric acid. Jung et al. noted that the cotton fabric specimens treated with McMM and $Zn(NO_3)_2$ produced high dry and wet wrinkle recovery angles, and when the treated fabrics were partially hydrolyzed with urea-phosphoric acid wrinkle recovery was destroyed completely. Re-treatments with MeMM restored wrinkle recovery, but with each hydrolysis the restoration decreased.

The use of carbamate finishing agents was introduced in 1961, and since that time they have been used for the pre-cure finishing of white goods. Carbamates have had several advantages over other agents. They are resistant to removal by hydrolysis during laundering, resistant to chlorine damage, and to reduced yellowing during cure. The main disadvantage of these agents is the high formaldehyde release.

Reid, Kullman, and Reinhardt (54) proposed and evaluated three general methods of reducing the free formaldehyde of carbamates. One method proposed improving the efficiency of methylolation. Another was the removal or destruction of the free formaldehyde by physical means. The third technique involved treating the solution with a chemical agent to consume the free formaldehyde. Results of the study showed that a high methylolation efficiency and low free formaldehyde could be achieved. The removal of formaldehyde by physical means was not promising. The chemical binding of formaldehyde offered some hope, but resistance to chlorine damage was evident.

At the Sixth U.S.D.A. Utilization Conference Reinhardt and Reid (2) described work done with cotton fabrics finished with dimethylol isopropyl carbamates. They found the fiber properties of the fabrics thus treated about the same as those cured with other alkyl carbamates. Durability of the finish to hydrolytic removal was sufficient for repeated commercial laundering, including the souring step, which prevented the necessity of an afterwash.

Work done with carbamates at the J. P. Stevens Research and Development Division, as reported by Sello (60), resulted in findings similar to those reported by Reinhardt and Reid. The experimental compounds were made of di-tri- and hexafunctional carbamates, with n-dimethylol tri carbamate giving the best all around results. Excellent resistance to hydrolysis during laundry souring was characteristic. It was, however, observed that after excessive acid hydrolysis the fabrics treated with trifunctional compounds were quite susceptible to chlorine damage. Strength and abrasion losses were about average for conventional durable press crosslinkers. The chlorine retention was nil for all the experimental carbamates. According to Abrahams (1), where resistance to chlorine yellowing was of concern, as with white fabrics, the carbamates proved most effective.

A number of newly-developed resins, some of which were developed by BASF Wyandotte (43), have been found to impart improved fabric properties without objectionable odors. A carbamate-based resin, Textile Resin 115, was designed for pre-cure applications. The free formaldehyde liberation has been found to be minimal even after the product has been packaged for an extended time. Two other new resins developed by Wyandotte are Fixapret C, methoxyethyl carbamate, with 3.0 percent free formaldehyde, and T. R. 98 which contains only 1.0 percent free formaldehyde. In post-cured durable press finishing Wyandotte has developed a minimal free formaldehyde glyoxal type resin designated as Fixapret CP-40. This resin requires less zinc nitrate catalyst than is required for other resins.

Since there had been no mechanism advanced to explain and correlate the various features and peculiarities of the base-catalyzed reaction of N-methylolamides with cellulose, Welch and Margavio (72) attempted such a correlation. The research was conducted with several N-methylol reagents. These were combined with silicones and other chemicals necessary for producing water repellent fabrics.

All treatments obtained good crease recovery values, but the higher values of 278° to 305° were obtained when methyl hydrogen silicones were added to the N-methylolacrylamide solution. The presence of N-methylolacrylamide greatly increased the silicone fixed in the fabric, but the N-methylolacrylamide reaction with cotton was not significantly increased by the presence of silicone. It was concluded that the two processes could be carried out simultaneously to produce a finish with good wrinkle recovery and with a high degree of water repellency.

Experimental studies at the Southern Regional Research Laboratories conducted by Perrier, Benerito, and Soignet (49) were designed to compare fabric properties obtained with commercially prepared reagents with those obtained with the pure compounds. The effects of storage time on fabric properties imparted by using these reagents in a delayed-cure process also were compared. The laboratory prepared reagents of DMDHEU and DMEU which were more than 98 percent pure. The two commercial products selected were Permafresh 183 (DMDHEU) and Rhonite R-1 (DMEU), which were used without further purification.

The fabrics were sulfonoethylated (SE) cotton and diethylaminoethyl (DEAE) cotton. The selection of these two "built-in acid sites" was based upon the fact that the acid function of one (SEAE) was activated by an increased temperature and the other (SE) was less dependent on temperature.

The nitrogen content of the SE-cotton fabrics was compared in delayed time periods before and after curing, and no advantages were gained in using the pure DMEU over the commercial solutions. Both reagents showed an increase in nitrogen content with increased time of storage. Similar results were obtained in the high temperature curing treatment with both reagents showing bound nitrogen of about 1.5 percent. The hydrochloride of DEAE-cotton proved to be a better catalyst with DMEU for longer periods of storage, for the nitrogen content of SE-cotton approached 1.0 percent in about a month, as compared to the negligible amounts added to the DEAE-cotton.

Results indicated that only pure DMDHEU could be used with SE-cotton in a delayed-cure process. The pure DMDHEU reagents were more effective than the commercial reagents in conditioned recovery of delayed-cure DEAE and SE-cottons. The wet recovery values were determined for both fabrics and reagents. These values were similar to those of conditioned values. Only after curing and conditioning were the pure DMDHEU values significantly higher than those with the commercial product.

Garments constructed from modified cotton and blended-modified cotton fabrics have shown less resistance to abrasion wear than 100 percent cotton fabrics. The belief that laundry equipment contributes to this damage prompted a study by the Whirlpool Corporation, under the direction of Peterson (50). The fabrics chosen for the study were current popular cotton fabrics found in the market. The laundry machines included 5 brand names of new and used machines which varied in interior materials. Some were agitators while others were tumbler washers and dryers.

Results showed that fabrics of untreated cotton and polyester-cotton blends were very resistant to laundry abrasion while the cotton wash-wear and permanent press fabrics had poor resistance to abrasion. The majority of machines, new and old, produced acceptable low levels of fabric abrasion. The used machines did reveal a very small increase over the new machines. The new stainless steel interiors produced more abrasion than did the other new and used machines of comparable types. Machine design, construction, and finishing materials influenced the amount of fabric abrasion produced by the machine.

In studying the effects of soaking, size of load, mechanical action, and washing temperature in home laundry machines, Löwendahl and Åsnes (35) concluded that all of these variables were of great importance in determining appearance ratings. The study was conducted using treated and untreated 100 percent cotton-polyester blended fabrics which were laundered in a domestic washing machine and line dried.

The effects of soaking the fabrics for 17 hours prior to washing showed lack of appearance deterioration.

In fact, there was an improvement for some fabrics. The shorter soaking time of 15 minutes had no influence on the appearance of the fabrics. Those in a half-dried condition were found to be especially sensitive to creasing, and the recovery in this state was affected by the resin treatment.

Other findings showed that the appearance of the all-cotton fabrics changed little during the various stages of the wash-wear cycle. In contrast, the cotton-polyester blended fabrics were less wrinkled than were the all-cotton from the machine after the prewash cycle. The drum speed had no influence on the appearance of the cotton samples, while the cotton-polyester samples deteriorated at higher drum speeds.

Data for effects of load size showed that it was very important not to overload the machine. The recommended load ratio was 40 to 50 percent of cage volume. Observations showed that fabrics must have sufficient space for continuous movement, or excessive wrinkling will occur.

Under the direction of Wylie and Erickson (74) five states in the western region participated in a study to determine the varying effects of environmental conditions on the performance of selected durable press garments during wearing and laundering. The garments chosen for the study were 65/35 polyester-cotton blends and 100 percent cotton shirts with durable press and soil release finishes. Selection of wearers was not random, but all were employed in office work.

In all comparisons the performance of the 65/35 polyester-cotton blended shirts had higher burst and tear strength values than the 100 percent cotton shirts. The worn and laundered shirts had higher strength values than did the garments which were laundered only. Little difference in tear strength was noted as a result of drying treatments, but tear strength did decrease as wear-laundering and laundering periods increased.

Morris, Schultz, and Prato (40) explored the relationship between the amount of wear, the wearer's evaluation of wear, and the individual differences of the wearers such as activity, build, and personality. Trousers composed of 50/50 cotton-polyester were worn by 22 men who were staff members or graduate students at the University of California.

The amount of wear was found to be significantly related to the wearer's estimate of physical activity. Low correlations were shown between the wearer's evaluation of the amount of wear on the trousers and the garment wear score for the same trousers. Thurstone Temperament

Schedule scores indicated that personality characteristics influence the wearer's evaluation of the severity of wear.

CHAPTER II

PLAN OF PROCEDURE

The procedure has been divided into the following sections: 1) a description of the experimental trousers, 2) the selection of wearers, 3) the laundering procedures, 4) the methods used for visual evaluations, and physical testing.

Description of Experimental Trousers

One hundred sixty pairs of all-cotton khaki trousers served as experimental garments in this study. The trousers were constructed from a 3/1 twill fabric processed with 4 different types of durable press finishes. Forty pairs of the trousers designated as Types 1 and 2 were representative of 2 types of vapor phase treatments. The other 2 types of trousers were finished by means of a conventional pad-dry-cure and a post-cured proprietary finish which previously had not been evaluated. The experimental trousers were styled with slant side pockets, hip pockets made with a double welt, a zippered fly, a looped waistband, and hemmed and creased legs.

Selection of Wearers

One hundred twenty pairs of experimental trousers, 30 pairs from each finishing treatment, were subjected to 20 periods of wear by a panel of men employed in maintenance positions on the campus of the Texas Woman's University. A balanced randomized block design was utilized in assigning the trousers, 1 pair of each of the 4 types, to the 30 respective panel members.

The panel members were instructed to wear the trousers for a minimum 8-hour work period before returning them to the laboratory for laundering. The experimental trousers were coded for identification purposes. The wearer's number, together with a number representative of the finish, was permanently marked inside the waistband of each pair of trousers. Of the remaining 40 pairs of experimental trousers, 32 pairs (8 pairs from the respective finishes) were designated to be laundered without previous wear. The remaining 8 pairs of trousers were reserved for initial testing.

Laundering Procedure

In preparation for laundering the experimental trousers, the zippers were closed, the waistband was fastened, and the trousers were folded along the leg creases. They were then weighed in 4-pound loads. The worn trousers with oil, grease, or heavy earth soil were given a spot treatment with a solvent provided for that purpose before they were laundered. The procedure consisted of brushing the soiled areas before applying a paste of equal parts of laundry detergent and water. Stubborn stains were treated with Picrin, a dry spotting agent, which was applied to the stain from a plastic applicator bottle and rubbed into the garment with a piece of trouser fabric. A second application of the paste mixture followed,and then the trousers were rinsed thoroughly with warm water. During the rinsing period the pockets were turned inside out. Trousers which did not require a pretreatment were placed in a pan of warm water, along with the treated trousers, where they remained for a short time before they were placed in the washer.

All laundering was done in an automatic home-type Imperial Mark XII, Whirlpool washer at 140 ± 2^{o} Fahrenheit following the general procedure given in the AATCC Test Method 124-1973 (4b). The wash cycle was set for 12 minutes, and 90 grams of Launette commercial laundry detergent were used. The water level and agitation speed were set on high, and the water was extracted with a high spin speed cycle. Immediately upon completion of the wash cycle the trousers were removed from the washer and placed in a home-type Imperial Mark XII Whirlpool dryer which was equipped with a cool-down cycle. The trousers were dried at the high temperature setting with super speed for 32 minutes.

Upon completion of the dry cycle, the trousers were removed immediately from the dryer to prevent wrinkling. The pockets were turned inside, and each pair of trousers was given a laundry mark to indicate that it had undergone another laundering period. The trousers then were folded along the leg creases and hung over wire hangers for redistribution or for evaluation.

Visual and Physical Evaluations

Throughout the study, visual and physical evaluations were made on the trousers. These evaluations were performed with reference to durable press appearance, crease retention, soiling, dimensional stability, crease wear, and broken yarns. Visual evaluations for smoothness, crease sharpness, and crease wear were determined at specific time intervals by a trained panel of 3 observers. The other evaluations were performed by the investigator.

At the completion of the study, testing included wrinkle recovery, breaking strength, tearing strength, and bursting strength. The worn trousers were evaluated after 20 wear-laundering periods, while those of the non-worn category were tested initially and after 5, 10, 15, and 20 laundering periods. Two pairs of the non-worn trousers representative of the 4 respective finishes were tested at each interval.

Before the test specimens were cut from the experimental trousers, each trouser section was given an identification number as follows: 1) right front, 2) left front, 3) right back, and 4) left back. As the specimens for the various tests were prepared, they were identified with regard to the yarn direction and the trouser area from which they were taken. Each pair of trousers yielded 4 warp and 4 filling specimens for the breaking, tearing, and wrinkle recovery tests and 4 specimens for the ball burst test.

The specimens were cut from the upper areas of the trousers which had presumably received the greatest amount of wear, and attempts were made to avoid excessively worn and mended areas. Specimens for the various tests were taken from the trousers as indicated in Figure 1. Before the various tests were attempted, all specimens were placed under standard conditions of 70 ± 2^{0} Fahrenheit and 65 ± 2 percent relative humidity as recommended in ASTM Designation: D 1776-67 (5e).

Durable Press Appearance

The durable press appearance of the trousers was determined by AATCC Test Method 124-1973 (4b) after each 5 wear-laundering and laundering periods. A semi-darkened room equipped with a fluorescent overhead lighting system and with walls draped with black-out curtains, to eliminate any possible light reflection, was prescribed for these evaluations. Three members rated the left leg of the trousers from the crotch to the hem as the trousers hung from a rod attached to the viewing board. The AATCC Photographic Standards for smoothness were placed on each side of the trouser leg as a requisite for making comparative ratings. Each panel member stood 4 feet from the viewing board and compared the smoothness of each pair of trousers, as closely as possible, with the Photographic Standards.

Crease Sharpness

Crease retention ratings were recorded before the trousers were worn or laundered. Thereafter, the creases were rated after 5, 10, 15, and 20 wear-laundering and laundering periods.

The physical conditions of the room and the methods used for displaying the trousers were the same as those used for rating the durable press appearance. As a means of holding the trouser leg straight during the evaluation period, a wire-clamp clothespin was fastened to the hem. Evaluations were made according to the procedure described in AATCC Test Method 88-1973 (4a), and independent ratings were recorded by the panel members as they compared the trouser creases to the AATCC Standards.

<u>Soiling</u>

Before and after each 5 laundering periods, the worn trousers were rated with regard to their soiling properties. This was a visual evaluation done by placing the trousers on a flat surface under a fluorescent light which was 18 inches above the trousers. During these evaluations the investigator was elevated above the viewing surface by the use of a high stool. This procedure allowed the vision to fall directly down upon the trousers eliminating shadows that would affect the rating.

The amount of soil was rated according to the following scale used by Roch (55), Turner (68), Ball (7), and Roemhildt (56):

Rating	Description of Soiling and Staining
5	Clean all over; no visible spots or stain
4	Light soil; small oil stains; pencil and ink marks or other discoloration

3 Medium soil; medium-sized or many oil, food or earth stains; shoe polish; small permanent stains

2 Dirty overall; localized ground-in soil; large oil stains; splattered paint; persistent discolorations

1 Heavy soil; dirty oil stain; large or many paint stains; other permanent, unsightly discolorations.

Wrinkle Recovery

This test was used to determine the recovery of the trouser fabric from creasing which could occur during laundering or during normal wear. The laboratory test specimens were cut on perfect grain, warp and filling, to the exact measurements of 1.2 centimeters in width and 4.0 centimeters in length.

The specimens were obtained from areas that had not been previously folded or in any manner deformed. They were tested face-to-face and back-to-back in accordance with ASTM Designation: D 1295-72 (5a).

Dimensional Stability

Dimensional changes in the experimental trousers were obtained after 5, 15, and 20 laundering periods from a 5-inch shrinkage square stitched parallel to the respective warp and filling yarns in the right hip areas of the non-worn trousers. At the intervals of evaluation the squares were measured using a metal ruler and a Suter yarn counter in accordance with ASTM D 1905-73 (5d). As a means of keeping the trousers flat during measurements, they were smoothed by hand and allowed to relax for a minimum of 10 minutes before the measurements were taken.

Crease Wear

The deterioration or thinness of the trouser creases due to the damage they sustained during wear and laundering was rated by Standards 2, 4, 6, 8, and 10, which were developed by Markezich (36). Standard 2 represented the greatest amount of wear, and Standard 10 was typical of the least amount of wear.

The crease on the right front trouser leg was evaluated by the 3 panel members in determining the amount of abrasion that had occurred after 5, 10, 15, and 20 wear-laundering and laundering periods. These evaluations were made in a darkened room by passing a fluorescent lighting device inside the trouser leg. The panel members compared the amount of light which penetrated the trouser creases to the standards which were placed over a light box.

Broken Yarns

An initial examination was made on each pair of trousers for broken yarns. Successive evaluations occurred after every fifth laundering period. All ruptured yarns were counted, and the location of the breaks was recorded with a different color of ink for each evaluation period on a diagram representative of the front and back views of the trousers (Figure 1). As holes, tears, and an excessive number of broken yarns appeared in the worn trousers between regular evaluation periods, the yarns involved were counted and the areas were mended before the trousers were issued for additional wear. When the trousers had become too worn to be acceptable to the wearer, they were removed from the study.

The broken yarns were counted over a light box with a Suter yarn counter. An overhead fluorescent light was placed 15 inches above the surface of the light box to provide additional light.

Breaking Strength

The grab method, outlined by ASTM Designation: 1682-70 (5c), was used to determine the breaking strength of the trousers. The test specimens were cut on true grain, warp and filling, 4 inches wide and 8 inches long, and the Scott Tensile Tester was used to record the number of pounds required to break the specimens. The breaking strength of each specimen was recorded to the nearest 0.1 pound.

Tearing Strength

Fabric tear strength was measured by using the Elmendorf Tear Tester equipped with the NBS and textile augmenting weights and the prescribed technique outlined in ASTM Designation: 1424-70 (5b). The specimens required for the test were rectangular and measured 2.5 inches by 4.0 inches, with the long dimensions parallel to the yarn direction to be tested. They were prepared by use of the NAEF Model B Punch Press fitted with the appropriate die for the test. The tearing strength data were reported in grams to the nearest full-scale division.

Bursting Strength

The bursting strength data were collected by rupturing a 4-inch square specimen using a Ball burst apparatus mounted on the Scott Tester. The bursting strength for each specimen tested was reported to the nearest 1.0 pound. This procedure was in accordance with Federal Test Standard Number 191, Method 5120 (65).

Fabric Count

The warp and filling fabric count for the worn and non-worn trousers was determined initially and after 5, 15, and 20 laundering periods. This count was taken on true grain for a length of 1 inch in 4 different areas of the trousers. The right and left front counts were taken between the front and side pocket and as close to the waistband as possible. The right and left back counts were taken below the hip pockets near the center of the garment section.

The designated trouser areas were laid smoothly and without tension on top of a light box, and the Suter yarn counter was used to determine the number of yarns per inch. This procedure was in accordance with ASTM Designation D1910 (5f).

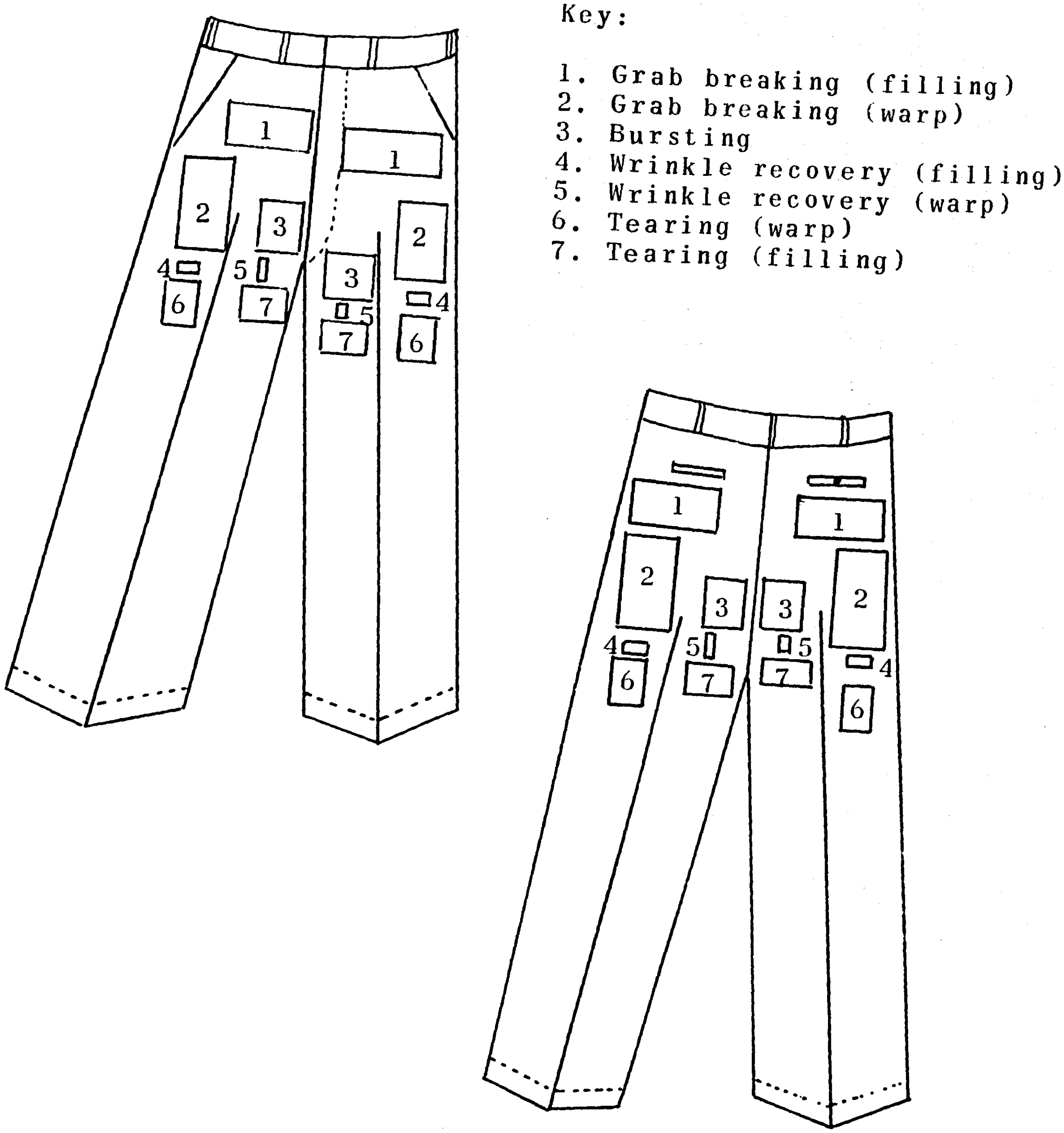

Fig. 1. Front and back trouser views showing location of test specimens.

CHAPTER III

PRESENTATION OF DATA AND DISCUSSION OF FINDINGS

The data presented in this chapter represent an evaluation of 4 types of durable press finishes which were applied to all-cotton khaki twill work trousers. All trousers were made from the same 3/1 twill fabric with the only differences being the type of finishes applied. The chemical modifications of the trousers designated as Type 1 vapor phase and Type 2 vapor phase were obtained through variations in the concentration of an exploratory reagent, and through time and temperature variants in the vapor or gaseous phase of the treatment. The other types of finishes represented the conventional pad-dry-cure process and a post-cured proprietary treatment. The finishes will be represented in the tables, figures, and discussion by the following abbreviations: Type 1 vapor phase, 1-VP; Type 2 vapor phase, 2-VP; pad-dry-cure, 3-PDC; and proprietary, 4-PCP.

Throughout the study, after 5, 10, 15, and 20 laundering periods, the trousers were evaluated for durable press appearance, crease retention, crease wear, soiling, and broken yarns. Dimensional stability and fabric count were determined after 5, 15, and 20 launderings. At the completion of the study, physical tests including wrinkle recovery, breaking strength, tearing strength, and bursting strength were applied to the worn trousers while the non-worn trousers were tested initially and after 5, 10, 15, and 20 laundering periods with respect to these parameters.

Two pairs of non-worn trousers, representative of each finish type, were removed from the study for evaluation purposes at each evaluation period. None of the worn trousers were removed deliberately, but many pairs of those treated with the pad-dry-cure and proprietary finishes were removed due to excessive wear. Figure 2 shows the accumulative number of trousers by finish type and period that were removed from the study because of excessive wear. The original design of a balanced randomized block for the worn-laundered trousers, therefore, was disrupted with failures from these 2 types of durable press treatments.

A rank order arrangement of the mean values obtained from each evaluation procedure is included in the discussion of the data which follow, with the highest level of performance in each instance being assigned Rank 1. The non-worn trousers are ranked by types and laundering periods, and the worn trousers by trouser types after each of the wear-laundering periods, when applicable, and in other instances after the completion of the study.

