MICROSCOPIC EVALUATION OF FIBER DAMAGE
CAUSED BY CANDIDA TROPICALIS

by 557

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INTRODUCTION

Since World War II, cutaneous diseases caused by microorganisms have been a problem with servicemen stationed in warm, moist climates, such as the Southwest Pacific, the Far East, and Viet Nam. In 1944, in the southwest Pacific, the admission rate to hospitals for skin diseases in the United States Armed Forces was 102 per 1,000 servicemen. The evacuation rate to the United States because of skin diseases was fifteen percent of all patients evacuated from the southwest Pacific. These skin diseases were caused by pathologic bacteria, fungi, and yeasts.

In Viet Nam, disability from skin diseases is often the major medical reason for disability of American troops. Military statistics show that dermatologic problems are the most common cause for outpatient visits, but the hospital admission rate is down to 28 per 1,000 servicemen per year and the evacuation rate was down to one percent in 1966. In Army hospitals the fourth most common cause of hospitalization is skin problems. However, many servicemen who have skin diseases are not hospitalized. In September, 1967, out of one Army combat unit of 450 men, 210 had foot skin diseases and 106 were unfit for field duty. The Air Force stationed at Cam Ranh Bay has reported that skin diseases are common and that fungus infections are the most common outpatient complaint (1).

Blank *et al.* (1, page 141) raised these questions--"Is dermatophytic infection being spread and perpetuated by inadequate laundry techniques and should the heavy, part wool, slow drying sock be changed to an easier drying, synthetic fabric for wet tropical conditions?"

Higdon (11) recommended changing the uniforms of servicemen from heavier fabrics to lighter weight fabrics as a step in the prevention of skin diseases. He found many cases of skin infections in the male military population in Japan but rarely found cases among women and civilian men. Higdon theorized that lighter weight and looser fitting clothing allow adequate ventilation to the skin. Without adequate ventilation, the skin temperature rises and moisture increases and thus provides a good environment for the growth of pathogenic microorganisms.

Microorganisms can be transmitted by fabrics through the wearing, handling, and washing of the fabric. The dissemination of microorganisms by fabrics had been a public health problem for years (13). Oliphant *et al.* (16) showed the transmission of Q Fever to laundry workers who handled laboratory textiles contaminated by the microorganism *Caxiella burneti*.

Dixon *et al.* (6) found that the type of fiber and fabric construction influenced recovery of microorganisms from inoculated fabrics. These researchers believe that in order to understand the dissemination of microorganisms by fabrics more basic research is needed on factors influencing the inoculation of fabrics, the survival and infectivity of microorganisms, and conditions of microbial release from fabrics.

Since there is a possibility that microbial skin infections can be transmitted by fabrics, it is advisable to understand what effect microorganisms have on fabrics. Therefore the objectives of this study were to identify microbial damage through microscopic examination of longitudinal sections of nylon, wool, and cotton fibers as caused by the fungi, *Candida tropicalis*, and to record the damage by taking photomicrographs of the longitudinal sections of the fibers.

REVIEW OF LITERATURE

A source of skin diseases can be a person's garments, such as socks which cover a humid area of the body. Little is known about the growth and survival of pathogenic fungi on fabrics and the effects of the fungi on the fabric. To understand microbial damage, information is needed about the functioning of the fungi, especially on their physiological processes and enzymatic systems, and about the effect of the microorganism on the fibers within the fabric. Of importance to this study is microbial damage to nylon-cotton and wool-cotton-nylon knitted sock material.

Fungi Comparison

Fungus is a general term referring to the microorganisms known as yeasts and molds. Yeasts and molds lack chlorophyl and cannot manufacture their own food supply; therefore, they live off other forms of living or dead organic matter. Fungi possess varied, active, and sometimes highly specialized enzyme systems which enable them to digest organic matter.

The terms yeast and mold are not mutually exclusive. Many of the fungal pathogens of men are dermorphic. They are molds in their normal saprophytic growth but are yeast or yeast-like in animal tissues or when incubated on enriched media at 37°C. Most organic substances in the earth's environment, such as vegetation, wood, keratin, chitin, bone, fat, oil, waxes and phenolic resins, are susceptible to degradation by fungi.

Mycoses are diseases in man which are caused by fungi. Most types of fungi have no affect on the tissues of man. But there are about fifty species of fungi which cause a dozen important mycoses in man plus another dozen of less severity or frequency. These diseases vary from the superficial skin infections such as dermatophytosis and cutaneous candidiasis to generalized mycoses such as coccidioedonycosis and histoplasmosis (15).

Candida albicans

The genus Candida is of the common pathogenic yeasts of which Candida albicans is probably the most familar to bacteriologists and to members of the medical profession. Candida albicans is the most frequent etiological agent of the mycosis, Candidiasis. Candidiasis lesions can occur in a wide variety of anatomical sites including the mucus membranes of the mouth, throat, lungs, and vagina. It frequently occurs on the skin, especially between the interdigital webs of the hands and feet, the axillae, the inframary and inguinal regions, and the nails of the hands and feet. It is the cause of thrush, a disease similar to Athlete's Foot. More rarely, Candida albicans can attack the heart, the meninges, the blood stream, and the bones and joints (15).

Conditions leading to maceration of the skin, such as frequent and continued immersion in water, are important environmental factors influencing Candidiasis. Species of Candida, including Candida albicans, are present in the normal oral cavity, upper respiratory passages, and intestinal tract, and on skin surfaces; thus endogenous source of infection is probably usual.

Candidiasis is almost world-wide in distribution. Prolific growth of Candida associated with tropical spure and probably associations with diets high in fruit and carbohydrates indicate some differences in the intestinal tract of man in different climatic zones and varied social and/or economic environments (8, p. 141).

Candida albicans is in the mycelia fungi phase when it produces

Candidiasis of tissues. This phase of the microorganism is enhanced by reduced oxygen tension, media with reduced nutrient concentration, liquid media, general alkaline condition, and high temperature (3).

Candida tropicalis

Dastidar (3) found the growth requirements of Candida albicans and Candida tropicalis to have similar characteristics. The optimum pH range was 5.0 to 6.0. Both grew well on dextrin; while on starch, the growth was moderate. Candida tropicalis formed the mycelial phase on all the carbohydrates while the behavior of Candida albicans was similar. Dastidar concluded that the organisms were able to regulate the pH of the medium to make it favorable for their growth. Emmons (8) found that both fungi grew on glucose, maltose, saccharose, arbutin, and galactose but not on lactose. Candida albicans did not use ethanol which Candida tropicalis did to a small degree. Candida species cannot utilize starch but grow well on dextrins which is a product of starch degradation. It is assumed that these fungi do not have the enzyme system necessary to break down the starch molecule (3).

Fungi Effects on Textile Fibers

The most or least suitable textile fiber for fungal growth has not been determined because not only the quality, but the method of manufacture, and the treatment before and after fabric construction have an influence on the life of fungi growing on the fibers. Most of the fungi growing on textiles, except black mildew, affect many fibers besides cotton (22, p. 199).

Cotton

Two concentric layers, the primary and secondary walls, form the cotton fiber. The thin, outer primary wall is covered with a cuticle. This layer is composed of vegetable waxes and fats, hemicellulose, pectins, and cellulose. The thick, secondary wall is cellulose primarily. The lumen, or center of the fiber, is filled with air generally but may also contain remains of dried protoplasm. The cotton fiber is 91-97 percent cellulose.

In textile technology, the secondary wall is the most important part of the fiber as it determines the character of the fiber. The primary wall is a protective covering of the secondary wall.

Cotton may be damaged at any point of its development after the cotton boll is opened. As the cotton dries within the boll, the cotton twists into helical ribbons. Cotton fibers tend to break primarily in the weak spots where the fiber convolutions change their directions. Some cracking and external damage to the fiber can be caused by sunlight while the fiber is in the open boll.

Microorganisms attack cotton primarily as a result of disease and damage caused by insects. If cotton is wetted by rain during its ripening period and after the bolls have opened, it can be stricken by microorganisms (bacteria, fungi, and mildew). Fibers attacked by microorganisms prior to ginning may be attacked only in the epidermis resulting in color loss. In more serious cases, the wall is penetrated resulting in lack of luster and loss in tensile strength. If the fibers have been ginned, microorganisms develop primarily in the lumen. The lumen is open at one end of the fiber after ginning and creates the possibility of development of microorganisms on the protein in the protoplasm remaining in the lumen. The microbial development in the lumen decreases fiber strength (24).

In Mandel's (14) study of microbial decomposition of cellulosic fibers approximately half of all fungi tested were able to destroy cellulosic fibers, with cotton being the most resistant. The attack involved penetration of the fiber wall, growth within the lumen, and digestion from within. The attack is rapid under favorable conditions of warm temperature and high humidity. The fungi secrete digestive enzymes which attack the cellulose. These enzymes are selective as each anzyme can digest only certain types of cellulose. Szathmary (22) found that fungi spores retain their vitality on vegetable materials and textiles even when in dry conditions. Culture tests on fungi growth have been successful three years after original growth.

Wool

Wool is a keratin fiber composed of amino acids. It is built of two layers--the epidermis (outer layer) and cortex (inner layer). These two layers have different chemical properties with the epidermis being less resistant to enzymes than the cortex. The epidermis is protected by a covering called the epicuticle (24).

Microorganisms attack wool during its growth on the animal, but most often they develop after shearing if the baled wool is stored in a moist, warm, and badly ventilated room (7). Wool contains many types of microorganisms. Many of these are harmless, but some microorganisms cause diseases in animals and often in humans, as well as damage to the fiber. Wool contains millions of microorganisms per gram. Doberczak (7) reported that 1 gram of greasy wool contained 300-4300 fungi, 55,000-400,000,000 bacteria, and 45,000-80,000 spores. Microorganisms are numerous in wool because of excellent living and growth conditions. They find sufficient substance in organic compounds found in wool, and many varieties live on the wool cortex. The moisture content of wool is an important factor favoring the development of microorganisms as the higher the moisture content, the more numerous the microorganisms are. The microorganisms enter wool from many sources, such as the soil, water, and air.

In favorable circumstances the development of microorganisms on wool is very rapid and abundant. Some bacteria and fungi cause the wool fibers to lose strength, luster, and color. Doberczak (7) states that scientists differ in opinion as to how microorganisms affect wool. A microscopic examination of wool damaged by microorganisms, mainly fungi, reveal undamaged scales either adhered to the fiber or separated from it. The cells of the cortex showed no damage and retained their shape and size. A loosening and separation of epidermis and cortex cells occured because of destruction of the intercellular substance by microorganisms.

Zylinski (24) stated that the enzymes produced by microorganisms attack the fiber scales and penetrate into the cortex layer, causing the decomposition of outer fibers and resulting in the falling off of the scales. Szathmary (22) found signs of fungi growth on wool to be pitting, pointed ends, spherical cavities, and superficial erosion. Microorganisms have a great faculty for destruction of wool and wool textiles. But it is not yet known how particular varieties of bacteria and fungi affect wool.

Synthetic Fibers

Materials made of synthetic fibers, such as nylon fibers are generally considered resistant to fungi as fungal effects are seldom observed. Szathmary (22) found that synthetic fibers are more resistant to the destructive activity of fungi as compared to vegetable and animal fibers, but on some synthetic fibers signs of fungal activity may be observed. There are not penetrating defects but superficial ones. The dermatophytes grown on synthetic fibers had three effects: (1) wide cavities of irregular shape developed, (2) small erosions turned the fibers jagged, and (3) thin synthetic filaments tapered away in length to become pointed needles on the spot of the perforation. Other fungi tested did not cause hole-like cavities (22).

It is not clear if synthetic fibers in textiles containing vegetable and animal material play a role in the development of fungus growth. At present it may be stated that they do not have an important role (22).

Zylinski (24) thought the fatty substances absorbed by polyamide fibers when used serve as excellent nutriment for bacteria, fungi and mildew which readily develop between the human body and underwear. Owing to low water permeability, microorganisms also find an excellent climate for growth due to considerable humidity (sweat).

Microscopic Evaluation of Fiber Damage

The microscope is an important instrument used in textile testing and research. It can be used to examine fabrics, yarns, and fibers. When examining fibers, the microscope can be used to identify fibers, determine quality of fibers, and detect fiber damage (10). The microscope is essential in the examination of fibers for microbial damage as this damage is invisible to the naked eye. When using the optical microscope, the fibers can be examined under two powers of magnification, 10X and 43X. The higher power, 43X, is used to detect fiber damage as this gives the highest magnification of the fibers.

Photomicrographs may be taken of the microscopic view seen through the microscope by attaching a camera to the vertical tube of the trinocular body of the microscopic evaluation (17) as they are a permanent record of the damage and can be used to verify damage seen through the microscope.

METHOD OF PROCEDURE

Definitions Of Terms Used In The Experimental Design

1. Run - the complete performance of a test procedure
2. Swatch - an 8" by 12" piece of wool-cotton-nylon pile knit or nylon-cotton plain knit fabric meeting military specifications MIL-S-48G(5) and MIL-S-1254(4) for sock material
3. Treatment - the uninoculated-unsoiled (T_1), uninoculated-soiled (T_2), inoculated-unsoiled (T_3), or inoculated-soiled (T_4) group of five swatches
4. Holding period - the holding time of 0 or 4 days at the end of which the swatches were laundered and sterilized and one swatch was removed for evaluation

Fabric Selection and Preparation

The cutaneous diseases incurred by servicemen often affect the foot area; therefore, sock material was used for this study. The types of sock material were: (1) a pile knit fabric of 50% wool, 30% nylon, and 20% cotton meeting Military Specification MIL-S-48G(5) and (2) a plain knit fabric of 60% nylon and 40% cotton meeting Military Specification MIL-S-1254(4). The material was knitted to specifications for the sole of the sock as this is the area most likely to be damp and thus provide a good environment for fungi growth. Also, the sole is the area where the infection usually enters the foot. Since dyes may support or inhibit microbial growth, and these fabrics are normally dyed black for Air Force personnel, they were dyed black for this study. The fabrics were knit in seamless tubes 7-8" in circumference and 24-36" in length.

The tubes were split and cut into 12" long swatches. A line of machine stitching was made one inch from each lengthwise edge. At one end five one-inch squares were marked by machine stitching on the outer edges of the fabric. The one inch squares were used to determine microbial survival counts. Each swatch was color coded by this stitching to indicate treatment, run, and holding period. All swatches were washed with detergent and dryed once to remove any finish remaining from the fabric construction and sterilized to remove all microorganisms.

Laundry Procedure

The laundry procedure most frequently used by military and non-military families in Manhattan, Kansas, was determined through preliminary interviews in a study on *Staphylococcus aureus* survival in laundering (18). This procedure was used in this study. A conventional automatic washer and electric dryer were used. The washer was equipped with a mini-basket to hold small loads and was used for the fabric swatches. The washer was set for the normal wash and wear cycle. A high sudsing, synthetic detergent containing whitening agents and enzymes was used in the 2% concentration recommended by the manufacturer. The electric dryer, which is regulated by an automatic electronic sensor, was set on delicate, which is the setting recommended for fabrics made of wool and synthetic fibers.

