# A COMPARISON OF THE FLAMMABILITY OF THREE TYPES OF FABRICS USED IN GIRLS' SLEEPWEAR


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CHAPTER I

# INTRODUCTION

According to statistics of the National Fire Protection Association (NFPA) 2,000 persons in the United States died during 1966 from burns caused by ignited clothing, and another 150,000 suffered non-fatal burns. Fires in bedding and upholstery accounted for another 3,100 deaths (13). The common sources of ignition for such fires are cigarettes, bonfires, and matches (18).

Deaths and injuries from burning clothing are found principally in two age groups--the very young and the elderly (13). The former often have not learned the significance of what is happening to them; the latter often suffer from disabilities and cannot protect themselves rapidly enough (9). Three times as many deaths occur in the age group under 5 years as do in the group from 5 years to 60 years. At 60 years of age the rate of deaths and injuries increases until it surpasses the group under 5 years (13). In England the death rate for females is 4 1/2 times that of males with small girls and elderly women composing a large part of this group. Children's nightdresses and open fires can be hazards contributing to such tragedies (21). Many of these burned individuals suffer months of pain, require extensive and expensive medical care, and incur permanent physical disfiguration; consequently, burns are considered among the most serious of injuries in terms of long-term effects and cost (9).

The NFPA statistics show that 78% of the clothing deaths were caused by ignited cotton fabric. The other 22% of the deaths were rather evenly distributed among ignited fabrics of natural fibers, synthetics, and blends as the causes of death (13).

Since the sleepwear worn by little girls is often the cause of many burn tragedies, this investigation was designed to determine the flammability of three types and qualities of fabrics that are commonly used in girls' sleepwear. The objectives of this study were:

1. To compare the rates of burning and ease of ignition of three qualities of cloth, namely 100% cotton plissé crepe, 100% cotton flannelette, and 35% cotton-65% Dacron polyester blend batiste.
2. To determine the effects of machine washing and two methods of drying on the rates of burning and ease of ignition of the fabrics (listed under objective 1).

# CHAPTER II

## REVIEW OF LITERATURE

Practically all textile fibers are organic in nature, and all organic compounds generally are capable of supporting combustion. When a source of ignition is applied to fabric, the organic fibers decompose and, in most cases, liberate decomposition products which are also highly combustible. Consequently the fabric bursts into flames. The remaining carbon char is subject to flameless combustion caused by a slow oxidation of the char. This process is noted by the glowing action which consumes the fabric and liberates additional heat that is much more intense than that of the flame (4).

Many factors must be considered to accurately interpret the flammability hazard of a textile fabric. These factors are: 1) the rate of burning of the fabric, 2) ease of ignition of the fabric, 3) volume and temperature of the flame and of noxious vapors evolved during combustion, 4) total heat produced, 5) ignition of the back of the fabric which results in actual contact of the flame with the skin surface, 6) ignition of the adjacent layers of fabric, such as undergarments, and 7) ease of extinguishing the burning fabric (12). These factors may vary for every fabric because they are directly influenced by the chemical and physical nature of the basic fiber or fibers, the yarn size and twist and method of yarn construction, the type of fabric construction, and the chemical additives and techniques used in finishing the fabric (4).

Cellulose fibers, such as cotton, linen, and rayon, as well as other fibers composed of carbon, hydrogen, and oxygen, burn in the manner previously described. However, initial temperature of ignition and the amount of oxygen required for combustion may vary for different fibers. Fibers of different chemical composition may possess flammability characteristics quite distinct from those of cellulose. The protein fibers, wool and silk, decompose rapidly and evolve decomposition products which are less flammable (4). These fibers also melt and therefore prevent the access of air and the transmission of enough heat to cause rapid combustion (6). Likewise, the synthetic fibers of the amino group, such as nylon, exhibit a similar burning behavior. Mixtures or blends of synthetic and natural fibers tend to burn rapidly because the natural fibers hold the synthetic fibers in place (19). Lawson and others (14) found that a mixture of 45% cotton-55% wool had almost the same flammability as 100% cotton.

Another characteristic which affects the flammability of a fabric is the physical character of the fiber. Natural fibers are generally irregular in shape, and therefore create an irregular yarn surface. In contrast, synthetic fibers are monofilaments of uniform size and form. Since initial combustion of a solid material is a surface reaction, the more irregular fibers offer a greater surface area and a higher air-surface ratio. Consequently, fabrics made of such fibers are somewhat more easily ignited (4).

The yarn size and degree of yarn twist, method of yarn and fabric construction and the weight and thickness of the fabric greatly affect the flammability of a fabric, regardless of the fiber content. Fabrics having a large air-fiber surface ratio, such as loosely woven piles and chenilles, ignite easily and burn rapidly (4). Other open constructions, such as organdies, voiles, nets, jersey knits, and sheers, plus napped and brushed surfaces are generally quite flammable (11). When the more flammable cellulosic fibers are used in such constructions, the resulting fabrics are highly combustible. Even when comparably nonflammable fibers, such as wool, are used in a loosely constructed fabric, they ignite and sustain a flame rather easily (4). Fabrics having close construction and tightly twisted yarns, such as canvas and duck, burn slowly (6) (11). Simms (19) stated that for any fabric, the rate at which flames spread, once ignition has occurred, depends upon the weight per unit area; that is, the lighter the fabric, the faster the rate at which flames spread over it.