Four different procedures were used in the analysis of the data. An analysis of variance was employed to determine significant differences between the variables when data from the initial trousers were not available. An analysis of covariance was used when initial data were recorded. These respective procedures were used on the worn and non-worn trousers' data to determine the effects of wear-laundering and laundering only on the 4 different finishes. Duncan's multiple range test was applied as a means of identifying differences in treatment means and in determining the effects of laundering periods on each finish type. Fisher's t-test was used as a measurement to determine significant differences between the mean values of the non-worn and worn trousers representative of each of the types.

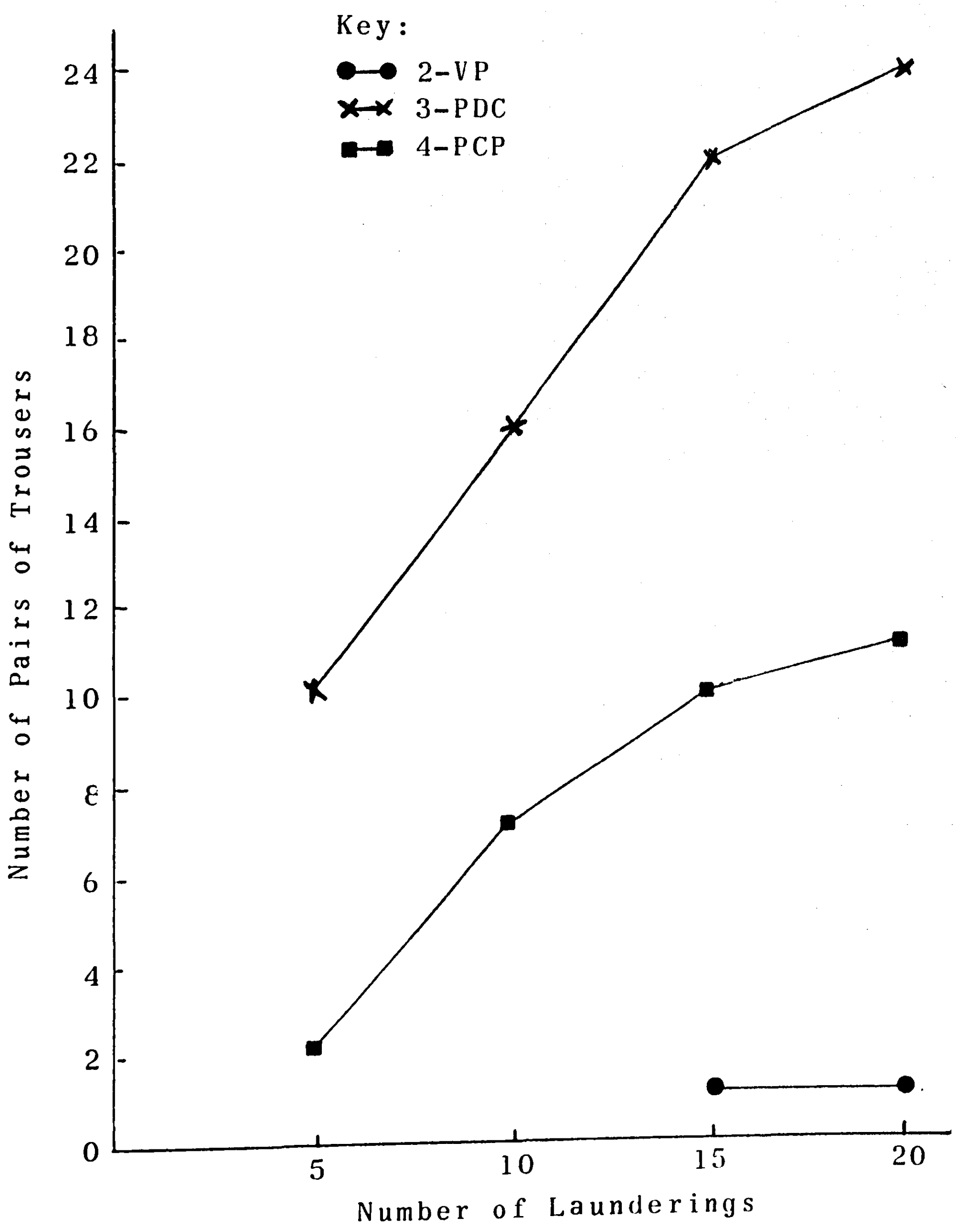

Fig. 2. Number of worn trousers removed by laundering periods due to excessive wear.

Durable Press Appearance

The experimental trousers were evaluated with reference to durable press performance after each 5 periods of laundering and wear-laundering. These evaluations were made by 3 panelists who were trained especially for that purpose. Thirty-two observations were required for evaluating the non-worn trousers and 374 for the worn and laundered trousers. Mean data from these evaluations and the results of an analysis of variance followed by Duncan's multiple range test are presented in Tables Ia through Ih and in Figure 3.

From a study of the mean durable press appearance values in Tables Ia and Ib, there is evidence that the values representative of the non-worn trousers ranged from a high of 4.0 to a low of 2.9 while the values for the worn trousers were confined to a narrower margin, from 3.9 to 3.2. Results of an analysis of these data, as shown in Table Ic, revealed that there was a significant difference between the mean scores of the non-worn trouser types averaged across laundering periods, and between laundering period mean scores averaged across trouser types. These differences were significant at the α 0.01 level. The general downward trend in durable press smoothness ratings for all-cotton trousers at successive laundering periods was in accord with findings by Roemhildt (56).

Results of a single factor analysis of variance, Table Id, for the worn trousers showed similar results with regard to trouser finish types. Significant differences were evident at each evaluation period.

In ranking the mean durable press appearance values, Rank 1 was assigned to the highest values. The rank ordered mean values, both for the non-worn and the worn trousers, are found in Tables Ie and If. These tables exhibit the superior performance of the pad-dry-cure and the proprietary treatments. The trousers thus treated were consistently ranked higher than were the 2 vapor phase treated types throughout the evaluation periods. The non-worn pad-dry-cure and proprietary treated trousers displayed respective mean values of 3.9 and 3.8; whereas, the 2 vapor phase treated trousers had respective values of 3.3 and 3.2. When the values for the various laundering periods were averaged across trouser types, the greatest degree of overall smoothness was evident after 5 laundering periods, and the poorest performance was observed after 15 laundering periods as indicated by respective ranks of 1 and 4.

A study of the data for the worn trousers, Table If, demonstrated similar rankings with one exception. The lowest overall durable press value was observed after 20 wear-laundering periods.

Duncan's multiple range test of differences in mean values for non-worn and worn trousers, Tables Ig and Ih, confirmed these findings. When paired with other trouser types the trousers finished with the pad-dry-cure and the proprietary treatments continued to display durable press values which were significantly superior to those displayed by the two vapor phase treatments. There were no significant differences in any of the comparisons between the pad-dry-cure and the proprietary finishes or between the two vapor phase finishes, except in one instance. Evidence of a significant difference was indicated at the α 0.05 probability level when the trousers finished by the pad-dry-cure and the proprietary treatment were paired after 15 laundering periods. In this instance the pad-dry-cure finish excelled. A comparison of the durable press appearance values from the non-worn trousers on the basis of laundering periods showed that the values after 5 laundering periods were significantly superior to those obtained at other intervals. No other differences were noted.

According to the results of Fisher's t-test, there were no significant variances between the durable press means of the non-worn and worn trousers after 20 laundering and wear-laundering periods. These results indicated that wear had no effect on the durable press ratings for the 4 different finishes.

TABLE Ia

MEAN DURABLE PRESS APPEARANCE VALUES AND STANDARD DEVIATIONS OF NON-WORN TROUSERS

Mean Values

Trouser Type	Number of Launderings				Type Mean
	5	10	15	20	
1-VP	3.6	2.9	3.1	3.2	3.5
2-VP	3.6	3.3	2.9	3.4	3.3
3-PDC	4.0	3.9	3.8	3.8	3.9
4-PCP	4.0	3.8	3.7	3.8	3.8
Period Mean	3.8	3.5	3.4	3.5	3.5

Standard Deviations

Trouser Type	Number of Launderings			
	5	10	15	20
1-VP	0.4	0.2	0.1	0.2
2-VP	0.4	0.0	0.4	0.2
3-PDC	0.0	0.1	0.0	0.1
4-PCP	0.0	0.0	0.0	0.0

TABLE Ib

MEAN DURABLE PRESS APPEARANCE VALUES AND STANDARD DEVIATIONS OF WORN TROUSERS

Mean Values

Trouser Type	Number of Launderings				Type Mean
	5	10	15	20	
1-VP	3.4	3.3	3.3	3.2	3.3
2-VP	3.4	3.3	3.2	3.2	3.3
3-PDC	3.9	3.9	3.9	3.8	3.9
4-PCP	3.9	3.7	3.7	3.7	3.8
Period Mean	3.6	3.5	3.4	3.3	3.5

Standard Deviations

Trouser Type	Number of Launderings			
	5	10	15	20
1-VP	0.2	0.2	0.2	0.2
2-VP	0.2	0.3	0.2	0.2
3-PDC	0.1	0.2	0.1	0.1
4-PCP	0.2	0.2	0.2	0.2

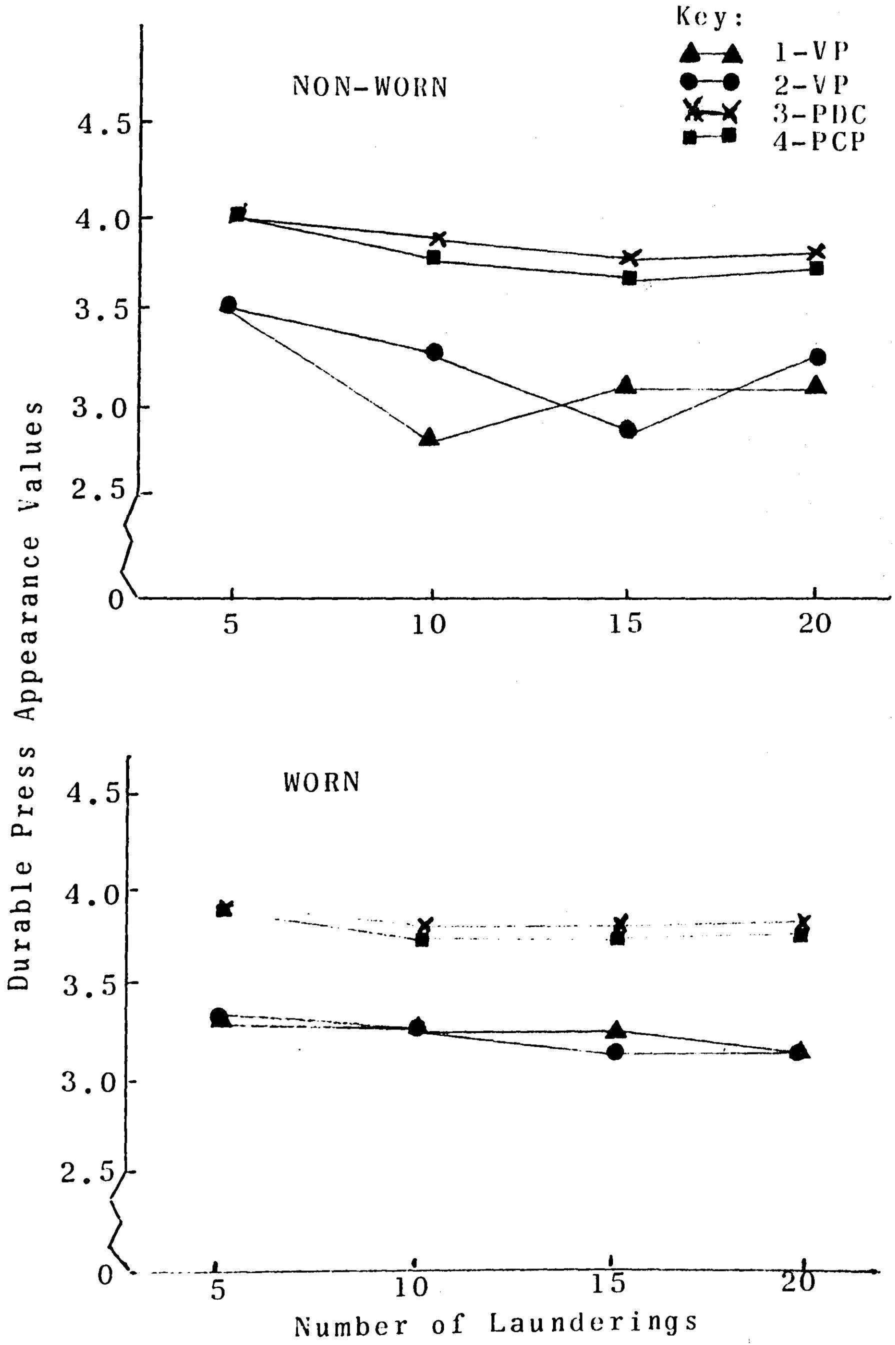

Fig. 3. Comparison of trouser types on the basis of durable press appearance values.

TABLE Ic

TWO-FACTOR ANALYSIS OF VARIANCE OF DURABLE PRESS APPEARANCE VALUES OF NON-WORN TROUSERS

Source of Variation	Degrees of Freedom	Mean Squares	F-Ratio	Probability of Greater F
Finish Types	3	1.04	30.89**	< 0.01
Launderings	3	0.23	6.54**	< 0.01
Interaction	9	0.04	1.17	0.38
Within	16	0.03		
Total	31			

**Indicates significance at $\alpha = 0.01$ level.

TABLE Id

SINGLE FACTOR ANALYSIS OF VARIANCE OF DURABLE PRESS APPEARANCE VALUES OF WORN TROUSERS

Wear Period	Source of Variation	Degrees of Freedom	Mean Squares	F-Ratio	Probability of Greater F
5	Between Types	3	2.4	74.99**	< 0.001
	Within	103	0.0		
	Total	106			
10	Between Types	3	2.2	36.41**	< 0.001
	Within	93	0.1		
	Total	96			
15	Between Types	3	2.0	52.77**	< 0.001
	Within	83	0.0		
	Total	86			
20	Between Types	3	1.8	39.78**	< 0.001
	Within	79	0.0		
	Total	82			

**Indicates significance at $\alpha = 0.01$ level or less.

TABLE Ie

RANK ORDERED MEAN DURABLE PRESS APPEARANCE VALUES OF NON-WORN TROUSERS

Types Averaged Across Launderings			Laundering Periods Averaged Across Types		
Rank*	Type	Mean	Rank*	Period	Mean
1	3-PDC	3.9	1	5	3.8
2	4-PCP	3.8	2	20	3.5
3	2-VP	3.3	3	10	3.5
4	1-VP	3.2	4	15	3.4

*Rank 1 assigned to highest durable press appearance value.

TABLE If

RANK ORDERED MEAN DURABLE PRESS APPEARANCE VALUES OF WORN TROUSERS BY PERIODS

Wear Period	Rank Order*	Trouser Type	Mean Durable Press Appearance	Period Averaged Over Types	
				Mean	Rank*
5	1 2 3 4	3-PDC 4-PCP 2-VP 1-VP	3.9 3.9 3.4 3.4	3.614	1
10	1 2 3 4	3-PDC 4-PCP 1-VP 2-VP	3.9 3.7 3.3 3.3	3.460	2
15	1 2 3 4	3-PDC 4-PCP 1-VP 2-VP	3.9 3.7 3.3 3.2	3.401	3
20	1 2 3 4	3-PDC 4-PCP 2-VP 1-VP	3.8 3.7 3.2 3.2	3.329	4

*Rank 1 assigned to highest durable press appearance score.

TABLE Ig

DUNCAN'S MULTIPLE RANGE TEST OF DIFFERENCES IN MEAN DURABLE PRESS APPEARANCE VALUES OF NON-WORN TROUSERS

Trouser Types Averaged Across Periods

Differences Between			Duncan Criterion	
Ranks	Types	Means	$\alpha = 0.05$	$\alpha = 0.01$
1-4	3-PDC - 1-VP	0.7**	0.2	0.3
1-3	3-PDC - 2-VP	0.6**	0.2	0.3
1-2	3-PDC - 4-PCP	0.0	0.2	0.3
2-4	4-PCP - 1-VP	0.7**	0.2	0.3
2-3	4-PCP - 2-VP	0.5**	0.2	0.3
3-4	2-VP - 1-VP	0.1	0.2	0.3

Laundering Periods Averaged Across Types

Differences Between			Duncan Criterion	
Ranks	Periods	Means	$\alpha = 0.05$	$\alpha = 0.01$
1-4	5-15	0.4**	0.2	0.3
1-3	5-10	0.3**	0.2	0.3
1-2	5-20	0.3**	0.2	0.3
2-4	20-15	0.1	0.2	0.3
2-3	20-10	0.1	0.2	0.3
3-4	10-15	0.1	0.2	0.3

**Indicates significance at $\alpha = 0.01$ level.

TABLE Ih

DUNCAN'S MULTIPLE RANGE TEST OF DIFFERENCES IN MEAN DURABLE PRESS APPEARANCE VALUES OF WORN TROUSERS BY PERIODS

Wear Period	Differences In			Duncan Criterion	
	Ranks	Types	Means	α = 0.05	α = 0.01
5	1-4	3-PDC - 1-VP	0.6**	0.1	0.1
	1-3	3-PDC - 2-VP	0.5**	0.1	0.1
	1-2	3-PDC - 4-PCP	0.0	0.1	0.1
	2-4	4-PCP - 1-VP	0.5**	0.1	0.1
	2-3	4-PCP - 2-VP	0.5**	0.0	0.1
	3-4	2-VP - 1-VP	0.1	0.0	0.1
10	1-4	3-PDC - 2-VP	0.6**	0.2	0.2
	1-3	3-PDC - 1-VP	0.6**	0.2	0.2
	1-2	3-PDC - 4-PCP	0.1	0.2	0.2
	2-4	4-PCP - 2-VP	0.5**	0.1	0.2
	2-3	4-PCP - 1-VP	0.5**	0.1	0.2
	3-4	1-VP - 2-VP	0.0	0.1	0.2
15	1-4	3-PDC - 2-VP	0.7**	0.2	0.2
	1-3	3-PDC - 1-VP	0.6**	0.2	0.2
	1-2	3-PDC - 4-PCP	0.2*	0.2	0.2
	2-4	4-PCP - 2-VP	0.5**	0.1	0.2
	2-3	4-PCP - 1-VP	0.5**	0.1	0.1
	3-4	1-VP - 2-VP	0.1	0.1	0.1
20	1-4	3-PDC - 1-VP	0.7**	0.2	0.3
	1-3	3-PDC - 2-VP	0.7**	0.2	0.3
	1-2	3-PDC - 4-PCP	0.2**	0.2	0.3
	2-4	4-PCP - 1-VP	0.5**	0.1	0.2
	2-3	4-PCP - 2-VP	0.5**	0.1	0.2
	3-4	2-VP - 1-VP	0.0**	0.1	0.1

*Indicates significance at α = 0.05 level.

**Indicates significance at α = 0.01 level.

Crease Retention

Data related to the crease retention properties of the experimental trousers, non-worn and worn, are presented in Tables IIa through Table IIi. Evaluations related to the creases were performed initially and after each 5 laundering periods by 3 panelists trained in the procedure as prescribed by AATCC 88c-1973 (4a). Forty observations were made in evaluating the non-worn and 495 for the worn trousers. A high percentage of failures in the trousers which were treated with the pad-dry-cure finish resulted in a reduction in the number of observations for these trousers.

The unadjusted mean crease retention values are shown in Table IIa,and the adjusted means and standard deviations are recorded in Tables IIb and IIc. A study of Table IIb and Figure 4 shows that the non-worn proprietary finished trousers displayed the highest overall mean value of 4.0. The other treatments followed with respective means of 3.8 for the pad-dry-cure; 3.2 for Type 2 vapor phase; and 2.6 for Type 1 vapor phase. Data from the worn trousers continued to show this same relationship, but the effects of wear were reflected in lower crease retention values being recorded for all 4 finishes. Similar results were obtained from 2 variations of a vapor phase treatment conducted by Sims (61). The performance of both trouser types studied by Sims decreased with each 5 additional wear-laundering periods.

An analysis of the mean data as presented in Tables IId and IIe indicated a significant difference between the trouser types and between laundering periods at the α 0.01 level as far as the non-worn trousers were concerned. The interaction of the 2 variables, however, was not significant. When a single factor analysis of variance was applied to the data from the worn trousers, significant differences again were noted between trouser types at each evaluation period.

Tables IIf and IIg provide a rank ordered arrangement of the mean crease retention values both for the non-worn and for the worn trousers. As can be noted from these tables, ranks ranged from 1 through 4 with Rank 1 being assigned to the trouser type with the highest crease sharpness value. An examination of the data with regard to ranks showed that the proprietary and the pad-dry-cure finishes constantly ranked 1 and 2. The rank order for laundering periods revealed that there were no differences in order for the non-worn and worn trousers. The deterioration of the creases was related to the number of laundering and wear-laundering periods to which the trousers were exposed.

When the means which were indicative of the non-worn trouser creases were paired for Duncan's multiple range test, Table IIh, a significant difference was indicated for each paired combination either at the α 0.05 or at the α 0.01 level. Generally, the more restrictive criterion was evident between the proprietary finish and the 2 vapor phase finishes. There was a significant difference, however, between the proprietary and pad-dry-cure finish at the α 0.05 level. When the pad-dry-cure finish was paired with the vapor phase finishes, significant differences were noted between Type 1 vapor phase at the α 0.01 level and between Type 2 vapor phase at the α 0.05 level. The 2 vapor phase finishes were found to differ significantly at the α 0.05 level. When laundering periods were paired, significant differences were shown when all periods were paired with Period 5.

Data for the worn trousers, Table IIi, were consistent in indicating a significant difference after each wear period when the crease retention values of the proprietary and the pad-dry-cure finishes were paired with the vapor phase finishes. There were no significant differences in any of the comparisons between the creases provided by the pad-dry-cure and the proprietary finishes, except in 1 instance. When paired after 20 laundering periods there was evidence of a significant difference at the α 0.05 level. In this instance the proprietary finish excelled. No significant differences were recorded for the paired vapor phase treatments with regard to crease retentive properties.

Fisher's t-test was applied to the mean values of the non-worn and worn trouser types. The results showed that after 20 laundering and wear-laundering periods wear had no effect on crease retention values.

As indicated by the data reviewed, the proprietary and pad-dry-cure finishes displayed an overall crease retention performance superior to that of the 2 vapor phase finishes. They, too, had the highest number of trouser failures.

TABLE IIa

UNADJUSTED MEAN CREASE RETENTION VALUES

Non-Worn Trousers

Trouser Type	Number of Launderings					Type* Mean
	0	5	10	15	20	
1-VP	4.85	3.50	2.50	2.50	1.80	2.57
2-VP	5.00	4.50	3.00	2.65	2.85	3.25
3-PDC	5.00	4.65	3.35	3.50	4.00	3.87
4-PCP	4.50	4.15	4.15	4.15	3.50	3.99
Period Mean	4.95	4.20	3.25	3.20	3.04	3.42

Worn Trousers

Trouser Type	Number of Launderings					Type Mean
	0	5	10	15	20	
1-VP	4.93	2.98	2.68	2.19	2.07	3.71
2-VP	4.90	2.91	2.50	2.37	2.13	3.70
3-PDC	4.93	4.18	4.00	3.84	2.95	4.97
4-PCP	4.96	4.08	3.93	3.72	3.68	5.09
Period Mean	4.93	3.46	3.10	2.75	2.52	4.36

*Does not include initial data.