Fabric Test Procedures

Five swatches of each fabric were subjected to one of the following treatments: (1) uninoculated-unsoiled, (2) uninoculated-soiled, (3) inoculated-unsoiled, and (4) inoculated-soiled (Figure 1, p. 46). The Department of Infectious Diseases, Kansas State University, did the soiling and inoculation of the fabrics.

The treatment application procedure for the uninoculated swatches consisted of premoistening with distilled water the uninoculated-unsoiled swatches [(T_1) (Table 1, p. 32)] and of premoistening with a sterile synthetic soil (Table 2, p. 33) the uninoculated-soiled swatches [(T_2) (Table 1, p. 32)]. The treatment application procedure for the inoculated swatches consisted of premoistening with distilled water and inoculating with the fungus, *Candida tropicalis*, the inoculated-unsoiled swatches [(T_3) (Table 1, p. 32)] and of premoistening with a sterile synthetic soil (Table 2, p. 33) and inoculating with the fungus, *Candida tropicalis*, the inoculated-soiled swatches [(T_4) (Table 1, p. 32)]. Inoculation of the swatches was done through an aerosol inoculation of a suspension of the microorganism, *Candida tropicalis*.

One swatch of each fabric was removed for examination at holding periods (A,B,C,D) as designated by the holding time of the swatches within the environmental chamber. The first holding period (A) was 0 days or was not held within the environmental chamber. A swatch of each fabric was washed, dryed, and sterilized. The remaining swatches were held within the chamber four days which represents time between sock wearing and washing. At the end of each remaining holding period (B,C,D) all swatches were washed, dryed, and sterilized, and a swatch of each fabric was removed for examination. The remaining swatches were uninoculated-unsoiled, uninoculated-soiled, inoculated-unsoiled, and inoculated-soiled as designated in Figure 1, p. 46, for each treatment.

The fourth sterilization of the swatches completed one run of each treatment. The uninoculated swatches were run once through the test procedures. The inoculated treatments were run three times using a new group of swatches for each run.

After each sterilized swatch was drawn at the various holding periods, yarns were removed from three randomly chosen areas within the center of each swatch. The wool-cotton-nylon knit fabric was composed of two types of yarns: (1) a 100% wool yarn which formed the pile of the fabric and (2) a two ply yarn made with a strand of nylon yarn and a strand of wool-cotton blend yarn. The cotton-nylon knit fabric was made from a two ply yarn consisting of one strand of nylon yarn and one strand of cotton yarn. These two ply yarns were separated for analysis.

Microscopic Evaluation of Microbial Damage

A small section of each yarn was placed on a glass slide and separated into individual fibers. These fibers were mounted on the slide with Permount, a permanent mounting media, and covered with a glass cover slip. Each slide was labeled as to treatment, run, holding period, and temperature (Table 1, p. 32).

The slides were divided into five groups for microscopic evaluation: (1) wool fibers; (2) wool-cotton blend fibers; (3) nylon fibers from the wool-cotton-nylon knit fabric; (4) nylon fibers from the nylon-cotton knit fabric; and (5) cotton fibers. Eighty-four slides were made for each group of fibers. The slides within each group were blind coded for the microscopic examination.

The microscopic analysis was done with an American Optical Company Series Four Microstar Trinocular microscope. The longitudinal fibers were studied using the 43 power objective, 10 power eyepieces, and substage illumination with a blue filter.

Five fields of view within each slide were studied. One eyepiece was equipped with reticle which has framing marks to indicate the exact area which will appear in the photomicrograph. This area within the framing marks was the area used for each field of view. The number of fibers within each field of view and the number of fibers showing the different types of fiber damage and the number of undamaged fibers were recorded. The presence of soil on the fibers also was noted. At the completion of examining each group of slides, the percentage of fiber damage was calculated for each type of damage at each holding period and run for each treatment: uninoculated-unsoiled, uninoculated-soiled, inoculated-unsoiled, inoculated-soiled. Graphs were made of these percentages to visually illustrate the type and amount of fiber damage viewed.

The cotton fibers were examined for cracks, breaks, internal corrosion, external corrosion, pits, dissolution of the lumen, and dissolution of wall material. The nylon fibers were examined for cracks, breaks, swelling, corrosion, and pits. The wool fibers were examined for cracks, breaks, loose and rough scales, absent scales, swelling, corrosion, and pits.

Statistical Analysis of Microscopic Evaluation

The Wilcoxon Test (21), a statistical test which shows level differences between two populations, was calculated on the percentage of fiber damage present in the uninoculated treatments and in the inoculated treatments for each of the three runs. This statistical test indicated if there was a difference in the percentages of fiber damage between the uninoculated treatments and the inoculated treatments. The Wilcoxon Test is a one-tail test calculated at the 95% level of probability.

Microscopic Evaluation By Photomicrographs

Photomicrographs were taken of one field of view from each slide. A table of random numbers was used to determine which view was to be photographed for the evaluation. A preliminary study indicated that the 35mm camera was the better of the two cameras that were available for fiber analysis. The photomicrographs made with a poloroid camera did not show as much fiber detail, especially within the fiber, as the photomicrographs made with the 35mm camera.

The photomicrographs were taken with a 35mm camera attached to the vertical tube of the trinocular body of the microscope. The magnification of the camera was 645 times when using the 43 power objective. The shutter speed was 1/10 and the light setting was 7.0 to 7.7. The darker wool, cotton, and nylon fibers were photographed at the higher settings. The variation in color value was caused by the fiber's dye absorption. The lower prism on the microscope was removed. The blue filter was used when photographing wool and nylon fibers but was not used when photographing the cotton fibers. Kodak Plus X Pan, black and white, panchromatic film was used.

The photomicrographs were arranged in sequence of treatment, holding period, and run for each group of fibers. They were mounted on heavy paper so that a visual comparison for progressive damage could be made from drawing period to drawing period within each treatment and from treatment to treatment. A visual evaluation was made of the photomicrographs to see if progressive damage could be detected.

RESULTS AND DISCUSSION

The amount of fiber damage by Candida tropicalis on two knit fabrics composed of: (1) 50% wool, 30% nylon, and 20% cotton and (2) 60% nylon and 40% cotton was studied with an American Optical Series Four Microstar Microscope and tabulated for the percentage of fiber damage. The Wilcoxon Test was calculated on the percentage of fiber damage between the uninoculated and inoculated treatments. The damage also was studied through black and white photomicrographs made with a 35mm camera attached to the vertical tube of the trinocular body of the microscope giving a magnification of 645 times.

Microscopic Analysis By Tabulation

The microscopic analysis was done as described in the procedure, p. 13-14. The percentage of fiber damage for each treatment was calculated from the results of the microscopic examination and made into graphs (Figure 2-12, p. 48-64).

Cotton Fibers

Cracks and pits were the most common types of damage present in the cotton fibers (Plate 1, Figures 2 and 3). Internal corrosion, dissolution of the lumen, and breaks also were observed (Plate 1, Figures 4, 5, and 6).

Graphs of the percentages of fiber damage show that the cotton fibers from wool-cotton-nylon fabric had a higher percentage of cracking than the cotton fibers in the nylon-cotton fabric (Figure 3, p.49). The cotton fibers from the nylon-cotton fabric had higher percentages of breaking, dissolution of lumen, internal corrosion, and pitting than the cotton fibers from the wool-cotton-nylon fabric.

The cotton fibers from the wool-cotton-nylon fabric showed small percentages of damage due to external corrosion and dissolution of wall material. The cotton fibers from the nylon-cotton fabric showed no signs of these types of damage (Table 3, p. 34).

The natural twist of the cotton fiber made many fibers difficult to microscopically evaluate for damage. The dyeing of the fabrics also added to this difficulty as the darker fibers were harder to evaluate for internal damage. The presence of soil on the fibers also increased the difficulty of seeing damage as the appearance of soil can be similar to pits and cracks as well as being a cover for damage on the fiber. Soil build-up was apparent after the launderings for the third and fourth holding periods (Plate IV, Figure 1).

Wool Fibers

Cracks, pits, and loose and rough scales were the types of damage most often present in the fibers viewed (Plate II, Figures 3, 4, and 5). Breaking, swelling, corrosion, and absent scales were seen in small amounts (Plate II, Figures 6, 7, 8, and 9). A small percent of breaks were observed in uninoculated-unsoiled fibers (4.8%) and the inoculated-soiled fibers (3.4%) from the wool yarn (Table 5, p. 38). Only the uninoculated-unsoiled fibers from the wool-cotton blend yarn had breaks (22.5%), (Table 6, p. 40). A small percent of swelling was seen in the uninoculated-unsoiled, uninoculated-soiled, and inoculated-unsoiled fibers of the wool yarn (Table 5, p. 38). The uninoculated-soiled fibers from the wool-cotton blend also showed swelling (Table 6, p. 40). A small percent of corrosion was present in all four treatments of the wool yarn (Table 5, p. 38). The uninoculated-soiled, inoculated-unsoiled, and inoculated-soiled fibers of the wool-cotton blend yarn also showed small percentages of corrosion (Table 6, p. 40). No absent scales could be detected in the wool fibers from the wool-cotton blend yarn (Table 6, p. 40). The inoculated-unsoiled fibers from the wool yarn showed 4.2% of absent scale damage after the second sterilization in the third holding period (Table 5, p. 38).

The graphs of percentage of loose and rough scales showed a decrease in damage as the fibers progressed through the test procedures (Figure 8, p. 58 and 59). A loss of scales as the fibers go from the first holding period to the fourth holding period could account for this decrease.

Internal damage was difficult to see whenever the fibers were darkly dyed. The dyeing of the fabric did not affect the observation of loose and rough fibers, but the build-up of soil on the fibers sometimes made this difficult. The wool fibers did not soil as readily as the cotton fibers. This was especially apparent in the wool-cotton blend fibers (Plate IV, Figure 2).

Some wool fibers viewed showed the two-toned color effect caused in the dyeing process by the natural crimp of the wool fiber (Plate II, Figure 10).

Nylon Fibers

Swelling, cracking, and pitting were the types of damage most often present (Plate III, Figure 2, 3, and 4). The nylon fibers from the nylon and cotton fabric had no breaks or corrosion (Table 7, p. 42). Breaks were seen in the inoculated treatments of the nylon fibers from the wool-cotton-nylon fabric. The percentage of breakage increased in the inoculated-soiled treatment. No corrosion was seen in these nylon fibers (Table 8, p. 44).

Nylon was hard to evaluate with the optical microscope because the delustrant used in the fiber to reduce shine is similar in appearance to pits. The darkness of the dyed fibers was another cause of difficulty in viewing the fiber, especially in the nylon fibers from the nylon-cotton fabric. The nylon fibers from the wool-cotton-nylon fabric were easier to evaluate as they were larger in size and did not appear as dark (Plate III, Figure 1).

Soil clung to the nylon fibers in the majority of the fields of view even in the fibers from the unsoiled treatments (Plate IV, Figure 3). By the third and fourth holding periods, many fibers were heavily soiled. All of the soiled and unsoiled fabrics were laundered together at the end of each holding period; therefore, the unsoiled fibers are soiled through the redeposition of soil during the laundry procedures.

The graphs of the percentages of fiber damage for all fibers (cotton, wool, and nylon) evaluated showed wide fluctuations of damage from one holding period to another (Figures 2-12, p. 47-65). No evidence of progressive damage could be seen.

Statistical Analysis Of Microscopic Evaluation

Cotton Fibers

The Wilcoxon test (21) was calculated on the percentages of pitting, dissolution of the lumen, breaking, internal corrosion, and cracking of the inoculated fibers and the uninoculated fibers for each of the three runs. It was not used on external corrosion or dissolution of wall materials as these types of damage were rarely present in the fibers viewed. No significant difference (p .05) was found in the percentages of cotton fibers with internal corrosion between uninoculated and inoculated fibers from the nylon-cotton fabric, but there was a significant difference between the percentages of cotton fibers with internal corrosion between uninoculated and inoculated fibers from the wool-cotton-nylon fabric. The significant difference between the percentages of fiber damage occured only in the second run on the nylon-cotton fabric.

Wool Fibers

The percentages of fibers with pitting, cracking, and rough and loose scales between the uninoculated and inoculated wool fibers were tested by the Wilcoxon test (21). The test indicated that there were no significant differences between the percentages of fiber damage for either the fibers from the 100% wool yarn or the fibers from the wool-cotton blend yarn.

Nylon Fibers

The Wilcoxon test (21) showed no significant differences in percentages of pitting and cracking between uninoculated and inoculated fibers from the nylon-cotton fabric and from the wool-cotton-nylon fabric or in the percentages of swelling for the inoculated and uninoculated fibers from the wool-cotton-nylon fabric. There was a significant difference between the percentages of swelling in runs two and three of the inoculated and uninoculated fibers from the nylon-cotton fabric.

Microscopic Evaluation By Photomicrographs

The photomicrographs of each group of fibers--wool, wool-cotton, cotton, nylon from the nylon-cotton fabric, and nylon from the wool-cotton-nylon fabric--were arranged in sequence as to treatment, holding period, and run. The arrangement of the photomicrographs made possible the visual examination for damage between treatments and between holding periods within each treatment.

Damage could be seen from each treatment for all the fibers viewed. Soil was seen on fibers from unsoiled treatments as well as on fibers from soiled treatments. Heavy soil was apparent in the photomicrographs taken of the final holding periods of all fibers. A wide variation in fiber size was seen in all the fibers but especially in the natural fibers of wool and cotton. Nylon is expected to be of uniform size since it is made under standard conditions, but the photomicrographs also showed variation in size within the nylon fibers.

Progressive damage could be seen in the cotton fibers as the internal damage increased from the first holding period to the last holding period within the inoculated treatments. The inoculated cotton fibers also showed more internal damage than the uninoculated fibers. Progressive damage could not be detected in the wool or nylon fibers.