Few fabrics are manufactured without being treated with dyestuffs, yarn lubricants, sizings, coatings, or other finishing agents. Many of these substances may be more combustible than the initial fabric or may greatly increase the rate of combustion. On the other hand, finishes that decrease the air-surface ratio may actually retard the fabric flammability (4). Paraffin, oil, and nitro cellulose finishes, which are used for water-proofing and soil-removing, can make ordinarily safe celluosic fabrics highly flammable. Flaming and burning may be so rapid that the wearer has little opportunity to take the clothing off before serious injury occurs (6). Many of the synthetic fibers, such as nylon, contain the delustering agent, titanium dioxide, which increases the viscosity of the melt, thus preventing it from falling away. This causes the flame to increase and to spread to adjacent areas. Undyed, unfinished nylon, however, does not support the spread of flames because of the free flowing melt which drops away (4).

Ease of ignition, which is basically the initiation of the thermal decomposition for the formation of flammable products, varies with the physical and chemical properties of the fabric constituents. With a sufficient air supply and fibers of low thermal stability, ignition is readily accomplished in seconds. In other instances, fibers having high thermal stability, such as the synthetic polymer resin type, melting of the fiber precedes the decomposition; therefore, a higher temperature of the melt is required before ignition takes place. This higher temperature produces a longer ignition period, and often because of the fluidity of the melt, the fabric drops away before combustibility sets in. Even though no fire occurs, the fabric probably can be considered dangerous because the heat absorbed from the melted fabric can cause serious burns. In comparing fabrics which burst into flames with those that melt, the danger lies in the difference between burns caused by a flash type fire or more serious burns from hot, melted fabric (4).

Once the fabric is ignited, the next important flammability property concerns flame propagation. The flame propagation of a fabric is also dependent upon the fiber flammability, the air-surface ratio, the fabric construction, and the flammability of the additives used in finishing the fabric. The fabric position greatly contributes to the flame propagation with the vertical position providing the greatest propagation. The vertical position permits the flame to spread to fresh fabric and permits greater air circulation (4).

The intensity of the heat resulting from the flame does not vary much, regardless of the type of fabric. Measurements show the flame temperature to range from 400 degrees to 500 degrees C. The reason for the small range is that the fuels supplying the flame are decomposition products containing low molecular hydrocarbons, aldehydes, carbon monoxide, and other incompletely oxidized substances. The important point concerning heat intensity is the temperature in relation to the surface area of fabric per unit area of time, with this temperature being greatly dependent upon the rapidity of the flame propagation (4).

Numerous tests are currently being used for determining the ease of ignition and rate of burning of fabrics--the two factors of flammability which are generally considered the most important. Many of these tests are limited to use on fabrics which have been rendered fire-resistant or are naturally fire-resistant because the sources of ignition are too severe for non-treated fabrics. The basic difference among most of these tests is the position of the fabric during testing. The three most common positions are vertical, horizontal, and an angle of 45°. Since the fabric position definitely affects the flame propagation and rate of burning, researchers are in disagreement as to which position gives the most accurate results.

Sandholzer (18) states that most people consider the vertical position preferable for testing clothing materials because it more closely simulates conditions of actual wear. However, most untreated rayon and cotton fabrics burn with such rapidity in the vertical position, that unless the samples are long and unwieldy, burning is too fast to permit accurate observation of the rate. Distinguishing between the travel of the flame front on the fabric and the tip of the flame above it is extremely difficult. Motion picture cameras are sometimes employed as an aid in determining the rate of burning and the flame position.

When the fabric is in a horizontal position, the burning is retarded, thus making differences in rates more pronounced. The flame front is clearly defined thereby making accurate measurements easier. Many researchers prefer the horizontal position as long as the results correlate with those obtained by the vertical test and indicate which fabrics are more hazardous in actual wear (18).

The 45° incline is a compromise between the vertical and horizontal positions. In this position the burning is slowed to a more easily measurable rate than in the vertical position; however, the flame front is still too poorly defined to be followed accurately by visual observations, and mechanical devices must be employed to determine the end point of the flame (18).

Besides the position of the cloth during testing, other factors such as the relative humidity and moisture content of the fabric, the size of the test specimen, and the handling of pile and napped fabrics produce variation in test results. Since the relative humidity is variable, and the natural moisture content and moisture absorption of fibers differ from one another, fabrics, before testing, must be subjected to a constant humidity and temperature environment or dried in an oven in order for these factors to be eliminated from the results. Johnstone (12) also pointed out that when a fabric is removed from a desiccator, the pile or nap absorbs moisture at a much faster rate than the body of the cloth and that this moisture produces an appreciable error.

Simms (19) states that the rate at which flames spread over any fabric is partially dependent on the fabric width; that is, the wider the piece, the faster the rate of spread. Richards (17) found that specimens of 4 to 6 inches in width gave faster flame speeds than did 2 inch specimens. He also states that the flame hazard for clothing depends on the speed the flame travels over the first 2 to 3 feet of fabric length. Speigelman (20) also found that in relation to the amount of cloth, a 30 inch long sample burned six times as fast as a 6 inch sample.

