THE PROTECTIVE VALUES OF POLYNUCLEAR DYES FOR CELLULOSIC AND POLYESTER FIBERS WHEN EXPOSED TO GAMMA RADIATION

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Approved:

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SUMMARY

Voluminous research has been done in recent years with the objective of improving textile materials and processes through many and various irradiation techniques. Some has proven successful and some has not. It was hoped that irradiation might prove to be a useful tool for improving some of the inherent structural properties or correcting chemical deficiencies of textile fibers. As a result of the considerable work in this field, the detrimental effect of irradiation on certain fibers has been confirmed.

In the present study, attempts were made to establish certain organic dyes as "protectors" (1). Protectors, if they accomplish their purpose, absorb a portion of the energy from the gamma radiation and, thereby, prevent some of the degradation of the fiber.

The three yarns used in this study were composed of polyester fibers, cotton fibers, and a blend of 65 per cent polyester and 35 per cent cotton fibers. Each of the types of yarns were dyed with three dyes selected for this study, 7,14-dibenzo-pyrenequinone, violanthrone, and 8,16-pyranthrenedione. The dyed yarns and the undyed control yarns were exposed to specific dosages of gamma radiation.

After exposure, the yarns were tested for strength, elongation, and toughness and the results tabulated (see Tables 11-25). The averages from these tables were recorded in Bar Charts 1-9, showing the comparative strength, elongation and toughness for each given yarn.

It was found that the dyed polyester yarns that were exposed had

as much as 7.6 per cent increase in strength as compared to the undyed, unexposed yarns. The blend yarns had an increase of 2.9 per cent in strength; however, the cotton yarns exhibited no increase.

While strength was the principal property to be investigated, it was found that the other properties, elongation and toughness, also exhibited trends of significance. In the case of each yarn, elongation was found to be less in the dyed, exposed yarns than in the undyed, exposed yarns. The polyester yarns, again, were the ones which were affected to the greatest extent. But in the case of toughness, the results were just the opposite, with the polyester yarns having the least change in toughness and the cotton yarns having the greatest.

CHAPTER I

INTRODUCTION

When gamma radiation was first used for industrial purposes, its degrading effect on certain polymers was not thought to be of great importance. It was, then, and even more today, used for such tasks as determining flaws in metallic objects (2), such as motor blocks, shafts, and gears. Little thought was given to its application on yarns or fabrics. Soon, though, such men as Charlesby (3), Armstrong and Rutherford (4), and Dasgupta et al. (5), became interested in ionizing radiation on polymers.

From these early studies stem the many research programs which are presently underway to discover the strange behaviors of certain polymers when irradiated.

Purpose of the Research

This investigation is directed toward further investigation of certain polynuclear compounds as "protectors". It is a confirmed fact that gamma radiation has a detrimental effect on polyester and cellulosic molecules. Because of this renowned reaction from gamma radiation, these two compounds and a blend of the two 65/35 polyester/cotton were chosen for this study.

This investigation is exploratory in nature, and its purpose is to determine the value of the chosen dyes, 7,14-dibenzo-pyrenequinone, violanthrone, and 8,16-pyranthrenedione in preventing degradation of the yarns made from the polyester and cellulosic compounds.

If by these means (protectors), methods are found to further improve the less desirable characteristics of the given yarns, it could prove to be of importance in industrial uses. The mechanics through which such a modification is brought about are not investigated in this study, but are of importance, of course. The main objective is to find a polynuclear dye or polynuclear dyes which will in some way inhibit the degradation of the selected yarns when irradiated.

It is believed that the organic dyes chosen, all of which are benzene ring-containing compounds, will serve as energy sinks (6), due to the high number of rings in the structure. The discovery of any other reaction or modification of the fibers under investigation will also be welcomed and considered to be of importance.

Survey of the Literature

Mr. Ismail B. Hannout (7), states that "the two most striking physical changes produced in irradiated polymers could be ascribed either to fracture of the main chain or of the side chain". The most common occurring of the two reactions is the first, which is usually described as "degradation". It is also the reaction from which stems the search for radiation "protectors". A main chain fracture results in a lower average molecular weight and an increase in the number of polymer molecules. For the latter case, or fracture of the side chain, Mr. Hannout (8), states:

> In the second case, (cross-linking) reactive side groups are formed which subsequently serve to link polymer molecules together to form branched structures. When the density of cross-linking is sufficiently high, closed loops are formed on a three dimensional network or gel, with the physical and chemical properties very different from those of the initially linear or branched molecules. For exam-

ple, this network is insoluble, although it may swell, and it can have highly elastic properties.

These two effects, main chain and side chain fracture, have been investigated extensively by Mr. Arthur Charlesby (9). He has presented theories on the mechanics of gamma radiation reactions and also of certain additives or protectors, as they shall be called in this investigation.

Arthur Charlesby states:

> Marked changes in sensitivity of a polymer to radiation may be produced by the use of additives which do not form part of the polymer chain itself. Where such additives reduce the effect of radiation on the polymer itself, they are often referred to as protectors. The amounts added may be quite low, of the order of a few per cent, and often considerably less. Although the energy absorbed directly by these additives is correspondingly small, their presence may modify the response of the polymer to radiation by a factor considerably greater than the proportion of additive present.

Charlesby's explanation deals with external additives, and so far very little work has been done with these protectors. While the mechanisms for radiation protection are not fully understood, it is thought there are three possibilities. The first of Charlesby's three theories is as follows:

(1) The protective additive may either dissipate the energy without suffering any permanent chemical change or it may be modified and cease to be active. If the latter is the case, the protective value of the additive decreases to zero as the additive is eventually used up or modified.

(2) The protective additive may repair the damage caused by radiation. In this case, as in the first, the additive may or may not be used up. In many polymers, the major reaction is a loss of hydrogen leaving a polymer radical R·. Protection against further reactions can

occur if the protector (AH) can itself furnish a hydrogen atom and remain as a radical of low activity.

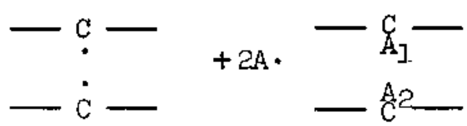
$$RH \longrightarrow R\cdot + H^{+}$$

$$AH + R\cdot \longrightarrow A\cdot + RH$$

If an electron is ejected from a polymer molecule by ionization, the additive may furnish the molecule with a replacement electron and itself be sufficiently stable to remain unaffected until it is able to recapture another electron.

Radical-radical reactions may be considered to fall under the same heading when they prevent further reaction by radicals produced on a polymer. For example, if crosslinking is assumed to take place by the interaction of the two radicals

additive molecules may combine with these radicals to form stable side chains or less reactive radicals, e.g.



A protective additive may also link the two polymer radical chains together in the case of degradation by main chain fracture and thereby heal a radiation-induced fracture. There will be no significant change in average molecule weight.

$$— \cdot + \cdot — + A \longrightarrow — A —$$

Although changes are not observed under experimental conditions used, it cannot be said that changes do not take place. In many of these instances, protection is not offered against radiation-induced chemical changes, as such, but the changes produced are converted from those being studied to others.

(3) The protecting additive may react with a radical formed elsewhere by radiation before this radical can attach and modify the polymer. In this case, protection is only offered against the indirect effect, although the additional possibility remains of some forms of repair protection also being present. Again, when polymers are irradiated in the presence of oxygen, the additive can react with the oxygen to prevent the formation of unstable peroxides on the polymer molecule, which may otherwise result in degradation.

In summary, these three broad classifications are: (a) removal of the absorbed energy before chemical changes occur, (b) inactivation of the chemical entities, e.g. radicals formed by radiation, and (c) protection of a polymer molecule against reactive entities produced elsewhere. In cases where the additive molecule is itself modified, the presence of surrounding polymer in considerable excess may be considered as a sensitizer of the additive molecule to radiation.