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FIGURE 1

UNDAMAGED

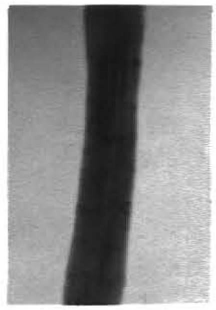

FIGURE 2

CRACKS

FIGURE 3

PITS

FIGURE 4

INTERNAL
CORROSION

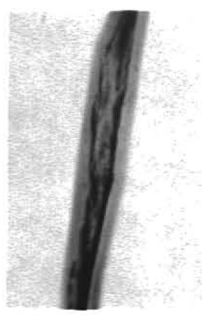

FIGURE 5

DISSOLUTION
OF LUMEN

FIGURE 6

BREAK

PLATE I

COTTON FIBERS

UNDAMAGED AND DAMAGED

FIGURE 1

UNDAMAGED

FIGURE 2

SCALES

FIGURE 3

CRACKS

FIGURE 4

PITS

FIGURE 5

LOOSE AND
ROUGH SCALES

FIGURE 6

BREAK

FIGURE 7

SWELLING

FIGURE 8

CORROSION

FIGURE 9

ABSENT SCALES

FIGURE 10

TWO-TONED
DYEING

PLATE II

WOOL FIBERS

UNDAMAGED AND DAMAGED

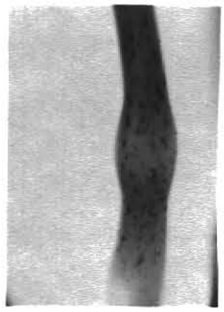

FIGURE 1

UNDAMAGED

FIGURE 2

CRACKS

FIGURE 3

SWELLING

FIGURE 4

PITS

PLATE III

NYLON FIBERS

UNDAMAGED AND DAMAGED

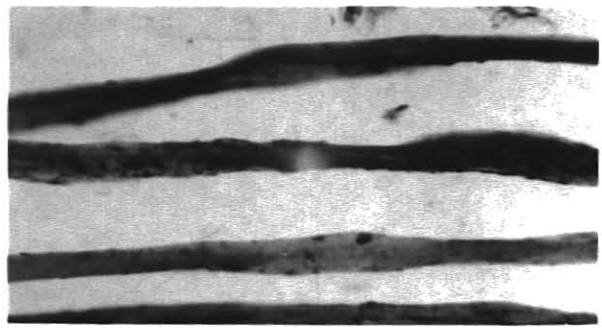

FIGURE 1

COTTON

FIGURE 2

WOOL

FIGURE 3

NYLON

PLATE IV

SOILED FIBERS

CONCLUSIONS AND RECOMMENDATIONS

The tabulation of fiber damage did not indicate progressive increases in the number of fibers damaged by inoculation with Candida tropicalis. The analysis of the tabulation method did show the types of damage which were most common for each fiber; such as cracking and pitting in the cotton fiber; cracking, pitting, and loose and rough scales in the wool fiber; and pitting in the nylon fiber.

The Wilcoxon statistical test (21) showed no significant difference ($p \leq .05$) between the percentages of fibers with breaks, dissolution of the lumen, pits, and cracks between the uninoculated cotton fibers and the inoculated cotton fibers from either the nylon-cotton fabric or the wool-cotton-nylon fabric. There was a significant difference between the percentages of fibers with internal corrosion between inoculated and uninoculated cotton fibers from the nylon-cotton fabric, but there was no significant difference between the percentages of fibers with internal corrosion between the inoculated and uninoculated cotton fibers from the wool-cotton-nylon fabric. There were no significant differences in the percentages of fibers with pits, cracks, and rough and loose scales between the uninoculated and inoculated wool fibers from either the 100% wool yarn or the wool-cotton blend yarn. The Wilcoxon test did not show any significant difference in percentages of fibers with pits and cracks between uninoculated and inoculated nylon fibers from the nylon-cotton fabric or the wool-cotton-nylon fabric or between the percentages of swelling for inoculated and uninoculated fibers from the wool-cotton-nylon fabric. There was significant difference between the percentages of fibers with swelling in the uninoculated and inoculated fibers from the nylon-cotton fabric.

The many damaged fibers in the uninoculated-unsoiled and uninoculated-soiled fibers could have been caused by attacks of microorganisms at many stages of development and production.

The photomicrographs showed damage in all treatments--uninoculated-unsoiled, uninoculated-soiled, inoculated-unsoiled, and inoculated-soiled--for all fibers viewed. Although analysis of the microscopic evaluation by percentage tabulation did not show progressive damage, the photomicrographs of the cotton fibers did show progression in amount and types of damage as the internal damage increased from the first holding period to the last holding period within the inoculated treatments. The results of the analysis by photomicrographs differ from the results by percentage tabulation because of the different magnifications seen through the microscope. The percentage tabulations were based on the visual examination at the magnification of 430 times. The magnification of the camera was 645 times so the photomicrographs showed more fiber details than could be seen by the eye looking through the microscope. The appearance of progressive damage in the cotton fibers illustrated the same microbial decomposition of cellulosic fibers as shown in Mandel's study (14).

Dastidar (3) stated that Candida growth was stimulated by amino acids. Therefore, fungi might be more attracted to the protein fibers than to the cellulose fibers. This could account for the lower level of dissolution of the lumen and internal corrosion in the cotton fibers from the wool-cotton blend yarn than in the cotton fibers from the nylon-cotton fabric. Further study is recommended on the growth of Candida tropicalis on wool and cotton fibers to determine if the fungus prefers protein fibers to cellulose fibers and would attack the wool fibers before attacking the cotton fibers.

There is disagreement on the effect of microorganisms on wool fibers (7,24), and this study did not help to solve this disagreement. Fewer loose and rough scales were seen as the swatches went through the treatments, but an examination by a more powerful microscope would be needed to determine if the scales had been removed from the fibers. The photomicrographs did not show any progression of damage.

Nor was any progressive damage seen in the nylon fibers. These results are in agreement with the general view that synthetic fibers are resistant to microbial attack (22).

To further understand the effect of fungi growth on textile fibers, physical test for tensile strength of the fabrics before and after inoculation with Candida tropicalis are recommended. These tests would show a loss of fiber strength if the fungi had an effect on the fibers.

To eliminate the soil build-up on the unsoiled fibers to be used for a microscopic study, it is recommended that the unsoiled swatches be washed separately from the soiled swatches. This would eliminate the redeposition of soil from the soiled swatches to the unsoiled swatches during the laundry procedures.

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APPENDIX

TABLE 1. CODING USED FOR INOCULATED AND UNINOCULATED AND SOILED AND UNSOILED FABRICS

	Code	Definition
Treatment	T_1	uninoculated-unsoiled
	T_2	uninoculated-soiled
	T_3	inoculated-unsoiled
	T_4	inoculated-soiled
Run	R_1	first performance of test procedures
	R_2	second performance of test procedures
	R_3	third performance of test procedures
Holding Period	A	0 days
	B	first 4 days
	C	second 4 days
	D	third 4 days
Temperature	37	37° Centigrade

TABLE 2. FORMULA FOR SYNTHETIC SOIL SOLUTION*

Compound	Amount
all purpose flour	15 g
cornstarch	15 g
powdered carbon	15 g
cane sugar	15 g/50 ml distilled water
vegetable oil	15 ml/100 ml distilled water
mineral oil	15 ml/100 ml distilled water
powdered milk	13.25 g/87.5 ml distilled water

NOTE: Sterilize first three compounds in ethylene oxide sterilizer. Autoclave remaining compounds. Blend all compounds in standard commercial blender for five minutes to form a relative stable emulsion. pH is 6.2.

*Redenour, G. M. "A Bacteriological Study of Automatic Clothes Washing," National Sanitation Foundation, 1951.

TABLE 3. PERCENTAGE OF COTTON FIBERS VIEWED FROM NYLON-COTTON FABRIC SHOWING DAMAGE IN FIVE MICROSCOPIC FIELDS.

TREATMENT, HOLDING PERIOD AND RUN	TYPES OF DAMAGE						
	Cracks	Breaks	Internal Corrosion	External Corrosion	Pits	Dissolution of Lumen	Dissolution of Wall
UNINOCULATED-UNSOILED							
$T_{1A}R_1$	51.5	3.0	6.1		63.6	6.1	
$T_{1B}R_1$	40.6	6.3	3.1		78.1	3.1	
$T_{1C}R_1$	71.9	3.1	6.3		68.8	15.6	
$T_{1D}R_1$	66.7	10.0	3.3		100.0	10.0	
UNINOCULATED-SOILED							
$T_{2A}R_1$	76.5	2.9	8.8		67.6	2.9	
$T_{2B}R_1$	61.3	6.5	16.1		67.7	12.9	
$T_{2C}R_1$	41.0		7.7		82.1	5.1	
$T_{2D}R_1$	35.1		8.1		81.1	10.8	
INOCULATED-UNSOILED							
$T_{3A}R_1$	62.9	11.4	20.0		74.3	11.4	
$T_{3B}R_1$	65.7	14.3			85.7	5.7	
$T_{3B}R_2$	33.3	11.1	7.4		48.1	7.4	
$T_{3B}R_3$	57.1	8.6	5.7		77.1	14.3	
$T_{3C}R_1$	48.8	2.4	9.8		82.9	9.8	

TABLE 3. (Contd.)

TREATMENT, HOLDING PERIOD AND RUN	TYPES OF DAMAGE: Cracks	Breaks	Internal Corrosion	External Corrosion	Pits	Dissolution of Lumen	Dissolution of Wall
INOCULATED-UNSOILED (contd.)							
$T_{3C}R_2$	42.4		15.2		75.8	9.1	
$T_{3C}R_3$	58.1	4.7	14.0		69.8	7.0	
$T_{3D}R_1$	50.0		6.3		90.6	12.5	
$T_{3D}R_2$	62.2		24.4		73.3	13.3	
$T_{3D}R_3$	52.8	8.3	5.6		86.1	5.6	
INOCULATED-SOILED							
$T_{4A}R_1$	50.0	3.3	6.7		86.7		
$T_{4B}R_1$	75.8	6.1	12.1		93.9	6.1	
$T_{4B}R_2$	73.1	15.4	11.5		92.3	11.5	
$T_{4B}R_3$	51.9	3.8	7.7		96.2	11.5	
$T_{4C}R_1$	54.3	6.5	6.5		69.6	4.3	
$T_{4C}R_2$	64.1	5.1	15.4		92.3	5.1	
$T_{4C}R_3$	51.2	14.0	4.7		81.4	9.3	
$T_{4D}R_1$	43.2	10.8	16.2		78.4	2.7	
$T_{4D}R_2$	47.6	11.9	9.5		76.2	7.1	
$T_{4D}R_3$	39.5	4.7	4.7		93.0	4.7	

N = 84 slides
5 counts per slide

TABLE 4. PERCENTAGE OF COTTON FIBERS VIEWED FROM WOOL-COTTON-NYLON FABRIC SHOWING DAMAGE IN FIVE MICROSCOPIC FIELDS.

TREATMENT, HOLDING PERIOD AND RUN	TYPES OF DAMAGE						
	Cracks	Breaks	Internal Corrosion	External Corrosion	Pits	Dissolution of Lumen	Dissolution of Wall
UNINOCULATED-UNSOILED							
$T_{1A}R_1$	74.1	3.7			40.7	3.7	
$T_{1B}R_1$	82.6				76.9		
$T_{1C}R_1$	86.4				59.1		
$T_{1D}R_1$	85.7	7.1	3.6		78.6		
UNINOCULATED-SOILED							
$T_{2A}R_1$	66.7		4.8		61.9		
$T_{2B}R_1$	45.2	3.2			58.1		
$T_{2C}R_1$	50.0			3.8	73.1		
$T_{2D}R_1$	32.0		4.0		76.0		
INOCULATED-UNSOILED							
$T_{3A}R_1$	78.3	8.7			65.2		
$T_{3B}R_1$	87.0		4.3		72.7	4.3	
$T_{3B}R_2$	72.0		8.0		48.0		
$T_{3B}R_3$	72.7	4.5	4.5		27.3		
$T_{3C}R_1$	74.1	3.7	14.8		51.9		
$T_{3C}R_2$	82.6	4.3	8.7		69.6	13.0	

TABLE 4. (Contd.)

TREATMENT, HOLDING PERIOD AND RUN	TYPES OF DAMAGE						
	Cracks	Breaks	Internal Corrosion	External Corrosion	Pits	Dissolution of Lumen	Dissolution of Wall
INOCULATED-UNSOILED (Contd.)							
$T_{3C}R_3$	81.8	4.5			63.6	4.5	
$T_{3D}R_1$	80.0		10.0		75.0	15.0	
$T_{3D}R_2$	95.5		13.6		90.0	9.1	
$T_{3D}R_3$	59.1				50.0		4.5
INOCULATED-SOILED							
$T_{4A}R_1$	69.6				43.5		
$T_{4B}R_1$	90.5	4.8	4.8		66.7		
$T_{4B}R_2$	66.7				50.0		
$T_{4B}R_3$	47.6	4.8	9.5		61.9	4.8	
$T_{4C}R_1$	42.3				73.1		
$T_{4C}R_2$	45.5	9.1	4.5		54.5	9.1	
$T_{4C}R_3$	60.0	9.1	4.5		11.1		
$T_{4D}R_1$	61.5	3.8			57.7		
$T_{4D}R_2$	64.0				84.0		
$T_{4D}R_3$	50.0	4.5			54.5		

N = 84 slides
5 counts per slide

TABLE 5. PERCENTAGE OF WOOL FIBERS VIEWED FROM WOOL-COTTON BLEND YARN FROM WOOL-COTTON-NYLON FABRIC SHOWING DAMAGE IN FIVE MICROSCOPIC FIELDS.

TREATMENT, HOLDING PERIOD AND RUN	TYPES OF DAMAGE						
	Cracks	Breaks	Loose and Rough Scales	Absent Scales	Swelling	Corrosion	Pits
UNINOCULATED-UNSOILED							
$T_{1A}R_1$	75.0	12.5	75.0				37.5
$T_{1B}R_1$	100.0		50.0				50.0
$T_{1C}R_1$	44.4		11.1				55.6
$T_{1D}R_1$	10.0	10.0	50.0				40.0
UNINOCULATED-SOILED							
$T_{2A}R_1$	46.6		46.6				33.3
$T_{2B}R_1$	60.0		10.0				40.0
$T_{2C}R_1$	9.0		45.0		9.0		45.5
$T_{2D}R_1$			50.0			12.5	25.0
INOCULATED-UNSOILED							
$T_{3A}R_1$	73.3		40.0			13.3	40.0
$T_{3B}R_1$	100.0		45.5				36.4
$T_{3B}R_2$	84.6		30.8				15.4
$T_{3B}R_3$	84.6		46.2				23.1
$T_{3C}R_1$	65.2		30.4				21.7
$T_{3C}R_2$	23.1		57.7				11.5

TABLE 5. (Contd.)

TREATMENT, HOLDING PERIOD AND RUN	TYPES OF DAMAGE: Cracks	Breaks	Loose and Rough Scales	Absent Scales	Swelling	Corrosion	Pits
INOCULATED-UNSOILED (Contd.)							
$T_{3C}R_3$	64.0		36.0				28.0
$T_{3D}R_1$	28.6		7.1				21.4
$T_{3D}R_2$	29.2		37.5				33.3
$T_{3D}R_3$	34.6		11.5				3.8
INOCULATED-SOILED							
$T_{4A}R_1$	47.8		60.9			8.7	69.6
$T_{4B}R_1$	28.6		71.4				33.3
$T_{4B}R_2$	53.6		32.1				60.7
$T_{4B}R_3$	66.7		71.4				19.0
$T_{4C}R_1$	42.9		28.6				38.1
$T_{4C}R_2$	59.1		18.2				22.7
$T_{4C}R_3$	18.2		31.8				45.5
$T_{4D}R_1$	8.0		12.0				52.0
$T_{4D}R_2$		3.4	44.8				62.1
$T_{4D}R_3$	34.8		43.5			4.3	34.8

N = 84 slides
5 counts per slide

TABLE 6. PERCENTAGE OF WOOL FIBERS VIEWED FROM WOOL-COTTON-NYLON FABRIC SHOWING DAMAGE IN FIVE MICROSCOPIC FIELDS.