For pile or napped fabrics, Johnstone (12) found considerable difference in rates of burning when the pile or nap was crushed or disturbed. Such fabrics should be treated with a combing device so that the surfaces of all specimens are the same.

Some of the flammability tests measure both ease of ignition and rate of burning, whereas some of the tests measure only one factor. In 1945 a committee from the American Association of Textile Chemists and Colorists began devising a flammability test to measure both of these factors. The test was finally adopted in 1952 by the Association as a standard test for flammability. It was revised in 1957 and again in 1962 and is referred to as the AATCC 33-1962 standard test method. The Flammable Fabrics Act of 1967 requires that all clothing fabrics must pass this standard test before the fabrics can be sold on the retail market. "The test is designed to indicate textiles which ignite easily and once ignited, burn with sufficient intensity and rapidity to be hazardous when worn (10)."

The basic procedure of this standard test for flammability of clothing textiles is as follows:

> Specimens are prepared and dried to place the fabric in its most flammable condition, prior to testing in a special apparatus consisting of a ventilated chamber enclosing a standardized ignition medium, specimen rack, and automatic timing device. The prepared specimen is held at an angle of 45°, a standardized flame is applied to the surface near the lower end for one second, and the time required for flaming to proceed

up the fabric a distance of five inches is recorded. Severance of the stopcord is a measure of intensity of burning. Ignition or fusing of the base of fabrics having a raised fiber surface is noted as an additional indication of intensity of burning (7).

Johnstone (12) stated that regarding ease of ignition, the AATCC method indicates that a plain-woven cotton fabric generally does not ignite in less than 3 seconds, while a material such as cotton or rayon sheer or heavily napped and long pile fabric usually ignites in the one second ignition period. Thus, the test appears to eliminate the highly flammable fabrics. In contrast, Elkand (3) stated that manufacturers using the AATCC test can easily show compliance with federal regulations, although the product burns comparatively quickly.

The horizontal test most frequently used is Federal Specifications Method 5906. This method is used to determine the comparative rates of burning of cloth and is satisfactory for cloth that has not been flameproofed, including pile and napped fabrics. The specimens are dried and clamped in a holder, leaving a 2 inch wide and 12½ inch long area exposed. The specimens are placed on a supporting track inside a metal test chamber and ignited with a standardized flame. The time required for a flame to travel across a 10 inch length of the specimen, marked off with heat-resistant wires, is determined (2).

Sandholzer (18), in 1948, used the horizontal and 45° incline test and compared the results of the two tests. She found that results of the two tests agreed in classifying rayon and cotton fabrics having an extra long or fine nap as being hazardous and in classifying ordinary flat-woven fabrics, sheeting, and cotton and rayon prints as not highly combustible. Among brushed rayon with a shorter nap, fleeced and tufted cotton materials, and fine light nets, the incline test classifies as unusually combustible a somewhat greater number of fabrics than does the horizontal test.

Lawson and others (14) recognizing the fallacies thus far mentioned about the vertical position test, devised a vertical test whereby the vertical burning speed was measured by continuously weighing the burning sample. Since fabrics lose weight at about the same rate at which they burn, the charted weight loss was used to calculate the vertical flame speed. The weight loss values were obtained by suspending the test samples on a torsion balance having an adjustable counter weight and concave mirror. A parallel beam of light was directed at the mirror which was focused on photographic paper wrapped around a rotating cylindrical drum in a camera. As the drum rotated, a continuous trace was left on the photographic paper, thus recording the movement of the mirror on the torsion beam. This movement was caused by a loss in weight of the test specimen.

Richards (17) experimented with three British Standard tests having different fabric positions and decided that only the vertical test came near to giving rate of burning results similar to those in actual wear. He modified the vertical test in several ways to make it more efficient. The procedure is to apply a small flame to the lower edge of a vertical specimen until it ignites. The time for the upper part of a flame to travel 25 inches up a strip of fabric is measured. This is achieved by stretching two threads, 25 inches apart, across the specimen and measuring the time between the burning of the two threads. Richards (17) also developed a test for determining the ease of ignition of a fabric. He found that the source which gave the most reproducible results was a microburner with a flame of 1 to 1.5 inches. He also found that a test employing a horizontal specimen gave the most significant differences in flame contact-time for the ignition of fabrics. The test involves attaching the fabric specimen to a frame and holding it horizontally while a flame is placed beneath the fabric. The minimum time of contact between flame and fabric that produces ignition of the fabric is determined.

Endler and Hurwitz (5) modified the AATCC 34-1966 standard test method which consists of igniting a fabric specimen, mounted in a vertical holder in a cabinet, with a standard flame for a specified time under controlled conditions. The test failed to give a realistic measure of the flammability of fabrics composed solely of thermoplastic fibers. Such test specimens generally fail to burn completely because the burning melt drops away. The modified test employed the use of a piece of 100% glass fiber marquisette, which was stapled between two layers of the test fabric. The gas flame was replaced by a "fuse" of polyester-cotton shirting that was stapled to the lower edge of the test specimen. The specimen was mounted in the frame and simultaneously the fuse was ignited and the timing begun. Their results showed that nylon and polyester fibers, which appeared to be nonflammable by the regular AATCC 34-1966 test, burned completely with the modified version.