A number of reaction mechanisms have been proposed to account for crosslinking, for degradation, and for the difference in radiation behavior of polymers in terms of their structure. Some relate to a single polymer only, others attempt a more general approach. In the opinion of many, none of these theories can be accepted without major reservations. There is a dire need for more experimental data of a basic character before firm conclusions can be reached as to radiation mechanisms. The large number of theories propounded in the last few years for the reactions observed in irradiated polymers are an indication of the uncertainty which prevails in the subject. Charlesby (10), has observed this indication and states, "further investigations may be expected to reveal far more complex chemical changes than the simple ones which have so far been adequate to explain the modified physical properties."

CHAPTER II

NATURE AND SOURCES OF GAMMA RADIATION

Gamma rays are electromagnetic radiations of extremely short wavelength. They penetrate most materials easily and cannot be deflected either by electric or magnetic fields. The term "gamma radiation" is used primarily to describe radiation from radioactive sources; whereas, the term "X-radiation," or X-rays, is used primarily to describe radiation from a machine.

It should be noted also that gamma rays, like other forms of electromagnetic radiation, are not continuous waves of radiation, but are individual photons with definite (quantum) amounts of energy. Gamma radiation is a very high energy X-ray given off by radioactive isotopes. Specific elements can be made radioactive and used as gamma ray sources. Cesium-137, used in this study, is recovered from spent fuel elements from nuclear reactors. The Cesium-137 is located in the Radioisotopes Laboratory at the Georgia Institute of Technology and is the property of the Division of Isotopes Development of the Atomic Energy Commission.

Isotopes Gamma Radiography Machines are usually very compact. They consist essentially of a lead storage pig, which is thick enough to contain safely the radioactive source, and a mechanical means of moving the source out of the pig and into exposure position by remote control. Another method is a mechanical means of placing the object to be irradiated into the pig. The latter method is somewhat analogous to the one employed at the Georgia Institute of Technology and used in this study.

The following figures and information regarding the gamma radiation source, Cesium-137, at the Georgia Institute of Technology were supplied by Dr. James A. Knight (11), from his extensive work in the field of gamma radiation. For future reference, dose rates in the outside positions of the Cs-137 irradiator are shown in detail below:

Position	Dose Rate (ev/hr-gm)
1	3.82×10^{19}
2	3.88×10^{19}
3	3.68×10^{19}
4	3.93×10^{19}
5	3.68×10^{19}
6	4.16×10^{19}
7	3.91×10^{19}
8	4.17×10^{19}
9	4.06×10^{19}
10	4.16×10^{19}
11	3.79×10^{19}
12	3.80×10^{19}

All of the above data were taken using 10 ml of 0.01 N ferrous ion solution in 0.8 N sulphuric acid. Irradiation times varied from 20 to 55 minutes, with most of the runs being 30 minutes. Approximately one-half of the ferrous ion was oxidized to ferric ion in 30 minutes.

The above data were taken with the center carrier and all of the outside carriers in place. All of the carriers were empty except the one in which the dosimeter was being irradiated.

The following data were taken with samples of the same ferrous ion solution with all of the sample carriers in place. The carriers in positions 11 and 1 contained 10 ml of cyclohexane in glass tubes. This presented to the entering radiation the same container and depth of solution as the dosimeter in position 12.

$$\text{Dose Rate} = 3.89 \times 10^{19} \text{ ev/hr-gm}$$

The following data were taken with samples of the same ferrous ion solution, with all of the sample carriers in place. The carriers in positions 11 and 1 and in the center position contained 10 ml, 10 ml, and 50 ml, respectively of cyclohexane in glass tubes. This presented to the radiation the same container and depth of solution as the dosimeter in position 12.

$$\text{Dose Rate} = 4.08 \times 10^{19} \text{ ev/hr-gm}$$

The following data were taken with samples of the same ferrous ion solution, with all sample containers in place. All of the outside containers were empty. Dosimetry was done in the center position. Fifty ml of dosimeter solution in the tube used in the center position was the same depth of solution as 10 ml in the tube used for dosimetry in the outside positions.

$$\text{Dose Rate} = 6.2 \times 10^{19} \text{ ev/hr-gm}$$

CHAPTER III

EXPERIMENTAL PROCEDURE

Yarn Preparation

The yarns for the study were made on the modern yarn manufacturing equipment in the A. French Textile School, Mill Section. The cotton yarns were made from average American upland cotton, middling, one-and-one-quarter inch staple. The polyester yarns were made from one-and-one-half inch staple. The 65/35 blends of polyester and cotton were made from the same stock as the previous two. The blend yarns were obtained from a supply made by Mr. Nelson Chao for an earlier study.

The yarns were clearly marked for identification and taken to the testing laboratory and conditioned for twenty-four hours at standard testing conditions, 65% RH and 70° F. All three lots were tested for evenness and the coefficient of variation (CV%) for each lot was determined and listed in Table 1. Skeins were made from samples from each lot and weighed on analytical balances to determine the counts and denier and listed in Table 2. It should be noted that it was of no great importance to make all three lots the same counts, so very little time was spent in attempting duplicate counts. The only importance the duplicating of counts had was in simplifying the dyeing procedures and calculations that followed.

The yarns were next made into skein samples (120 yards), five from each lot. The identification of these lots is listed in Table 3.

Dyeing

Each of the fifteen skeins was thoroughly scoured. The cotton skeins were scoured by boiling for one hour in a 30:1 bath containing two per cent OWF NaOH. They were rinsed with hot H_2O and then cold H_2O until neutral to litmus indicator. They were next hand-squeezed and dried in an oven for four hours at 212° F.

The polyester skeins were scoured in a one per cent Alkanol HCS* and 99 per cent H_2O solution at 160° F for five minutes with mild agitation. They were then rinsed in 160° F H_2O, hand-squeezed, and dried at 160° F for four hours.

The 65/35 blend polyester/cotton yarns were first scoured using the cotton scouring formula and then scoured using the polyester scour formula. They were hand-squeezed and placed in an oven and dried for four hours at 160° F.

The fifteen samples were again conditioned in the testing laboratory for twenty-four hours while the dye solutions were being made.

Three dyes were used and are listed as Dye No. 1, 7,14-dibenzopyrenequinone; Dye No. 2, violanthrone; and Dye No. 3, 8,16-Pyranthrenedione.

The dye formulas are listed in Table 4. The dye solutions were made up to contain ten per cent by weight of dyestuff.

Each of the three dye solutions was put in a one liter beaker and properly identified. The skeins were placed in the beakers one at a time and each time agitated briefly to insure thorough wetting. The skeins were then passed through a wringer with the weight on the top roll held

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*This is a duPont trade name.

constant throughout the entire dyeing operation. The skeins were next hung in a room at about 80° F to dry for twenty-four hours and were then taken to the testing laboratory to condition for twenty-four hours.

This dyeing operation was carried out in such a manner that the dye remained attached to the yarn in a fixed position during the irradiation process. Handling was held to a minimum. These dyes did not need to meet standards, such as wash fastness, normally required for dyes used on apparel and commercial fabrics.

It was found that heating the dyed yarns to any extent while still wet introduced the problem of dye migration. This was first noticed when dyed skeins were placed in the oven at 212° F to dry. Several lots were dried at other elevated temperatures and dye migration still persisted.

Accordingly, it was decided that rapid drying in air currents in the oven caused the dye migration. It was observed that the concentration of color collected on the outside of a wave in the skein as shown below:

These projections naturally dry first as they are subjected more directly to the hot air currents. As the dye solution dries, it leaves the dye pigments on the fiber, but being the first to dry, this area begins to absorb moisture from the adjoining areas. This in turn takes pigments from one section and concentrates them in another. Consequently, the procedure of allowing the yarns to dry for twenty-four hours, at 80° F, outside an oven was adopted. This was carried out by placing the skeins on skein racks immediately after dyeing and wringing, so that they would be slightly taut during drying.