TREATMENT, HOLDING PERIOD AND RUN	TYPES OF DAMAGE						
	Cracks	Breaks	Loose and Rough Scales	Absent Scales	Swelling	Corrosion	Pits
UNINOCULATED-UNSOILED							
$T_{1A}R_1$	39.1		47.8			8.7	47.8
$T_{1B}R_1$	83.4		72.7		4.5	4.5	27.3
$T_{1C}R_1$	19.0	4.8	52.4		4.8		42.9
$T_{1D}R_1$	37.5		50.0				16.7
UNINOCULATED-SOILED							
$T_{2A}R_1$	31.8		27.3				59.1
$T_{2B}R_1$	63.6		31.8		4.5	4.5	50.0
$T_{2C}R_1$	10.0		30.0				40.0
$T_{2D}R_1$	4.8		4.8				38.1
INOCULATED-UNSOILED							
$T_{3A}R_1$	58.3		37.5	4.2			58.3
$T_{3B}R_1$	42.3		50.0			3.8	50.0
$T_{3B}R_2$	87.5		41.7				33.3
$T_{3B}R_3$	35.3		52.9				11.8
$T_{3C}R_1$	53.8		69.2		7.7		23.1
$T_{3C}R_2$	62.5		50.0				25.0

TABLE 6. (Contd.)

TREATMENT, HOLDING PERIOD AND RUN	TYPES OF DAMAGE						
	Cracks	Breaks	Loose and Rough Scales	Absent Scales	Swelling	Corrosion	Pits
INOCULATED-UNSOILED (Contd.)							
$T_{3C}R_3$	38.5						69.2
$T_{3D}R_1$	30.8		7.7				38.5
$T_{3D}R_2$	13.3		33.3				44.4
$T_{3D}R_3$	42.9		21.4				42.9
INOCULATED-SOILED							
$T_{4A}R_1$	90.0		36.4				36.4
$T_{4B}R_1$	14.2		28.6				57.1
$T_{4B}R_2$	86.7		13.3				33.3
$T_{4B}R_3$	76.9		15.4				38.5
$T_{4C}R_1$	16.7		16.7				33.3
$T_{4C}R_2$	81.8		27.3				45.5
$T_{4C}R_3$	68.8		31.3				25.0
$T_{4D}R_1$	18.2		9.0			18.2	54.5
$T_{4D}R_2$	7.7		23.1				46.2
$T_{4D}R_3$	16.2		41.7				66.7

N = 84 slides
5 counts per slide

TABLE 7. PERCENTAGE OF NYLON FIBERS VIEWED FROM NYLON-COTTON FABRIC SHOWING DAMAGE IN FIVE MICROSCOPIC FIELDS.

TREATMENT, HOLDING PERIOD AND RUN	TYPES OF DAMAGE: Cracks	Breaks	Swelling	Corrosion	Pits
UNINOCULATED-UNSOILED					
$T_{1A}R_1$	6.1		3.0		48.5
$T_{1B}R_1$			9.4		40.6
$T_{1C}R_1$			11.1		37.0
$T_{1D}R_1$	16.1		9.7		42.0
UNINOCULATED-SOILED					
$T_{2A}R_1$	17.2		3.4		6.9
$T_{2B}R_1$	23.3		13.3		40.0
$T_{2C}R_1$	9.1		6.1		
$T_{2D}R_1$	6.3		3.1		34.4
INOCULATED-UNSOILED					
$T_{3A}R_1$	10.3		3.4		44.8
$T_{3B}R_1$	6.9		10.3		51.7
$T_{3B}R_2$	8.8		5.9		35.3
$T_{3B}R_3$	3.4		3.4		51.7
$T_{3C}R_1$	11.1		11.1		33.3
$T_{3C}R_2$			2.9		57.1

TABLE 7. (Contd.)

TREATMENT, HOLDING PERIOD AND RUN	TYPES OF DAMAGE: Cracks	Breaks	Swelling	Corrosion	Pits
INOCULATED-UNSOILED (Contd.)					
$T_{3C}R_3$	2.9		5.9		47.1
$T_{3D}R_1$			3.2		38.7
$T_{3D}R_2$			2.7		51.4
$T_{3D}R_3$	9.4		31.3		68.8
INOCULATED-SOILED					
$T_{4A}R_1$	5.1		7.7		41.0
$T_{4B}R_1$					33.3
$T_{4B}R_2$	20.0		3.3		76.7
$T_{4B}R_3$	5.0		2.5		20.0
$T_{4C}R_1$	7.1				21.4
$T_{4C}R_2$	2.5				22.5
$T_{4C}R_3$	2.7				24.3
$T_{4D}R_1$	11.8		11.8		44.1
$T_{4D}R_2$	2.9				48.6
$T_{4D}R_3$			2.4		43.9

N = 84 slides
5 counts per slide

TABLE 8. PERCENTAGE OF NYLON FIBERS VIEWED FROM WOOL-COTTON-NYLON FABRIC SHOWING DAMAGE IN FIVE MICROSCOPIC FIELDS.

TREATMENT, HOLDING PERIOD AND RUN	TYPES OF DAMAGE				
	Cracks	Breaks	Swelling	Corrosion	Pits
UNINOCULATED-UNSOILED					
$T_{1A}R_1$					60.0
$T_{1B}R_1$					56.7
$T_{1C}R_1$	7.7		3.8		61.5
$T_{1D}R_1$			3.8		57.7
UNINOCULATED-SOILED					
$T_{2A}R_1$	4.0		4.0		64.0
$T_{2B}R_1$					42.3
$T_{2C}R_1$					48.1
$T_{2D}R_1$			4.3		56.5
INOCULATED-UNSOILED					
$T_{3A}R_1$					32.0
$T_{3B}R_1$			3.6		75.0
$T_{3B}R_2$	3.1				84.4
$T_{3B}R_3$	3.7				59.3
$T_{3C}R_1$	3.3		13.3		56.7
$T_{3C}R_2$	10.0		6.7		80.0

TABLE 8. (Contd.)

TREATMENT, HOLDING PERIOD AND RUN	TYPES OF DAMAGE: Cracks	Breaks	Swelling	Corrosion	Pits
INOCULATED-UNSOILED (Contd.)					
$T_{3C}R_3$			3.3		51.6
$T_{3D}R_1$					54.8
$T_{3D}R_2$		3.7	7.4		63.0
$T_{3D}R_3$	5.6				66.7
INOCULATED-SOILED					
$T_{4A}R_1$		3.7			25.9
$T_{4B}R_1$		4.2			58.3
$T_{4B}R_2$	7.1				17.9
$T_{4B}R_3$	3.4		6.9		41.4
$T_{4C}R_1$		3.7			48.1
$T_{4C}R_2$	3.4				27.6
$T_{4C}R_3$			4.5		31.8
$T_{4D}R_1$					40.0
$T_{4D}R_2$			8.0		56.0
$T_{4D}R_3$					55.2

N = 84 slides
5 counts per slide

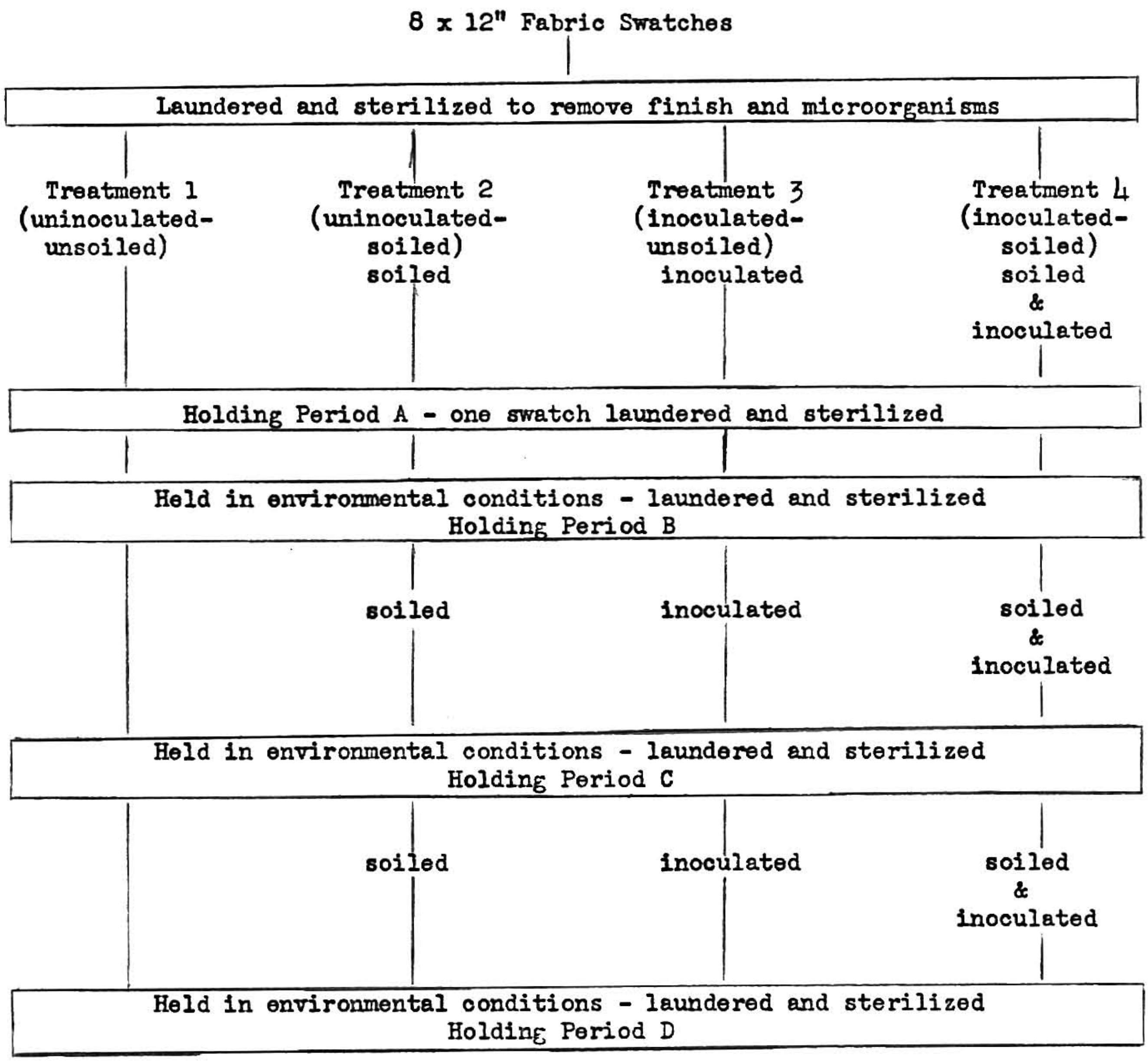

FIGURE 1

FLOW CHART OF TEST PROCEDURES

CODING FOR FIGURES 2-12

	Code	Definition
Treatment	T_1	uninoculated-unsoiled
	T_2	uninoculated-soiled
	T_3	inoculated-unsoiled
	T_4	inoculated-soiled
Holding Period	A	swatch drawn at 0 days
	B	swatch drawn at end of first 4 days
	C	swatch drawn at end of second 4 days
	D	swatch drawn at end of third 4 days
Run	R_1	first performance of test procedures
	R_2	second performance of test procedures
	R_3	third performance of test procedures
Graph Lines	R_1 - T_1, T_3 and T_4	————
	R_1 - T_2	–·–·–·
	R_2 - T_3 and T_4	·······
	R_3 - T_3 and T_4	------

THIS BOOK CONTAINS NUMEROUS PAGES WITH DIAGRAMS THAT ARE CROOKED COMPARED TO THE REST OF THE INFORMATION ON THE PAGE.

THIS IS AS RECEIVED FROM CUSTOMER.