TABLE IIb

COVARIANCE ADJUSTED MEAN CREASE RETENTION VALUES AND STANDARD DEVIATIONS OF NON-WORN TROUSERS

Mean Values

Trouser Type	Number of Launderings				Type Mean
	5	10	15	20	
1-VP	3.5	2.5	2.5	1.8	2.5
2-VP	4.5	2.9	2.6	2.9	3.2
3-PDC	4.6	3.3	3.5	3.9	3.8
4-PCP	4.4	4.1	4.1	3.7	4.0
Period Mean	4.5	3.1	3.1	3.0	3.4

Standard Deviations

Trouser Type	Initial	Number of Launderings			
		5	10	15	20
1-VP	0.1	0.7	0.7	0.3	0.7
2-VP	0.1	0.7	0.0	0.5	0.2
3-PDC	0.0	0.5	0.5	0.7	0.0
4-PCP	0.4	0.3	0.2	0.2	0.7
Overall	0.2	0.6	0.7	0.8	0.9

TABLE IIc

COVARIANCE ADJUSTED MEAN CREASE RETENTION VALUES AND STANDARD DEVIATIONS OF WORN TROUSERS

Mean Values

Trouser Type	Number of Launderings				Type Mean
	5	10	15	20	
1-VP	2.9	2.7	2.2	2.1	2.4
2-VP	2.9	2.5	2.4	2.1	2.4
3-PDC	4.2	4.0	3.8	2.9	3.7
4-PCP	4.1	3.9	3.7	3.7	3.8
Period Mean	3.5	3.3	3.0	2.7	3.1

Standard Deviations

Trouser Type	Initial	Number of Launderings			
		5	10	15	20
1-VP	0.2	0.6	0.6	0.6	0.6
2-VP	0.5	0.5	0.5	0.6	0.6
3-PDC	0.1	0.4	0.2	0.5	0.6
4-PCP	0.1	0.2	0.3	0.5	0.4
Overall	0.2	0.8	0.8	0.9	0.9

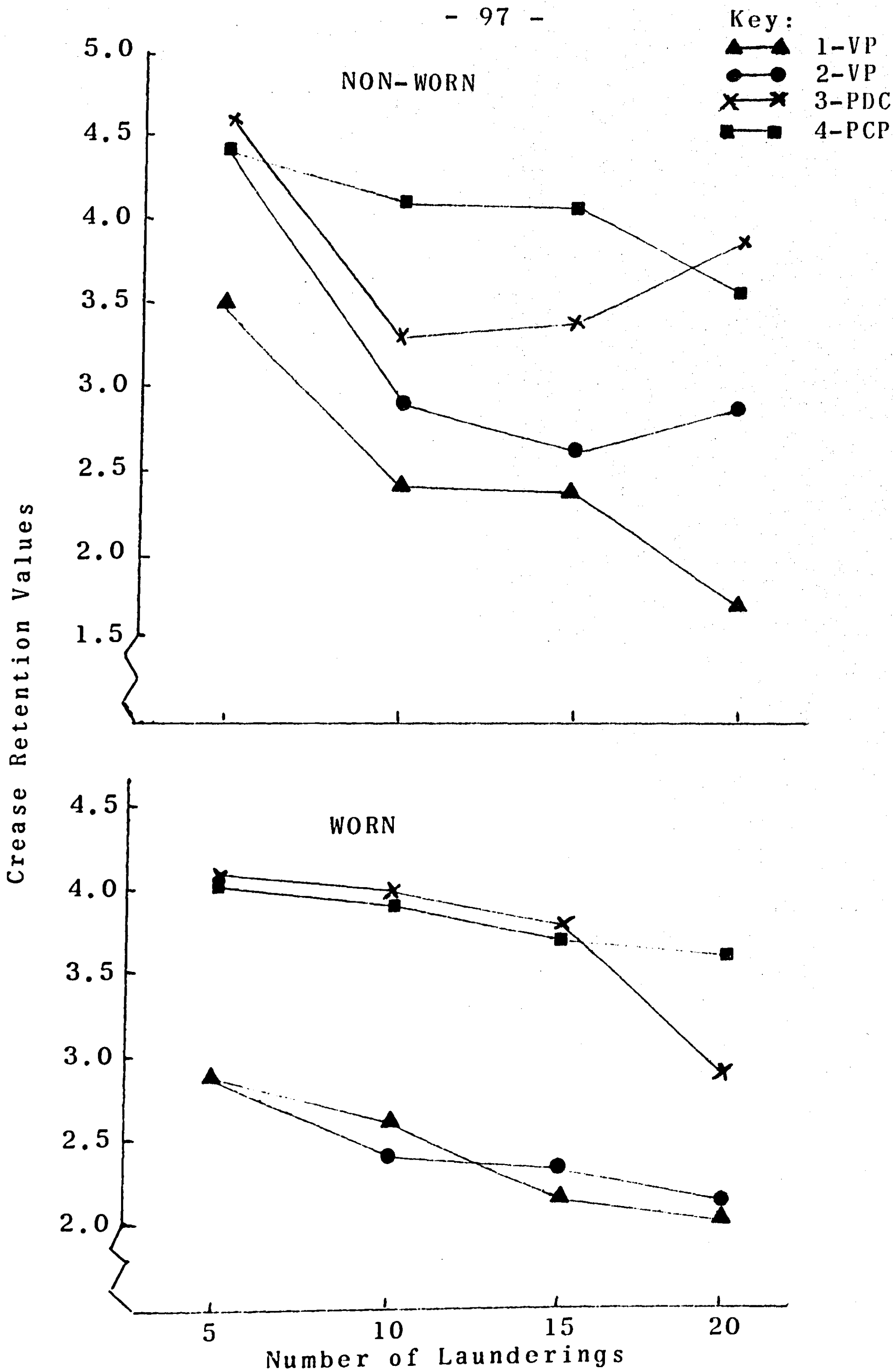

Fig. 4. Comparison of trouser types on the basis of crease retention values.

TABLE IId

TWO-FACTOR ANALYSIS OF COVARIANCE, CREASE RETENTION ADJUSTED MEAN VALUES OF NON-WORN TROUSERS

Source of Variation	Degrees of Freedom	Mean Squares	F-Ratio	Probability of Greater F
Finish Types	3	3.5	13.66**	< 0.01
Launderings	3	2.1	8.49**	< 0.01
Interaction	9	0.3	1.11	0.41
Within	15	0.3		
Total	30			

**Indicates significance at $\alpha = 0.01$ level.

TABLE IIe

ANALYSIS OF COVARIANCE OF CREASE RETENTION VALUES OF WORN TROUSERS

Wear Period	Source of Variation	Degrees of Freedom	Mean Squares	F-Ratio	Probability of Greater F
5	Between Types	3	12.3	50.57**	< 0.01
	Within	102	0.3		
	Total	105			
10	Between Types	3	14.3	67.54**	< 0.01
	Within	92	0.2		
	Total	95			
15	Between Types	3	13.8	44.69**	< 0.01
	Within	82	0.3		
	Total	85			
20	Between Types	3	11.9	37.58**	< 0.01
	Within	79	0.3		
	Total	82			

**Indicates significance at $\alpha = 0.01$ level.

TABLE IIf

RANK ORDERED MEAN CREASE RETENTION VALUES
OF NON-WORN TROUSERS

Types Averaged Across Launderings			Laundering Periods Averaged Across Types		
Rank*	Type	Mean	Rank*	Period	Mean
1	4-PCP	4.0	1	5	4.5
2	3-PDC	3.8	2	10	3.1
3	2-VP	3.2	3	15	3.1
4	1-VP	2.6	4	20	3.0

*Rank 1 assigned to highest crease retention score.

TABLE IIg

RANK ORDERED MEAN CREASE RETENTION VALUES
OF WORN TROUSERS BY PERIODS

Wear Period	Rank Order*	Trouser Type	Adjusted Mean Crease Retention	Period Averaged Over Types	
				Mean	Rank*
5	1 2 3 4	3-PDC 4-PCP 1-VP 2-VP	4.2 4.1 3.0 2.9	3.4607	1
10	1 2 3 4	3-PDC 4-PCP 1-VP 2-VP	4.0 3.9 2.7 2.5	3.1093	2
15	1 2 3 4	3-PDC 4-PCP 2-VP 1-VP	3.8 3.7 2.4 2.2	2.7506	3
20	1 2 3 4	4-PCP 3-PDC 2-VP 1-VP	3.7 3.0 2.1 2.1	2.5179	4

*Rank 1 assigned to highest crease retention score.

TABLE IIh

DUNCAN'S MULTIPLE RANGE TEST OF DIFFERENCES IN MEAN CREASE RETENTION VALUES OF NON-WORN TROUSERS

Trouser Types Averaged Across Periods

Differences Between			Duncan Criterion	
Ranks	Types	Means	α = 0.05	α = 0.01
1-4	4-PCP - 1-VP	1.9**	0.56	0.74
1-3	4-PCP - 2-VP	1.2**	0.54	0.72
1-2	4-PCP - 3-PDC	0.6*	0.51	0.69
2-4	3-PDC - 1-VP	1.3**	0.54	0.72
2-3	3-PDC - 2-VP	0.6*	0.51	0.69
3-4	2-VP - 1-VP	0.7*	0.51	0.69

Laundering Periods Averaged Across Types

Differences Between			Duncan Criterion	
Ranks	Periods	Means	α = 0.05	α = 0.01
1-4	5-20	1.5**	0.56	0.74
1-3	5-15	1.4**	0.54	0.72
1-2	5-10	1.3**	0.51	0.69
2-4	10-20	0.1	0.54	0.72
2-3	10-15	0.1	0.51	0.69
3-4	15-20	0.1	0.51	0.69

*Indicates significance at α = 0.05 level.
**Indicates significance at α = 0.01 level.

TABLE IIi

DUNCAN'S MULTIPLE RANGE TEST OF DIFFERENCES IN MEAN CREASE RETENTION VALUES OF WORN TROUSERS BY PERIODS

Wear Period	Differences In			Duncan Criterion	
	Ranks	Types	Adjusted Means	α = 0.05	α = 0.01
5	1-4	3-PDC - 2-VP	1.3**	0.31	0.41
	1-3	3-PDC - 1-VP	1.2**	0.30	0.40
	1-2	3-PDC - 4-PCP	0.1	0.29	0.39
	2-4	4-PCP - 2-VP	1.2**	0.28	0.36
	2-3	4-PCP - 1-VP	1.1**	0.26	0.35
	3-4	1-VP - 2-VP	0.1	0.26	0.34
10	1-4	3-PDC - 2-VP	1.5**	0.32	0.42
	1-3	3-PDC - 1-VP	1.3**	0.31	0.41
	1-2	3-PDC - 4-PCP	0.1	0.31	0.41
	2-4	4-PCP - 2-VP	1.4**	0.27	0.35
	2-3	4-PCP - 1-VP	1.2**	0.26	0.34
	3-4	1-VP - 2-VP	0.2	0.24	0.31
15	1-4	3-PDC - 1-VP	1.7**	0.48	0.36
	1-3	3-PDC - 2-VP	1.5**	0.47	0.62
	1-2	3-PDC - 4-PCP	0.1	0.47	0.62
	2-4	4-PCP - 1-VP	1.5**	0.34	0.44
	2-3	4-PCP - 2-VP	1.3**	0.32	0.43
	3-4	2-VP - 1-VP	0.2	0.29	0.39
20	1-4	4-PCP - 1-VP	1.6**	0.36	0.47
	1-3	4-PCP - 2-VP	1.5**	0.35	0.46
	1-2	4-PCP - 3-PDC	0.7*	0.53	0.70
	2-4	3-PDC - 1-VP	0.9**	0.53	0.70
	2-3	3-PDC - 2-VP	0.8**	0.51	0.67
	3-4	2-VP - 1-VP	0.1	0.29	0.39

*Indicates significance at α = 0.05 level.
**Indicates significance at α = 0.01 level.

Soiling

A preliminary step to laundering the worn experimental trousers included a visual examination of each pair and the assignment of a soil rating value before and after the first laundering cycle. Successive evaluations occurred before and after each fifth laundering period. The rating scale ranged from 1 to 5, with a value of 5 indicating the least amount of soiling. The total number of observations required to obtain the data was 928. Data representative of soiling values are tabulated in Tables IIIa through IIIc and graphically presented in Figure 5.

As evidenced from the mean soiling values obtained before and after laundering and shown in Table IIIa, all 4 trouser finishes showed some soil release properties. The soiling values after laundering were higher than they were before laundering with 2 exceptions. After 15 and 20 laundering periods, the trousers finished with the proprietary finish displayed a mean value of 3.6 before and after laundering and, therefore, showed no evidence of soil release. The pad-dry-cure finished trousers failed to release any soil during the twentieth laundering period as indicated by a soiling value of 3.7 before and after the laundering period.

A study of the mean soil release values, Table IIIb, indicated that the highest adjusted soil release score, 0.81, was recorded for Type 2 vapor phase finish after the first laundering period. The lowest mean of 0.01 was reported for the proprietary finish after 20 laundering periods. After 5, 10, and 15 laundering periods, the high and low soil release scores varied between the 4 finishes. After 5 and 10 laundering periods, there were tie scores between the 2 vapor phase finishes and the pad-dry-cure finish. After 20 laundering periods the 2 vapor phase treatments were shown to be more effective in the release of soil than were the other finishes.

An examination of the data in Table IIIc indicated that no significant differences were found between the trouser types at any evaluation period with regard to soil release values. Soil ratings recorded by Ball (7) reflected similar findings by indicating there were no significant differences between 2 delayed cured durable press finishes for all-cotton and cotton-polyester trousers.

In the study reported in this manuscript, 6 pairs of the pad-dry-cure finished trousers and 19 pairs of the proprietary finished trousers completed the study. These trousers were worn by men who were not involved in heavy maintenance work and, consequently, they were not as soiled as were the vapor phase treated trousers. The soil release values could be misleading for no attempt was made to regulate the amount of soiling. The ratings were often reflective of physical activity and weather conditions.

TABLE IIIa

MEAN SOIL VALUES OF WORN TROUSERS BEFORE AND AFTER LAUNDERING

Trouser Type	Number of Launderings									
	1		5		10		15		20	
	Before	After	Before	After	Before	After	Before	After	Before	After
1-VP	3.3	3.9	3.6	3.7	3.3	3.7	3.4	3.5	3.2	3.4
2-VP	3.6	4.3	3.5	3.9	3.3	3.6	3.4	3.6	3.4	3.9
3-PDC	3.5	4.1	3.5	3.9	3.6	3.8	3.7	3.9	3.7	3.7
4-PCP	3.4	3.9	3.6	3.8	3.6	3.7	3.6	3.6	3.5	3.5
Totals	3.4	4.05	3.6	3.8	3.4	3.7	3.5	3.7	3.4	3.6

TABLE IIIb

COVARIANCE ADJUSTED MEAN SOIL RELEASE VALUES AND STANDARD DEVIATIONS OF WORN TROUSERS

Mean Values

Trouser Type	Number of Launderings				
	1	5	10	15	20
1-VP	0.55	0.14	0.34	0.11	0.15
2-VP	0.81	0.33	0.32	0.22	0.10
3-PDC	0.67	0.33	0.34	0.22	0.04
4-PCP	0.58	0.20	0.23	0.04	0.01
Period Mean	0.65	0.25	0.31	0.15	0.75

Standard Deviations

Trouser Type	Number of Launderings				
	1	5	10	15	20
1-VP	0.7	0.3	0.5	0.3	0.4
2-VP	0.7	0.5	0.6	0.4	0.3
3-PDC	0.6	0.5	0.5	0.4	0.0
4-PCP	0.9	0.4	0.4	0.0	0.0
Totals	0.7	0.4	0.5	0.3	0.3

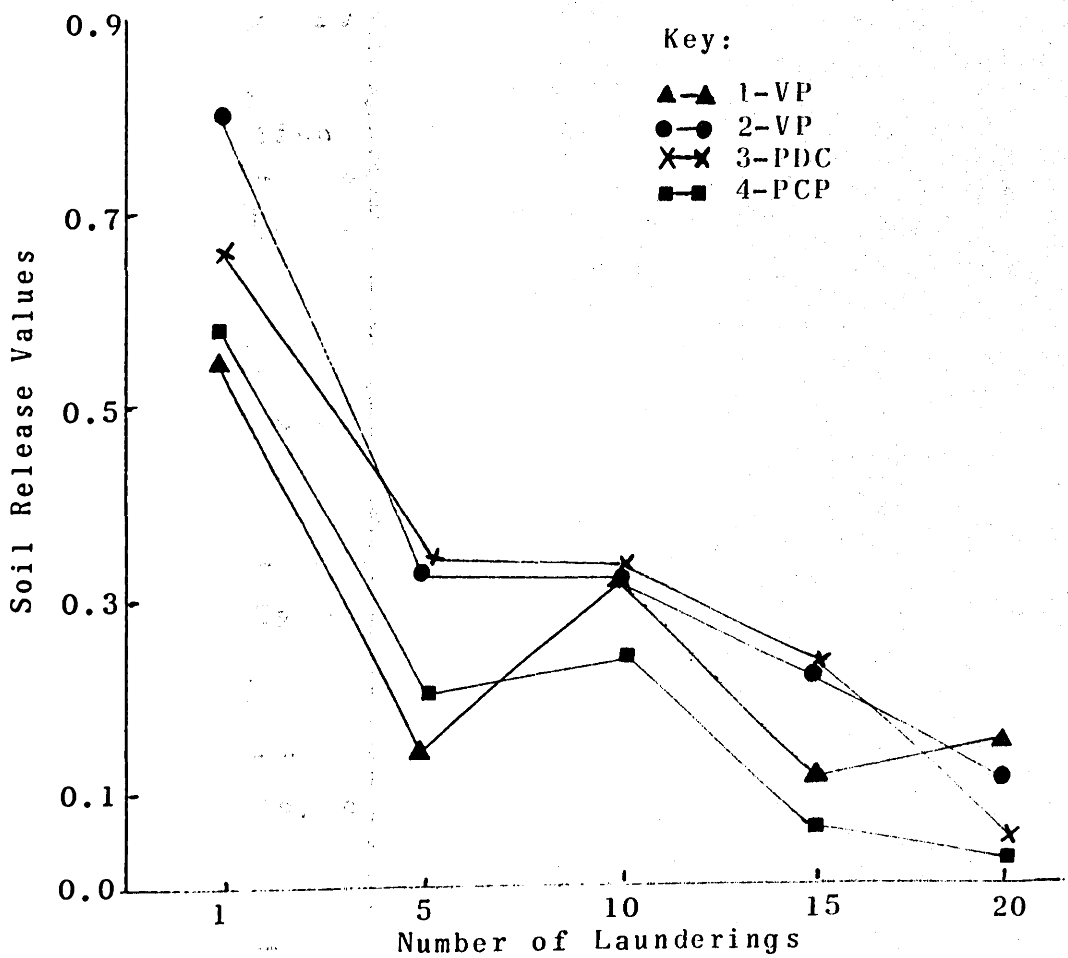

Fig. 5. A comparison of the worn trouser types on the basis of adjusted soil release values.

TABLE IIIc

ANALYSIS OF COVARIANCE OF SOIL RELEASE VALUES OF WORN TROUSERS

Wear Period	Source of Variation	Degrees of Freedom	Mean Squares	F-Ratio	Probability of Greater F
1	Between Types	2	0.3	1.10	0.36
	Within	88	0.3		
	Total	91			
5	Between Types	3	0.3	1.87	0.14
	Within	102	0.1		
	Total	105			
10	Between Types	3	0.0	0.43	0.73
	Within	89	0.1		
	Total	92			
15	Between Types	3	0.1	1.87	0.14
	Within	81	0.1		
	Total	84			
20	Between Types	3	0.1	0.97	0.41
	Within	79	0.1		
	Total	82			

Wrinkle Recovery Performance

Wrinkle recovery values were determined warpwise and fillingwise for the non-worn trousers initially and after each 5 laundering periods, and for the worn trousers at the termination of the 20 wear-laundering periods. The specimens were prepared from the areas of each pair of trousers as shown in Figure 1. Thirty-two observations were made in evaluating the non-worn trousers with regard to their recovery from wrinkles, and 71 were required for the worn trousers.

Mean wrinkle recovery values which were obtained by combining the warp plus the filling values for the trousers are tabulated along with the standard deviations in Table IVa. A study of the data from the non-worn trousers showed that the pad-dry-cure and the proprietary finishes provided a higher recovery performance at each laundering period than did the 2 vapor phase finishes. Results also showed that the wrinkle recovery values for all types of trousers deteriorated as the number of laundering periods increased. There was an exception to this finding. After 10 laundering periods the recovery of the Type 2 vapor phase finished trousers showed a slight increase of 2 points over the previous evaluation period. The highest earned wrinkle recovery score was reported for the pad-dry-cure finish with an initial mean of 311.5. The lowest mean was recorded for Type 2 vapor phase finish, after 20 laundering periods, but the margin of difference between the 2 vapor phase finishes at this point was very slight with means of 233.0 for Type 1 and 230.5 for finish Type 2. Values obtained from the worn trousers after 20 laundering periods were higher than those from the trousers that were laundered only, although the relationship remained the same in both categories of trousers. These relationships are graphically illustrated in Figure 6.

When crease-resisting cotton fabrics were evaluated in other laboratories, the reported wrinkle recovery values for the selected vapor treatments were higher than those recorded for the 2 vapor phase treatments evaluated in this study. Guthrie (23) found that cotton fabrics treated with HCl-paraformaldehyde vapors produced wrinkle recovery angles of 270°. Marsh (37) recorded wrinkle recovery values of 283°, warp plus filling, using cotton fabrics and gaseous formaldehyde. Further study by Mehta (39) concerning wrinkle recovery performance showed that cotton fabrics treated with varying percentages of glyoxal produced wrinkle recovery values ranging from 216° to 277°.

Results of a 2 factor analysis of variance on the wrinkle recovery data from the non-worn trousers are recorded in Table IVc. These data showed a significant difference between trouser finishes, and between laundering periods. The interaction between types and periods, however, was not significant. The results of a single factor analysis of variance, Table IVd, showed there was a significant difference between the trouser finishes with regard to the wrinkle recovery properties of the trousers which had been exposed to 20 wear-laundering periods.

The rank ordered arrangement of the mean wrinkle recovery values is given in Tables IVe and IVf. Rank 1 was assigned to the highest recovery score. As is evident from these data the pad-dry-cure and proprietary finishes were consistently awarded ranks 1 and 2, respectively. The lower ranks, 3 and 4, were assigned to the 2 vapor phase finishes. This rank order was noted both for the non-worn and for the worn trousers indicating that wear had no effect on the rank order of the wrinkle recovery values for the 4 trouser finishes.

When the mean values from the non-worn trousers were paired for Duncan's multiple range test, Table IVg, the pad-dry-cure treatment displayed wrinkle recovery values superior to those recorded for the other finishes. A superior performance by the proprietary finish was indicated when trousers of that finish were compared with those from the vapor phase treatments. When the 2 vapor phase treatments were paired, no significant differences were shown. These same relationships existed for the worn trousers, with 1 exception. The Type 1 vapor phase treatment was significantly better with regard to wrinkle recovery properties than was the Type 2 vapor phase treatment. These data are recorded in Table IVh.

A comparison of the data concerning laundering periods (Table IVe) and their effect upon finish types revealed that there were significant differences between the initial wrinkle recovery values and the values obtained at the laundering periods. The wrinkle recovery values recorded after 5 laundering periods were significantly different when paired with those obtained after 15 and 20 periods. A significant difference also was shown between values obtained after 10 and 20 laundering periods. Advantages were noted for the lesser number of launderings in all instances. The trousers treated with the pad-dry-cure and the proprietary finishes displayed a better over-all wrinkle recovery performance than did the 2 types of vapor phase treated trousers.

Fisher's t-test was applied to provide an additional analysis of the wrinkle recovery performance of the non-worn and worn trousers. Results showed that wear had an effect on the Type 1 vapor phase and the proprietary finished trousers after 20 laundering periods. When the non-worn and worn mean values for Type 2 vapor phase and for the pad-dry-cure treated trousers were compared, wear was shown to have had no effect.

TABLE IVa

MEAN WRINKLE RECOVERY VALUES (WARP + FILLING)

Trouser Type	Non-Worn Trousers						Worn Trousers
	Number of Launderings					Type Mean	After 20 Launderings
	0	5	10	15	20		
1-VP	269.0	250.0	238.0	234.0	233.0	244.8	246.4
2-VP	265.0	244.5	246.5	234.0	230.5	244.1	236.0
3-PDC	311.5	294.5	284.5	281.5	273.0	289.0	286.4
4-PCP	300.5	286.5	281.0	276.0	258.5	280.5	276.5
Period Mean	286.5	268.9	262.5	256.4	248.8	264.6	252.7

TABLE IVb

STANDARD DEVIATIONS OF WRINKLE RECOVERY VALUES

Trouser Type	Non-Worn Trousers						Worn Trousers
	Number of Launderings					Type Mean	After 20 Launder-ings
	0	5	10	15	20		
1-VP	4.2	22.6	5.7	7.1	4.2	16.5	8.5
2-VP	9.9	13.4	13.4	4.2	2.1	14.7	11.8
3-PDC	0.7	7.8	6.4	3.5	4.2	14.4	8.2
4-PCP	0.7	6.4	0.0	2.8	2.1	14.7	8.1
Period Mean	21.7	25.7	22.6	24.3	19.2	25.2	20.1

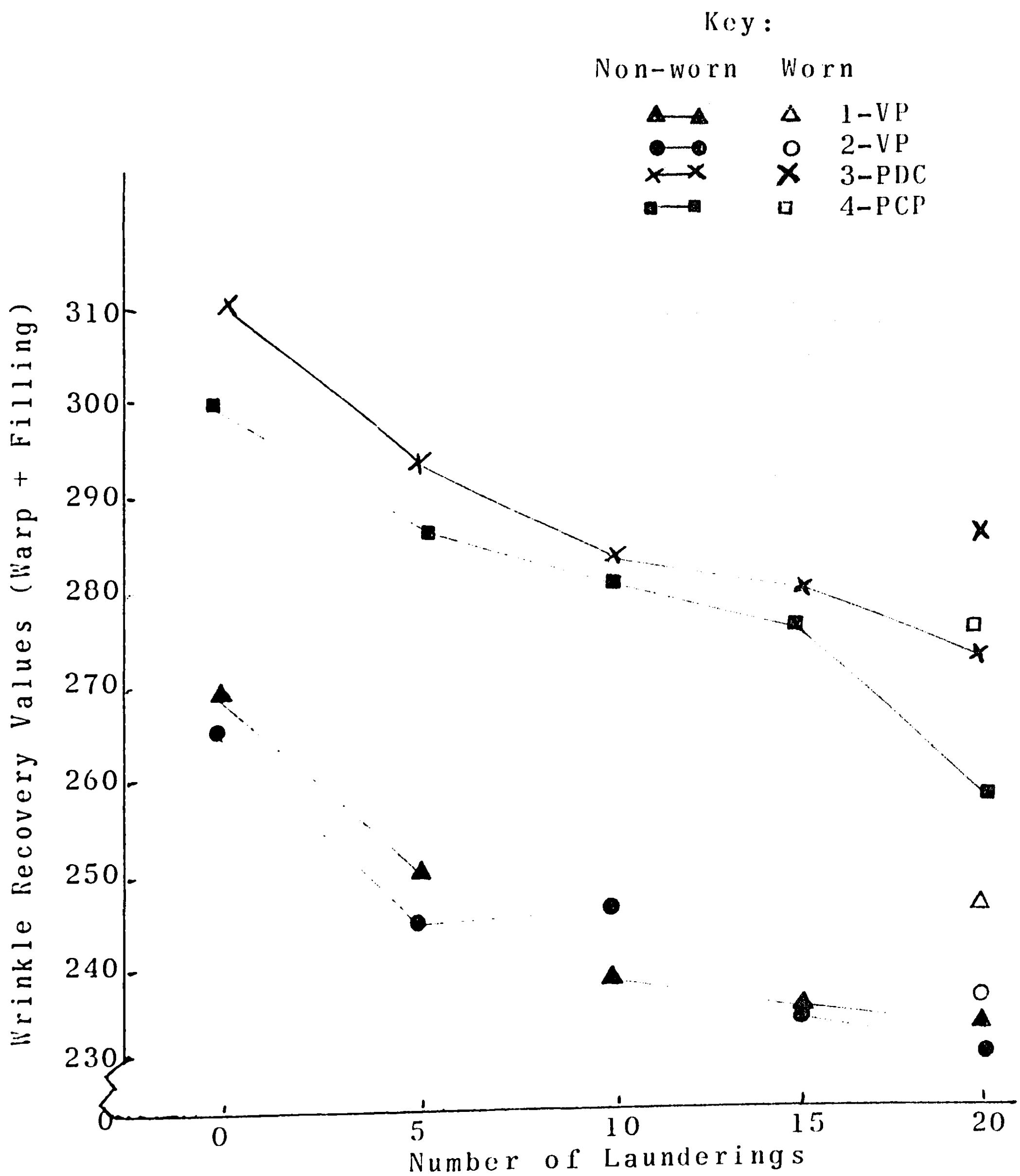

Fig. 6. Comparison of trouser types on the basis of wrinkle recovery values.