Exposure

The dyed yarns were weighed immediately after the wringing process, and the moisture pickup was determined (Table 5). After drying, sixty yards were taken from each skein for exposure tests. These small skeins were carefully coiled and placed in special culture tubes. The tubes were 19.0 millimeters in outside diameter and 127 millimeters in length. The yarns were forced to the bottom two inches of the tube to expose them to the portion of the radiation field that had been found to be most even.

The twelve samples were taken to the radioisotopes laboratory and each sample was exposed for three hours. Table 6 shows the exposure, dosages, and the holes used in the experiment. Holes, six, eight, and ten were chosen because they admit practically identical dosages. Three holes were used so that each of the four polyester samples could be exposed in hole number six, each of the four blend samples in hole number eight, and each of the four cotton samples in hole number ten. These precautions were taken so that the dosages for each type yarn were essentially identical and only a negligible difference between the polyester, blend, and cotton yarns existed.

Testing

After exposure, the yarns were allowed to condition for twenty-four hours at 65% RH and 70° F. These conditions were used throughout this study. All fifteen lots were individually tested on the Instron Tester. Breaking strength, elongation and toughness were calculated and tabulated in Table 7.

The Instron Tester was set up as shown in Table 8 and was checked periodically during testing to insure accurate results.

On all the Instron tests performed in this study, stress-strain diagrams were made, and the integrator reading, full-scale reading, sample identification, and reading number were recorded directly on the Instron Chart at the time the sample was broken. The figures taken from the charts are the figures tabulated in Tables 11-25.

The breaking strength was read directly from the charts and recorded in pounds. The elongation was calculated from the crosshead speed, chart speed, and actual length in inches recorded on the chart from start to breaking point. The formula is shown below:

$$\% \text{ Elongation} = \frac{\text{Crosshead Speed x Number Divisions x Inches/Division x 100}}{\text{Chart Speed x Sample Length (inches)}}$$

$$\% \text{ Elongation} = \frac{\text{6 x Number Divisions x 1/10 x 100}}{\text{Chart Speed x 10}}$$

$$\% \text{ Elongation} = \frac{\text{6 x Number Divisions}}{\text{Chart Speed}}$$

The toughness of the sample, or area under the stress-strain diagram, is defined as the work done in breaking and is expressed as grams-centimeter per denier-centimeter. This was calculated by using the integrator reading. This reading was recorded on the chart as each diagram was made. The following formula was used to calculate the toughness of each yarn:

$$\text{Toughness} = \frac{\frac{\text{Integrator Reading}}{5{,}000} \times \text{Full-Scale Reading (Grams)} \times \frac{\text{Crosshead Speed}}{\text{Specimen Length}}}{\text{Sample Denier}}$$

$$\text{Toughness} = K \times \frac{\text{Integrator Reading}}{\text{Denier}}$$

Where K is as follows:

K = 0.05448 for Full-Scale of One Pound
K = 0.10896 for Full-Scale of Two Pounds

This was further simplified by using the sample denier from Table 2 and is:

Toughness (Polyester) = 4581 x Integrator Reading

Toughness (Blend) = 249 x Integrator Reading

Toughness (Cotton) = 277 x Integrator Reading

CHAPTER IV

DISCUSSION OF RESULTS

The data have been summarized in Figures 1-9. Figures 1-3 are the polyester bar charts, Figures 4-6 the cotton bar charts, and Figures 7-9 the blend bar charts.

In Figures 1, 4, and 7, the vertical axis represents strength expressed in pounds. The horizontal axis has no numerical value, but depicts the different yarn samples.

Figures 2, 5, and 8 are the elongation charts with the vertical axis representing per cent elongation.

The relative toughness of each sample is illustrated in Figures 3, 6, and 9. The values are in grams-centimeter per denier-centimeter.

In each figure, it should be noted that the last sample is an undyed, unexposed sample and is used as the basis for comparison to study the effect of the gamma radiation.

The percentage changes in this report are, therefore, based on the undyed, unexposed yarns to demonstrate better the protection, or modification values, imparted by the dyes used. Consequently, it should be clearly understood that per cent increase and decrease are based on the original specimens rather than on the undyed, exposed specimens.

It was found that each of the three yarns reacted differently to the irradiation. Because of this, each yarn will be discussed separately in this section.

Polyester Yarns

Figure 1, which exhibits change in yarn strength with irradiation, shows the following:

Undyed, exposed yarns lost 2.5 per cent; exposed yarns dyed with Dye Number 1 gained 7.6 per cent; exposed yarns dyed with Dye Number 2 lost 2.5 per cent; and exposed yarns dyed with Dye Number 3 lost 5.6 per cent.

The effect of increasing the strength and toughness of the yarn dyed with Dye Number 1 and irradiated was wholly unexpected. In view of these results, it is felt that Dye Number 1 should be considered as a valuable modifier in future experiments with gamma radiation. It exhibited radical and unexpected behavior.

The reason for these sizeable deviations from the expected with the polyester and polyester/cotton blend yarns is not explained in this project. Since the object of this study was to determine if certain polynuclear dyes do act as protectors, the physical or chemical reasons will be left for future studies. A possible explanation is that some modification must have taken place, such as crosslinking of molecules in the polyester. In this case, the problem poses a great challenge and opportunity for advanced study along these lines.

Cotton Yarns

Figure 4 records the effect of irradiation on the strength of cotton yarns. Undyed, exposed cotton yarns lost 10.2 per cent; exposed yarns dyed with Dye Number 1 lost 6.1 per cent; exposed yarns dyed with Dye Number 2 lost 7.0 per cent; and exposed yarns dyed with Dye Number 3 lost

6.2 per cent.

Figure 5 exhibits the effect of irradiation on the elongation of the yarns. Undyed, exposed yarns exhibited no change; exposed yarns dyed with Dye Number 1 lost 4.1 per cent; exposed yarns dyed with Dye Number 2 lost 7.7 per cent; and exposed yarns dyed with Dye Number 3 lost 9.1 per cent.

Figure 6 records changes in toughness. Undyed, exposed yarns lost 14.2 per cent; exposed yarns dyed with Dye Number 1 lost 12.2 per cent; exposed yarns dyed with Dye Number 2 lost 12.6 per cent; and Dye Number 3 lost 11.2 per cent.

These results are in accord with our expectation and are consistent, i.e. Dye Number 1 did not produce anomalous effect with cotton.

<u>Polyester/Cotton Blend Yarns</u>

Figure 7 records the changes in strength due to irradiation. Undyed, exposed yarns lost 5.0 per cent; exposed yarns dyed with Dye Number 1 gained 2.9 per cent; exposed yarns dyed with Dye Number 2 gained 2.9 per cent; and exposed yarns dyed with Dye Number 3 lost 1.4 per cent.

Figure 8 shows the effect in elongation of the blend yarns. Undyed, exposed yarns lost 2.2 per cent. Exposed yarns dyed with Dye Number 1 lost 14.1 per cent; exposed yarns dyed with Dye Number 2 lost 12.5 per cent; and exposed yarns dyed with Dye Number 3 lost 14.9 per cent.

Figure 9 records changes in elongation. Undyed, exposed yarns lost 5.7 per cent. Exposed yarns dyed with Dye Number 1 lost 17.6 per cent; exposed yarns dyed with Dye Number 2 lost 11.3 per cent; and Dye Number 3 lost 15.7 per cent.