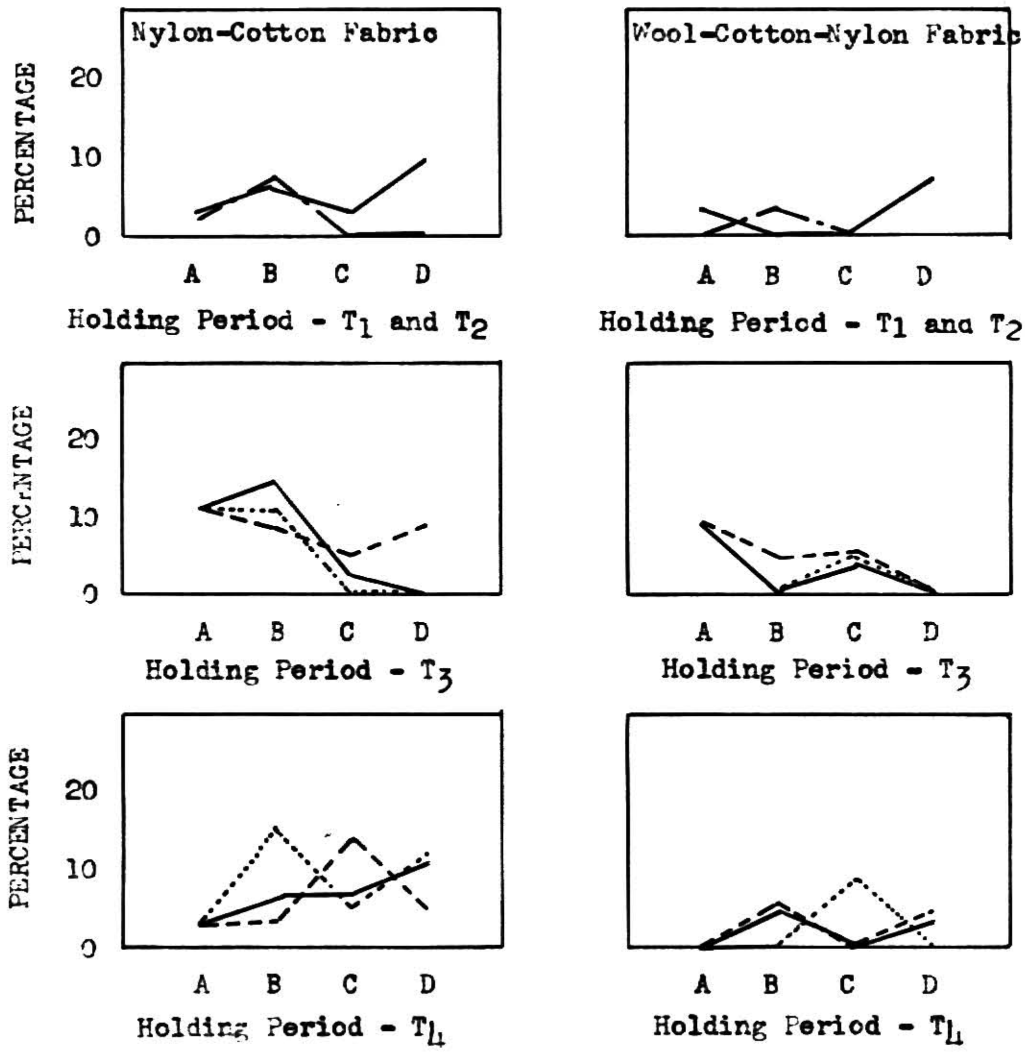

FIGURE 2

PERCENTAGE OF COTTON FIBERS SHOWING BREAKS FROM
NYLON-COTTON AND WOOL-COTTON-NYLON FABRICS

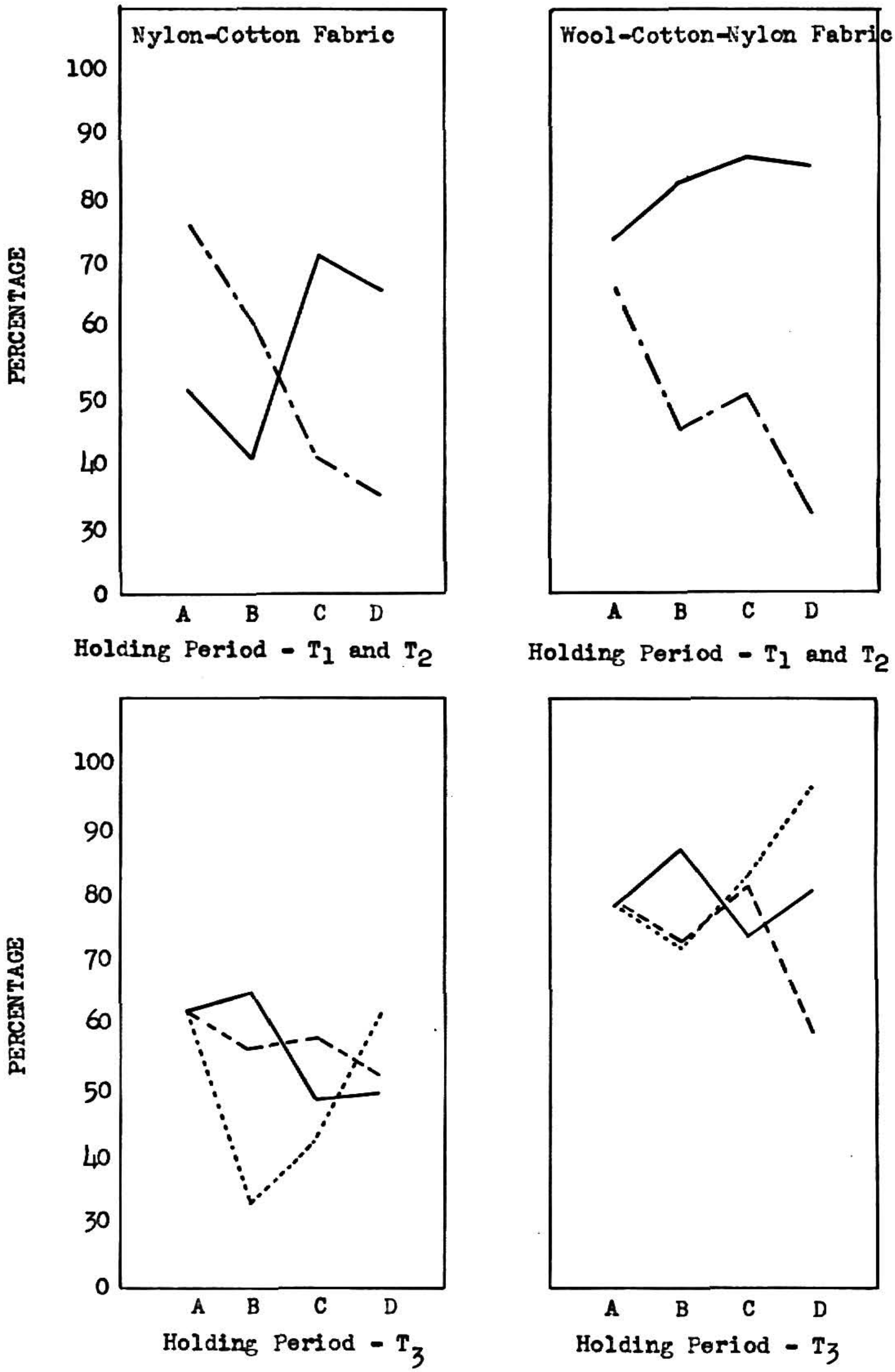

FIGURE 3

PERCENTAGE OF COTTON FIBERS SHOWING CRACKS FROM NYLON-COTTON AND WOOL-COTTON-NYLON FABRICS

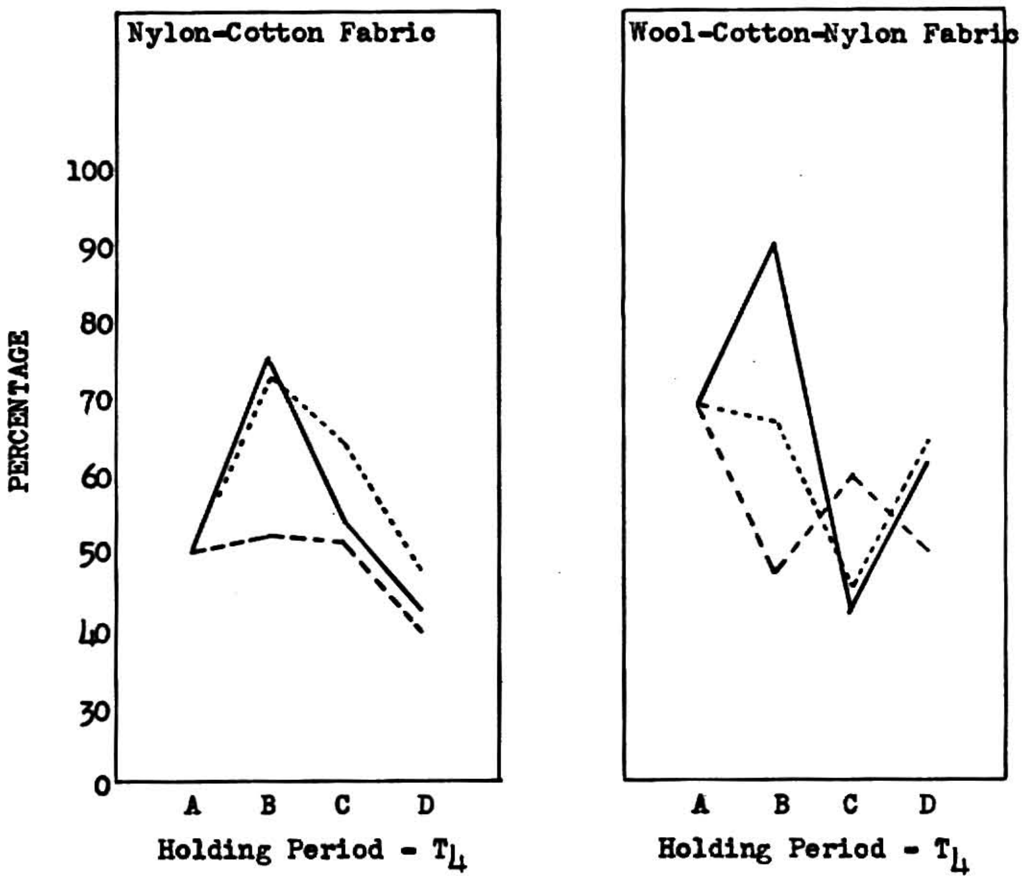

FIGURE 3 (Contd.)

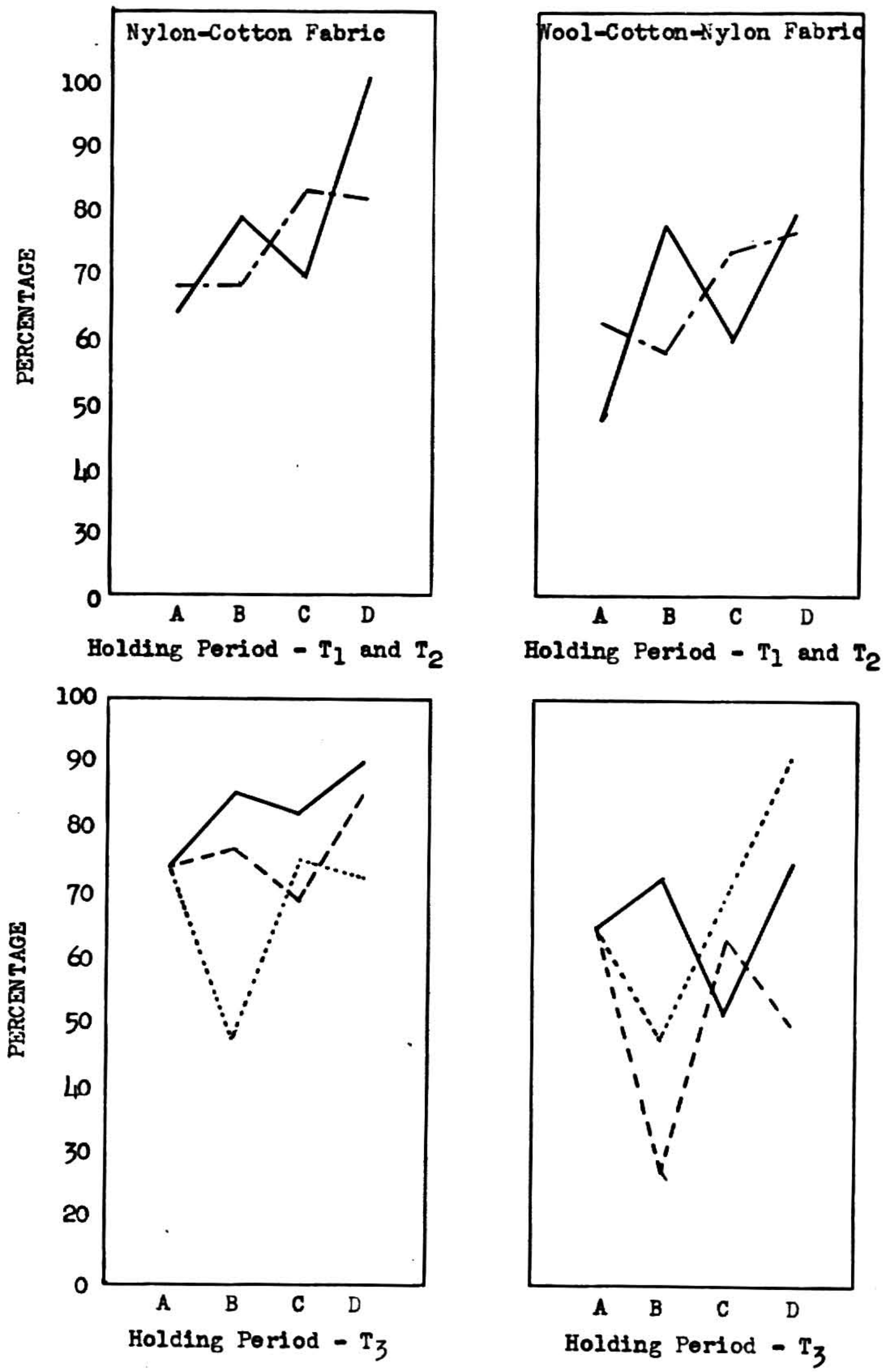

FIGURE 4

PERCENTAGE OF COTTON FIBERS SHOWING PITS FROM NYLON-COTTON AND WOOL-COTTON-NYLON FABRICS

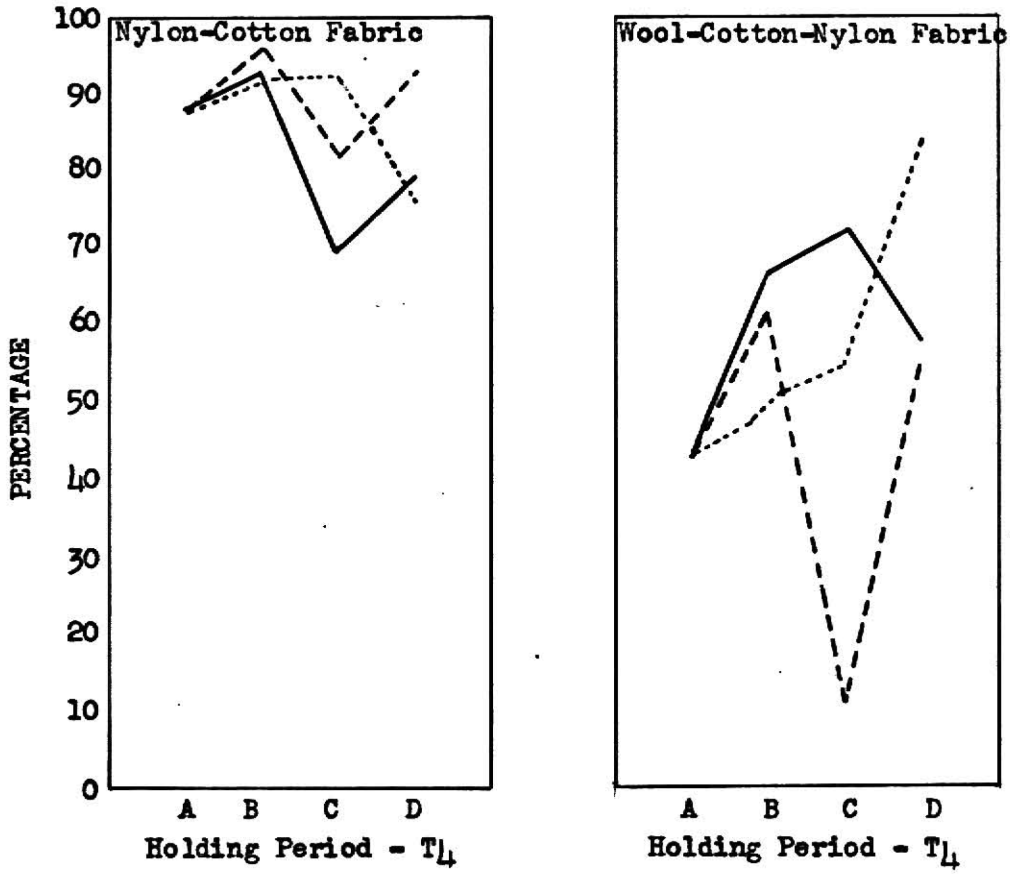

FIGURE 4 (Contd.)