TABLE IVc

TWO-FACTOR ANALYSIS OF VARIANCE OF WRINKLE RECOVERY VALUES OF NON-WORN TROUSERS

Source of Variation	Degrees of Freedom	Mean Squares	F-Ratio	Probability of Greater F
Finish Types	3	5534.9	85.35**	< 0.01
Launderings	4	1642.3	25.33**	< 0.01
Interaction	12	28.2	0.44	0.93
Within	20	64.9		
Total	39			

**Indicates significance at $\alpha = 0.01$ level.

TABLE IVd

SINGLE FACTOR ANALYSIS OF VARIANCE OF WRINKLE RECOVERY VALUES OF WORN TROUSERS

Wear Period	Source of Variation	Degrees of Freedom	Mean Squares	F-Ratio	Probability of Greater F
20	Between	3	7393.0	79.83**	< 0.01
	Within	67	92.6		
	Total	70			

**Indicates significance at $\alpha = 0.01$ level.

TABLE IVe

RANK ORDERED MEAN WRINKLE RECOVERY VALUES OF NON-WORN TROUSERS

Types Averaged Across Launderings			Laundering Periods Averaged Across Types		
Rank*	Type	Mean	Rank*	Period	Mean
1	3-PDC	289.0	1	0	286.5
2	4-PCP	280.5	2	5	268.9
3	1-VP	244.8	3	10	262.5
4	2-VP	244.1	4	15	256.4
			5	20	248.8

*Rank 1 assigned to highest wrinkle recovery score.

TABLE IVf

RANK ORDERED MEAN WRINKLE RECOVERY VALUES
OF WORN TROUSERS

Wear Period	Rank Order*	Trouser Type	Mean
20	1	3-PDC	286.4
	2	4-PCP	276.5
	3	1-VP	246.4
	4	2-VP	236.0

*Rank 1 assigned to highest wrinkle recovery score.

TABLE IVg

DUNCAN'S MULTIPLE RANGE TEST OF DIFFERENCES IN MEAN WRINKLE RECOVERY VALUES OF NON-WORN TROUSERS

Trouser Types Averaged Across Periods

Differences Between			Duncan Criterion	
Ranks	Types	Means	$\alpha = 0.05$	$\alpha = 0.01$
1-4	3-PDC - 2-VP	44.9**	7.97	10.61
1-3	3-PDC - 1-VP	44.2**	7.73	10.33
1-2	3-PDC - 4-PCP	8.5*	7.35	9.90
2-4	4-PCP - 2-VP	36.4**	7.73	10.33
2-3	4-PCP - 1-VP	35.7**	7.35	9.90
2-4	1-VP - 2-VP	0.7	7.35	9.90

Laundering Periods Averaged Across Types

Differences Between			Duncan Criterion	
Ranks	Periods	Means	$\alpha = 0.05$	$\alpha = 0.01$
1-5	0-20	37.8**	9.11	12.00
1-4	0-15	30.1**	8.91	11.87
1-3	0-10	24.0**	8.64	11.55
1-2	0- 5	17.6**	8.22	11.07
2-5	5-20	20.1**	8.91	11.87
2-4	5-15	12.5**	8.64	11.55
2-3	5-10	6.4	8.22	11.07
3-5	10-20	13.8**	8.64	11.55
3-4	10-15	6.1	8.22	11.07
4-5	15-20	7.7	8.22	11.07

*Indicates significance at $\alpha = 0.05$ level.
**Indicates significance at $\alpha = 0.01$ level

TABLE IVh

DUNCAN'S MULTIPLE RANGE TEST OF DIFFERENCES IN MEAN WRINKLE RECOVERY VALUES OF WORN TROUSERS

Wear Period	Differences in			Duncan Criterion	
	Ranks	Types	Means	α = 0.05	α = 0.01
20	1-4	3-PDC - 2-VP	50.4**	10.32	13.53
	1-3	3-PDC - 1-VP	39.9**	9.86	12.99
	1-2	3-PDC - 4-PCP	9.9*	9.86	13.12
	2-4	4-PCP - 2-VP	40.5**	6.59	8.69
	2-3	4-PCP - 1-VP	30.1**	6.07	8.08
	3-4	1-VP - 2-VP	10.4**	5.46	7.26

*Indicates significance at α = 0.05 level.
**Indicates significance at α = 0.01 level.

Dimensional Stability

Tests were conducted to determine the dimensional stability of the experimental trousers after 5, 15, and 20 laundering periods. These evaluations were made on 2 pairs of non-worn trousers representative of each of the 4 finish types, both in the warp and filling directions, at each evaluation period. Statistical data concerning the stability of the trousers are presented in Table Va through Table Ve.

The laundering period means for dimensional stability are recorded in Tables Va and Vb. Minus values denote that shrinkage occurred in the trousers while plus values, as shown for the filling direction of the trousers with the proprietary finish and in the Type 1 vapor phase treated trousers, represent a stretching of the fabric. The warp-wise data indicated that all trouser types experienced a degree of shrinkage. Higher overall warp shrinkage values were noted for the trousers finished by the 2 vapor phase treatments with mean values of -2.3 and -2.5 percent. The proprietary finished trousers experienced the lowest percentage of change with a mean value of -1.2.

A perusal of Table Vb discloses that the proprietary finished trousers had an expansion in yarn length in the filling direction while the other trouser types experienced little or no percentage change in this dimension. These data are illustrated in Figure 7.

Statistical results concerning a 2-factor analysis of variance are reported in Table Vc. From these data significant differences between the warpwise dimensional change of the 4 trouser types, and between laundering period mean values, can be observed. The interaction between finishes and laundering periods, however, was non-significant. The fillingwise data designate no significant differences between the finishes, the number of launderings, or between the interaction effects of the 2 variables.

A rank ordered arrangement of mean values, with respect to the change in dimensional stability, is shown in Table Vd. The rank of 1 was assigned to the smallest percentage of change. In the warp direction, for finishes averaged across laundering periods, superior performances were observed for the proprietary and the pad-dry-cure finishes. The vapor phase finishes were ranked third and fourth.

When laundering period means were compared, the rank order was found to be proportionate to the number of laundering periods with the fewest number receiving the rank of 1. Fillingwise comparisons of all trouser types revealed that the highest rank of 1 was awarded to the

Type 1 vapor phase, and rank number 4 was earned by the proprietary finish. The respective mean values of 0.1 and 2.4 indicated a stretching of the trousers rather than a shrinkage. When laundering period means were compared, the data showed laundering period 20 in Rank 1 with a mean value of 0.14, and Rank 3 was assigned to laundering period 15 with a mean of 1.04.

Data compiled from Duncan's multiple range test of differences in the mean percentage of change in dimensions for the warp direction are provided in Table Ve. These data showed that the proprietary and the pad-dry-cure finished trousers were significantly more stable than were those finished by the vapor phase treatment. No significant differences were noted for the paired combinations of the vapor phase finishes or for the proprietary and pad-dry-cure finishes. The only significant difference at the α 0.05 level was between the paired combinations of pad-dry-cure and the Type 1 vapor phase finish. Differences between laundering periods were shown to be significant in comparisons of 5 and 20 laundering periods and of 15 and 20 periods. In both instances the fewest number of launderings accounted for the superior performances.

TABLE Va

MEAN PERCENT CHANGE IN DIMENSIONAL STABILITY AND STANDARD DEVIATIONS OF NON-WORN TROUSERS, WARP DIRECTION

Mean Values

Trouser Type	Number of Launderings			Type Mean
	5	15	20	
1-VP	-1.7	-2.1	-3.3	-2.3
2-VP	-1.6	-2.6	-3.3	-2.5
3-PDC	-1.0	-1.6	-1.7	-1.4
4-PCP	-0.9	-1.0	-1.7	-1.2
Period Mean	-1.3	-1.8	-2.5	-1.8

Standard Deviations

Trouser Type	Number of Launderings			Type Mean
	5	15	20	
1-VP	0.4	0.8	0.5	0.9
2-VP	0.0	0.1	1.1	0.9
3-PDC	0.6	0.5	0.4	0.5
4-PCP	0.2	0.4	1.1	0.7
Period Mean	0.5	0.7	1.1	0.9

TABLE Vb

MEAN PERCENT CHANGE IN DIMENSIONAL STABILITY AND STANDARD DEVIATIONS OF NON-WORN TROUSERS, FILLING DIRECTION

Mean Values

Trouser Type	Number of Launderings			Type Mean
	5	15	20	
1-VP	0.5	-0.1	-0.3	0.1
2-VP	-0.3	-0.2	-0.5	-0.3
3-PDC	-0.5	-0.1	0.0	-0.2
4-PCP	1.5	4.5	1.3	2.4
Period Mean	0.3	1.1	0.1	0.5

- denotes shrinkage

Standard Deviations

Trouser Type	Number of Launderings			Type Mean
	5	15	20	
1-VP	0.7	0.1	0.2	0.5
2-VP	0.4	0.1	0.5	0.3
3-PDC	0.4	0.1	0.0	0.3
4-PCP	2.2	6.4	2.5	3.6
Period Mean	1.2	3.2	1.2	2.0

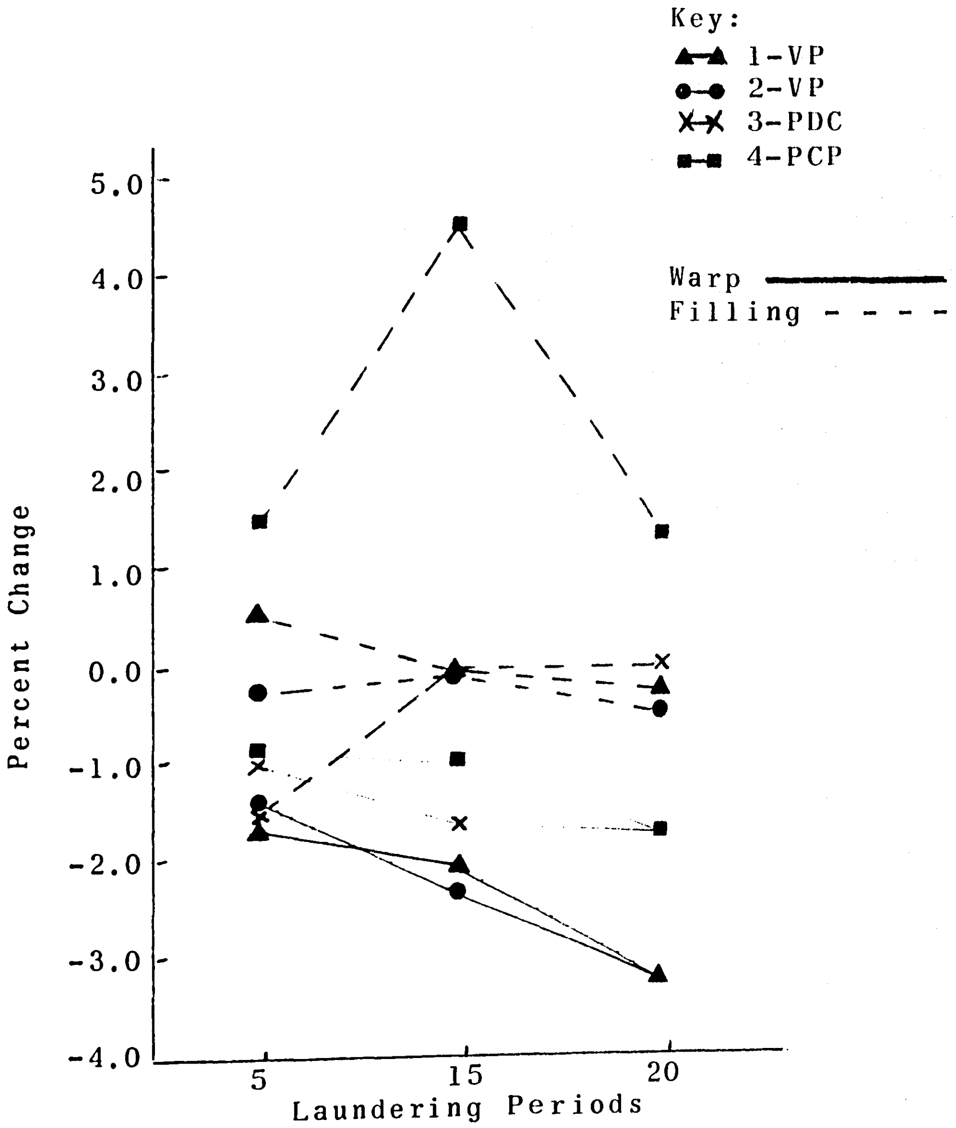

Fig. 7. Comparison of non-worn trouser types on the basis of dimensional change, warp and filling.

TABLE Vc

TWO-FACTOR ANALYSIS OF VARIANCE OF PERCENT CHANGE IN DIMENSIONAL STABILITY OF NON-WORN TROUSERS

Warp

Source of Variation	Degrees of Freedom	Mean Squares	F-Ratio	Probability of Greater F
Finish Types	3	2.5	6.95**	0.005
Launderings	2	2.8	7.92**	0.006
Interaction	6	0.2	0.54	0.77
Within (error)	12	0.4		
Total	23			

**Indicates significance at $\alpha = 0.01$ level.

Filling

Source of Variation	Degrees of Freedom	Mean Squares	F-Ratio	Probability of Greater F
Finish Types	3	9.8	2.24	0.14
Launderings	2	1.8	0.42	0.66
Interaction	6	1.8	0.40	0.86
Within	12	4.4		
Total	23			

TABLE Vd

RANK ORDERED MEAN PERCENT CHANGE IN DIMENSIONAL STABILITY VALUES OF NON-WORN TROUSERS

Warp

Types Averaged Across Launderings			Laundering Periods Averaged Across Types		
Rank*	Type	Mean	Rank*	Period	Mean
1	4-PCP	-1.18	1	5	-1.28
2	3-PDC	-1.40	2	15	-1.79
3	1-VP	-2.32	3	20	-2.47
4	2-VP	-2.47			

Filling

Types Averaged Across Launderings			Laundering Periods Averaged Across Types		
Rank*	Type	Mean	Rank*	Period	Mean
1	1-VP	0.07	1	20	0.14
2	3-PDC	-0.18	2	5	0.31
3	2-VP	-0.30	3	15	1.04
4	4-PCP	2.40			

*Rank 1 assigned to smallest percent change.

TABLE Ve

DUNCAN'S MULTIPLE RANGE TEST OF DIFFERENCES IN MEAN PERCENT CHANGE IN DIMENSIONAL STABILITY OF NON-WORN TROUSERS (WARP DIRECTION)

Trouser Types Averaged Across Periods

Differences Between			Duncan Criterion	
Ranks	Types	Means	$\alpha = 0.05$	$\alpha = 0.01$
1-4	4-PCP - 2-VP	1.29**	0.76*	1.02*
1-3	4-PCP - 1-VP	1.14**	0.74*	0.99*
1-2	4-PCP - 3-PDC	0.22	0.70	0.95
2-4	3-PDC - 2-VP	1.07**	0.74*	0.99*
2-3	3-PDC - 1-VP	0.92*	0.70*	0.95
3-4	1-VP - 2-VP	0.15	0.70	0.95

Laundering Periods Averaged Across Types

Differences Between			Duncan Criterion	
Ranks	Periods	Means	$\alpha = 0.05$	$\alpha = 0.01$
1-3	5-20	1.19**	0.64*	0.86*
1-2	5-15	0.51	0.61	0.82
2-3	15-20	0.68*	0.61	0.82

*Indicates significance at $\alpha = 0.05$ level.
**Indicates significance at $\alpha = 0.01$ level.

Crease Wear

An evaluation of the experimental trousers was conducted by 3 panelists to determine the effect of laundering and wear-laundering on crease wear. Thirty-two evaluations were required for the non-worn trousers and 374 for the worn trousers. The mean crease wear values tabulated in Tables VIa and VIb and diagrammatically presented in Figure 8 are typical of the performance of each trouser type throughout the laundering periods. A statistical analysis of these values, results of which are shown in Tables VIc through VIh, serve as the basis for the following discussion.

The mean values representative of the vapor phase finished trousers were higher than those which were established for the remainder of the experimental trousers. Respective overall mean scores ranging from 9.8 to 10.0 were recorded for the worn and non-worn trousers in these categories. The creases of the pad-dry-dure finished trousers became progressively thinner with each evaluation period. The proprietary finish indicated better resistance to crease wear than did the pad-dry-cure finish with mean values of 8.1 and 7.5 for the non-worn and worn trousers, respectively. The overall percentage of change in crease wear values for the worn trousers ranged from 0.47 percent for Type 1 vapor phase finish to 80 percent for the trousers finished with the pad-dry-cure finish.

Significant differences were found to exist when an analysis of variance was applied to the data from the non-worn trousers, Table VIc. These data point to the fact that as laundering and wear-laundering progressed significant differences between the mean crease wear values of the various finish types persisted. Significant differences also were indicated between laundering periods and in the interaction between laundering and trouser types. When a single factor analysis of variance was applied to the crease wear data from the worn trousers, Table VId, significant differences between trouser types were evident at each evaluation period.

The superior performance of the vapor phase finished trousers was apparent when mean crease wear values were arranged in rank order as shown in Tables VIe and VIf. The mean values in these tables demonstrate the excellent resistance of these trousers to crease wear by repeatedly ranking them in first and second places. The low levels of performance by the pad-dry-cure treatment were in accord with findings at other research laboratories by Hollies and Getchell (27) and by Gagliardi Research Corporation (69). The rank order for laundering periods showed decreasing mean values for crease wear with each evaluation period.

Intercomparisons of the mean values for the non-worn and worn trousers treated with the 4 finishes were evaluated by the use of Duncan's multiple range test, and data from these tests are recorded in Tables VIg and VIh. When trouser types were compared on the basis of the overall data, all paired combinations exhibited significant differences, except in instances when the vapor phase finishes were compared. The proprietary finish provided higher crease wear values than were provided by the pad-dry-cure finish. The paired data for laundering periods showed that laundering period 5 had the least effect on crease wear values. A significant difference, α 0.01 level, was shown when laundering period 5 was paired with periods 15 and 20. The other paired combination which showed a significant difference was between laundering periods 10 and 20 with period 10 having the lower score. All other comparisons showed non-significant results.

When Fisher's t-test was applied to the means of the non-worn and worn trouser types after 20 laundering periods, the pad-dry-cure finished trousers indicated that wear had an effect on crease wear. All other finishes showed no effects of wear on crease wear performance.

TABLE VIa

MEAN CREASE WEAR VALUES AND STANDARD DEVIATIONS OF NON-WORN TROUSERS

Mean Values

Trouser Type	Number of Launderings				Type Mean
	5	10	15	20	
1-VP	10.0	10.0	10.0	10.0	10.0
2-VP	9.6	10.0	10.0	10.0	9.9
3-PDC	8.0	6.4	5.0	3.4	5.7
4-PCP	8.6	8.4	8.0	7.4	8.1
Period Mean	9.08	8.68	8.25	7.68	8.42

Standard Deviations

Trouser Type	Number of Launderings				Type Mean
	5	10	15	20	
1-VP	0.0	0.0	0.0	0.0	0.0
2-VP	0.5	0.0	0.0	0.0	0.2
3-PDC	0.0	0.5	1.4	0.9	1.9
4-PCP	0.9	0.5	0.0	0.9	0.7
Overall	0.9	1.6	2.3	2.9	2.0

TABLE VIb

MEAN CREASE WEAR VALUES AND STANDARD DEVIATIONS OF WORN TROUSERS

Mean Values

Trouser Type	Number of Launderings				Type Mean
	5	10	15	20	
1-VP	9.9	9.9	9.9	9.9	9.9
2-VP	10.0	9.9	9.8	9.8	9.8
3-PDC	6.2	4.0	2.4	2.0	3.6
4-PCP	8.3	7.9	7.3	6.6	7.5
Period Mean	8.85	8.66	8.60	8.57	8.67

Standard Deviations

Trouser Type	Number of Launderings				
	5	10	15	20	
1-VP	0.2	0.2	0.2	0.2	
2-VP	0.0	0.3	0.5	0.6	
3-PDC	1.1	1.4	0.8	0.0	
4-PCP	0.5	0.3	0.9	1.3	
Overall	1.6	2.1	2.3	2.4	

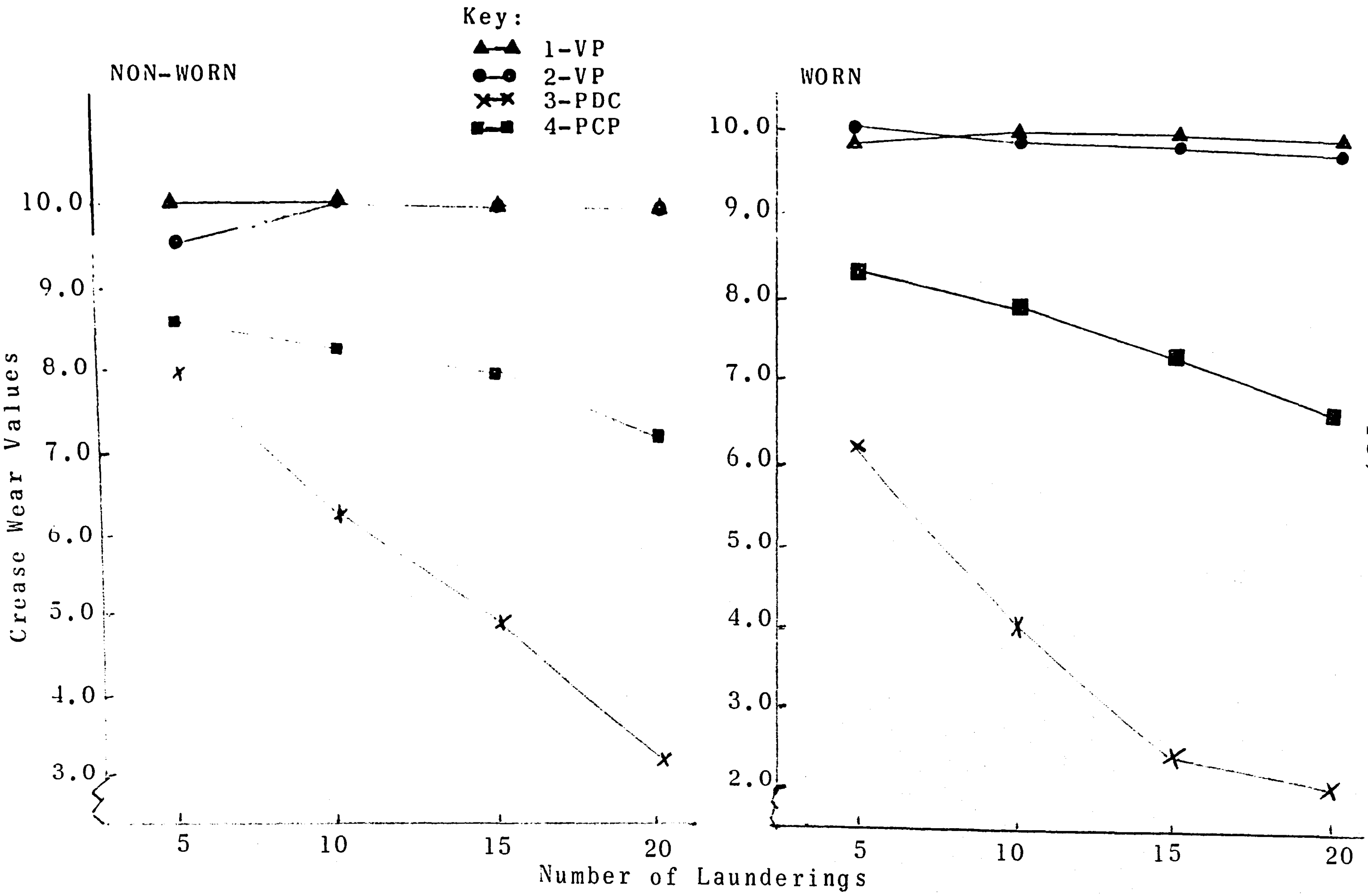

Fig. 8. Comparison of trouser types on the basis of crease wear values.