## Flammable Fabrics Act

In 1953 Congress passed the Flammable Fabrics Act. The passage of this act was brought about by concern over burn fatalities and injuries and particularly by a series of fatal accidents in 1945 involving small boys wearing cowboy chaps made of a highly flammable rayon pile. Six years later concern was aroused again when several young girls were fatally burned while wearing the so-called "torch sweaters" which exploded into flames in the presence of a lighted match or cigarette. The 1953 act was narrowly drawn to prevent the marketing of highly flammable textiles used in certain types of wearing apparel (16) (15). Since a high rate of burn injuries continued, Congress realized the inadequacies of the bill. Consequently, in 1967 the act was amended to extend coverage to all types of apparel, including footwear, hats, and gloves. It also covers textiles used in furnishings and any material that will be used as a textile fabric. However, application of the broadened law will be impossible until the Secretary of Commerce sets a standard for the items. Such a standard will be based on a found need to protect the public against unreasonable risk of occurrence of fire leading to death, injury, or significant property damage (8) (1).

CHAPTER III

# METHODS AND MATERIALS

The victims of burn tragedies are often little girls clad in their nightwear. Since few, if any, fire-resistant fabrics are available in materials suitable for sleepwear, this experiment was designed to determine how flammable common sleepwear fabrics are and how their flammability is affected by laundering.

## Fabrics

Three of the most commonly used fabrics for girls' sleepwear, 100% cotton flannelette, 100% cotton plissé crepe, and 35% cotton-65% Dacron polyester blend batiste, were selected as test materials for the experiment. For each type of fabric, three qualities, varying in yarn size and twist, cloth count, and fabric weight, were also selected. Thus, a total of 9 fabrics were used in the experiment. Fabric descriptions are given in Table I.

## Sampling

Three flammability tests, rate of burning, horizontal ease of ignition, and vertical ease of ignition, were made on specimens of the 9 test fabrics. For each test, three groups containing 5 specimens of each fabric were administered one of 3 treatments--no laundering, washing and line drying, and washing and machine drying. Each test included 135 specimens, making a total of 405 specimens for the entire

TABLE I

DESCRIPTIVE ANALYSIS OF THE TEST FABRICS

| Fabric | Cloth Count (Yarns/Inch) | | Yarn Number (Indirect System) | | Yarn Twist (Turns/Inch) | | Fabric Weight (Oz./Sq. Yard) |
|---|---|---|---|---|---|---|---|
| | W | F | W | F | W | F | |
| CREPE PLISSE | | | | | | | |
| Low Quality | 78 | 55 | 29.5 | 35.2 | 21 | 25 | 2.9 |
| Medium Quality | 74 | 70 | 34.2 | 37.3 | 19 | 25 | 2.8 |
| High Quality | 110 | 92 | 51.1 | 44.0 | 28 | 31 | 2.4 |
| FLANNELETTE | | | | | | | |
| Low Quality | 42 | 42 | 32.3 | 13.5 | 17 | 13 | 2.9 |
| Medium Quality | 47 | 42 | 25.1 | 12.0 | 16 | 14 | 3.6 |
| High Quality | 46 | 42 | 27.9 | 12.6 | 17 | 13 | 3.5 |
| BATISTE | | | | | | | |
| Low Quality | 98 | 73 | 44.9 | 46.6 | 25 | 27 | 2.7 |
| Medium Quality | 101 | 71 | 44.7 | 33.8 | 22 | 23 | 2.5 |
| High Quality | 102 | 73 | 51.4 | 47.7 | 22 | 25 | 2.6 |

experiment.

Samples were cut slightly larger than test specimen size to allow for shrinkage and fraying during laundering. The actual size of the specimens for each test were: rate of burning, 28 inches by 8 inches; horizontal ease of ignition, 4.5 inches by 4.5 inches; and vertical ease of ignition, 3 inches by 3 inches. The specimens for each test were cut in alternating rows so that they would be distributed throughout the fabrics. The warp yarns and nap were cut in the same direction for every sample with the warp being the test direction. As each specimen was cut it was randomly assigned to a treatment and coded as to fabric quality, treatment, and sample number.