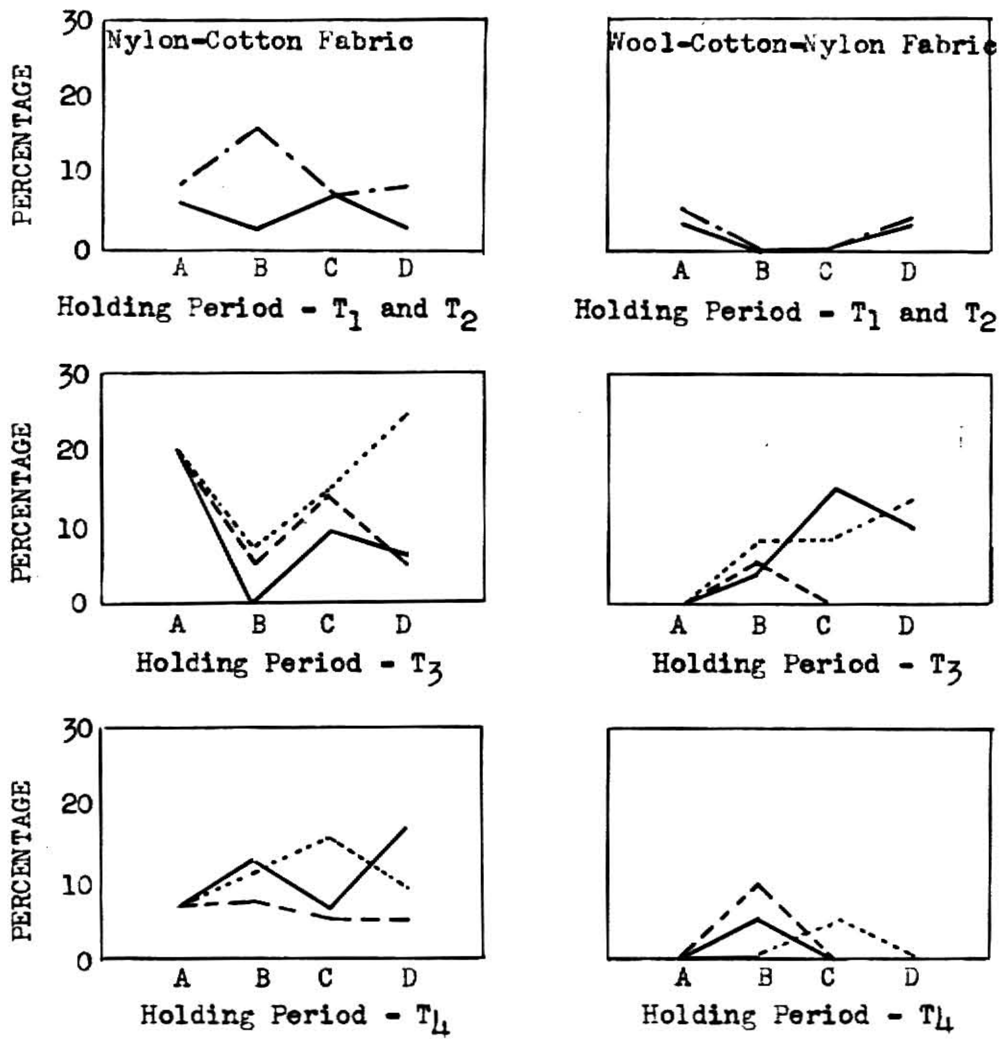

FIGURE 5

PERCENTAGE OF COTTON FIGERS SHOWING INTERNAL CORROSION FROM NYLON-COTTON AND WOOL-COTTON-NYLON FABRICS

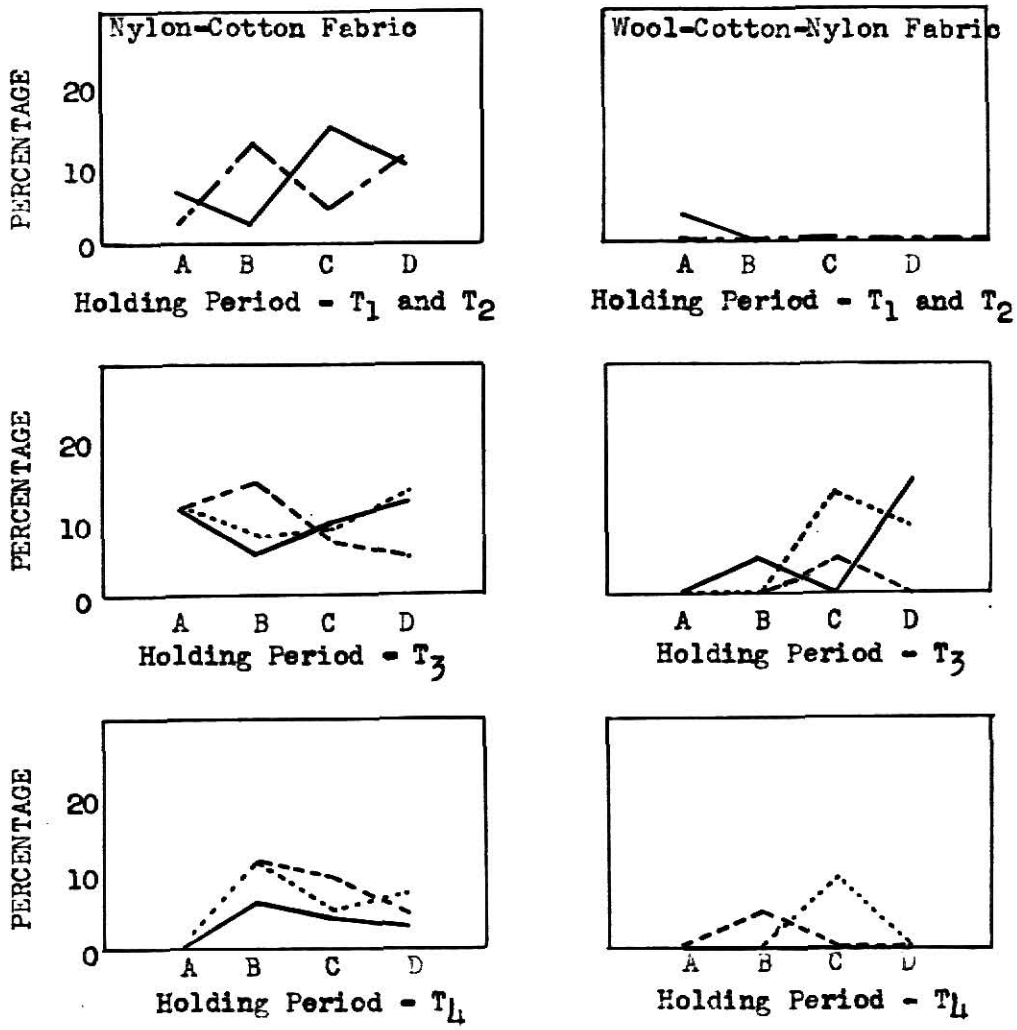

FIGURE 6

PERCENTAGE OF COTTON FIBERS SHOWING DISSOLUTION OF LUMEN FROM NYLON-COTTON AND WOOL-COTTON-NYLON FABRICS

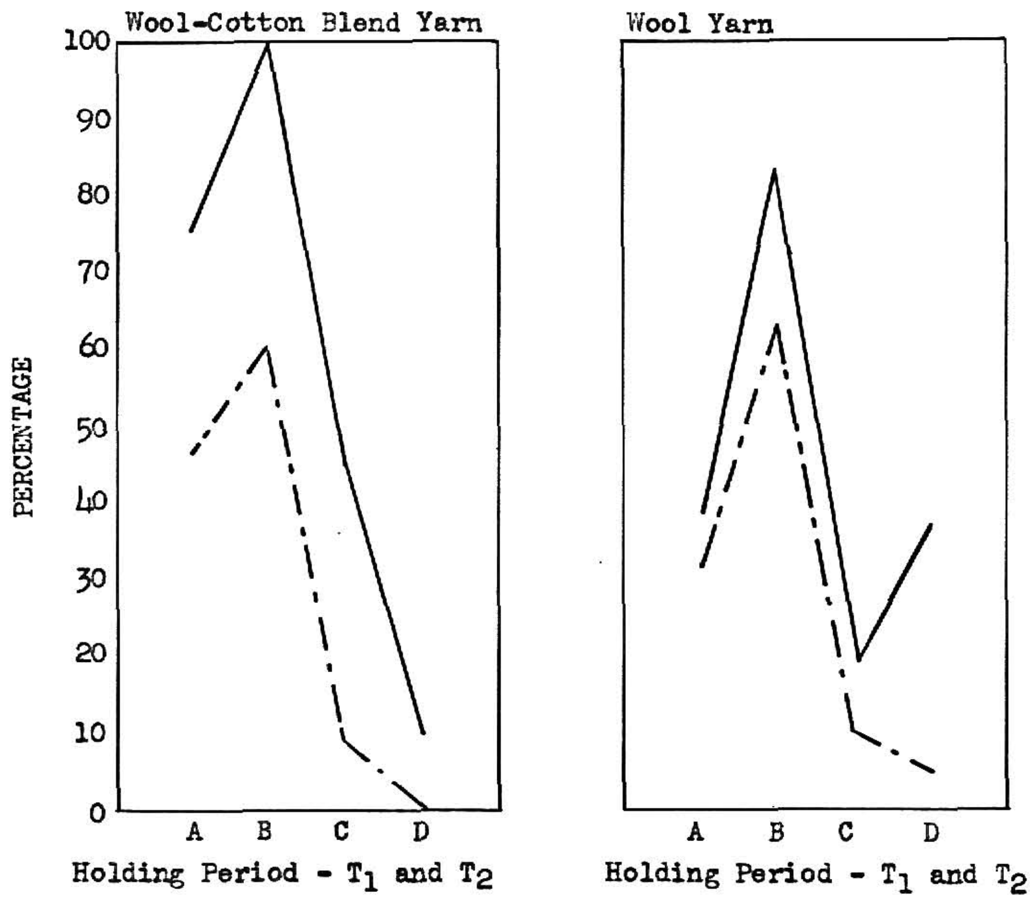

FIGURE 7.

PERCENTAGE OF WOOL FIBERS SHOWING CRACKS FROM WOOL-COTTON BLEND YARN AND 100% WOOL YARN FROM WOOL-COTTON-NYLON FABRIC

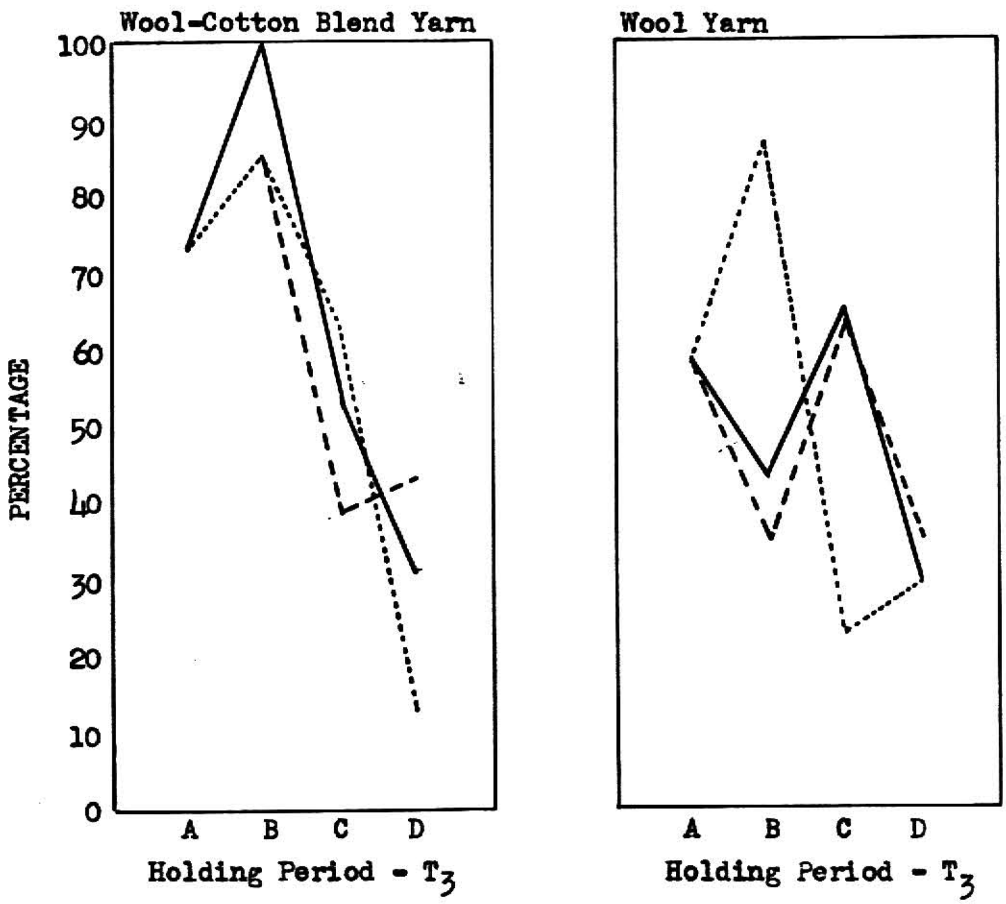

FIGURE 7 (Contd.)

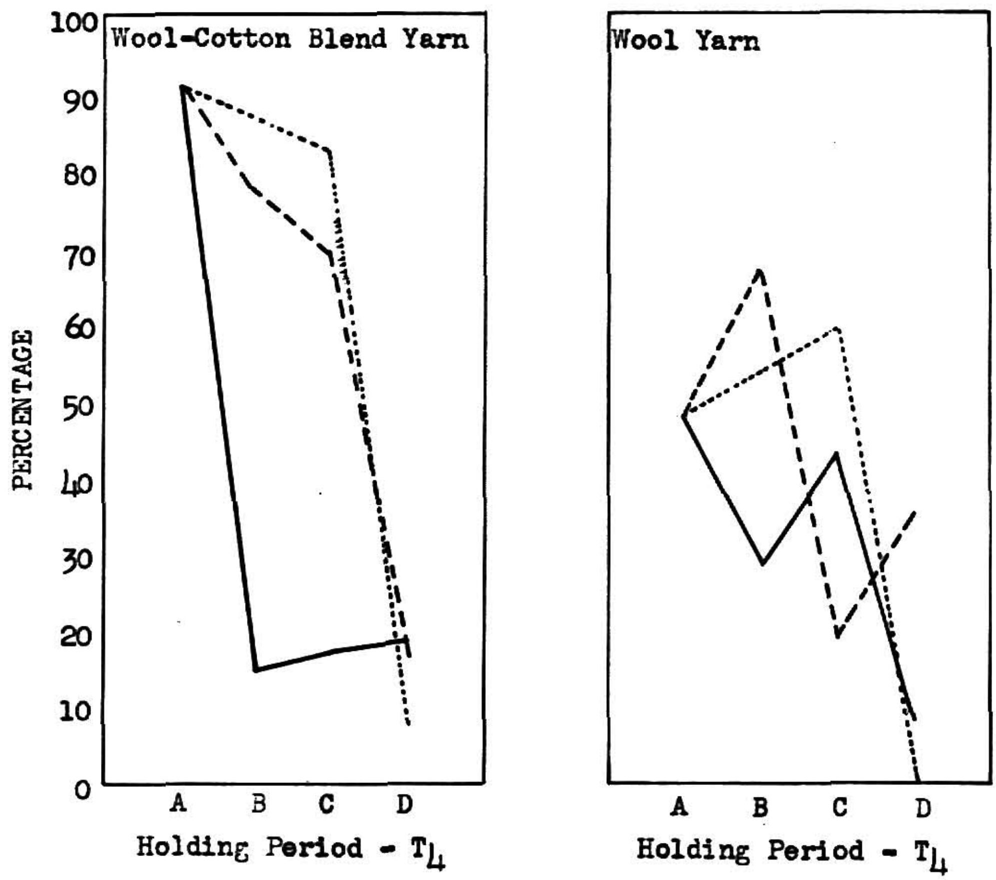

FIGURE 7 (Contd.)