TABLE VIc

TWO-FACTOR ANALYSIS OF VARIANCE OF CREASE WEAR VALUES OF NON-WORN TROUSERS

Source of Variation	Degrees of Freedom	Mean Squares	F-Ratio	Probability of Greater F
Finish Types	3	32.98	100.15**	0.01
Launderings	3	2.87	8.73**	0.01
Interaction	9	1.87	5.69**	0.01
Within	16	0.33		
Total	31			

**Indicates significance at $\alpha = 0.01$ level.

TABLE VId

SINGLE FACTOR ANALYSIS OF VARIANCE OF CREASE WEAR VALUES OF WORN TROUSERS

Wear Period	Source of Variation	Degrees of Freedom	Mean Squares	F-Ratio	Probability of Greater F
5	Between Types	3	74.7	244.63**	0.01
	Within	103	0.3		
	Total	106			
10	Between Types	3	130.7	420.52**	0.01
	Within	92	0.3		
	Total	95			
15	Between Types	3	146.0	453.77**	0.01
	Within	83	0.3		
	Total	86			
20	Between Types	3	144.5	289.06**	0.01
	Within	80	0.5		
	Total	83			

**Indicates significance at $\alpha = 0.01$ level.

TABLE VIe

RANK ORDERED MEAN CREASE WEAR VALUES
OF NON-WORN TROUSERS

Types Averaged Across Launderings			Laundering Periods Averaged Across Types		
Rank*	Type	Mean	Rank*	Period	Mean
1	1-VP	10.0	1	5	9.1
2	2-VP	9.9	2	10	8.7
3	4-PCP	8.1	3	15	8.3
4	3-PDC	5.7	4	20	7.7

*Rank 1 assigned to highest crease wear score.

TABLE VIf

RANK ORDERED MEAN CREASE WEAR VALUES OF WORN TROUSERS BY PERIODS

Wear Period	Rank Order*	Trouser Type	Mean Crease Wear	Period Averaged Over Types	
				Mean	Rank*
5	1 2 3 4	2-VP 1-VP 4-PCP 3-PDC	10.0 9.9 8.3 6.2	8.85421	1
10	1 2 3 4	1-VP 2-VP 4-PCP 3-PDC	9.9 9.9 7.9 4.0	8.66042	2
15	1 2 3 4	1-VP 2-VP 4-PCP 3-PDC	9.9 9.8 7.3 2.4	8.60460	3
20	1 2 3 4	1-VP 2-VP 4-PCP 3-PDC	9.9 9.8 6.6 2.0	8.57143	4

*Rank 1 assigned to highest crease wear score.

TABLE VIg

DUNCAN'S MULTIPLE RANGE TEST OF DIFFERENCES IN MEAN CREASE WEAR VALUES OF NON-WORN TROUSERS

Trouser Types Averaged Across Periods

Differences Between			Duncan Criterion	
Ranks	Types	Means	$\alpha = 0.05$	$\alpha = 0.01$
1-4	1-VP - 3-PDC	4.3**	0.64	0.85
1-3	1-VP - 4-PCP	1.9**	0.62	0.82
1-2	1-VP - 2-VP	0.1	0.59	0.79
2-4	2-VP - 3-PDC	4.2**	0.62	0.82
2-3	2-VP - 4-PCP	1.8**	0.59	0.79
3-4	4-PCP - 3-PDC	2.4**	0.59	0.79

Laundering Periods Averaged Across Types

Differences Between			Duncan Criterion	
Ranks	Periods	Means	$\alpha = 0.05$	$\alpha = 0.01$
1-4	5-20	1.4**	0.64	0.85
1-3	5-15	0.8**	0.61	0.82
1-2	5-10	0.4	0.58	0.79
2-4	10-20	1.0**	0.62	0.82
2-3	10-15	0.4	0.59	0.79
3-4	15-20	0.6	0.59	0.79

**Indicates significance at $\alpha = 0.01$ level.

TABLE VIh

DUNCAN'S MULTIPLE RANGE TEST OF DIFFERENCES IN MEAN CREASE WEAR VALUES OF WORN TROUSERS BY PERIODS

Wear Period	Differences In			Duncan Criterion	
	Ranks	Types	Means	α = 0.05	α = 0.01
5	1-4	2-VP - 3-PDC	3.8**	0.35	0.45
	1-3	2-VP - 4-PCP	1.7**	0.31	0.41
	1-2	2-VP - 1-VP	0.1	0.29	0.38
	2-4	1-VP - 3-PDC	3.8**	0.34	0.44
	2-3	1-VP - 4-PCP	1.6**	0.29	0.39
	3-4	4-PCP - 3-PDC	2.1**	0.33	0.43
10	1-4	1-VP - 3-PDC	5.9**	0.40	0.53
	1-3	1-VP - 4-PCP	2.0**	0.33	0.43
	1-2	1-VP - 2-VP	0.0	0.29	0.38
	2-4	2-VP - 3-PDC	5.9**	0.39	0.51
	2-3	2-VP - 4-PCP	2.0**	0.31	0.41
	3-4	4-PCP - 3-PDC	3.9**	0.39	0.51
15	1-4	1-VP - 3-PDC	7.5**	0.49	0.64
	1-3	1-VP - 4-PCP	2.7**	0.35	0.45
	1-2	1-VP - 2-VP	0.1	0.29	0.39
	2-4	2-VP - 3-PDC	7.4**	0.48	0.63
	2-3	2-VP - 4-PCP	2.5**	0.33	0.44
	3-4	4-PCP - 3-PDC	4.9**	0.48	0.63
20	1-4	1-VP - 3-PDC	8.0**	0.69	0.90
	1-3	1-VP - 4-PCP	3.4**	0.44	0.58
	1-2	1-VP - 2-VP	0.2	0.37	0.49
	2-4	2-VP - 3-PDC	7.8**	0.67	0.88
	2-3	2-VP - 4-PCP	3.2**	0.42	0.56
	3-4	4-PCP - 3-PDC	4.6*	0.66	0.88

*Indicates significance at α = 0.05 level.
**Indicates significance at α = 0.01 level.

Broken Yarns

The effect of the 4 different durable press finishes on the trousers, with regard to their resistance to yarn rupture, is shown in Table VIIa through Table VIIh and in Figures 9 and 10. The ruptured yarns were counted initially and after each fifth laundering period and recorded on a diagram representative of the trouser style as shown in Figure 1. Forty observations were made for the non-worn trousers and 495 for the worn trousers.

The mean numbers of broken yarns, warp and filling combined, for the non-worn and worn trouser types are tabulated along with the standard deviations in Tables VIIa and VIIb. Figures 9 and 10 give a comparison of mean values by laundering periods. As discernable from the illustrations, the pad-dry-cure trousers displayed the highest number of ruptured yarns at each evaluation period with a mean of 1831.5 and 4704.3 after 20 laundering periods for the non-worn and worn trousers, respectively. These mean values far exceeded the means for all the other finishes. Similar findings with regard to yarn rupture were observed in laundering of pad-dry-cure trouser cuffs by Reeves et al. (52). The research team noted that 6 to 10 laundering cycles produced holes in the test trouser cuffs.

The results of a 2-factor and a single factor analysis of variance are shown in Tables VIIc and VIId, respectively. These data present evidences of significant differences at the α 0.01 level between trouser finishes. Significant differences were evident between laundering periods and in the interaction between laundering periods and trouser types for the non-worn trousers.

A rank order of the mean values, based on the efficiency of each treatment, is shown in Tables VIIe and VIIf. Rank 1 was assigned to the lowest score. These data continue to emphasize the differences between the trouser treatments by consistently ranking the vapor phase finishes in positions 1 and 2. The rank order for laundering periods averaged across finishes for the non-worn trousers showed a progressively lower rank for each successive evaluation period.

The evaluations made by Duncan's multiple range test for differences in mean broken yarn values for the non-worn trousers are tabulated in Table VIIg. All combinations paired with the pad-dry-cure finish showed that these trousers were significantly inferior to the other trouser types with regard to the number of broken yarns. When the vapor phase finishes were paired, no significant differences were observed. A non-significant difference also was noted when the Type 2 vapor phase and the proprietary finishes were paired. A study of the data with reference to laundering periods averaged across trouser types showed significant differences for all comparisons. The fewest number of launderings in each comparison gave the superior results.

Data for paired combinations related to worn trousers are shown in Table VIIh. At all evaluation periods the pad-dry-cure finish was found to be significantly inferior to the other types. After 15 and 20 laundering periods, the proprietary finish was significantly less resistant to yarn rupture than were the vapor phase finishes. The 2 vapor phase finishes displayed evidences of a superior performance when compared to the other trouser types. When compared with one another, they were not significantly different.

The application of Fisher's t-test showed that wear had an effect on the number of broken yarns of the trousers finished by the pad-dry-cure process when the non-worn and worn trousers were compared after 20 laundering periods. Wear had no effect on the other finishes as far as the number of broken yarns was concerned.

The overall comparative performance of the vapor phase treated trousers would suggest satisfactory products.

A review of the mean values, however, could reverse this assumption; for all trousers sustained an excessive number of broken yarns. The investigator noted that the excessive wear, however, was related to the waistband where a stiff buckram-like fabric with an abrasive surface had been used as the supporting fabric.

TABLE VIIa

MEAN NUMBER OF BROKEN YARNS AND STANDARD DEVIATIONS, WARP AND FILLING, OF NON-WORN TROUSERS

Mean Values

Trouser Type	Number of Launderings					Type Mean
	0	5	10	15	20	
1-VP	0.5	17.0	73.0	177.0	358.0	156.3
2-VP	7.2	41.5	78.0	232.5	430.5	195.6
3-PDC	1.1	92.5	465.0	996.0	1831.5	846.3
4-PCP	3.4	24.5	150.0	388.0	591.5	288.5
Period Mean	3.1	48.9	191.5	448.4	802.9	371.7

Standard Deviations

Trouser Type	Number of Launderings					Type Overall
		5	10	15	20	
1-VP		4.2	14.1	49.5	36.8	140.9
2-VP		17.7	5.7	43.1	181.7	178.7
3-PDC		2.1	123.0	110.3	229.8	706.4
4-PCP		3.5	45.3	7.1	95.5	236.8
Overall		32.3	179.0	351.3	651.9	465.7

TABLE VIIb

MEAN NUMBER OF BROKEN YARNS AND STANDARD DEVIATIONS, WARP AND FILLING, OF WORN TROUSERS

Mean Values

Trouser Type	Number of Launderings				
	0	5	10	15	20
1-VP	1.2	38.7	112.1	286.9	589.8
2-VP	6.4	48.2	200.5	388.8	827.7
3-PDC	0.9	591.7	1311.9	3285.1	4704.3
4-PCP	3.9	73.9	396.9	814.2	1539.3
Period Mean	3.1	153.6	380.2	717.7	1180.6

Standard Deviations

Trouser Type	Number of Launderings				
	0	5	10	15	20
1-VP	3.5	42.4	63.4	151.4	284.0
2-VP	3.8	33.8	316.2	290.5	501.1
3-PDC	1.6	740.7	785.7	1296.6	1399.3
4-PCP	5.5	71.1	589.2	553.4	794.1
Total	4.4	380.9	594.8	977.9	1210.1

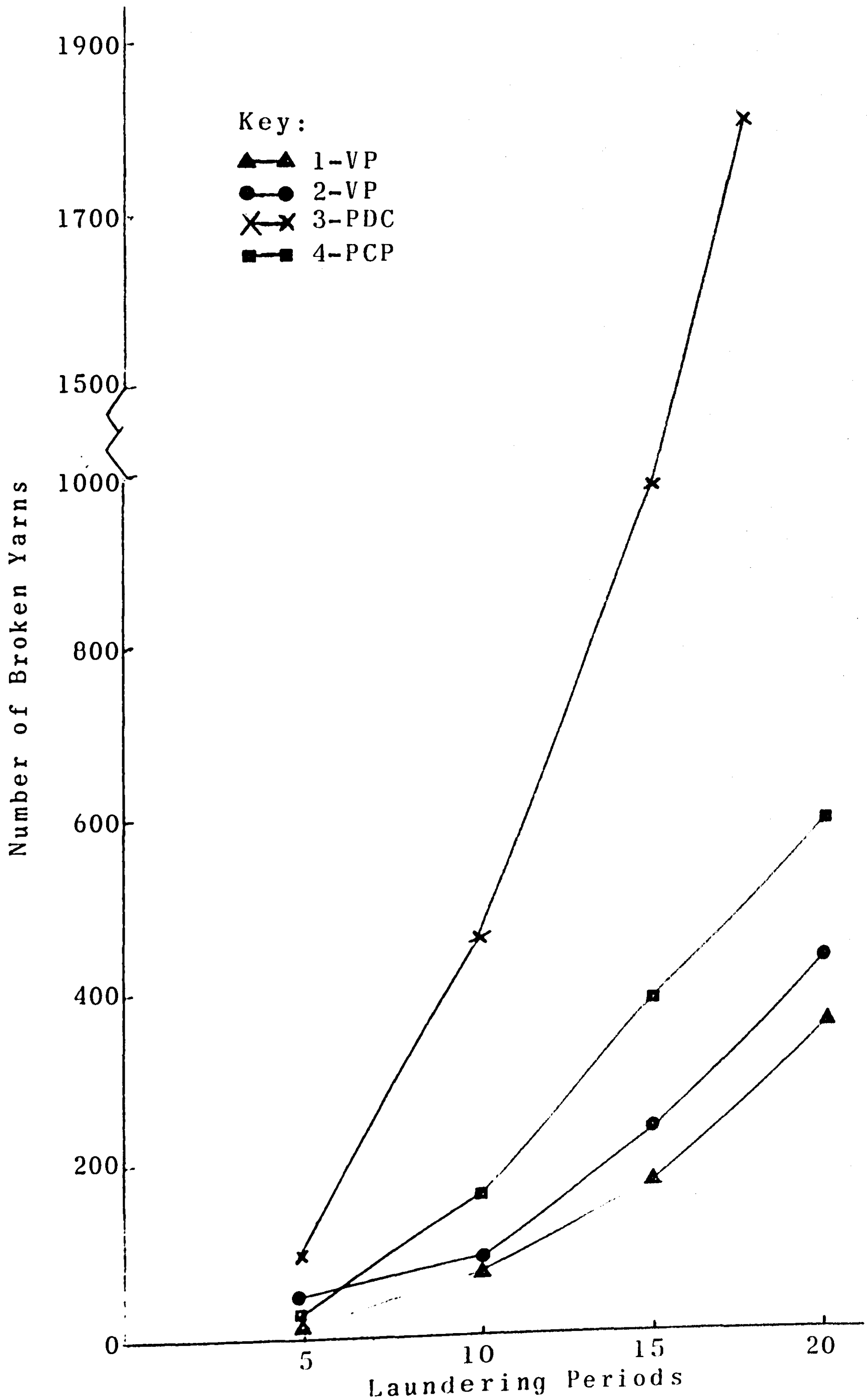

Fig. 9. Comparison of non-worn trouser types on the basis of broken yarns.

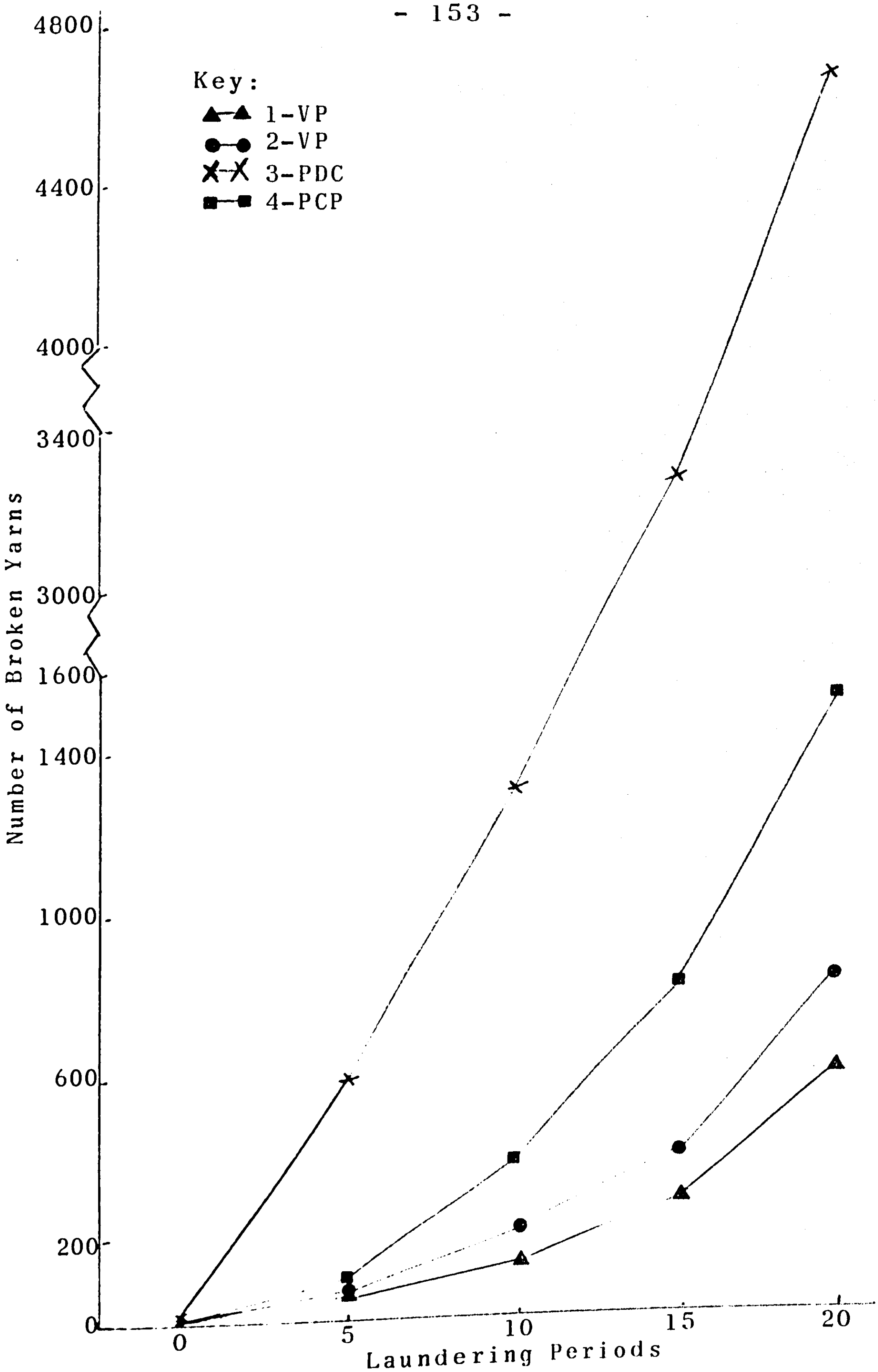

Fig. 10. Comparison of worn trouser types on the basis of broken yarns.

TABLE VIIc

TWO-FACTOR ANALYSIS OF VARIANCE OF BROKEN YARN VALUES OF NON-WORN TROUSERS

Source of Variation	Degrees of Freedom	Mean Squares	F-Ratio	Probability of Greater F
Finish Types	3	825442.8	101.13**	0.01
Launderings	3	884619.2	108.38**	0.01
Interaction	9	162636.2	19.93**	0.01
Within	16	8162.2		
Total	31			

**Indicates significance at α = 0.01 level.

TABLE VIId

SINGLE FACTOR ANALYSIS OF VARIANCE OF BROKEN YARN VALUES OF WORN TROUSERS

Wear Period	Source of Variation	Degrees of Freedom	Mean Squares	F-Ratio	Probability of Greater F
5	Between Types	3	1579717.1	15.29**	< 0.01
	Within	103	103297.5		
	Total	106			
10	Between Types	3	5094936.6	25.37**	< 0.01
	Within	93	200834.4		
	Total	96			
15	Between Types	3	20541937.4	82.71**	< 0.01
	Within	83	248375.2		
	Total	86			
20	Between Types	3	30343125.9	79.56**	< 0.01
	Within	80	381406.6		
	Total	83			

**Indicates significance at $\alpha = 0.01$ level.

TABLE VIIe

RANK ORDERED MEAN NUMBER OF BROKEN YARNS OF NON-WORN TROUSERS

Types Averaged Across Launderings			Laundering Periods Averaged Across Types		
Rank*	Type	Mean	Rank*	Period	Mean
1	1-VP	156.3	1	5	43.9
2	2-VP	196.6	2	10	191.5
3	4-PCP	288.5	3	15	488.4
4	3-PDC	846.3	4	20	802.9

*Rank 1 assigned to smallest score.

TABLE VIIf

RANK ORDERED MEAN NUMBER OF BROKEN YARN VALUES OF WORN TROUSERS BY LAUNDERING PERIOD

Wear Period	Order*	Trouser Type	Mean	Period Averaged Over Types	
				Mean	Rank*
0	1	3-PDC	.9		
	2	1-VP	1.3		
	3	4-PCP	3.9		
	4	2-VP	6.4		
5	1	1-VP	38.7	153.6261	1
	2	2-VP	48.2		
	3	4-PCP	73.9		
	4	3-PDC	591.7		
10	1	1-VP	112.1	380.1546	2
	2	2-VP	200.5		
	3	4-PCP	396.9		
	4	3-PDC	1311.9		
15	1	1-VP	286.9	717.7471	3
	2	2-VP	388.8		
	3	4-PCP	814.2		
	4	3-PDC	3285.1		
20	1	1-VP	589.8	1180.5595	4
	2	2-VP	827.7		
	3	4-PCP	1539.3		
	4	3-PDC	4704.3		

*Rank 1 assigned to smallest score.

TABLE VIIg

DUNCAN'S MULTIPLE RANGE TEST OF DIFFERENCES IN MEAN BROKEN YARN VALUES OF NON-WORN TROUSERS

Trouser Types Averaged Across Periods

Differences Between			Duncan Criterion	
Ranks	Types	Means	$\alpha = 0.05$	$\alpha = 0.01$
1-4	1-VP - 3-PDC	690.0**	100.01	133.13
1-3	1-VP - 4-PCP	132.3**	96.94	129.56
1-2	1-VP - 2-VP	39.4	92.25	124.22
2-4	2-VP - 3-PDC	650.6**	96.94	129.56
2-3	2-VP - 4-PCP	92.9	92.25	124.22
3-4	4-PCP - 3-PDC	557.8**	92.25	124.22

Laundering Periods Averaged Across Types

Differences Between			Duncan Criterion	
Ranks	Periods	Means	$\alpha = 0.05$	$\alpha = 0.01$
1-4	5-20	759.0**	100.01	133.13
1-3	5-15	404.5**	96.94	129.56
1-2	5-10	147.6**	92.25	124.22
2-4	10-20	611.4**	96.94	129.56
2-3	10-15	256.9**	92.25	124.22
3-4	15-20	354.5**	92.25	124.22

**Indicates significance at $\alpha = 0.01$ level.

TABLE VIIh

DUNCAN'S MULTIPLE RANGE TEST OF DIFFERENCES IN MEAN NUMBER OF BROKEN YARN VALUES OF WORN TROUSERS BY PERIODS

Wear Period	Differences In			Duncan Criterion	
	Ranks	Types	Means	α = 0.05	α = 0.01
5	1-4	1-VP - 3-PDC	553.0**	201.6	264.5
	1-3	1-VP - 4-PCP	35.2	179.4	236.4
	1-2	1-VP - 2-VP	9.5	166.0	220.8
	2-4	2-VP - 3-PDC	543.5**	195.2	257.3
	2-3	2-VP - 4-PCP	25.7	170.5	226.8
	3-4	4-PCP - 3-PDC	517.8**	189.7	252.2
10	1-4	1-VP - 3-PDC	1199.8**	315.2	413.4
	1-3	1-VP - 4-PCP	284.8*	261.4	344.4
	1-2	1-VP - 2-VP	88.4	231.5	307.8
	2-4	2-VP - 3-PDC	1111.4**	305.2	402.3
	2-3	2-VP - 4-PCP	196.4	248.5	330.4
	3-4	4-PCP - 3-PDC	915.0**	303.9	404.1
15	1-4	1-VP - 3-PDC	2998.2**	430.9	565.2
	1-3	1-VP - 4-PCP	527.2**	302.7	399.0
	1-2	1-VP - 2-VP	101.9	259.6	345.2
	2-4	2-VP - 3-PDC	2896.3**	418.8	552.0
	2-3	2-VP - 4-PCP	425.4**	289.8	385.3
	3-4	4-PCP - 3-PDC	2470.9**	417.1	555.0
20	1-4	1-VP - 3-PDC	4114.5**	600.1	787.2
	1-3	1-VP - 4-PCP	949.5**	381.0	502.2
	1-2	1-VP - 2-VP	237.9	321.7	427.8
	2-4	2-VP - 3-PDC	3876.6**	582.9	768.2
	2-3	2-VP - 4-PCP	711.6**	364.4	484.9
	3-4	4-PCP - 3-PDC	3165.0**	578.5	769.3

*Indicates significance at α = 0.05 level.
**Indicates significance at α = 0.01 level.