Laundering Procedure and Preparation of Samples for Testing

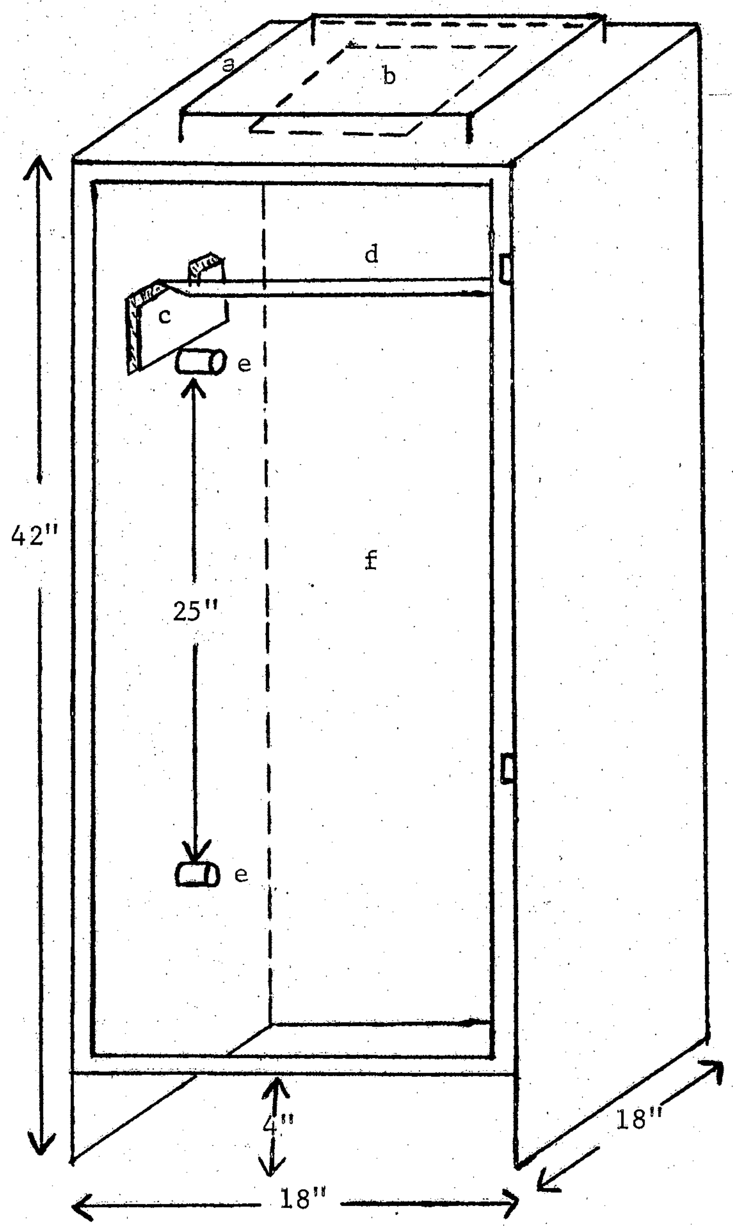
The samples which were to be laundered were sorted as to the method of drying. These two groups were placed into separate commercial laundry bags to facilitate sorting for the drying process. The two bags of samples were washed 5 times in an automatic Maytag agitator-type washer on a regular cycle having a single rinse cycle. The water temperature averaged 115° F., and 1/3 cup Punch was added to each washing cycle. When the washing cycle was complete, the specimens to be machine-dried were removed from the laundry bag and placed in a Maytag gas dryer having an automatic eye for determining the length of drying time. The specimens dried for approximately 15 minutes. The samples to be line-dried were hung on indoor lines and were allowed to dry until the next day.

After the last laundering, the samples were cut to the size required for the burning tests. In order to simulate the gathers often found in girls' sleepwear, the rate of burning test specimens were stitched 1/2 inch from the upper edge with a long basting stitch and then gathered to 4 inches in width. The lower edge of the vertical ease of ignition specimens were given a 3/16 inch hem to simulate the narrow hem often used to finish flounces and ruffles that decorate sleepwear.

The specimens for each test were randomly assigned to an experimental block so that each block contained a specimen of each fabric and treatment.

Test Chamber

The test chamber utilized in the experiment was a modification of the chamber used in the AATCC 34-1966 standard test method. The dimensions of the inside of the chamber were: 42 inches high, 17½ inches wide, and 18 inches deep. The chamber was constructed of 5/8 inch plywood with an interlining of 3/16 inch asbestos cement board. A hinged door made of 1/4 inch wire-reinforced glass was suspended 4 inches from the base of the chamber to allow for air circulation. The top of the chamber had a 6 inch square opening, covered with a 15 inch square baffle of asbestos cement board to allow for the passage of combustion fumes. See Figure 1. Large paper clips attached to a small rod were used to suspend the specimens. Two supply spools of No. 50 mercerized black cotton thread were attached 25 inches apart on the left side of the chamber. During the rate of burning test, the threads were pulled across the test specimen to the right side of the chamber where they were guided through two corresponding staples and anchored with weights. A microburner, having a 1/4 inch internal diameter tube and connected to a natural gas line, provided the source of ignition. The test chamber was situated under an exhaust fan which was used after the burning




a. 15" Square Baffle

b. 6" Square Hole

c. Rod Holder

d. Rod

e. Thread Spools

f. Glass Door Pane

Figure 1. Test Chamber

of each test specimen to remove the combustion fumes.

Description of Test Procedure

The test specimens in this experiment were not conditioned in a constant humidity and temperature environment nor dried in an oven so the specimens would contain their normal amount of moisture. The ambient temperature and relative humidity were recorded with a sling psychrometer before and after each series of burnings. Since fabrics absorb moisture in relation to the relative humidity, an attempt was made to have the variation in temperature and humidity as small as possible. The specimens were not burned if the humidity was over 75%. The temperatures during the rate of burning test ranged from 67° to 81°; the relative humidity ranged from 42% to 53%. The temperatures during the ease of ignition tests ranged from 75° to 85°; the relative humidity ranged from 65% to 70%.