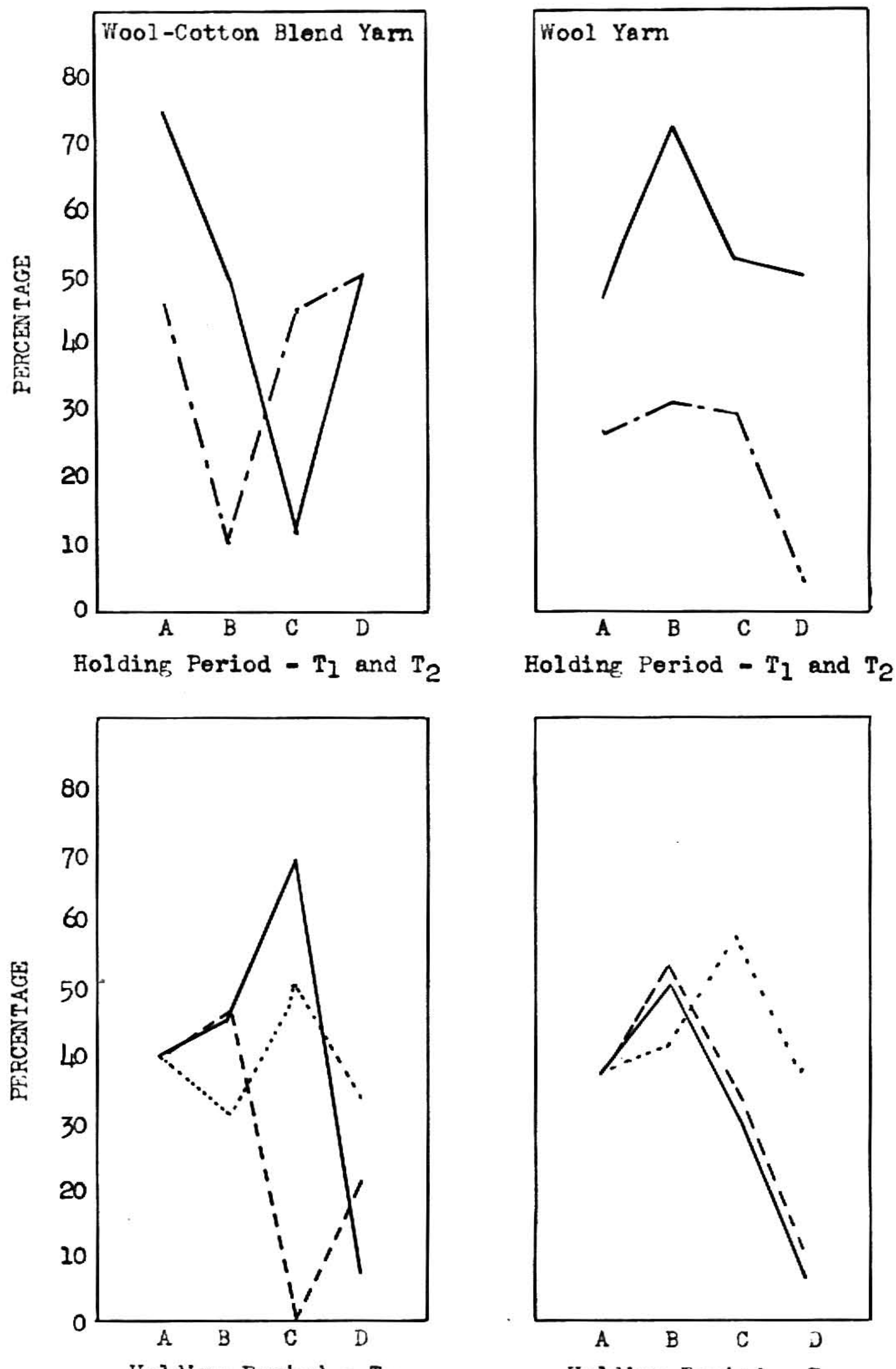

FIGURE 8

PERCENTAGE OF WOOL YARN SHOWING ROUGH AND LOOSE SCALES FROM WOOL-COTTON BLEND YARN AND 100% WOOL YARN FROM WOOL-COTTON-NYLON FABRIC

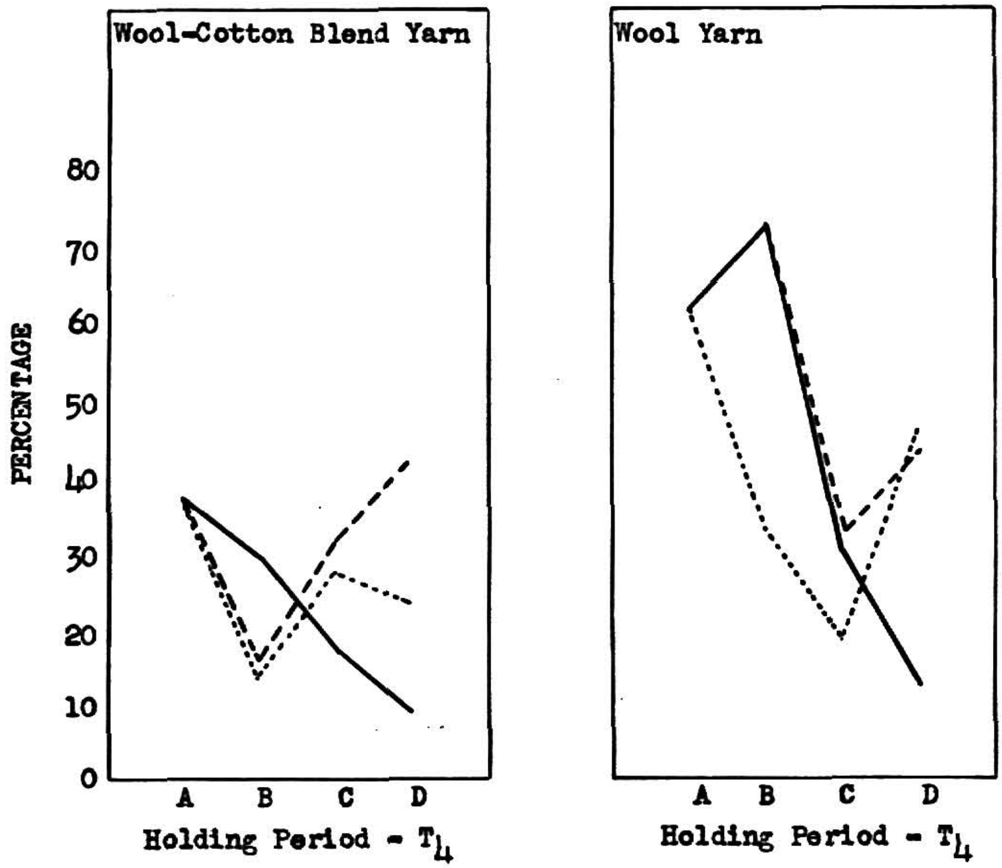

FIGURE 8 (Contd.)

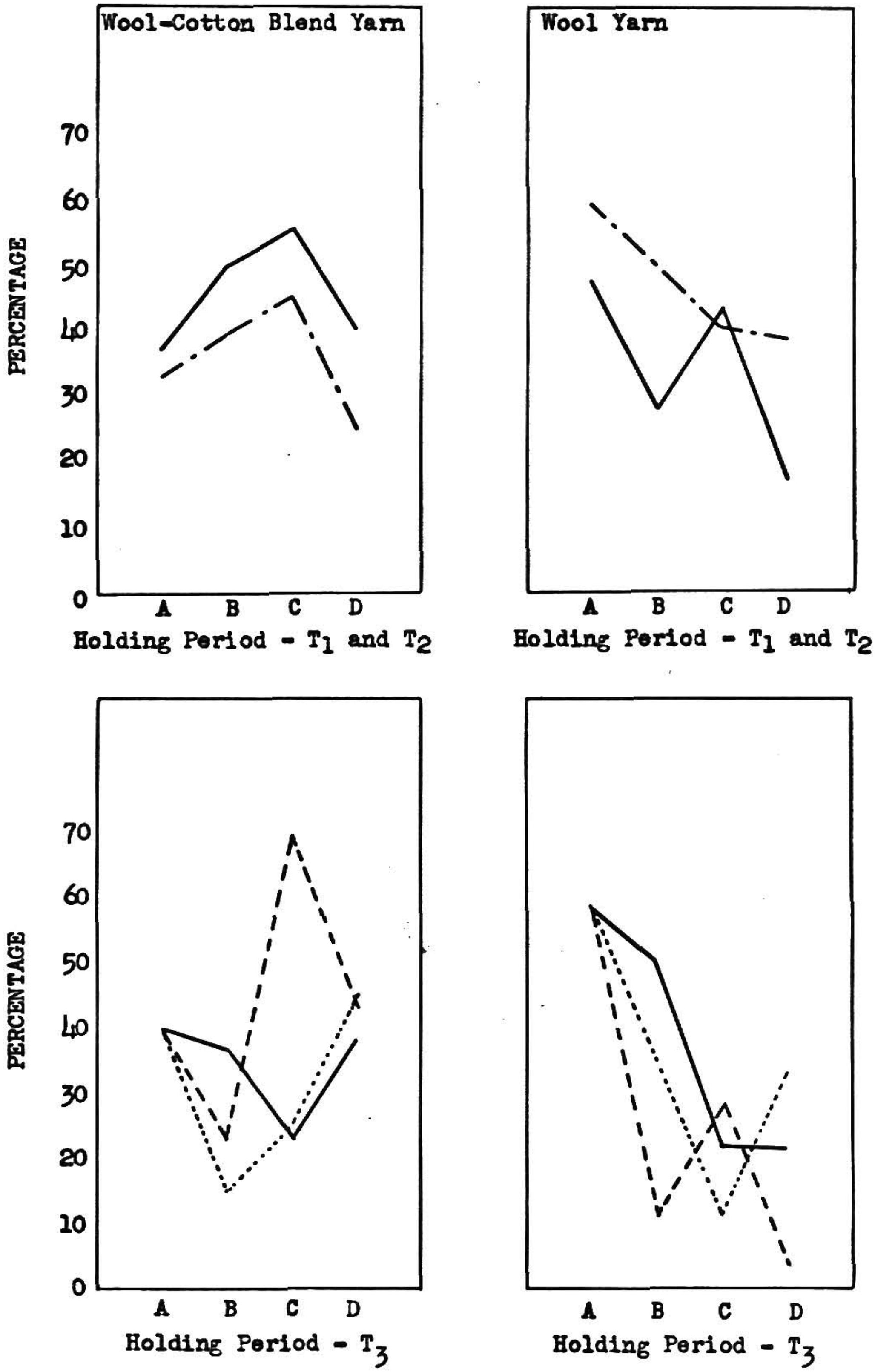

FIGURE 9

PERCENTAGE OF WOOL FIBERS SHOWING PITS FROM WOOL-COTTON BLEND AND 100% WOOL YARN FROM WOOL-COTTON-NYLON FABRIC

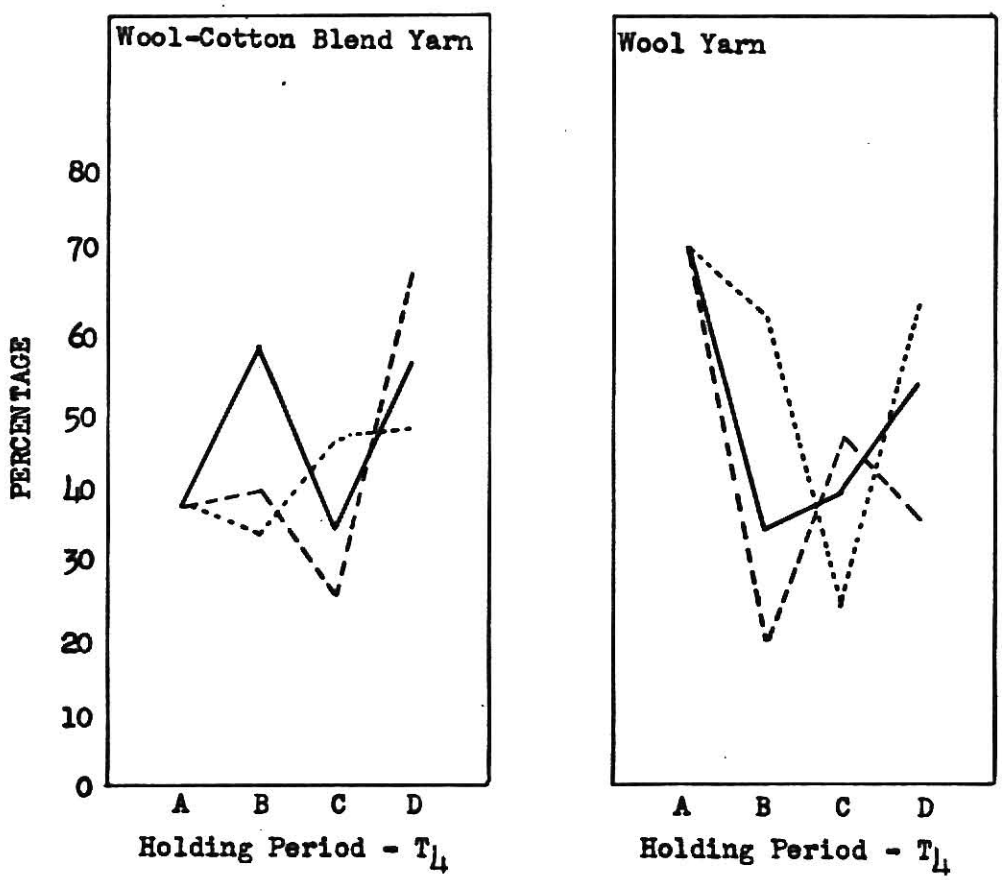

FIGURE 9 (Contd.)