It is to be noted that again Dye Number 1 imparted an unexpected result in strength gain, roughly in proportion to the percentage of the polyester content. Dye Number 2 produced a similar effect.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The three dyes, 7,14-dibenzo-pyrenequinone, violanthrone, and 8,16-pyranthrenedione explored in this study do offer a range of protection for certain fibers against degradation from gamma radiation, and, in some cases, they appear to have modified the fiber structure. The polyester yarns had the widest range of effect in strength, elongation, and toughness. The strength variations of the polyester yarns actually ranged from a 10.4 per cent increase to a 3.2 per cent decrease. The cotton and polyester/cotton blend yarn results had less variation.

It is felt that the proof of these dyes as protectors is of primary importance, but the discovery of the radical behavior of the polyester and polyester/cotton blend yarns indicates a need for additional work.

Recommendations

It is recommended that further studies be made on polyester yarns alone in search of an explanation for their unexpected increase in strength when irradiated in the presence of 7,14-dibenzo-pyrenequinone.

Also, the unexplained behavior of the polyester/cotton blend yarns definitely offers an interesting area for further investigation. It is apparent from the present investigation that their reactions follow neither the trends of the polyester yarns nor those of the cotton yarns and neither are they always intermediate.

Another suggestion is that in future studies with synthetic yarns, fine monofilament be used instead of spun yarns. In this way, a minimum coefficient of variation in evenness and strength might be obtained.

It is also thought that monofilament might be immersed in a homogeneous dye solution for irradiation and, thereby, eliminate the complications of actually dyeing the specimen to be studied. It would also be possible, in this way, to determine more precisely the quantity of dye being exposed. In this way, the structure of the dye molecule, concentration of dye, or type of yarn could be varied one at at time to determine their different effects due to irradiation.

APPENDICES

Table 1. Uster Evenness Results

Polyester		Blend		Cotton	
Reading	Correction	Reading	Correction	Reading	Correction
21.0	0	18.0	0	19.0	-7
21.0	+2	17.0	-2	17.5	-7
19.5	+1	16.0	-2	16.5	-5
19.0	-2	16.0	-1	17.0	-3
18.5	0	15.0	-1	20.0	0
22.0	+1	15.5	-2	17.5	-2
21.5	+1	16.0	-3	18.5	-1
22.0	+1	17.0	-2	19.0	0
21.5	0	17.5	-2	18.0	+1
22.0	0	17.0	-2	19.0	+1
AVERAGE					
20.8	+0.4	16.5	-1.7	18.2	-2.3
CV%					
20.4		18.0		20.2	

Table 2. Size Determination

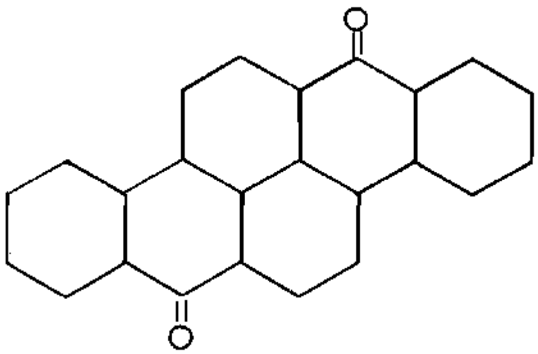
Polyester Weights (60 yds)	Blend Weights (60 yds)	Cotton Weights (60 yds)
2.2380 Grams	2.0670 Grams	1.8286 Grams
2.2228 Grams	2.0808 Grams	1.8768 Grams
2.2490 Grams	2.0518 Grams	1.8164 Grams
2.2396 Grams	2.0332 Grams	1.8720 Grams
AVERAGE		
2.2374 Grams	2.0582 Grams	1.8485 Grams
COTTON COUNTS		
22.35	24.29	27.05
DENIER		
237.8	218.8	196.5

Table 3. Identification of Dye Code

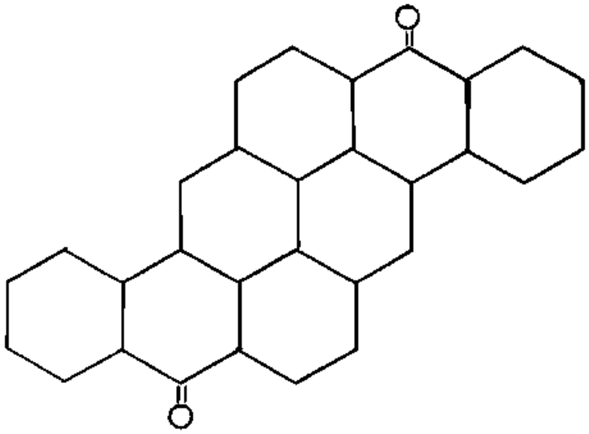
Code	Identification
P-1	Polyester dyed with Dye No. 1 (to be exposed)
P-2	Polyester dyed with Dye No. 2 (to be exposed)
P-3	Polyester dyed with Dye No. 3 (to be exposed)
P-4	Polyester undyed (to be exposed)
P-5	Polyester undyed (not to be exposed)
C-1	Cotton dyed with Dye No. 1 (to be exposed)
C-2	Cotton dyed with Dye No. 2 (to be exposed)
C-3	Cotton dyed with Dye No. 3 (to be exposed)
C-4	Cotton undyed (to be exposed)
C-5	Cotton undyed (not to be exposed)
B-1	Blend dyed with Dye No. 1 (to be exposed)
B-2	Blend dyed with Dye No. 2 (to be exposed)
B-3	Blend dyed with Dye No. 3 (to be exposed)
B-4	Blend undyed (to be exposed)
B-5	Blend undyed (not to be exposed)

Table 4. Dye Formulas

Dye No. 1 7,14-Dibenzo-pyrenequinone



Dye No. 2 Violanthrone



Dye No. 3 8,16-Pyranthrenedione

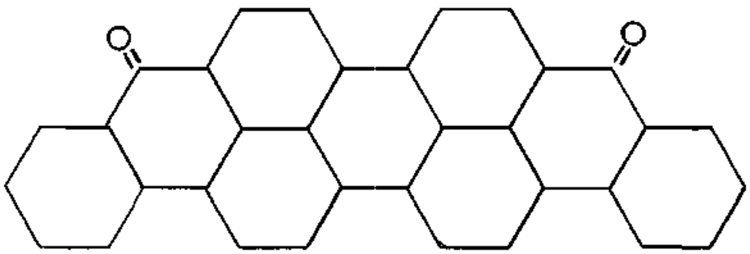


Table 5. Dye Weights

Sample	Yarn Weight	Moisture Weight	Dyestuff Weight	% Dye	Dye Weight	Moles of Dye
P-1	2.2380	4.0124	0.4012	17.0	0.0682	$= \frac{0.0682}{332}$ 0.0002054
P-2	2.2228	3.7826	0.3782	21.4	0.0810	$= \frac{0.0810}{406}$ 0.0001995
P-3	2.2490	3.2243	0.3224	39.8	0.1283	$= \frac{0.1283}{456}$ 0.0002814
C-1	1.8286	3.0083	0.3008	17.0	0.0511	$= \frac{0.0511}{332}$ 0.0001539
C-2	1.8768	3.2211	0.3221	21.4	0.0689	$= \frac{0.0689}{406}$ 0.0001697
C-3	1.8164	2.5336	0.2534	39.8	0.1010	$= \frac{0.1010}{456}$ 0.0002215
B-1	2.0670	3.9580	0.3958	17.0	0.0673	$= \frac{0.0673}{332}$ 0.0002027
B-2	2.0808	3.2984	0.3298	21.4	0.0706	$= \frac{0.0706}{406}$ 0.0001739
B-3	2.0518	2.4922	0.2492	39.8	0.0992	$= \frac{0.0992}{456}$ 0.0002175