Breaking Strength

The non-worn experimental trousers were evaluated for their breaking strength performance initially and after being subjected to 5, 10, 15, and 20 laundering periods, while the worn trousers were evaluated only after 20 wear-laundering periods. The resultant data were calculated in pounds and recorded in Tables VIIIa through VIIIe for the warpwise values, and in Tables IXa through IXe for the fillingwise values. Forty observations were made in evaluating the non-worn trousers and 71 for the worn trousers. Thirteen pairs of the worn trousers which were used for visual evaluations were reserved for illustrative purposes and were not included in the destructive tests. Comparisons of the data with reference to the effects of laundering and wear-laundering on mean breaking strength values are illustrated in Figure 11.

The mean warpwise breaking strength values and standard deviations of these values are recorded in Tables VIIIa and VIIIb. These data and those shown in Figure 11 reveal that the trousers which were cured by the vapor phase treatments displayed higher breaking strength values than did the trousers finished by means of the other two treatments. The data for the non-worn and worn trousers showed that the pad-dry-cure finished trousers experienced the lowest warpwise breaking strength with mean values of 104.1 and 61.3 pounds for the final evaluation periods.

An intercomparison of warpwise breaking strength values was made between types and between laundering periods for the non-worn and between types only for the worn trousers by means of an analysis of variance procedure. The data displayed a significant difference between both sources of variance for the non-worn category while differences between trouser finishes were disclosed for the worn trousers, Table VIIIc.

The rank order arrangement of the warpwise breaking strength values for the non-worn and worn trousers is recorded in Table VIIId. As has been mentioned earlier, the rank of 1 was assigned to the highest mean value. These data demonstrated the superior performance of the vapor phase treatments by consistently ranking these finishes higher than the pad-dry-cure and proprietary finishes. The worn trousers treated with Types 1 and 2 vapor phase finishes offered respective warp breaking resistance of 123.2 and 108.9 pounds while the mean values for the proprietary and pad-dry-cure treated trousers were 89.5 and 61.3 pounds, respectively. These data continue to affirm the notably higher performances of the vapor phase treated trousers. Laundering periods averaged across finishing types for the non-worn trousers showed the highest rank for the initial values. The other laundering periods were assigned ranks in descending order.

Differences in mean values for the non-worn and worn trousers were determined by the application of Duncan's multiple range test, Table VIIIe. When paired trouser types were evaluated across laundering periods, the data confirmed a significant difference, α 0.01, for all paired types. The superior performance was noted for the Type 1 vapor phase treated trousers which showed a significant difference between all other finishes. The warp breaking strength performance of the Type 2 vapor phase treated trousers was significantly better than that of the pad-dry-cure and the proprietary finishes, and the proprietary finish had the advantage over the pad-dry-cure treatment. The initial values were shown to be superior in warp breaking strength resistance when these values were paired with those obtained at the other laundering periods. Other paired periods showed that trousers laundered the fewest times had the highest breaking strength values.

An analysis of the fillingwise mean breaking strength values for the trousers, as recorded in Tables IXa and IXb, again indicated a lower value for the pad-dry-cure finished trousers than for those treated by the other finishes. The final fillingwise mean breaking strength values for the worn trousers ranged from a mean of 45.2 pounds for the Type 1 vapor phase to a mean of 30.8 pounds for the pad-dry-cure finished trousers.

An analysis of variance of the data, Table IXc, revealed significant differences between the non-worn trouser types and in the interaction of trouser types and laundering periods. Non-significant differences were revealed, however, between laundering periods. In the worn trousers significant differences were evident between finishes.

A rank order arrangement, of the mean fillingwise breaking strength values, is shown in Table IXd. As can be observed, the arrangement for the fillingwise values was the same as that for the warpwise values. The higher ranks were obtained by the Types 1 and 2 vapor phase treated trousers with respective means of 61.7 and 59.1 pounds for the non-worn trousers. The mean values for the non-worn proprietary and pad-dry-cure finishes were 47.6 and 43.8 pounds, respectively. Rank order for laundering periods averaged across trouser types showed that the highest filling breaking strength values were obtained after 15 laundering periods and the lowest values were recorded for the initial trousers.

Other findings similar to those displayed by the warp direction were observed when Duncan's multiple range test was applied to the fillingwise mean values. The vapor phase treated trousers continued to show a superior performance over the other finishes. When the vapor phase treatments were paired,the Type 1 treatment was found to be superior with regard to breaking strength in the filling direction (Table IXe). The non-worn proprietary treated trousers were significantly better than were the pad-dry-cure finished trousers in this regard.

The superior performance of the vapor phase treated fabrics is supported by findings from research conducted by Jutras, Cicione, and Kenney (29). Results from this research illustrated higher tensile strength values for the vapor phase treated fabrics when comparisons were made with fabrics treated by the pad-dry-cure finish.

When a comparison of the non-worn and worn trousers was made after 20 laundering periods, with one exception, wear was shown to have had an effect upon all trouser types. The one exception was in the filling direction when the pad-dry-cure finished trousers were compared.

TABLE VIIIa

MEAN WARP BREAKING STRENGTH VALUES

Trouser Type	Non-Worn Trousers						Worn Trousers
	Number of Launderings					Type Mean	After 20 Launderings
	0	5	10	15	20		
1-VP	169.3	156.9	157.5	156.9	150.4	159.1	123.2
2-VP	152.4	147.5	140.0	140.3	139.9	144.0	108.9
3-PDC	121.4	119.0	112.5	108.1	104.1	113.0	61.3
4-PCP	135.8	128.6	127.9	125.2	121.5	127.8	89.6
Period Mean	144.7	138.0	134.5	132.6	129.0	135.7	106.6

TABLE VIIIb

STANDARD DEVIATIONS OF WARP BREAKING STRENGTH VALUES

Trouser Type	Non-Worn Trousers						Worn Trousers
	Number of Launderings					Type Mean	After 20 Launderings
	0	5	10	15	20		
1-VP	0.4	1.1	2.1	4.0	6.2	6.9	9.3
2-VP	3.8	2.1	3.5	4.6	0.3	5.9	9.1
3-PDC	1.2	2.8	3.9	3.7	0.6	7.1	9.7
4-PCP	9.5	3.0	4.0	0.0	2.5	6.1	15.2
Period Mean	19.6	16.1	17.8	19.5	19.1	18.3	20.8

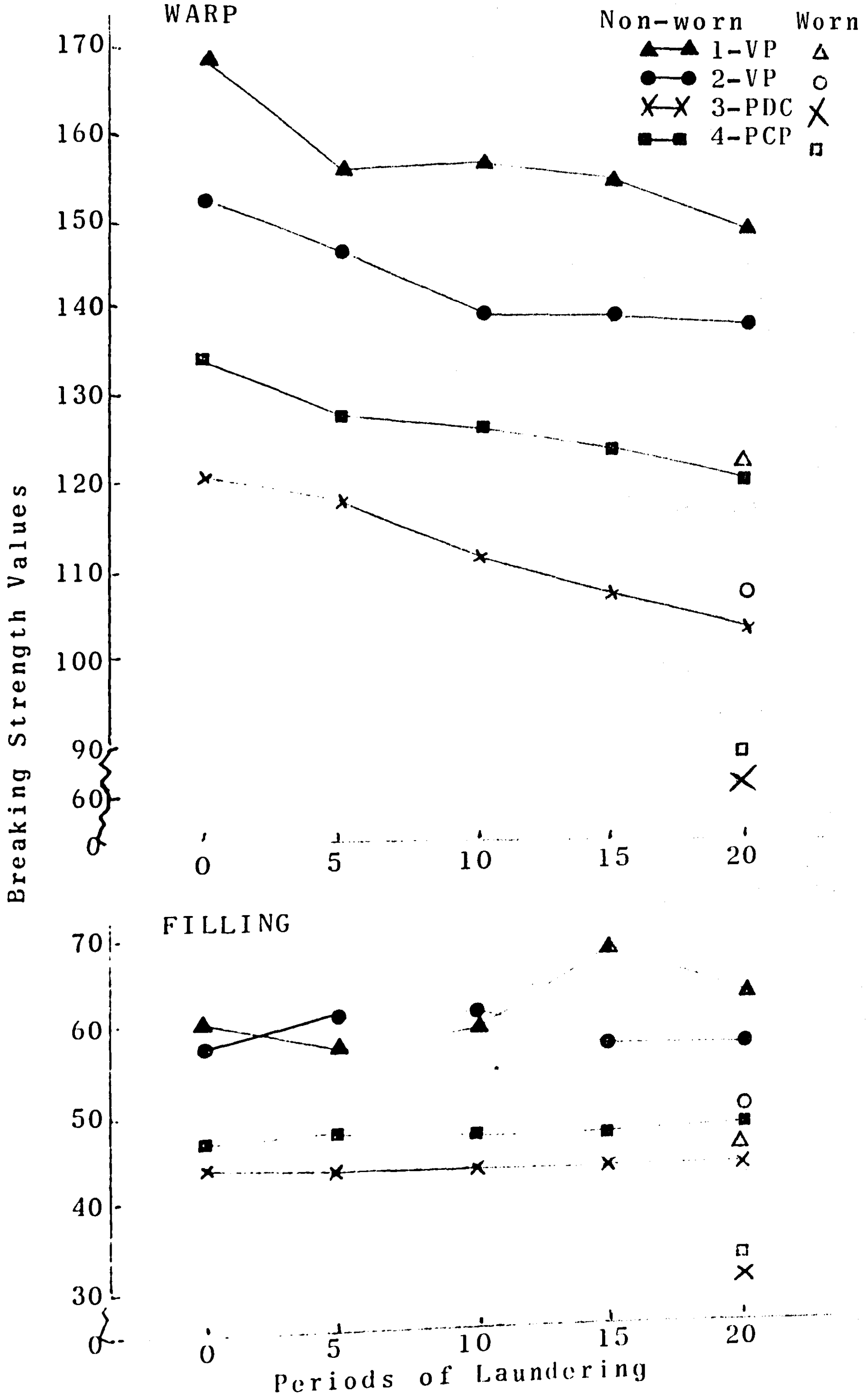

Fig. 11. Comparison of trouser types on the basis of breaking strength values.

TABLE VIIIc

ANALYSIS OF VARIANCE OF WARP BREAKING STRENGTH VALUES

Non-Worn Trousers

Source of Variation	Degrees of Freedom	Mean Squares	F-Ratio	Probability of Greater F
Between Types	3	3841.9	281.64**	0.01
Between Periods	4	284.9	20.88**	0.01
Interaction	12	11.1	0.81	0.63
Within (error)	20	13.6		
Total	39			

Worn Trousers, 20 Launderings

Source of Variation	Degrees of Freedom	Mean Squares	F-Ratio	Probability of Greater F
Between Types	3	7485.6	63.46**	0.01
Within Types	67	118.0		
Total	70			

**Significance at $\alpha = 0.01$ level.

TABLE VIIId

RANK ORDERED MEAN WARP BREAKING STRENGTH VALUES

Non-Worn Trousers

Types Averaged Across Launderings			Laundering Periods Averaged Across Types		
Rank*	Type	Mean	Rank*	Period	Mean
1	1-VP	158.2	1	0	144.7
2	2-VP	144.0	2	5	138.0
3	4-PCP	127.8	3	10	134.5
4	3-PDC	113.0	4	15	132.6
			5	20	129.0

Worn Trousers

Types Averaged Across Launderings		
Rank*	Type	Mean
1	1-VP	123.2
2	2-VP	108.9
3	4-PCP	89.5
4	3-PDC	61.3

*Rank 1 assigned to largest mean.

TABLE VIIIe

DUNCAN'S MULTIPLE RANGE TEST OF DIFFERENCES IN MEAN WARP BREAKING STRENGTH VALUES

Non-Worn Trouser Types Averaged Across Periods

Differences Between			Duncan Criterion	
Ranks	Types	Means	α = 0.05	α = 0.01
1-4	1-VP - 3-PDC	45.2**	3.7	4.9
1-3	1-VP - 4-PCP	30.4**	3.5	4.7
1-2	1-VP - 2-VP	14.2**	3.4	4.5
2-4	2-VP - 3-PDC	31.0**	3.5	4.7
2-3	2-VP - 4-PCP	16.2**	3.4	4.5
3-4	4-PCP - 3-PDC	14.8**	3.4	4.5

Laundering Periods Averaged Across Types

Differences Between			Duncan Criterion	
Ranks	Periods	Means	α = 0.05	α = 0.01
1-5	0-20	15.7**	4.2	5.5
1-4	0-15	12.1**	4.1	5.4
1-3	0-10	10.2**	4.0	5.3
1-2	0-5	6.7**	3.8	5.1
2-5	5-20	9.1**	4.1	5.4
2-4	5-15	5.4**	4.0	5.3
2-3	5-10	3.6	3.8	5.1
3-5	10-20	5.5**	4.0	5.3
3-4	10-15	1.9	3.8	5.1
4-5	15-20	3.6	3.8	5.1

Worn Trouser Types Averaged Across Periods

Differences Between			Duncan Criterion	
Ranks	Types	Means	α = 0.05	α = 0.01
1-4	1-VP - 3-PDC	61.9**	11.5	15.1
1-3	1-VP - 4-PCP	33.6**	7.2	9.5
1-2	1-VP - 2-VP	14.2**	6.2	8.2
2-4	2-VP - 3-PDC	47.7**	11.3	14.9
2-3	2-VP - 4-PCP	19.4**	7.1	9.4
3-4	4-PCP - 3-PDC	28.3**	11.1	14.8

*Indicates significance at α = 0.05 level.
**Indicates significance at α = 0.01 level.

TABLE IXa

MEAN FILLING BREAKING STRENGTH VALUES

Trouser Type	Non-Worn Trousers						Worn Trousers
	Number of Launderings					Type Mean	After 20 Launderings
	0	5	10	15	20		
1-VP	60.8	57.6	59.4	68.5	62.5	61.7	45.2
2-VP	57.9	61.8	61.1	57.8	57.3	59.2	39.3
3-PDC	44.4	43.9	43.9	43.2	43.6	43.8	30.8
4-PCP	47.0	47.5	47.6	47.6	48.5	47.6	33.9
Period Mean	52.5	52.7	53.0	54.3	53.0	53.1	39.8

TABLE IXb

STANDARD DEVIATIONS OF FILLING BREAKING STRENGTH VALUES

Trouser Type	Non-Worn Trousers						Worn Trousers
	Number of Launderings					Type Mean	After 20 Launder-ings
	0	5	10	15	20		
1-VP	0.4	1.6	0.2	0.0	0.7	4.0	4.0
2-VP	0.5	1.1	1.6	2.5	0.4	2.3	4.0
3-PDC	0.9	1.6	1.2	2.8	3.0	1.6	11.1
4-PCP	0.7	2.1	2.3	0.8	1.4	1.3	8.1
Period Mean	7.5	7.9	8.0	10.5	8.0	8.0	6.8

TABLE IXc

ANALYSIS OF VARIANCE OF FILLING BREAKING STRENGTH VALUES

Non-Worn Trousers

Source of Variation	Degrees of Freedom	Mean Squares	F-Ratio	Probability of Greater F
Between Types	3	760.4	317.63**	0.01
Between Periods	4	3.9	1.61	0.21
Interaction	12	13.7	5.73**	0.01
Within (error)	20	2.4		
Total	39			

Worn Trousers

Source of Variation	Degrees of Freedom	Mean Squares	F-Ratio	Probability of Greater F
Between Types	3	580.5	17.32**	0.01
Within Types	67	33.5		
Total	70			

**Significant at $\alpha = 0.01$ level.

TABLE IXd

RANK ORDERED MEAN FILLING BREAKING STRENGTH VALUES

Non-Worn Trousers

Types Averaged Across Launderings			Laundering Periods Averaged Across Types		
Rank*	Type	Mean	Rank*	Period	Mean
1	1-VP	61.7	1	15	54.3
2	2-VP	59.1	2	10	52.9
3	4-PCP	47.6	3	20	52.9
4	3-PDC	43.8	4	5	52.7
			5	0	52.5

Worn Trousers

Types Averaged Across Launderings		
Rank*	Type	Mean
1	1-VP	45.2
2	2-VP	39.3
3	4-PCP	33.9
4	3-PDC	30.8

*Rank 1 assigned to largest mean.

TABLE IXe

DUNCAN'S MULTIPLE RANGE TEST OF DIFFERENCES IN MEAN FILLING BREAKING STRENGTH VALUES

Non-Worn Trousers Averaged Across Periods

Differences Between			Duncan Criterion	
Ranks	Types	Means	α = 0.05	α = 0.01
1-4	1-VP - 3-PDC	18.0**	1.5	2.0
1-3	1-VP - 4-PCP	14.1**	1.5	2.0
1-2	1-VP - 2-VP	2.6**	1.4	1.9
2-4	2-VP - 3-PDC	15.4**	1.5	2.0
2-3	2-VP - 4-PCP	11.5**	1.4	1.9
3-4	4-PCP - 3-PDC	3.9**	1.4	1.9

Worn Trousers Averaged Across Periods

Differences Between			Duncan Criterion	
Ranks	Types	Means	α = 0.05	α = 0.01
1-4	1-VP - 3-PDC	14.4**	6.1	8.0
1-3	1-VP - 4-PCP	11.2**	3.8	5.1
1-2	1-VP - 2-VP	5.9**	3.3	4.4
2-4	2-VP - 3-PDC	8.5**	6.0	7.9
2-3	2-VP - 4-PCP	5.4**	3.8	5.0
3-4	4-PCP - 3-PDC	3.1	5.9	7.9

**Indicates significance at α = 0.01 level.

Tearing Strength

The experimental trousers were measured for fabric tearing strength at the same test intervals mentioned for breaking strength and by the prescribed technique referred to in Chapter II. Results of these evaluations are found in Tables Xa through Xe for the warp direction and in Tables XIa through XIe for the filling direction. As was found to be the case with the breaking strength determinations, 40 observations were required for the assessment of the resistance to tearing of the non-worn trousers and 71 for the worn trousers.

Warpwise tearing strength values are recorded in Table Xa. An analysis of these values indicated that in the non-worn trousers warp strength losses were sustained by the vapor phase finished trousers during progressive launderings while the pad-dry-cure and the proprietary finished trousers increased in strength values. The greatest strength loss, 27.7 percent, due to laundering was observed for the Type 2 vapor phase treated trousers. The trousers which were representative of the Type 1 vapor phase finish showed a loss of 13.3 percent in resistance to warp tearing throughout the 20 laundering periods. The tearing strength of the pad-dry-cure and the proprietary finishes increased 20.0 and 26.0 percent, respectively.

These increases, however, in warp tearing by the latter mentioned trouser types did not result in values equal to the higher strength values which were attained by the vapor phase treatments. Additional data recorded in Table Xa show that 20 wear periods contributed to the tearing strength of the vapor phase treated trousers. Increases of 12 and 18 percent, respectively, were noted for Types 1 and 2 trousers when data from the worn trousers were compared with those from the non-worn trousers. This increase in tearing strength values was not shown for the pad-dry-cure and proprietary finishes. The percentages of loss in warp tearing strength due to wear incurred by the pad-dry-cure and proprietary treatments were 13 and 14 percent, respectively. A graphic comparison of the trouser types with regard to warp tearing strength values is recorded in Figure 12.

These increases for the vapor phase treatments are in contrast to those observed by Campbell and Staples (11). A study of cotton print cloth which had been impregnated with various nitrogenous compounds and crosslinked in the presence of formaldehyde vapors showed that warp losses ranged from zero to 40 percent. Swidler, Gamarra, and Jones (66) reported similar tearing strength losses in a study of cotton twill fabrics which were exposed to formaldehyde and sulfur dioxide vapors. These losses were noted both for the warp and filling directions.

Data from the analysis of warpwise tearing strength values, Tables Xb and Xc, revealed significant differences at the α 0.01 level between trouser types and in the interaction between types and laundering periods, but non-significant differences between laundering periods for the non-worn trousers. The data from the worn trousers indicated significant differences between trouser types.

A rank order of the mean tearing strength values was shown to be the same both for the non-worn and worn trousers. The superior performances of the vapor phase finishes are demonstrated in Table Xd. These finishes were consistently ranked higher than the proprietary and pad-dry-cure finishes. The values for the worn trousers showed that Rank 1 was earned by the Type 1 vapor phase treated trousers with a mean warp tearing resistance of 3084 grams, while the pad-dry-cure trousers fell into Rank 4 with a mean of 1235 grams. When the laundering periods were averaged across finishes, the initial tearing strength values ranked first and those after 20 laundering periods were in the Rank 5 position.

The preceding findings related to warp tearing strength were confirmed when Duncan's multiple range test was utilized, Table Xe. All pairwise finishes, regardless of the non-worn or worn classifications, were significantly different at the α 0.01 level. In every comparison associated with the vapor phase treated trousers, these trousers proved to be superior in their resistance to tearing in the warp direction. Additional findings were favorable to the proprietary finish over the pad-dry-cure finish.

Fisher's t-test indicated that wear contributed to increases in warp tearing strength values for the vapor phase treated trouser types, and those trousers finished by the proprietary treatment when the mean values for the non-worn and worn trousers were compared after 20 laundering periods. A difference in tearing strength was not shown when comparisons were made between worn and non-worn pad-dry-cure trousers.

The fillingwise tearing strength data for the non-worn and worn trousers are given in Table XIa and in Figure 13. These data reflect relationships similar to those displayed by the warpwise data. The percentages of change were less, however, fillingwise than in the warp direction. The non-worn trousers representative of the Types 1 and 2 vapor phase treatments decreased in tearing strength values by 1.4 and 4.9 percent, respectively. The pad-dry-cure finished trousers showed an increase in values of 3.8 percent, while an increase of 1.8 percent was recorded for the proprietary finish. These findings are in contrast to those reported by Sterling Pile Fabrics (21), for the pad-dry-cure corduroy fabric evaluated in that study lost in filling tearing strength value by 4.4 percent.

The data presented in Tables XIb and XIc are indicative of significant differences between trouser types, non-worn and worn, with regard to their resistance to fillingwise tearing. Non-significant differences were noted between laundering periods and in the interaction between trouser types and laundering periods for the trousers in the non-worn category.

The order of ranking for the filling tearing strength values is shown in Table XId. The highest rank for the non-worn trousers was awarded to the Type 1 vapor phase finish, while the pad-dry-cure finish was assigned a Rank 4 position. This same rank order was shown for the worn trousers. A ranking of the laundering periods on the basis of mean values showed that the fifth laundering period contributed the greatest amount to the fillingwise resistance to tearing while 10 laundering periods proved to be the most harmful.

The results of pairwise evaluations showed all combinations of types averaged across periods to be significantly different at the α 0.01 level. As was found to be the case in the warp direction, the vapor phase treatments, fillingwise, were significantly superior to the remainder of the finishes with regard to the resistance they offered to tearing. The proprietary finish provided a greater resistance than was observed for the pad-dry-cure treatment. These findings are shown in Table XIe.

Wear had no effect on the fillingwise tearing strength retention values when comparisons were made between the non-worn and worn trousers of each type after 20 laundering periods. These results were determined by Fisher's t-test.