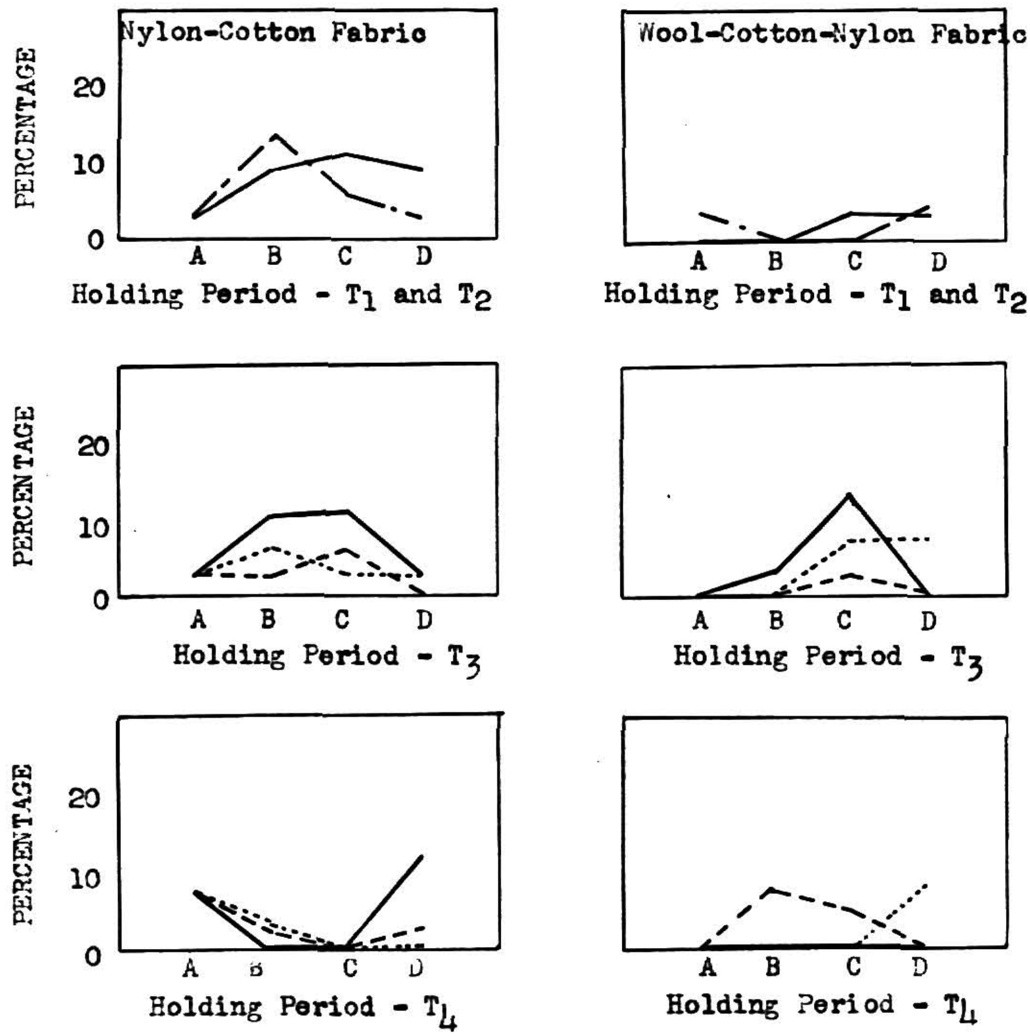

FIGURE 10

PERCENTAGE OF NYLON FIBERS SHOWING SWELLING FROM NYLON-COTTON AND WOOL-COTTON-NYLON FABRICS

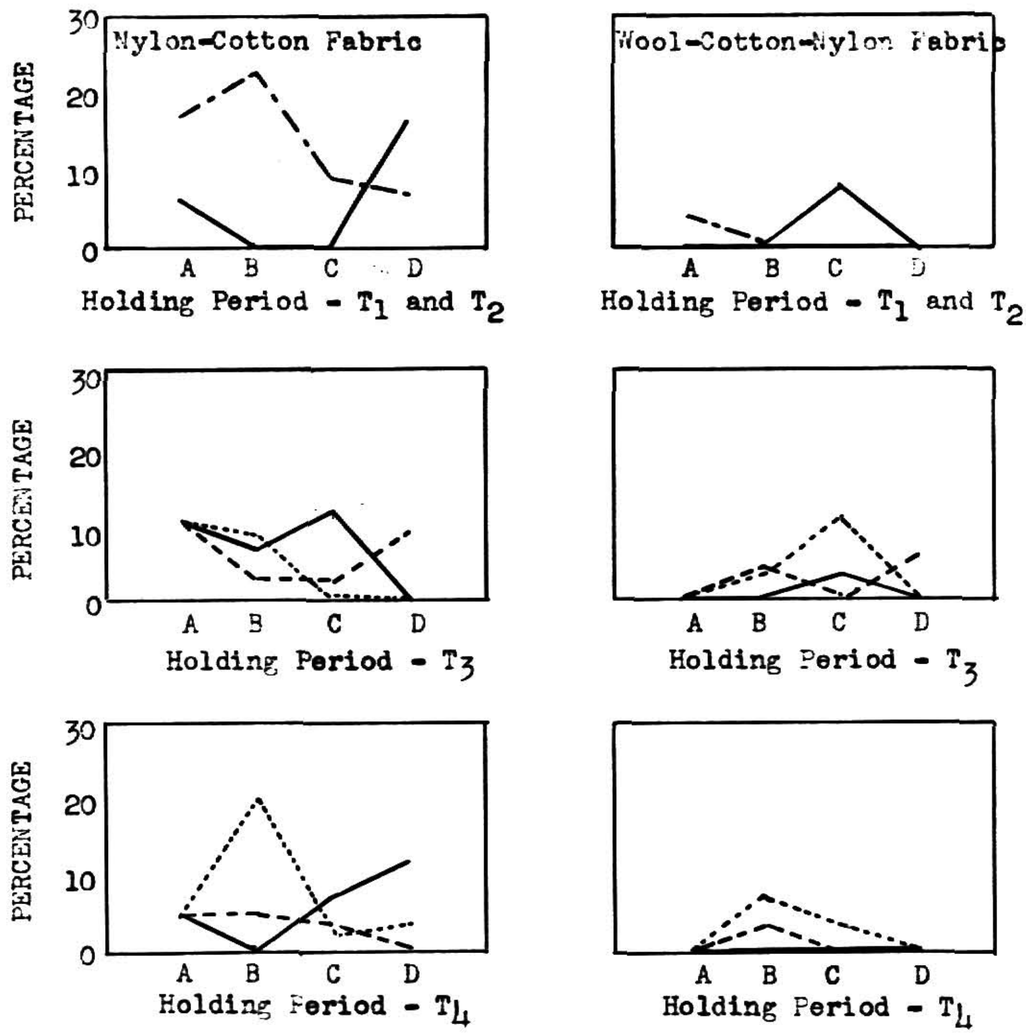

FIGURE 11

PERCENTAGE OF NYLON FIBERS SHOWING CRACKS FROM NYLON-COTTON AND WOOL-COTTON-NYLON FABRICS

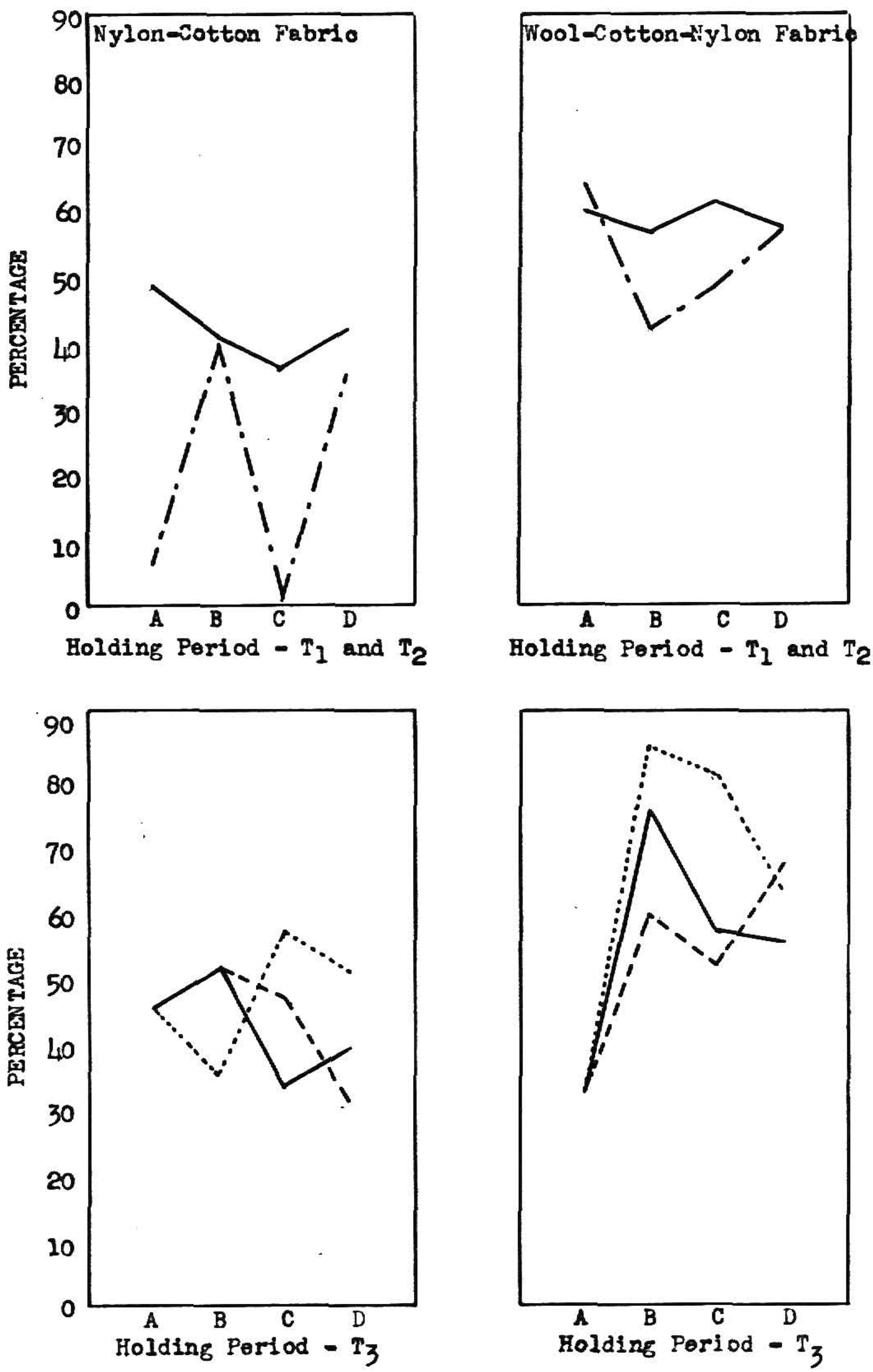

FIGURE 12

PERCENTAGE OF NYLON FIBERS SHOWING CRACKS FROM NYLON-COTTON AND WOOL-COTTON-NYLON FABRICS

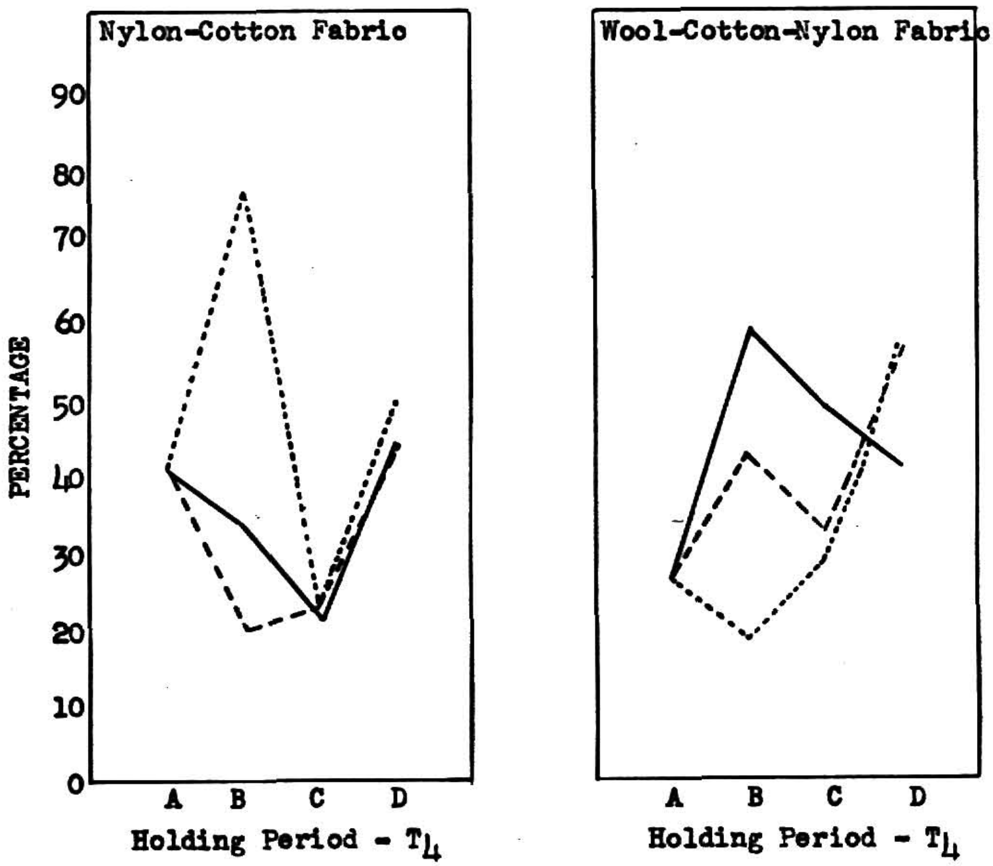

FIGURE 12 (Contd.)

MICROSCOPIC EVALUATION OF FIBER DAMAGE
CAUSED BY CANDIDA TROPICALIS

by

Delores Hendrickson

B. S., Kansas State Teachers College, 1967

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Clothing, Textiles, and Interior Design

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1971

The type and extent of damage caused by Candida tropicalis to fibers of knitted nylon-cotton and wool-cotton-nylon sock fabrics was examined by microanalysis and photomicrographic evaluation.

The sock fabrics composed of 60% nylon-40% cotton and 50% wool-30% nylon-20% cotton were uninoculated-unsoiled, uninoculated-soiled, inoculated-unsoiled, or inoculated-soiled. After treatment, the fabrics were held in an environmental chamber for four days at 37°C and 100% relative humidity, then laundered and sterilized before being subjected to the same treatment two additional times. A swatch was drawn after each sterilization for evaluation. From each of the swatches, longitudinal fibers were mounted permanently on slides for microscopic evaluation. Five fields of view were marked, and one field of view was randomly chosen to be photographed.

The number of fibers, the presence of soil, and the amount of fiber damage were recorded for each field of view on the 420 slides evaluated. Photomicrographs were made of one field of view on each slide.

Cotton fibers showed cracks, pits, internal corrosion, and dissolution of the lumen. Wool fibers showed cracks, pits, and loose and rough scales. Nylon fibers exhibited pits. The Wilcoxon Statistical Test ($p \leq .05$) showed differences in percentage of damage between uninoculated and inoculated fibers only in the internal corrosion of cotton fibers of the nylon-cotton fabric and in swelling of nylon fibers of the nylon-cotton fabric. Although the tabulation analysis showed no linear progression of increased damage in any fiber, the photomicrographs showed internal corrosion progression in the Candida tropicalis inoculated cotton fibers.