Table 6. Exposure Time and Dosages

Sample	Hole Number	Total Time Exposed	Dosage (ev)
P-1	6	3 hours	2.80×10^{20}
C-1	10	3 hours	2.31×10^{20}
B-1	8	3 hours	2.58×10^{20}
P-2	6	3 hours	2.80×10^{20}
C-2	10	3 hours	2.31×10^{20}
B-2	8	3 hours	2.58×10^{20}
P-3	6	3 hours	2.80×10^{20}
C-3	10	3 hours	2.31×10^{20}
B-3	8	3 hours	2.58×10^{20}
P-4	6	3 hours	2.80×10^{20}
C-4	10	3 hours	2.31×10^{20}
B-4	8	3 hours	2.58×10^{20}

Table 7. Yarn Test Averages

Sample	Breaking Strength (Pounds)	Elongation (%)	Toughness
	Polyester Test Averages		
P-1	1.026	23.52	0.215
P-2	0.930	22.36	0.186
P-3	0.901	22.16	0.186
P-4	0.929	23.92	0.194
P-5	0.954	23.60	0.196
	Cotton Test Averages		
C-1	0.587	8.44	0.445
C-2	0.581	8.12	0.443
C-3	0.586	8.00	0.450
C-4	0.561	8.80	0.435
C-5	0.625	8.80	0.507
	65/35 Polyester/Cotton Blend Test Averages		
B-1	0.675	17.12	0.131
B-2	0.674	17.44	0.141
B-3	0.649	16.96	0.134
B-4	0.623	19.48	0.150
B-5	0.656	19.92	0.159

Table 8. Instron Tester Settings

Cell	"C"
Jaws	Pneumatic
Crosshead Speed	6" per minute
Chart Speed	5" per minute
Specimen Length	10 inches
Full-Scale Load	
Polyester	2 pounds
Cotton	1 pound
Blend	1 pound

Table 9. Protective Values

Sample	Strength		Elongation		Toughness	
	% Increase	% Decrease	% Increase	% Decrease	% Increase	% Decrease
P-4		2.5	1.4			1.0
P-1	7.6			0.9	9.7	
P-2		2.5		5.3		5.1
P-3		5.6		6.1		5.1
C-4		10.2		0		14.2
C-1		6.1		4.1		12.2
C-2		7.0		7.7		12.6
C-3		6.2		9.1		11.2
B-4		5.0		2.2		5.7
B-1	2.9			14.1		17.6
B-2	2.9			12.5		11.3
B-3		1.1		14.9		15.7

Table 10. Gram Molecular Weights of Dyes

Dye Number	Atoms	Number	Atomic Wt./Atom	Total Atomic Wt.
1	C	24	12	288
	H	2	16	32
	O	12	1	12
				TOTAL 332 GMW
2	C	30	12	360
	H	2	16	32
	O	14	1	14
				TOTAL 406 GMW
3	C	34	12	408
	H	2	16	32
	O	16	1	16
				TOTAL 456 GMW

Table 11. Test Results from Polyester Yarns Dyed with 7,14-Dibenzo-Pyrenequinone (Exposed)

Sample Number	Integrator Reading	Calculated Toughness	Elongation Divisions	Calculated Elongation	Tensile Strength (pounds)
1	391	0.1792	18	21.6	0.89
2	501	0.2296	21	24.2	1.04
3	375	0.1718	19	22.8	0.84
4	351	0.1608	18	21.6	0.82
5	348	0.1595	18	21.6	0.80
6	331	0.1517	17	20.4	0.78
7	515	0.2360	20	24.0	1.13
8	504	0.2309	20	24.0	1.09
9	495	0.2268	20	24.0	1.10
10	442	0.2025	19	22.8	0.98
11	562	0.2575	20	24.0	1.21
12	443	0.2030	18	21.6	1.03
13	520	0.2383	22	26.4	1.06
14	547	0.2506	20	24.0	1.17
15	475	0.2176	20	24.0	1.04
16	482	0.2209	21	25.2	1.00
17	426	0.1952	20	24.0	0.94
18	605	0.2772	21	25.2	1.28

(continued)

Table 11. (Concluded)

Sample Number	Integrator Reading	Calculated Toughness	Elongation Division	Calculated Elongation	Tensile Strength (pounds)
19	560	0.2566	21	25.2	1.21
20	320	0.1466	18	21.6	0.75
21	564	0.2584	21	25.2	1.18
22	664	0.3042	21	25.2	1.38
23	342	0.1567	17	20.4	0.84
24	398	0.1724	19	22.8	0.90
25	499	0.2286	20	24.0	1.08
26	446	0.2044	19	22.8	0.97
27	470	0.2154	20	24.0	1.02
28	488	0.2236	19	22.8	1.10
29	440	0.2016	19	22.8	0.98
30	587	0.2690	22	26.4	1.17
AVERAGE		0.2152		23.5	1.03

Table 12. Test Results from Polyester Yarns Dyed with Violanthrone (Exposed)

Sample Number	Integrator Reading	Calculated Toughness	Elongation Division	Calculated Elongation	Tensile Strength (pounds)
1	468	0.2144	20	24.0	1.06
2	345	0.1581	17	20.4	0.82
3	247	0.1132	14	16.8	0.65
4	503	0.2305	20	24.0	1.07
5	578	0.2648	20	24.0	1.23
6	443	0.2030	19	22.8	1.02
7	507	0.2323	20	24.0	1.12
8	455	0.2085	20	24.0	1.02
9	414	0.1897	18	21.6	0.94
10	393	0.1801	18	21.6	0.93
11	426	0.1952	20	24.0	0.92
12	379	0.1737	18	21.6	0.89
13	224	0.1026	15	18.0	0.58
14	490	0.2245	21	25.2	1.04
15	463	0.2121	20	24.0	1.01
16	363	0.1663	19	22.8	0.85
17	439	0.2011	20	24.0	0.98
18	363	0.1663	18	21.6	0.87

(continued)

Table 12. (Concluded)

Sample Number	Integrator Reading	Calculated Toughness	Elongation Division	Calculated Elongation	Tensile Strength (pounds)
19	354	0.1622	18	21.6	0.83
20	434	0.1989	19	22.8	1.00
21	341	0.1562	17	20.4	0.84
22	404	0.1851	19	22.8	0.92
23	488	0.2236	20	24.0	1.08
24	451	0.2066	20	24.0	0.99
25	249	0.1141	16	19.2	0.66
26	310	0.1420	18	21.6	0.74
27	326	0.1494	17	20.4	0.79
28	548	0.2511	20	24.0	1.20
29	436	0.1998	19	22.8	1.01
30	364	0.1668	19	22.8	0.85
AVERAGE		0.1864		22.4	0.93

Table 13. Test Results from Polyester Yarns Dyed with 8,16-Pyranthrenedione (Exposed)

Sample Number	Integrator Reading	Calculated Toughness	Elongation Division	Calculated Elongation	Tensile Strength (pounds)
1	305	0.1398	16	19.2	0.74
2	388	0.1778	19	22.8	0.89
3	282	0.1292	16	19.2	0.70
4	409	0.1874	19	22.8	0.91
5	523	0.2396	21	25.2	1.07
6	264	0.1210	16	19.2	0.66
7	597	0.2735	21	25.2	1.23
8	379	0.1737	18	21.6	0.89
9	356	0.1631	17	20.4	0.82
10	564	0.2584	21	25.2	1.15
11	320	0.1466	17	20.4	0.80
12	476	0.2181	20	24.0	1.03
13	381	0.1746	19	22.8	0.86
14	420	0.1924	19	22.8	0.92
15	289	0.1324	16	19.2	0.74
16	508	0.2328	19	22.8	1.14
17	509	0.2332	20	24.0	1.07
18	429	0.1966	20	24.0	0.96