TABLE Xa

MEAN WARP TEARING STRENGTH VALUES

Trouser Type	Non-Worn Trousers						Worn Trousers
	Number of Launderings					Type Mean	After 20 Launder-ings
	0	5	10	15	20		
1-VP	3188	3050	2988	2950	2763	2988	3084
2-VP	3025	2663	2588	2413	2188	2575	2575
3-PDC	1188	1263	1288	1450	1425	1323	1235
4-PCP	1588	1575	1650	1863	2000	1735	1714
Period Mean	2447	2137	2128	2169	2094	2155	2480

TABLE Xb

STANDARD DEVIATIONS OF WARP TEARING STRENGTH VALUES

Trouser Type	Non-Worn Trousers						Worn Trousers
	Number of Launderings					Type Mean	After 20 Launder-ings
	0	5	10	15	20		
1-VP	229.8	176.8	88.4	141.4	88.4	186.1	197.1
2-VP	212.1	17.7	53.0	88.4	17.7	303.7	204.4
3-PDC	88.4	17.7	53.0	35.4	35.4	112.1	105.5
4-PCP	123.7	176.8	176.8	159.1	282.8	227.4	128.8
Period Mean	942.3	796.8	738.2	611.2	522.8	700.0	648.3

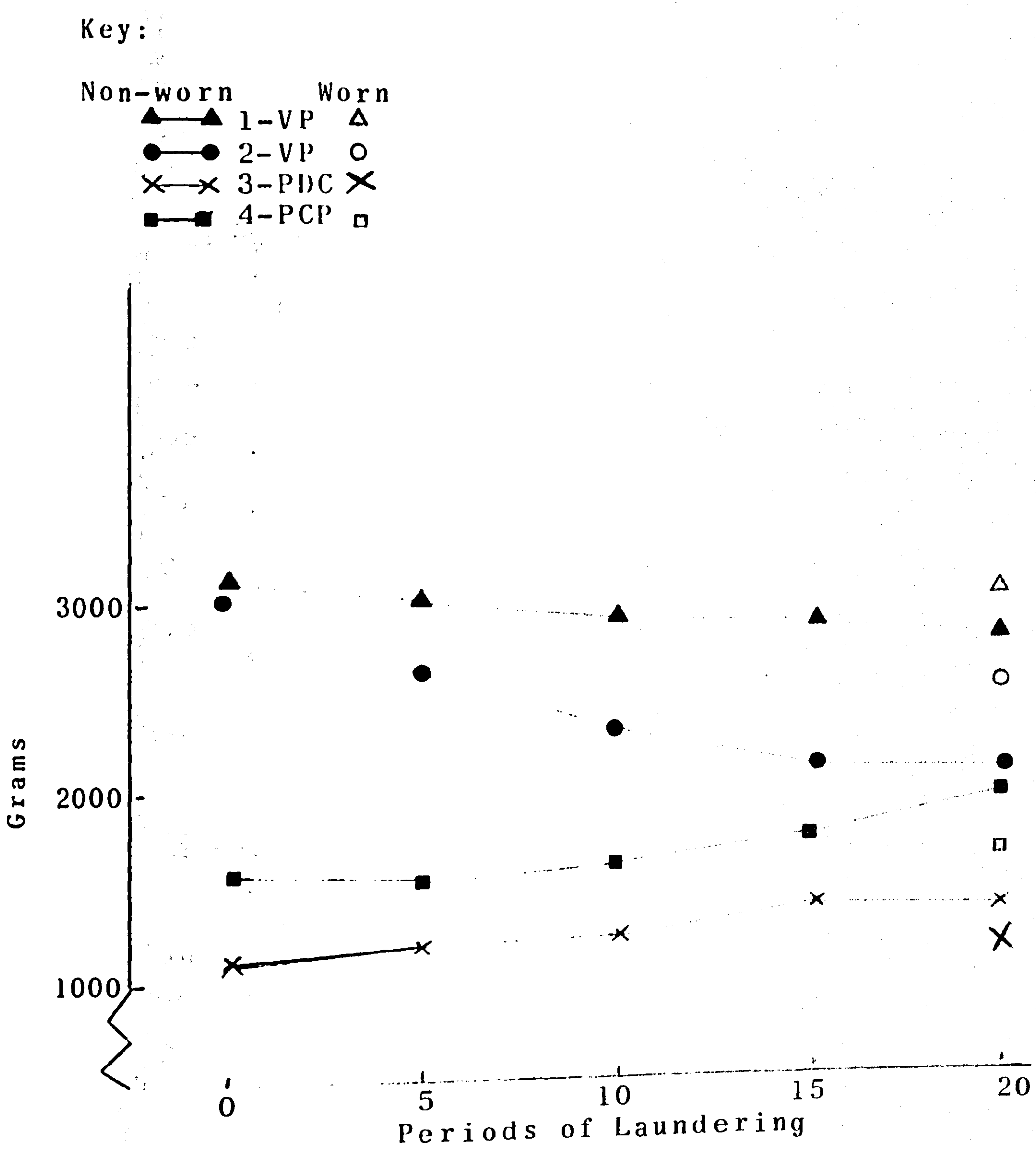

Fig. 12. Comparison of trouser types on the basis of warp tearing strength values.

TABLE Xc

ANALYSIS OF VARIANCE OF WARP TEARING STRENGTH VALUES

Non-Worn Trousers

Source of Variation	Degrees of Freedom	Mean Squares	F-Ratio	Probability of Greater F
Between Types	3	5796375.0	311.21**	0.01
Between Periods	4	26820.3	1.44	0.25
Interaction	12	103341.1	5.55**	0.01
Within (error)	20	18625.0		
Total	39			

Worn Trousers

Source of Variation	Degrees of Freedom	Mean Squares	F-Ratio	Probability of Greater F
Between Types	3	9067582.7	273.4**	0.01
Within	67	33166.4		
Total	70			

**Significant at $\alpha = 0.01$ level.

TABLE Xd

RANK ORDERED MEAN WARP TEARING STRENGTH VALUES

Non-Worn Trousers

Types Averaged Across Launderings			Laundering Periods Averaged Across Types		
Rank*	Type	Mean	Rank*	Period	Mean
1	1-VP	2987.5	1	0	2246.9
2	2-VP	2575.0	2	15	2168.8
3	4-PCP	1735.0	3	5	2137.5
4	3-PDC	1322.5	4	10	2128.1
			5	20	2093.8

Worn Trousers, 20 Launderings

Types Averaged Across Launderings		
Rank*	Type	Mean
1	1-VP	3084.3
2	2-VP	2575.0
3	4-PCP	1714.1
4	3-PDC	1235.0

*Rank 1 assigned to highest score.

TABLE Xe

DUNCAN'S MULTIPLE RANGE TEST OF DIFFERENCES IN MEAN WARP TEARING STRENGTH VALUES

Non-Worn Trouser Types Averaged Across Periods

Differences Between			Duncan Criterion	
Ranks	Types	Means	α = 0.05	α = 0.01
1-4	1-VP - 3-PDC	1665.0**	135.1	179.9
1-3	1-VP - 4-PCP	1252.5**	131.0	175.0
1-2	1-VP - 2-VP	412.5**	124.6	167.8
2-4	2-VP - 3-PDC	1252.5**	131.0	175.0
2-3	2-VP - 4-PCP	840.0**	124.6	167.8
3-1	4-PCP - 3-PDC	412.5**	124.6	167.8

Worn Trouser Types Averaged Across Periods

Differences Between			Duncan Criterion	
Ranks	Types	Means	α = 0.05	α = 0.01
1-4	1-VP - 3-PDC	1849.3**	192.7	252.7
1-3	1-VP - 4-PCP	1370.2**	120.9	159.3
1-2	1-VP - 2-VP	509.3**	103.4	137.5
2-4	2-VP - 3-PDC	1340.0**	189.1	249.2
2-3	2-VP - 4-PCP	860.9**	118.6	157.7
3-4	4-PCP - 3-PDC	479.1**	186.7	248.2

**Indicates significance at α = 0.01 level.

TABLE XIa

MEAN FILLING TEARING STRENGTH VALUES

Trouser Type	Non-Worn Trousers						Worn Trousers
	Number of Launderings					Type Mean	After 20 Launderings
	0	5	10	15	20		
1-VP	1775	1788	1750	1750	1750	1763	1862
2-VP	1788	1775	1750	1725	1700	1748	1732
3-PDC	1000	1062	1013	1075	1038	1038	980
4-PCP	1388	1375	1300	1400	1413	1375	1339
Period Mean	1488	1500	1453	1488	1475	1480	1640

TABLE XIb

STANDARD DEVIATIONS OF FILLING TEARING STRENGTH VALUES

Trouser Type	Non-Worn Trousers						Worn Trousers
	Number of Launderings					Type Mean	After 20 Launderings
	0	5	10	15	20		
1-VP	176.8	53.0	35.4	35.4	70.7	70.0	98.9
2-VP	17.7	106.1	70.7	70.7	70.7	64.0	90.2
3-PDC	35.4	53.0	17.7	0.0	17.7	37.7	67.1
4-PCP	17.7	70.7	35.4	35.4	17.7	51.4	49.1
Period Mean	353.3	327.8	337.1	296.1	305.6	308.0	283.8

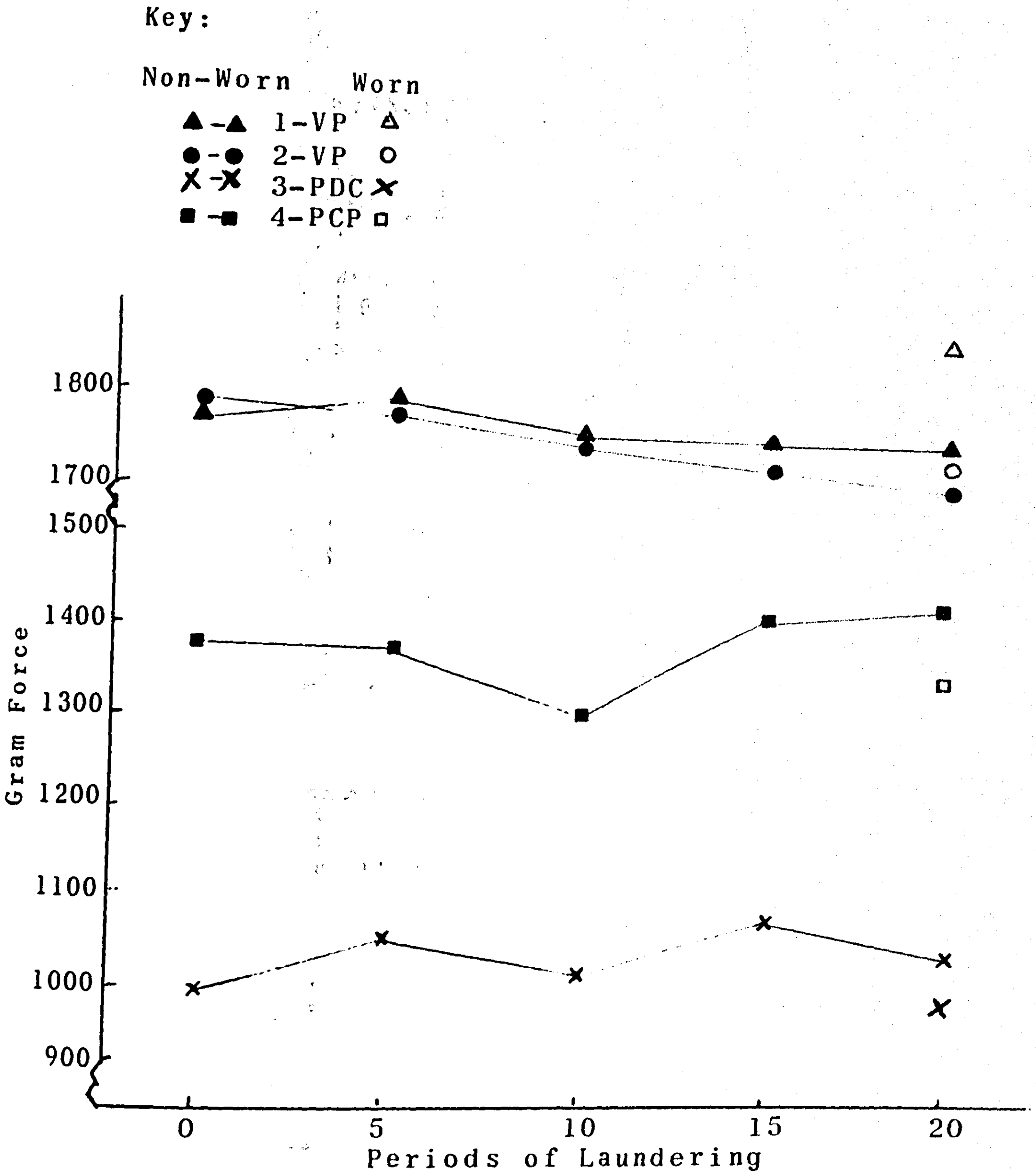

Fig. 13. Comparison of trouser types on the basis of filling tearing strength values.

TABLE XIc

ANALYSIS OF VARIANCE OF FILLING TEARING STRENGTH VALUES

Non-Worn Trousers

Source of Variation	Degrees of Freedom	Mean Squares	F-Ratio	Probability of Greater F
Between Types	3	1193973.0	295.00**	<0.01
Between Periods	4	2515.6	0.62	0.65
Interaction	12	2203.1	0.54	0.85
Within (error)	20	4046.9		
Total	39			

Worn Trousers

Source of Variation	Degrees of Freedom	Mean Squares	F-Ratio	Probability of Greater F
Between Types	3	1716925.4	235.99**	<0.01
Within	67	7275.3		
Total	70			

**Significance at $\alpha = 0.01$ level.

TABLE XId

RANK ORDERED MEAN FILLING TEARING STRENGTH VALUES

Non-Worn Trousers

Types Averaged Across Launderings			Laundering Periods Averaged Across Types		
Rank	Type	Mean	Rank	Period	Mean
1	1-VP	1762.5	1	5	1500.0
2	2-VP	1747.5	2.5	15	1487.5
3	4-PCP	1375.0	2.5	0	1487.5
4	3-PDC	1037.5	4	20	1475.0
			5	10	1453.1

Worn Trousers, 20 Launderings

Types Averaged Across Launderings		
Rank	Type	Mean
1	1-VP	1862.0
2	2-VP	1731.5
3	4-PCP	1339.1
4	3-PDC	980.0

TABLE XIe

DUNCAN'S MULTIPLE RANGE TEST OF DIFFERENCES IN MEAN FILLING TEARING STRENGTH VALUES

Non-Worn Trouser Types Averaged Across Periods

Differences Between			Duncan Criterion	
Ranks	Types	Means	α = 0.05	α = 0.01
1-4	1-VP - 3-PDC	725.0**	63.0	83.9
1-3	1-VP - 4-PCP	387.5**	61.1	81.6
1-2	1-VP - 2-VP	15.0	58.1	78.2
2-4	2-VP - 3-PDC	710.0**	61.1	81.6
2-3	2-VP - 4-PCP	372.5**	58.1	78.2
3-4	4-PCP - 3-PDC	337.5**	58.1	78.2

Worn Trouser Types Averaged Across Periods

Differences Between			Duncan Criterion	
Ranks	Types	Means	α = 0.05	α = 0.01
1-4	1-VP - 3-PDC	882.0**	90.2	118.4
1-3	1-VP - 4-PCP	522.9**	56.6	74.6
1-2	1-VP - 2-VP	130.5	48.4	64.4
2-4	2-VP - 3-PDC	751.5**	88.6	116.7
2-3	2-VP - 4-PCP	392.4**	55.6	73.9
3-1	4-PCP - 3-PDC	359.1**	87.4	116.3

**Indicates significance at α = 0.01 level.

Bursting Strength

Data which resulted from an evaluation of the bursting strength performance of the experimental trousers have been recorded in Tables XIIa through XIIe. Data were calculated in pounds per inch at the intervals shown in Table XIIa. The observations were made on 40 pairs of non-worn trousers and 71 pairs of worn trousers.

Mean bursting strength values as recorded in Table XIIA and illustrated in Figure 14 revealed the superior performance of the trousers finished by the 2 vapor phase treatments both in the non-worn and in the worn categories. The overall mean values for the non-worn Types 1 and 2 vapor phase treated trousers were 109.8 and 104.6 pounds, respectively. Values for the worn trousers at the termination of the study were slightly lower, but the relationship remained the same. A comparison of the non-worn and worn trousers by types after 20 laundering periods showed percentage losses in bursting strength values, due to wear, to range from a high of 16.4 percent for the proprietary finish to a low of 7.9 for the Type 1 vapor phase finish. The pad-dry-cure and Type 2 vapor phase finishes displayed respective percentage losses of 14.2 and 13.2. These findings are in contrast to those reported by Wylie and Erickson (74). The researchers found worn and laundered durable press shirts to have higher strength values than did those which were laundered only. The statistical results as recorded in Table XIIc showed the existence of significant differences between trouser finishes for the non-worn and worn trousers. Non-significant differences were shown both between laundering periods and in the interaction between trouser types and laundering periods for the non-worn trousers.

The relative rankings, Table XIId, of the mean bursting strength values consistently placed the vapor phase finishes in Ranks 1 and 2 and the proprietary and pad-dry-cure finishes in Ranks 3 and 4, respectively. The rank order for laundering periods averaged across types shows that the fifth laundering period was awarded the highest rank of 1 with Period 10 given the lowest rank of 5.

Duncan's multiple range tests of pairwise differences in mean values are tabulated in Table XIIe. A study of the data from the non-worn trousers indicated significant differences for all pairwise combinations, with 1 exception. The paired vapor phase finishes were not significantly different with regard to mean bursting strength values. In the worn trousers differences between these trouser types were significant at the α 0.05 level after 20 periods of laundering. Other comparisons gave results identical to those mentioned above for the non-worn trousers.

Fisher's t-test was applied to provide a comparison between the bursting strength performances of the non-worn and worn trousers. These results indicated that wear had no effect on any of the trouser type means after 20 laundering and wear-laundering periods.

TABLE XIIa

MEAN BURSTING STRENGTH VALUES

Trouser Type	Non-Worn Trousers						Worn Trousers
	Number of Launderings					Type Mean	After 20 Launder-ings
	0	5	10	15	20		
1-VP	108.5	113.3	111.7	108.8	106.7	109.8	99.9
2-VP	109.0	108.9	109.6	92.2	99.4	104.6	94.6
3-PDC	66.4	77.3	65.9	85.1	78.2	74.6	57.0
4-PCP	88.5	87.2	77.9	84.4	89.5	85.5	73.9
Period Mean	93.1	96.7	91.3	93.6	93.4	93.6	89.3

TABLE XIIb

STANDARD DEVIATION OF BURSTING STRENGTH VALUES

Trouser Type	Non-Worn Trousers						Worn Trousers
	Number of Launderings					Type Mean	After 20 Launderings
	0	5	10	15	20		
1-VP	10.8	1.1	9.2	1.1	7.2	5.9	11.4
2-VP	5.4	9.5	8.7	0.7	4.9	7.8	8.1
3-PDC	11.3	2.5	5.8	13.4	0.4	9.9	3.2
4-PCP	4.7	1.0	0.1	1.6	9.2	5.6	6.5
Period Mean	19.8	16.4	21.8	11.8	12.4	16.1	16.1

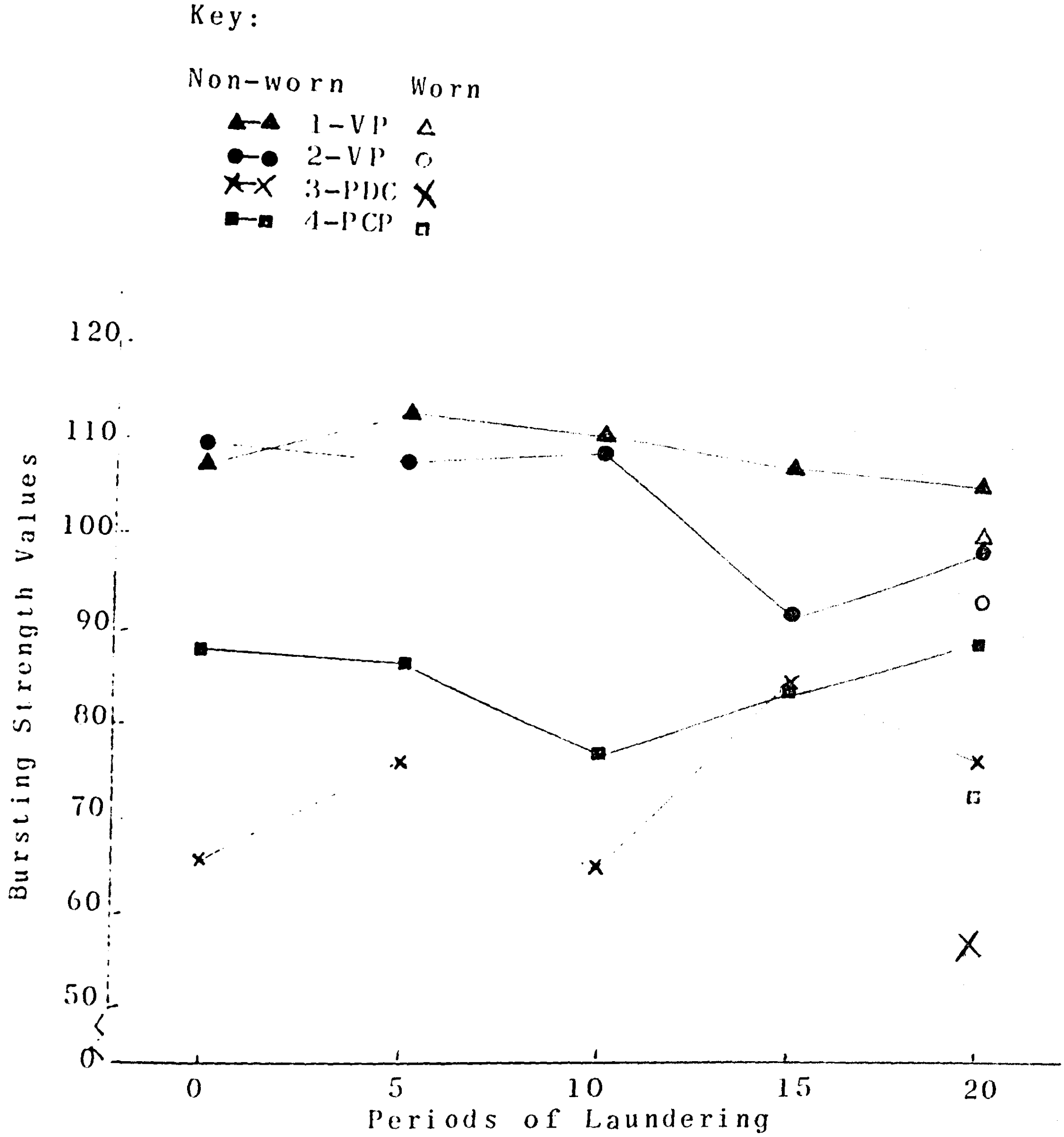

Fig. 14. Comparison of trouser types on the basis of bursting strength values.

TABLE XIIc

ANALYSIS OF VARIANCE OF BURSTING STRENGTH VALUES

Non-Worn Trousers

Source of Variation	Degrees of Freedom	Mean Squares	F-Ratio	Probability of Greater F
Between Types	3	2704.9	58.03**	0.01
Between Periods	4	30.4	0.65	0.63
Interaction	12	81.2	1.74	0.13
Within (error)	20	46.6		
Total	39			

Worn Trousers

Source of Variation	Degrees of Freedom	Mean Squares	F-Ratio	Probability of Greater F
Between Types	3	4216.2	51.30**	0.01
Within (error)	67	82.9		
Total	70			

**Significance at $\alpha = 0.01$ level.

TABLE XIId

RANK ORDERED MEAN BURSTING STRENGTH VALUES

Non-Worn Trousers

Types Averaged Across Launderings			Laundering Periods Averaged Across Types		
Rank	Type	Mean	Rank	Period	Mean
1	1-VP	109.8	1	5	96.7
2	2-VP	104.6	2	15	93.6
3	4-PCP	85.5	3	20	93.4
4	3-PDC	74.6	4	0	93.1
			5	10	91.3

Worn Trousers, 20 Launderings

Types Averaged Across Launderings		
Rank	Type	Mean
1	1-VP	99.9
2	2-VP	94.6
3	4-PCP	73.9
4	3-PDC	57.0

TABLE XIIe

DUNCAN'S MULTIPLE RANGE TEST OF DIFFERENCES IN MEAN BURSTING STRENGTH VALUES

Non-Worn Trouser Types Averaged Across Periods

Differences Between			Duncan Criterion	
Ranks	Types	Means	$\alpha = 0.05$	$\alpha = 0.01$
1-4	1-VP - 3-PDC	35.2**	6.8	9.0
1-3	1-VP - 4-PCP	24.3**	6.6	8.8
1-2	1-VP - 2-VP	5.2	6.2	8.4
2-4	2-VP - 3-PDC	30.1**	6.6	8.8
2-3	2-VP - 4-PCP	19.1**	6.2	8.4
3-4	4-PCP - 3-PDC	10.9**	6.2	8.4

Worn Trouser Types Averaged Across Periods

Differences Between			Duncan Criterion	
Ranks	Types	Means	$\alpha = 0.05$	$\alpha = 0.01$
1-4	1-VP - 3-PDC	42.8**	9.6	12.6
1-3	1-VP - 4-PCP	25.9**	6.0	7.9
1-2	1-VP - 2-VP	5.3*	5.2	6.8
2-4	2-VP - 3-PDC	37.6**	9.4	12.4
2-3	2-VP - 4-PCP	20.7**	5.9	7.9
3-4	4-PCP - 3-PDC	16.9**	9.3	12.4

*Significant at $\alpha = 0.05$ level.
**Significant at $\alpha = 0.01$ level.

Fabric Count

The mean fabric count representative of the 4 types of non-worn and worn trousers provided in Tables VIIIa and VIIIb has been included for those who are interested in the relationship between the number of yarns and the fabric performance. As discernible from these data, fabric count was affected only to a limited degree either by the finish type or by the number of laundering or wear-laundering periods.