The rate of burning and horizontal ease of ignition tests used in this experiment were modifications of those used by Richards (17). The rate of burning test provided a method of determining the rate at which a strip of fabric burns when a flame is applied to the lower edge. The specimen was vertically suspended in the test chamber. The threads were stretched horizontally across the specimen at distances of 1 inch and 26 inches from the lower edge of the specimen and anchored with weights. The thread must be in contact with the specimen or the results will vary. The edge of the specimen was ignited with a 1/2 inch microburner flame, the burner was withdrawn, and the door of the chamber was closed to avoid draughts. The time was measured with a stopwatch to the nearest .1 second from the burning of the lower thread and dropping of the weight to the burning of the upper thread and dropping of that weight. Any abnormal behavior of the specimen during the testing, such as surface flashing, was recorded.

The horizontal ease of ignition test provided a method for determining the ease with which a fabric ignites when a specified flame is placed beneath it. The test specimen was mounted in a 7 inch square metal frame, having a 3.5 inch square center opening. The frame was placed horizontally on a ring stand inside the chamber so that the surface of the fabric to be tested was facing downwards. A microburner with a 1 1/8 inch flame was slid beneath the specimen so that the top of the burner was 1 inch below the lower surface of the specimen. A stop was provided so that the position of the microburner was the same each time. The timing was begun when the microburner reached its position and was stopped when the fabric flamed. A strategically located mirror was used to see the underneath side of the fabric and to determine when flaming occurred. The time was recorded to the nearest .1 second.

The vertical ease of ignition test was used to determine the ease with which a vertically suspended fabric ignites when passed over a flame. A frame having a 2 inch square opening was placed horizontally on a ring stand in the test chamber. A microburner was centered under the opening so that a 1 1/4 inch flame was even with the surface of the frame. A test specimen clasped in forceps was passed over the tip of the flame. Timing was begun when the fabric touched the flame and stopped when the fabric edge began flaming. The time was recorded to the nearest .1 second.

A randomized complete-block design with a factorial arrangement of treatments was used to analyze the data obtained from the three tests. The 5 experimental blocks in each test contained 3 types of fabric, 3 qualities of fabric, and 3 laundering treatments.

CHAPTER IV

# RESULTS AND DISCUSSION

Results for the three flammability tests are given in Table II. A comparison of the means showed the fabrics having the fastest, medium, and slowest rate of burning were plissé, flannelette, and batiste, respectively. Analysis of variance for the rate of burning test (Table III) showed a significant difference in rate of burning for fabric and quality. Orthogonal contrasts were made to compare the rates of burning of the two 100% cotton fabrics with the cotton-polyester blend and to compare flannelette with plissé crepe. Both of these contrasts showed a significant difference at the 1% level in the rate of burning. The analysis of variance also showed a significant fabric by quality interaction that indicated that the quality levels for each fabric behaved differently and did not establish a definite pattern for rate of burning. A graphical representation of this interaction is shown in Figure 2.

Visual observations of the behavior of the specimens during the rate of burning tests indicated that the speed a flame travels up a strip of fabric is affected by the manner in which the fabric twists and turns while burning. The batiste blend curled in such a way that often the flame became trapped within the fabric. When this happened, the rate of burning was decreased. All three qualities of the cotton-polyester blend produced large amounts of black, acrid smoke. The melt

TABLE II

MEANS IN SECONDS FOR RATE OF BURNING AND EASE OF IGNITION OF THREE TYPES AND QUALITIES OF FABRICS SUBJECTED TO DIFFERENT LAUNDERING TREATMENTS

| Fabric | Rate of Burning | | | | Horizontal Ease of Ignition | | | | Vertical Ease of Ignition | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Treatment* | | | | Treatment* | | | | Treatment* | | | |
| | 1 | 2 | 3 | Mean | 1 | 2 | 3 | Mean | 1 | 2 | 3 | Mean |
| PLISSÉ CREPE | | | | | | | | | | | | |
| Low | 9.8 | 9.6 | 9.4 | 9.6 | 2.3 | 2.2 | 2.2 | 2.2 | 0.8 | 0.8 | 0.9 | 0.8 |
| Medium | 8.0 | 8.3 | 8.7 | 8.4 | 2.2 | 2.8 | 2.3 | 2.2 | 0.9 | 0.9 | 0.8 | 0.9 |
| High | 8.4 | 8.5 | 9.4 | 8.8 | 2.1 | 2.0 | 2.7 | 2.3 | 0.8 | 0.9 | 0.8 | 0.8 |
| Mean | 8.8 | 8.8 | 9.2 | 8.9 | 2.2 | 2.1 | 2.4 | 2.2 | 0.8 | 0.9 | 0.8 | 0.8 |
| FLANNELETTE | | | | | | | | | | | | |
| Low | 8.9 | 8.9 | 9.5 | 9.1 | 2.5 | 2.4 | 2.3 | 2.4 | 0.8 | 0.8 | 0.8 | 0.8 |
| Medium | 11.0 | 12.1 | 12.3 | 11.8 | 2.3 | 2.8 | 2.7 | 2.6 | 0.8 | 0.9 | 0.9 | 0.9 |
| High | 9.4 | 10.9 | 10.8 | 10.3 | 1.9 | 2.3 | 2.1 | 2.1 | 0.7 | 0.9 | 0.9 | 0.9 |
| Mean | 9.7 | 10.6 | 10.9 | 10.4 | 2.2 | 2.5 | 2.4 | 2.4 | 0.8 | 0.9 | 0.9 | 0.9 |
| BATISTE | | | | | | | | | | | | |
| Low | 19.4 | 17.0 | 18.0 | 18.2 | 1.8 | 1.8 | 1.8 | 1.8 | 0.7 | 0.8 | 0.7 | 0.8 |
| Medium | 11.1 | 12.9 | 13.2 | 12.4 | 1.4 | 1.6 | 1.7 | 1.6 | 0.8 | 0.7 | 0.8 | 0.8 |
| High | 15.9 | 15.8 | 16.0 | 15.9 | 1.8 | 1.9 | 1.6 | 1.8 | 0.7 | 0.8 | 0.8 | 0.8 |
| Mean | 15.5 | 15.3 | 15.8 | 15.5 | 1.7 | 1.8 | 1.7 | 1.7 | 0.7 | 0.8 | 0.8 | 0.8 |