(continued)

Table 13. (Concluded)

Sample Number	Integrator Reading	Calculated Toughness	Elongation Division	Calculated Elongation	Tensile Strength (pounds)
19	378	0.1732	18	21.6	0.88
20	352	0.1613	17	20.4	0.85
21	491	0.2250	21	25.2	1.04
22	375	0.1718	16	19.2	0.68
23	481	0.2204	20	24.0	1.06
24	372	0.1705	19	22.8	0.84
25	267	0.1223	15	18.0	0.68
26	380	0.1741	18	21.6	0.86
27	500	0.2291	22	26.4	0.98
28	209	0.0958	14	16.8	0.57
29	586	0.2685	22	26.4	1.14
30	377	0.1727	18	21.6	0.86
AVERAGE		0.1858		22.2	0.90

Table 14. Test Results from Polyester Yarns Undyed (Exposed)

Sample Number	Integrator Reading	Calculated Toughness	Elongation Division	Calculated Elongation	Tensile Strength (pounds)
1	580	0.2658	23	27.6	1.13
2	391	0.1792	19	22.8	0.88
3	445	0.2039	21	25.2	0.98
4	381	0.1746	20	24.0	0.83
5	368	0.1686	20	24.0	0.84
6	627	0.2873	23	27.6	1.22
7	324	0.1485	17	20.4	0.79
8	444	0.2034	22	26.4	0.92
9	463	0.2121	20	24.0	1.00
10	467	0.2140	22	26.4	0.95
11	277	0.1269	16	19.2	0.76
12	361	0.1654	19	22.8	0.82
13	285	0.1306	17	20.4	0.69
14	418	0.1915	20	24.0	0.93
15	358	0.1640	20	24.0	0.82
16	394	0.1805	19	22.8	0.90
17	317	0.1452	18	21.6	0.74
18	400	0.1833	20	24.0	0.88

(continued)

Table 14. (Concluded)

Sample Number	Integrator Reading	Calculated Toughness	Elongation Division	Calculated Elongation	Tensile Strength (pounds)
19	547	0.2506	22	26.4	1.11
20	488	0.2236	22	26.4	1.00
21	393	0.1801	19	22.8	0.91
22	390	0.1787	19	22.8	0.90
23	478	0.2190	20	24.0	1.04
24	562	0.2575	23	27.6	1.10
25	527	0.2415	20	24.0	1.12
26	500	0.2291	21	25.2	1.06
27	368	0.1686	19	22.8	0.84
28	410	0.1878	19	22.8	0.92
29	380	0.1741	19	22.8	0.90
30	380	0.1741	19	22.8	0.89
AVERAGE		0.1943		23.9	0.93

Table 15. Test Results from Polyester Yarns Undyed (Unexposed)

Sample Number	Integrator Reading	Calculated Toughness	Elongation Division	Calculated Elongation	Tensile Strength (pounds)
1	379	0.1736	19	22.8	0.88
2	340	0.1557	18	21.6	0.83
3	579	0.2652	22	26.4	1.22
4	436	0.1997	19	22.8	1.04
5	318	0.1456	18	21.6	0.75
6	413	0.1892	19	22.8	0.94
7	460	0.2107	20	24.0	1.02
8	469	0.2148	20	24.0	1.04
9	553	0.2533	22	26.4	1.16
10	554	0.2537	20	24.0	1.25
11	524	0.2400	22	26.4	1.13
12	328	0.1502	17	20.4	0.86
13	479	0.2194	22	26.4	0.96
14	543	0.2487	22	26.4	1.15
15	330	0.1511	18	21.6	0.77
16	437	0.2001	20	24.0	0.96
17	312	0.1429	17	20.4	0.75
18	468	0.2143	20	24.0	1.04

(continued)

Table 15. (Concluded)

Sample Number	Integrator Reading	Calculated Toughness	Elongation Division	Calculated Elongation	Tensile Strength (pounds)
19	519	0.2377	22	26.4	1.05
20	412	0.1887	21	25.2	0.92
21	285	0.1305	17	20.4	0.68
22	400	0.1832	19	22.8	0.89
23	470	0.2153	20	24.0	1.04
24	316	0.1447	17	20.4	0.75
25	417	0.1910	20	24.0	0.92
26	322	0.1475	19	22.8	0.73
27	437	0.2001	20	24.0	1.01
28	256	0.1172	17	20.4	0.65
29	472	0.2162	20	24.0	1.05
30	585	0.2679	23	27.6	1.18
AVERAGE		0.1956		23.6	0.95

Table 16. Test Results from Polyester/Cotton Blend Yarns Dyed with 7,14-Dibenzo-Pyrenequinone (Exposed)

Sample Number	Integrator Reading	Calculated Toughness	Elongation Division	Calculated Elongation	Tensile Strength (pounds)
1	832	0.2072	18	21.6	0.85
2	529	0.1317	15	18.0	0.62
3	479	0.1193	14	16.8	0.65
4	897	0.2234	19	22.8	0.87
5	428	0.1066	13	15.6	0.66
6	426	0.1061	14	16.8	0.60
7	483	0.1203	14	16.8	0.65
8	714	0.1778	17	20.4	0.76
9	429	0.1068	14	16.8	0.56
10	740	0.1843	17	20.4	0.75
11	545	0.1357	14	16.8	0.69
12	310	0.0772	12	14.4	0.54
13	689	0.1716	16	19.2	0.79
14	316	0.0787	11	13.2	0.59
15	390	0.0971	12	1414	0.62
16	907	0.2258	18	21.6	0.89
17	480	0.1195	14	16.8	0.70
18	281	0.0700	12	14.4	0.49

(continued)

Table 16. (Concluded)

Sample Number	Integrator Reading	Calculated Toughness	Elongation Division	Calculated Elongation	Tensile Strength (pounds)
19	700	0.1743	17	20.4	0.73
20	490	0.1220	14	16.8	0.65
21	327	0.0814	11	13.2	0.60
22	426	0.1061	13	15.6	0.60
23	708	0.1763	17	20.4	0.78
24	615	0.1531	15	18.0	0.80
25	302	0.0752	11	13.2	0.55
26	221	0.0550	10	12.0	0.47
27	514	0.1280	15	18.0	0.68
28	500	0.1245	14	16.8	0.68
29	451	0.1123	13	15.6	0.64
30	604	0.1504	14	16.8	0.78
AVERAGE		0.1306		17.1	0.68

Table 17. Test Results from Polyester/Cotton Blend Yarns Dyed with Violanthrone (Exposed)

Sample Number	Integrator Reading	Calculated Toughness	Elongation Division	Calculated Elongation	Tensile Strength (pounds)
1	500	0.1245	13	15.6	0.70
2	746	0.1858	16	19.2	0.77
3	517	0.1287	14	16.8	0.65
4	371	0.0924	11	13.2	0.60
5	720	0.1793	17	20.4	0.74
6	546	0.1360	14	16.8	0.66
7	448	0.1116	13	15.6	0.63
8	826	0.2057	17	20.4	0.84
9	415	0.1033	12	14.4	0.62
10	659	0.1641	16	19.2	0.72
11	764	0.1902	17	20.4	0.81
12	601	0.1496	16	19.2	0.63
13	365	0.0909	12	14.4	0.55
14	614	0.1529	16	19.2	0.67
15	815	0.2020	17	20.4	0.81
16	384	0.0956	12	14.4	0.62
17	498	0.1240	14	16.8	0.64
18	520	0.1295	14	16.8	0.62

(continued)

Table 17. (Concluded)