TABLE XIIIa

ADJUSTED MEAN FABRIC COUNT, NON-WORN TROUSERS

Warp Direction

Trouser Type	Number of Launderings			Type Mean
	5	15	20	
1-VP	111.5	111.7	111.8	111.7
2-VP	111.4	111.3	111.4	111.3
3-PDC	111.4	110.7	110.7	110.9
4-PCP	111.2	111.4	112.1	111.5
Period Mean	111.4	111.2	111.8	111.4

Filling Direction

Trouser Type	Number of Launderings			Type Mean
	5	15	20	
1-VP	52.1	52.8	53.0	52.6
2-VP	51.0	51.3	51.8	51.4
3-PDC	51.8	52.5	52.5	52.3
4-PCP	51.5	52.1	52.1	51.9
Period Mean	51.6	52.2	52.4	52.0

TABLE XIIIb

MEAN FABRIC COUNT VALUES, WORN TROUSERS

Warp Direction

Trouser Type	Number of Launderings		
	5	15	20
1-VP	111.2	111.4	111.5
2-VP	111.7	111.5	111.6
3-PDC	110.3	110.8	110.7
4-PCP	111.6	111.8	111.8
Period Mean	111.3	111.5	111.6

Filling Direction

Trouser Type	Number of Launderings		
	5	15	20
1-VP	52.2	52.5	53.0
2-VP	51.4	51.7	52.1
3-PDC	51.9	52.4	52.3
4-PCP	51.5	51.9	52.1
Period Mean	51.8	52.1	52.4

CHAPTER IV

SUMMARY

This investigation was conducted to determine the performance of 4 durable press finishes which were applied to all-cotton work trousers. The experimental trousers were constructed from a 3/1 khaki twill fabric and commercially finished with 4 durable press finishes. The finishes included 2 variations of the vapor phase finish, a conventional pad-dry-cure finish, and a proprietary finish.

One hundred sixty pairs of trousers served as experimental garments with 40 pairs representative of each of the 4 finishes. Thirty pairs were exposed to 20 wear-laundering periods; 8 pairs were laundered without previous wear; and 2 pairs of each type served as controls.

The trousers were evaluated at specified time intervals throughout the study for durable press appearance, crease retention, crease wear, soiling, broken yarns, and dimensional stability. At the completion of the study, physical tests including wrinkle recovery, breaking strength, tearing strength, and bursting strength were applied to the worn trousers while the non-worn trousers were tested initially and after 5, 10, 15, and 20 laundering periods with respect to these parameters. The relative performance of the trousers was determined through an application of the analysis of variance technique, Duncan's multiple range test and Fisher's t-test to the mean data.

Comparisons of the durable press appearance data obtained at each evaluation period revealed that despite the high failure rate the pad-dry-cure and the proprietary finishes provided a superior performance to that provided by the 2 vapor phase treatments both in the non-worn and worn trouser categories. There were no significant differences in any comparisons between the pad-dry-cure and the proprietary treatments, except in 1 instance, or between the 2 vapor phase finishes. The exception was related to the superior performance of the pad-dry-cure finished trousers over those treated with the proprietary finish after 15 laundering periods. After the first 5 laundering periods, the smoothness values for all finishes decreased proportionately as the number of laundering periods increased.

The mean values of the non-worn and worn trousers were compared after 20 laundering periods by the application of Fisher's t-test. The results showed that wear had no effect upon the durable press appearance of the trousers.

With regard to crease retention values, generally, the same performance pattern was observed as mentioned above for the durable press appearance. In the non-worn category of trousers, however, significant differences in crease retention values, favorable to the proprietary treatment over the pad-dry-cure and to the Type 2 vapor phase treatment over Type 1, were found. All trouser types showed a continual decline in mean crease values with additional laundering and wear-laundering periods. When comparisons were made between the mean values of the 4 trouser finishes after 20 laundering and wear-laundering periods, wear was shown to have had no effect on crease retention values.

In no instance did finishing treatment demonstrate soil release properties superior to those displayed by another in the worn trouser category. As wear and laundering continued, soil removal became more difficult as indicated by a decrease in the soil removal values.

The durable press finishing formulation which had been applied by the pad-dry-cure process provided the highest wrinkle recovery values irrespective of whether the trousers were non-worn or worn. The proprietary finished trousers ranked next, followed by the 2 types of vapor phase cured trousers. In the final evaluation of the worn trousers, the Type 1 vapor phase treatment provided higher wrinkle recovery values than were provided by the Type 2 treatment. Generally, all treatments showed a decrease in wrinkle recovery values as the number of laundering or wear-laundering periods increased.

Wear was shown to have had an effect on the Type 1 vapor phase and the proprietary finished trousers after 20 laundering periods. When other trouser finishes were compared on the basis of mean wrinkle recovery values, non-significant differences were observed.

In the warp direction all trousers experienced some degree of shrinkage during the 20 laundering periods, but the trousers finished with the proprietary durable press treatment demonstrated more resistance to warpwise dimensional change than did the other finishes. This performance, however, did not surpass, to a significant degree, that displayed by the pad-dry-cure finish. Differences were not evident between the 2 vapor phase treatments concerning the warp stability which they provided. When mean warp stability values were compared for laundering intervals, significant differences were noted when comparisons between values after 5 and 15 periods were made with those after 20 laundering periods. In both instances the fewest number of launderings accounted for the greatest degree of performance.

An analysis of the fillingwise changes in dimensional stability showed that trouser types were not significantly different in this regard. No significant differences were found when laundering periods were paired.

As far as crease-wear performance was concerned the vapor phase treated trousers (non-worn and worn) were consistently better than were those treated with the proprietary and pad-dry-cure finishes. The least acceptable performance was noted in the trousers with the pad-dry-cure finish.

In reviewing the effects of the 4 durable press finishes on the resistance of the trousers to yarn rupture, the superior performance of the Type 1 vapor phase finish was observed. The second most desirable behavior was reported for vapor phase finish Type 2. Although excessive numbers of ruptured yarns were evident, both in the proprietary and in the pad-dry-cure finished trousers, the pad-dry-cure far exceeded all finish types in total number of broken yarns. This behavioral pattern was indicated both for the non-worn and for the worn trousers. Additional findings related to yarn rupture were associated with laundering periods. As the number of laundering or wear-laundering periods increased, so did the number of broken yarns.

Wear did have an effect on the broken yarn values of the trousers finished by the pad-dry-cure treatment when the non-worn and worn trousers were compared after 20 laundering and wear-laundering periods. When the other finishes were compared, wear was shown to have had no effect with regard to the number of broken yarns.

An evaluation of the breaking strength values from the standpoint of finishing processes and irrespective of laundering and wear-laundering treatments pointed to the superior performance of the trousers which were cured by the 2 vapor phase treatments over those treated by the pad-dry-cure and proprietary processes. Additional comparisons showed the Type 1 vapor phase treatment to give the most desirable breaking strength values and the pad-dry-cure to give the poorest. These findings were evidenced both in the warp and filling directions.

A comparison of the overall breaking strength values with regard to laundering revealed that the initial values were superior when paired with those from the laundering and wear-laundering periods. Other paired periods showed that the fewest number of launderings provided the highest breaking strength values.

When a comparison of the non-worn and worn trousers was made after 20 laundering periods, wear was shown to have had an effect upon the warp breaking strength of all trouser types. In the filling direction, when the pad-dry-cure finished trousers were compared, no significant differences were observed between the mean breaking strength values.

Warpwise tearing strength tests disclosed results similar to those observed for the breaking strength tests. The vapor phase finishes provided a greater resistance to tearing than did either the pad-dry-cure or the proprietary finishes. Additional findings were favorable to the proprietary finish over the pad-dry-cure finish. In the non-worn trousers, tearing strength values declined for the vapor phase finished trousers and increased for the pad-dry-cure and the proprietary finished trousers with each 5 additional laundering periods. These increases, however, for the latter mentioned trouser types did not give values which were equal to the higher strength values provided by the vapor phase treatments. Wear contributed to increases in tearing strength values for the vapor phase treated trousers, but an increase was not shown for the pad-dry-cure and the proprietary finished garments.

The fillingwise data reflected relationships similar to those displayed by the warpwise data. No significant differences were indicated between periods of laundering.

An overall observation directs attention to the fact that a more acceptable resistance to tearing was provided by trousers that were finished with the Type 1 vapor phase finish. This finish showed superior strength, both in warp and filling directions, followed by the Type 2 vapor phase, the proprietary, and the pad-dry-cure finishes in the order mentioned.

A review of the bursting strength resistance demonstrated by the experimental trousers indicated that the non-worn and worn trousers constructed from fabrics treated with Types 1 and 2 vapor phase finishes exhibited a superior performance to that provided by the pad-dry-cure and the proprietary finishes. A comparison of the initial bursting strength values and those after 20 laundering periods showed that the non-worn trousers treated with the vapor phase finishes lost in bursting strength values while those treated with the proprietary and pad-dry-cure finishes increased in bursting strength resistance. The worn trousers all showed a decrease in bursting strength resistance. In the non-worn trousers no difference was indicated between the resistance provided by the vapor phase finishes; however, in the worn trousers differences between these trouser types were significant at the α 0.05 level after 20 launderings.

Wear had no effect on the bursting strength values of the vapor phase treated trousers. There was, however, evidence that wear did have an effect on the bursting strength values of trousers finished with the pad-dry-cure and the proprietary treatments.

As a final summary relative to the overall performance of the 4 durable press finishes on the all-cotton trousers, the rank order arrangement of the trousers with regard to the various parameters of testing is provided in Table XIV. A study of these data from the standpoint of appearance ratings showed that trousers finished with the pad-dry-cure treatment received the highest ratings; whereas, the highest ratings for strength values were observed for the 2 vapor phase treatments.

As shown in Table XIV, the trousers with the Type 1 vapor phase treatment gave the best overall performance as evidenced by the smallest sum of ranks. The poorest overall performance was by the pad-dry-cure finish with the largest sum of ranks. This relationship was noted both for the non-worn and the worn trousers.

TABLE XIV

RANK ORDER ARRANGEMENT BY TROUSER TYPES AFTER 20 LAUNDERING AND WEAR-LAUNDERING PERIODS

Type of Evaluation	Rank Order and Trouser Type							
	Non-Worn				Worn			
	1 VP	2 VP	3 PDC	4 PCP	1 VP	2 VP	3 PDC	4 PCP
Durable Press Appearance	4	3	1	2	4	3	1	2
Crease Retention	4	3	2	1	4	3	2	1
Wrinkle Recovery	3	4	1	2	3	4	1	2
Stability--								
Warp	3	4	2	1				
Filling	2	4	3	1				
Crease Wear	1	2	4	3	1	2	4	3
Broken Yarns	1	2	4	3	1	2	4	3
Breaking--								
Warp	1	2	4	3	1	2	4	3
Filling	1	2	4	3	1	2	3	4
Bursting	1	2	4	3	1	2	4	3
Tearing--								
Warp	1	2	4	3	1	2	4	3
Filling	1	2	4	3	1	2	4	3
Total Ranks	23	32	37	28	18	24	31	27

REFERENCES

1. Abrahams, David H. "Durable Press Review and Outlook." <u>American Dyestuff Reporter</u> 60 (January 1971): 17-18.

2. "Advances in Cotton Research." Sixth USDA Utilization Conference. <u>American Dyestuff Reporter</u> 55 (May 23, 1966): 36-75.

3. Alexander, Edward N. "Deferred Cure Processes for Durable Press." <u>American Dyestuff Reporter</u> 55 (August 1, 1966): 28-31.

4. American Association of Textile Chemists and Colorists, <u>Technical Manual</u>, 49 (1973).

   a. AATCC Test Method 88c-1973. "Appearance of Creases in Wash-and-Wear Items After Home Laundering."

   b. AATCC Test Method 124-1973. "Appearance of Durable Press Fabrics After Repeated Home Launderings."

5. American Society for Testing and Materials. <u>ASTM Standards, Textile Materials--Yarns, Fabrics, General Methods</u>, Part 24 (1973).

   a. ASTM Designation: D 1295-72. "Wrinkle Recovery of Woven Textile Fabrics Using the Vertical Strip Apparatus."

   b. ASTM Designation: D 1424-70. "Tear Resistance of Woven Fabrics by Falling-Pendulum (Elmendorf) Apparatus."

   c. ASTM Designation: D 1682-70. "Breaking Load and Elongation of Textile Fabrics."

   d. ASTM Designation: D 1905-73. "Dimensional Changes in Laundering of Woven or Knitted Textiles."

e. ASTM Designation: D 1776-67. "Conditioning Textiles and Textile Products for Testing."

f. ASTM Designation: D 1910-70. "Construction Characteristics of Woven Fabrics."

6. Arceneaux, Richard L.; Fujimoto, Reginald A.; Reid, J. David; and Reinhardt, Robert M. "Crosslinking of Cotton with Gaseous Formaldehyde." American Dyestuff Reporter 51 (July 23, 1962): 45-52.

7. Ball, Helen McDaniel. "Evaluation of the Appearance of Men's Worn and Non-Worn Durable Press Work Trousers of All-Cotton and Cotton-Polyester Blends." Ph. D. Dissertation, Texas Woman's University, May 1971.

8. Berni, Ralph J.; Gonzales, Elwood J.; and Jung, Hilda A. "Rates and Mechanisms of Reactions Between Cotton and N-Methylolated Compounds." American Dyestuff Reporter 61 (April 1972): 44-51.

9. Bertoniere, Noelle R.; Martin, Lawrence F.; Blouin, Florine A.; and Rowland, Stanley P. "Alteration of the Pore Structure of Cotton by the Wet-Fixation Durable-Press Process." Textile Research Journal 42 (December 1972): 734-39.

10. Bertoniere, Noelle R.; Blouin, Florine A.; Martin, Lawrence F.; and Rowland, Stanley P. "Effects of Polymerization Parameters of Methylolated Melamines Upon the Wet-Fixation Durable-Press Process for Treating Cotton Fabrics." Textile Research Journal 44 (February 1974): 140-46.

11. Campbell, H. J., and Staples, M. L. "Chemical Modification of Cotton by Vapor Treatment." Textile Chemist and Colorist 1 (February 12, 1969): 33-36.

12. Cashen, Norton A. "Chemical Cure and Resin Fixation in Cotton Textiles by Sublimation Drying Under Vacuum." Textile Chemist and Colorist 6 (April 1974): 37-39.

13. Cashen, Norton A.; Reinhardt, Robert M.; and Reid, David. "Fiberset Process for Durable Press Finishing." Textile Chemist and Colorist 6 (February 1974): 29-33.

14. Conner, C. James. "Vapor Phase Reaction of Formaldehyde With Silicone Treated Cotton." American Dyestuff Reporter 54 (August 16, 1965): 28.

15. Cooper, A. S., Jr.; Reeves, W. A.; Walker, A. M.; Hoffman, M. J.; and Moore, N. B. "Performance Qualities of Cotton Fabric Treated by PREFERENTIAL Crosslinking Methods and Delayed Curing Processes." American Dyestuff Reporter 54 (September 13, 1965): 89-94.

16. Denyes, Wells. "Durable-Press--The Role of Polyesters." Modern Textile Magazine 47 (September 1966): 79-84.

17. Encyclopedia of Textiles, 2nd ed. (1972) "Permanent Press."

18. Franklin, William E.; Madacsi, John P.; and Rowland, Stanley P. "Activated Recurable Cotton Durable-Press Fabrics." Textile Chemist and Colorist 6 (March 1974): 29-33.

19. Franklin, W. E.; Madacsi, J. P.; and Rowland, S. P. "Recurable Durable-Press Fabrics." Textile Research Journal 42 (May 1972): 274-79.

20. Gagliardi, D. D.; Jutras, W. J., Jr.; and Shippee, F. B. "Vapor Phase Reactions on Cotton. Part I: General Considerations and Partial Results." Textile Research Journal 36 (February 1966): 168-76.

21. "Getting Durable Press for Corduroy Fabrics the Pad-Dry-Cure Way." Textile World 118 (November 1968): 122-24.

22. Goldstein, Herman B. "Some Aspects of Textile Finishing." Textile Chemist and Colorist 3 (January 1971): 39-44.

23. Guthrie, John D. "Impacting Wrinkle Resistance to Cotton Fabrics With Vapor from HCL-Paraformaldehyde." American Dyestuff Reporter 51 (July 9, 1962): 31-35.

24. Hartis, Gayle. "All Cotton Fabrics for Durable Press." Textile Forum 27 (Spring 1969): 11-12.

25. Hearne, Virginia Grimes, and Broome, Esther Roberts. "Permanent Press Performance." Journal of Home Economics 59 (December 1967): 794-97.

26. Hollies, Norman R. S. "Wet-Fixation DP Process--Polymer Deposition." Textile Research Journal 37 (April 1967): 277-87.

27. Hollies, Norman R. S., and Getchell, Nelson F. "Wet-Fixation Process for Improved Durable-Press Cotton." Textile Research Journal 37 (February 1967): 70-76.

28. Jung, H. J.; Benerito, R. R.; Gonzales, E. J.; and Berni, R. J. Part I: "Fabric Properties of Cottons Modified with Methylated Methylol-Melamine Before and After Urea-Phosphoric Acid Hydrolysis." American Dyestuff Reporter 61 (March 1972): 64-67.

29. Jutras, W. J., Jr.; Cicione, R. J.; and Kenney, V. S. "A Review of Vapor Phase Finishing." Textile Chemist and Colorist 1 (August 27, 1969): 21-25.

30. Keating, Esmond; Haydel, Chester H.; and Knoepfler, Nestor B. "Pad-Dry Formaldehyde Treatment for Cotton." Textile Chemist and Colorist 1 (May 21, 1969): 7-8.

31. Kopacz, B. M., and Perkins, R. M. "A Status Report on All-Cotton Durable Press Research." Textile Chemist and Colorist 1 (January 29, 1969): 22-29.

32. Kullman, Russell M. H., and Reinhardt, Robert M. "Crosslinking Cotton in an Unheated Dehydrating Atmosphere." Textile Research Journal 44 (January 1974): 24-29.

33. Leonard, Tony M. "All-Cotton Durable Press New Chemicals and Techniques." Textile Forum 27 (Winter 1969): 12-17.

34. Lofton, John T.; Harper, Robert J.; Graham, C. O.; and Blanchard, Eugene J. "Polymer Treated Cotton Yarn Improves Durable Press Denims." American Dyestuff Reporter 60 (January 1971): 21-26.

35. Löwendahl, Reidun, and Åsnes, Harold. "Laundering Conditions for Improved Wash-and-Wear Appearance." Textile Research Journal 42 (July 1972): 404-409.

36. Markezich, Anthony R. "Progress in the Development of Edge Abrasion Test Standards." American Dyestuff Reporter 55 (November 21, 1966): 39-42.

37. Marsh, J. T. "Crease Recovery and Gaseous Formaldehyde." Textile Recorder 84 (July 1966): 90, 91-95.

38. Marsh, J. T. "Tensile Strength in Crease-resist Cottons." Textile Recorder 83 (December 1965): 60-61.

39. Mehta, R. D. "Reactions of Glyoxal with Carbamoylethylated and Carboxyethylated Cotton for Improved Wrinkle Resistance." Textile Research Journal 42 (September 1972): 505-511.

40. Morris, Mary Ann; Schultz, Howard G.; and Prato, Harriet H. "The Influence of Individual Differences on Garment Wear and Wear Evaluation." Textile Research Journal 42 (August 1972): 468-70.

41. Nasr, Hussein I. "Radiation Modification of Cotton Fabrics Part I; Crosslinking Cotton Using Multifunctional Monomers." Textile Research Journal 42 (August 1972): 497-99.

42. Nasr, Hussein I. "Radiation of Cotton Fabrics Part II: Catalytic Effect of Grafted Acids." Textile Research Journal 43 (October 1973): 607-608.

43. "New Resins Improve Fabric Finishes, Reduce Free Formaldehyde." BASF Wyandotte Corporation. Textile Chemist and Colorist 4 (August 1972).

44. "New Sanforized Finish Cuts Denim Wrinkling." Daily News Record (September 1973): 1, 19.

45. "New Ways to Finish Cotton Detailed at NCC Event." American Dyestuff Reporter 55 (November 7, 1966): 933-37.

46. Nirenberg, Robert. "KORATRON--The Truth in Permanent Press." American Dyestuff Reporter 54 (September 13, 1965): 95-96.

47. Parikh, D. V.; Frick, J. G., Jr.; and Iwata, A. "Post-Cure Finishing of Cotton With a Steam-Cure Process." American Dyestuff Reporter 60 (October 1971).

48. "Permanent Press Comes to the U.K." Textile Recorder 80 (April 1966): 61.

49. Perrier, Dorothy M.; Benerito, Ruth R.; and Soignet, Donald M. "Comparison of Sulfonoethylated Cotton and Diethylaminoethylated Cotton as Built-In Catalysts for Delay Cure Processes." Textile Research Journal 42 (March 1972): 167-71.

50. Peterson, Edward C. "Fabric Abrasion During Laundering." Textile Chemist and Colorist 1 (November 1969): 18-22.

51. Prahl, Helmut F.; Tovey, Henry; and Underwood, Chester E. "Short Investigation of Grafting as a Method for Improving Abrasion Resistance of Crosslinked Cotton." Textile Research Journal 36 (March 1966): 245-50.

52. Reeves, Wilson A.; Cooper, Albert S., Jr.; Sloan, William G.; and Harper, Robert J., Jr. "All-Cotton Fabrics for Durable-Press." Textile Industries 129 (October 1965): 74-88, 103.

53. Reinhardt, Robert M., and Cashen, Norton A. "Strong Lewis Acid Salts as Catalysts in Mild-Cure Finishing Treatments for Wrinkle Resistance." Textile Research Journal 42 (June 1972): 335-37.

54. Reid, J. David; Kullman, Russell M. H.; and Reinhardt, Robert M. "Carbamate Agents with Low Formaldehyde

Release for Post-Cure Durable Press." American Dyestuff Reporter 59 (June 1970): 26-34.

55. Roch, Delilah Manire. "The Serviceability of Boys' Durable Press Trousers of Cotton-Synthetic Blends as Revealed by Wear and Laboratory Test." Ph. D. Dissertation, Texas Woman's University, August 1969.

56. Roemhildt, Lavera Dallman. "The Durability and Appearance of All-Cotton and Cotton-Polyester Work Trousers After Wear and Laundering." Ph. D. Dissertation, Texas Woman's University, May 1974.

57. Rowland, Stanley P. "Basic Aspects of the Cross-linking of Cotton." American Dyestuff Reporter 58 (November 1969): 15-18, 41.

58. Rowland, Stanley P. "The Mechanisms of Durable Press." Textile Chemist and Colorist 4 (August 1972): 33-39.

59. Rowland, S. P.; Cirino, V. O.; Bullock, A. L.; Wade, C. P.; and Mason, J. S. "The Fate of a Monofunctional N-Methylol Reagent on Pad-Dry-Cure Reaction with Cotton." Textile Research Journal 44 (March 1974): 220-24.

60. Seventeenth Chemical Finishing Conference. Textile World 118 (November 1968): 128-32.

61. Sims, Mary Ann. "Comparison of the Effects of Two Pressing Times on Vapor-Phase Finished Trousers." Master's Thesis, Texas Woman's University, September 1974.

62. Sloan, W. G.; Hoffman, M. J.; Moore, H. B.; and Cooper, A. S., Jr. "Relationship of the Distribution of Crosslinks to the Physical Properties of Cotton Fabrics." American Dyestuff Reporter 61 (January 1962): 45-48.

63. Smith, Leonard. "New Principles and Developments in Durable Press Cottons." Textile Recorder 84 (July 1966): 92-95.

64. Steele, Richard. "The Crosslinking of Cellulose." Textile Chemist and Colorist 54 (January 4, 1965): 19-25.

65. Superintendent of Documents, General Service Administration. Federal Test Method Standard No. 191. Method 5120, 31 (December 1968). "Strength of Cloth; Ball Bursting Method."

66. Swidler, R.; Gamarra, J. P.; and Jones, B. W. "The Gaseous Formaldehyde/Sulfur Dioxide Durable Press Process." Textile Chemist and Colorist 3 (February 1971): 41-44.

67. "The New Sanforized Company--New Technologies." American Fabrics 97 (Spring/Summer 1973): 47-48.

68. Turner, Louise Phillips. "Evaluation of the In-Use Performance of Men's Durable Press Work Trousers Made of All-Cotton and Cotton-Polyester Blends." Ph. D. Dissertation, Texas Woman's University, August 1969.

69. "Vapor Process for All-Cotton Permanent Press." American Dyestuff Reporter 55 (January 3, 1966): 50.

70. Verburg, Gerald B.; Parikh, D. V.; and Vail, Sidney L. "Low Temperature Steam Setting of Resins." Textile Chemist and Colorist 1 (December 1969): 17-21.

71. Warfield, Carol L., and Fickle, Mary Jo. "Wear Patterns in Boys Jeans." Textile Chemist and Colorist 5 (September 1973): 39-43.

72. Welch, Clark M., and Margavio, Matthew F. "Activated Imines as Intermediates in Base-Catalyzed Crosslinking of Cotton by N-Methylol Agents." Textile Research Journal 5 (September 1973): 495-501.

73. Wilson, Katherine; Gamarra, Jose; and Swidler, Ronald. "Vapor-Phase Treatment of Cotton Fabrics with Formaldehyde Catalyzed by Sulfur Dioxide." Textile Research Journal 38 (April 1968): 401-415.

74. Wylie, Mary Jean, and Erickson, Nancy C. "Tear and Burst Strength of Durable Press Shirts." Textile Chemist and Colorist 5 (November 1973): 57-61.