*KEY: Treatment 1 = control; Treatment 2 = washing, line drying; Treatment 3 = washing, machine drying.

TABLE III

ANALYSIS OF VARIANCE

| Source of Variation | Degrees of Freedom | Rate of Burning Mean Square | Horizontal Ease of Ignition Mean Square | Vertical Ease of Ignition Mean Square |
|---|---|---|---|---|
| Total | 134 | | | |
| Blocks | 4 | 2.53 | $0.85^{**}$ | $0.17^{**}$ |
| Fabrics (F) | 2 | $536.37^{**}$ | $5.26^{**}$ | $0.13^{**}$ |
| Quality (Q) | 2 | $22.61^{**}$ | 0.13 | 0.02 |
| Treatment (T) | 2 | 4.36 | 0.26 | 0.07 |
| FXQ | 4 | $68.10^{**}$ | $0.45^{**}$ | 0.01 |
| FXT | 4 | 1.41 | 0.18 | 0.02 |
| QXT | 4 | 4.47 | 0.17 | 0.01 |
| FXQXT | 8 | 1.68 | 0.19 | 0.02 |
| Error | 104 | 1.50 | 0.11 | 0.03 |
| CV | | 11% | 16% | 21% |

$^{**}$Significant at the 1% level

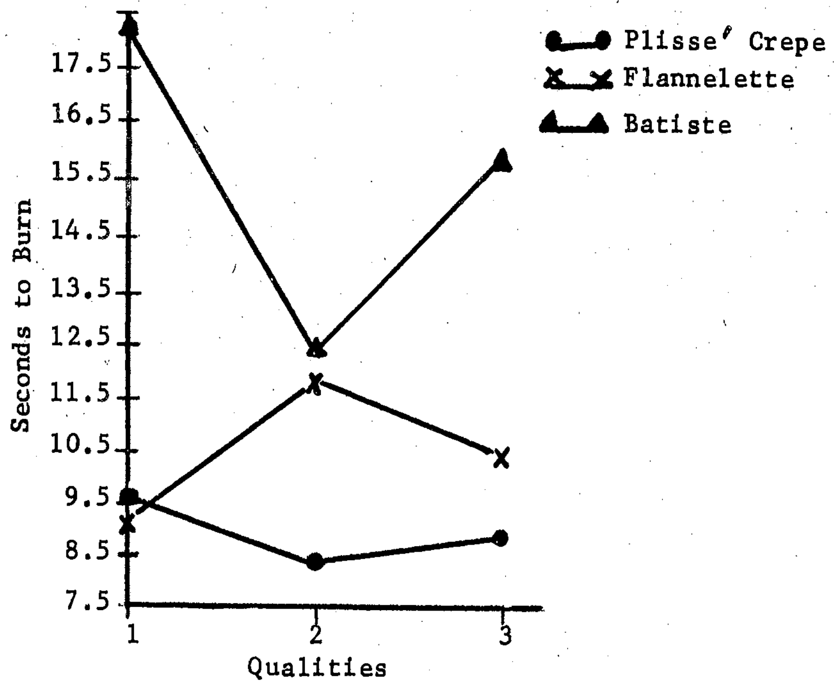



Figure 2. Rate of Burning Means Over Treatments for All Fabrics and Qualities

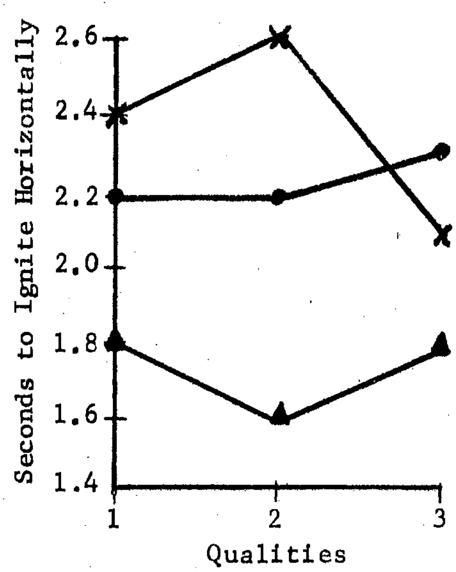



Figure 3. Means Over Treatments for All Fabrics and Qualities

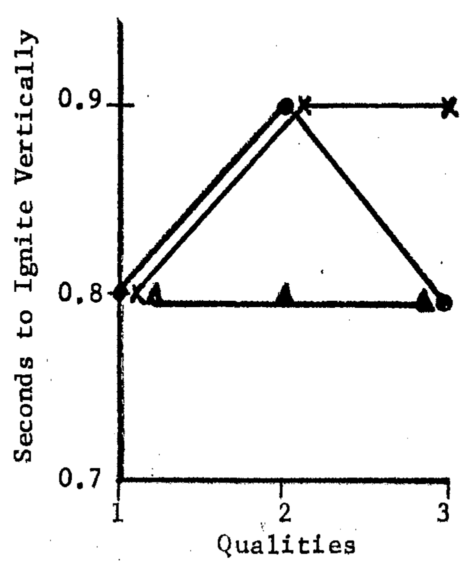



Figure 4. Means Over Treatments for All Fabrics and Qualities

of the low and high qualities of batiste dropped from the burning fabric. The medium quality batiste did not produce a dropping melt but became a spiral of brittle char. This fabric had a resin finish which may possibly have contributed to the difference in behavior.

The plissé and flannelette responded similarly during the rate of burning test. The flame sped rapidly up the fabric specimens and burned the threads before the sides and bottom were completely burned.

Analysis of variance for the two ease of ignition tests (Table III) showed a significant difference among fabrics. Orthogonal contrasts for the ease of ignition tests were also made. The comparisons for the horizontal ease of ignition test showed a significant difference at the 1% level between the 100% cotton fabrics and the cotton-polyester blend; whereas the comparison between the two cotton fabrics was significant at the 5% level. The vertical ease of ignition comparison showed only a significant difference between the 100% cotton fabrics and the cotton-polyester blend. The analysis of variance for the horizontal ease of ignition test also showed a significant fabric by quality interaction. A graphical representation of this interaction is shown in Figure 3. Figure 4 indicates a fabric by quality interaction for the vertical ease of ignition test although the analysis of variance does not indicate an interaction. The coefficient of variability for the vertical test shows that the experimental error was probably too high to detect interaction with only 5 blocks.

Each of the three qualities of batiste appeared to respond similarly during the horizontal ease of ignition test. The specimens ignited rapidly on the underneath test surface with the flame immediately burning through to the upper surface and consuming the specimen. The flannelette and plissé samples were slower to ignite and the flame burned on the underneath side for several seconds before it penetrated the upper surface.

The mean results in Table III indicate that specimens in the vertical ease of ignition test ignited much more rapidly than the specimens in the horizontal test. However, both tests ranked the fabrics in the same order of ignition with the batiste being the first to ignite, the plissé second, and flannelette third. The major difficulty encountered with the ease of ignition tests, particularly the vertical test, was the inability to determine when the specimens were ignited and to then measure this time on a stopwatch; therefore, the precision of the measurement was affected by the operator's response.