Sample Number	Integrator Reading	Calculated Toughness	Elongation Division	Calculated Elongation	Tensile Strength (pounds)
19	560	0.1394	15	18.0	0.63
20	642	0.1599	17	20.4	0.65
21	417	0.1038	12	14.4	0.64
22	444	0.1106	12	14.4	0.63
23	697	0.1736	17	20.4	0.70
24	756	0.1882	17	20.4	0.75
25	695	0.1731	16	19.2	0.77
26	641	0.1596	15	18.0	0.74
27	381	0.0949	12	14.4	0.62
28	505	0.1257	15	18.0	0.60
29	437	0.1088	13	15.6	0.59
30	501	0.1247	14	16.8	0.63
AVERAGE		0.1410		17.4	0.67

Table 18. Test Results from Polyester/Cotton Blend Yarns Dyed with 8,16-Pyranthrenedione (Exposed)

Sample Number	Integrator Reading	Calculated Toughness	Elongation Division	Calculated Elongation	Tensile Strength (pounds)
1	573	0.1427	15	18.0	0.66
2	919	0.2288	18	21.6	0.86
3	574	0.1429	15	18.0	0.67
4	550	0.1370	14	16.8	0.64
5	621	0.1546	16	19.2	0.68
6	585	0.1457	14	16.8	0.70
7	260	0.0647	10	12.0	0.50
8	441	0.1098	13	15.6	0.63
9	259	0.0645	10	12.0	0.51
10	267	0.0665	10	12.0	0.51
11	271	0.0675	10	12.0	0.50
12	407	0.1013	13	15.6	0.57
13	815	0.2029	19	22.8	0.72
14	946	0.2356	19	22.8	0.83
15	658	0.1638	16	19.2	0.69
16	425	0.1058	13	15.6	0.61
17	432	0.1076	13	15.6	0.63
18	645	0.1606	16	19.2	0.66

(continued)

Table 18. (Concluded)

Sample Number	Integrator Reading	Calculated Toughness	Elongation Division	Calculated Elongation	Tensile Strength (pounds)
19	740	0.1842	16	19.2	0.81
20	393	0.0979	13	15.6	0.53
21	293	0.0730	10	12.0	0.57
22	665	0.1656	16	19.2	0.74
23	450	0.1121	13	15.6	0.59
24	394	0.0981	12	14.4	0.62
25	384	0.0956	12	14.4	0.57
26	323	0.0804	11	13.2	0.56
27	609	0.1516	16	19.2	0.67
28	335	0.0834	12	14.4	0.53
29	1099	0.2737	20	24.0	0.95
30	834	0.2077	19	22.8	0.78
AVERAGE		0.1342		17.0	0.65

Table 19. Test Results from Polyester/Cotton Blend Yarns Undyed (Exposed)

Sample Number	Integrator Reading	Calculated Toughness	Elongation Division	Calculated Elongation	Tensile Strength (pounds)
1	489	0.1218	15	18.0	0.55
2	600	0.1494	17	20.4	0.60
3	605	0.1506	17	20.4	0.59
4	667	0.1661	18	21.6	0.60
5	512	0.1275	15	18.0	0.58
6	1051	0.2617	22	26.4	0.87
7	510	0.1270	15	18.0	0.57
8	678	0.1688	16	19.2	0.70
9	256	0.0637	11	13.2	0.44
10	770	0.1917	19	22.8	0.70
11	624	0.1554	16	19.2	0.64
12	432	0.1076	14	16.8	0.56
13	900	0.2241	20	24.0	0.76
14	632	0.1574	16	19.2	0.67
15	220	0.0548	9	10.8	0.49
16	836	0.2082	19	22.8	0.73
17	834	0.2077	19	22.8	0.76
18	407	0.1013	15	18.0	0.51

(continued)

Table 19. (Concluded)

Sample Number	Integrator Reading	Calculated Toughness	Elongation Division	Calculated Elongation	Tensile Strength (pounds)
19	498	0.1240	14	16.8	0.62
20	643	0.1601	19	22.8	0.66
21	430	0.1071	14	16.8	0.52
22	858	0.2136	20	24.0	0.70
23	495	0.1233	15	18.0	0.60
24	1007	0.2507	22	26.4	0.80
25	317	0.0789	12	14.4	0.47
26	583	0.1452	16	19.2	0.61
27	326	0.0812	12	14.4	0.51
28	772	0.1922	18	21.6	0.71
29	368	0.0916	13	15.6	0.50
30	764	0.1902	19	22.8	0.67
AVERAGE		0.1501		19.5	0.62

Table 20. Test Results from Polyester/Cotton Blend Yarns Undyed (Unexposed)

Sample Number	Integrator Reading	Calculated Toughness	Elongation Division	Calculated Elongation	Tensile Strength (pounds)
1	745	0.1855	18	21.6	0.72
2	720	0.1793	18	21.6	0.69
3	525	0.1307	14	16.8	0.61
4	445	0.1108	14	16.8	0.55
5	606	0.1509	17	20.4	0.62
6	633	0.1576	17	20.4	0.60
7	862	0.2146	20	24.0	0.75
8	1081	0.2692	21	25.2	0.89
9	914	0.2276	19	22.8	0.81
10	663	0.1651	17	20.4	0.67
11	796	0.1915	18	21.6	0.70
12	418	0.1041	13	15.6	0.59
13	687	0.1711	18	21.6	0.66
14	357	0.0889	12	14.4	0.60
15	606	0.1509	17	20.4	0.62
16	810	0.2017	23	27.6	0.77
17	928	0.2311	20	24.0	0.80
18	781	0.1945	19	22.8	0.71

(continued)

Table 20. (Concluded)

Sample Number	Integrator Reading	Calculated Toughness	Elongation Division	Calculated Elongation	Tensile Strength (pounds)
19	466	0.1160	14	16.8	0.60
20	812	0.2022	19	22.8	0.77
21	811	0.2019	19	22.8	0.72
22	607	0.1511	18	21.6	0.60
23	812	0.2022	18	21.6	0.77
24	767	0.1910	19	22.8	0.67
25	382	0.0951	13	15.6	0.55
26	508	0.1265	15	18.0	0.57
27	280	0.0697	11	13.2	0.49
28	308	0.0767	11	13.2	0.51
29	369	0.0919	13	15.6	0.50
30	430	0.1071	13	15.6	0.57
AVERAGE		0.1586		19.9	0.66

Table 21. Test Results from Cotton Yarns Dyed with 7,14-Dibenzo-Pyrenequinone (Exposed)

Sample Number	Integrator Reading	Calculated Toughness	Elongation Division	Calculated Elongation	Tensile Strength (pounds)
1	241	0.6676	8	9.6	0.78
2	222	0.6149	8	9.6	0.75
3	169	0.4681	7	8.4	0.61
4	146	0.4044	6	7.2	0.58
5	175	0.4848	7	8.4	0.62
6	136	0.3767	7	8.4	0.53
7	135	0.3740	6	7.2	0.52
8	155	0.4292	7	8.4	0.56
9	159	0.4404	7	8.4	0.57
10	192	0.5318	7	8.4	0.65
11	158	0.4377	7	8.4	0.57
12	131	0.3622	7	8.4	0.50
13	190	0.5263	7	8.4	0.67
14	114	0.3158	6	7.2	0.49
15	185	0.5125	7	8.4	0.64
16	152	0.4210	7	8.4	0.57
17	110	0.3047	6	7.2	0.49
18	153	0.4238	7	8.4	0.58

(continued)

Table 21. (Concluded)

Sample Number	Integrator Reading	Calculated Toughness	Elongation Division	Calculated Elongation	Tensile Strength (pounds)
19	125	0.3463	7	8.4	0.48
20	132	0.3656	7	8.4	0.53
21	116	0.3213	7	8.4	0.50
22	180	0.4986	7	8.4	0.63
23	140	0.3878	7	8.4	0.55
24	155	0.4294	7	8.4	0.55
25	155	0.4294	7	8.4	0.58
26	140	0.3878	7	8.4	0.53
27	190	0.5263	8	9.6	0.65
28	194	0.5374	8	9.6	0.67
29	190	0.5263	8	9.6	0.65
30	174	0.4820	7	8.4	0.61
AVERAGE		0.4445		8.44	0.59