A comparison of the means for the rate of burning and ease of ignition tests indicated that batiste was the fastest to ignite, but after ignition, required the longest time to burn. Plissé was the second fastest to ignite, but the fastest to burn; whereas flannelette was the slowest to ignite, but burned at a rate between plissé and batiste.

CHAPTER V

# SUMMARY AND CONCLUSIONS

The sleepwear worn by little girls is often the cause of many burn tragedies; therefore, this investigation was designed to determine the flammability hazard of three of the more common sleepwear fabrics. Test specimens of three qualities of 100% cotton flannelette, 100% cotton plissé crepe, and 35% cotton-65% Dacron polyester blend batiste were washed 5 times and either line dried or machine dried. A control group was given no treatment. The warp direction was tested in a draught-free chamber to determine vertical rate of burning, vertical ease of ignition, and horizontal ease of ignition.

The data were analyzed as a randomized complete-block design with a factorial arrangement of treatments. Analysis of the data for the three tests showed a significant difference of rate of burning and ease of ignition among fabrics. The analysis of variance for the rate of burning and horizontal ease of ignition tests showed a significant fabric by quality interaction. The rate of burning analysis of variance also showed a significant quality effect.

These results indicate that the variations in yarn size and twist and cloth count and weight among the qualities of fabrics were great enough to produce a significant difference in rate of burning among the qualities. The laundering effect was nonsignificant which indicates that the washed fabrics were as flammable as the new ones. Machine drying apparently did not fluff the fabrics, particularly the flannelette, to produce any differences between these two methods of drying.

The coefficients of variability indicate that the experimental error for the three tests was high and was much higher for the ease of ignition tests than for the rate of burning test. If the experimental error was reduced, the effects of quality and laundering might more precisely be determined. The variance of a mean effect could be reduced by improving the technique and increasing the number of blocks. The rate of burning test could be improved by placing the test specimen in a vertical holder which would eliminate the twisting of the specimen during the testing. The reliability of all three tests also could be improved by using automatic timing devices. The ease of ignition test might also be improved by impinging an automatic flame on a fabric for a designated period of time, and if the fabric does not ignite within the time period, increments of time should continue until the fabric ignites. The researcher's experience with the three flammability tests and the coefficients of variability agree that the rate of burning test was the most reliable of the three tests.

This study indicated that the three sleepwear fabrics ignited easily and burned rapidly. The consumer may choose a cotton-polyester blend batiste which ignites rapidly, burns slower than flannelette or plissé, but melts into a syrupy mass which causes severe burns; or she may choose a 100% cotton plissé or flannelette which is slower to ignite, but burns rapidly with a flash-type flame which can also cause serious burns.

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