Table 22. Test Results from Cotton Yarns Dyed with Violanthrone (Exposed)

Sample Number	Integrator Reading	Calculated Toughness	Elongation Division	Calculated Elongation	Tensile Strength (pounds)
1	224	0.6205	7	8.4	0.71
2	146	0.4044	6	7.2	0.58
3	157	0.4349	7	8.4	0.60
4	182	0.5041	7	8.4	0.63
5	162	0.4487	7	8.4	0.58
6	194	0.5374	7	8.4	0.62
7	204	0.5651	7	8.4	0.70
8	144	0.3989	6	7.2	0.56
9	167	0.4626	7	8.4	0.59
10	135	0.3740	6	7.2	0.51
11	153	0.4238	7	8.4	0.59
12	142	0.3933	7	8.4	0.54
13	142	0.3933	6	7.2	0.56
14	134	0.3712	7	8.4	0.51
15	100	0.2770	6	7.2	0.42
16	166	0.4598	7	8.4	0.60
17	172	0.4764	7	8.4	0.61
18	108	0.2992	6	7.2	0.45

(continued)

Table 22. (Concluded)

Sample Number	Integrator Reading	Calculated Toughness	Elongation Division	Calculated Elongation	Tensile Strength (pounds)
19	133	0.3685	6	7.2	0.53
20	156	0.4321	7	8.4	0.56
21	160	0.4432	7	8.4	0.61
22	167	0.4626	7	8.4	0.59
23	126	0.3490	6	7.2	0.50
24	198	0.5485	8	9.6	0.62
25	174	0.4820	7	8.4	0.62
26	172	0.4764	7	8.4	0.59
27	184	0.5097	8	9.6	0.61
28	185	0.5125	7	8.4	0.67
29	180	0.4709	7	8.4	0.62
30	136	0.3767	6	7.2	0.54
AVERAGE		0.4426		8.1	0.58

Table 23. Test Results from Cotton Yarns Dyed with 8,16-Pyranthrenedione (Exposed)

Sample Number	Integrator Reading	Calculated Toughness	Elongation Division	Calculated Elongation	Tensile Strength (pounds)
1	115	0.3186	6	7.2	0.48
2	131	0.3629	6	7.2	0.52
3	112	0.3102	6	7.2	0.49
4	175	0.4848	7	8.4	0.61
5	194	0.5374	8	9.6	0.66
6	146	0.4044	6	7.2	0.58
7	220	0.6094	8	9.6	0.67
8	151	0.4183	7	8.4	0.56
9	163	0.4515	7	8.4	0.61
10	164	0.4543	7	8.4	0.60
11	183	0.5069	7	8.4	0.64
12	198	0.5485	7	8.4	0.70
13	76	0.2105	5	6.0	0.38
14	194	0.5374	5	6.0	0.46
15	182	0.5041	7	8.4	0.63
16	175	0.4848	7	8.4	0.64
17	135	0.3740	6	7.2	0.54
18	161	0.4460	7	8.4	0.60

(continued)

Table 23. (Concluded)

Sample Number	Integrator Reading	Calculated Toughness	Elongation Division	Calculated Elongation	Tensile Strength (pounds)
19	179	0.4958	7	8.4	0.62
20	138	0.3823	6	7.2	0.54
21	236	0.6537	8	9.6	0.76
22	219	0.6066	8	9.6	0.74
23	164	0.4543	7	8.4	0.61
24	135	0.3740	6	7.2	0.54
25	170	0.4709	7	8.4	0.60
26	163	0.4515	7	8.4	0.58
27	202	0.5595	7	8.4	0.67
28	107	0.2964	6	7.2	0.46
29	117	0.3241	6	7.2	0.48
30	163	0.4515	6	7.2	0.62
AVERAGE		0.4495		8.0	0.59

Table 24. Test Results from Cotton Yarns Undyed (Exposed)

Sample Number	Integrator Reading	Calculated Toughness	Elongation Division	Calculated Elongation	Tensile Strength (pounds)
1	151	0.4183	7	8.4	0.54
2	154	0.4266	7	8.4	0.57
3	194	0.5374	8	9.6	0.63
4	110	0.3047	6	7.2	0.45
5	222	0.6149	8	9.6	0.72
6	240	0.6648	8	9.6	0.73
7	153	0.4238	7	8.4	0.55
8	117	0.3241	7	8.4	0.47
9	155	0.4294	8	9.6	0.53
10	147	0.4072	8	9.6	0.51
11	181	0.5014	7	8.4	0.62
12	138	0.3823	7	8.4	0.50
13	136	0.3767	7	8.4	0.54
14	107	0.2964	6	7.2	0.45
15	194	0.5374	8	9.6	0.63
16	103	0.2853	7	8.4	0.43
17	108	0.2992	8	9.6	0.57
18	180	0.4986	8	9.6	0.60

(continued)

Table 24. (Concluded)

Sample Number	Integrator Reading	Calculated Toughness	Elongation Division	Calculated Elongation	Tensile Strength (pounds)
19	138	0.3823	7	8.4	0.51
20	128	0.3546	6	7.2	0.50
21	151	0.4183	7	8.4	0.55
22	155	0.4294	7	8.4	0.57
23	152	0.4210	8	9.6	0.52
24	164	0.4543	8	9.6	0.57
25	167	0.4626	8	9.6	0.60
26	204	0.5651	8	9.6	0.67
27	128	0.3546	7	8.4	0.50
28	222	0.6149	9	10.8	0.68
29	111	0.3075	6	7.2	0.48
30	196	0.5429	7	8.4	0.65
AVERAGE		0.4345		8.8	0.56

Table 25. Test Results from Cotton Yarns Undyed (Unexposed)

Sample Number	Integrator Reading	Calculated Toughness	Elongation Division	Calculated Elongation	Tensile Strength (pounds)
1	119	0.3296	6	7.2	0.47
2	211	0.5845	8	9.6	0.71
3	119	0.3296	5	6.0	0.49
4	138	0.3823	6	7.2	0.53
5	222	0.6149	8	9.6	0.72
6	179	0.4958	7	8.4	0.63
7	193	0.5346	8	9.6	0.66
8	161	0.4460	7	8.4	0.57
9	144	0.3989	7	8.4	0.53
10	205	0.5679	7	8.4	0.63
11	178	0.4931	7	8.4	0.62
12	251	0.6953	8	9.6	0.78
13	172	0.4764	8	9.6	0.58
14	128	0.3546	7	8.4	0.51
15	193	0.5346	8	9.6	0.65
16	122	0.3379	7	8.4	0.47
17	208	0.5762	8	9.6	0.69
18	238	0.6593	8	9.6	0.74

(continued)

Table 25. (Concluded)

Sample Number	Integrator Reading	Calculated Toughness	Elongation Division	Calculated Elongation	Tensile Strength (pounds)
19	206	0.5706	8	9.6	0.68
20	245	0.6787	8	9.6	0.76
21	211	0.5845	8	9.6	0.66
22	158	0.4377	7	8.4	0.54
23	142	0.3933	7	8.4	0.54
24	148	0.4100	7	8.4	0.54
25	217	0.6011	8	9.6	0.71
26	152	0.4210	7	8.4	0.58
27	202	0.5595	7	8.4	0.71
28	235	0.6510	8	9.6	0.74
29	164	0.4543	7	8.4	0.60
30	224	0.6205	8	9.6	0.60
AVERAGE		0.5065		8.8	0.63

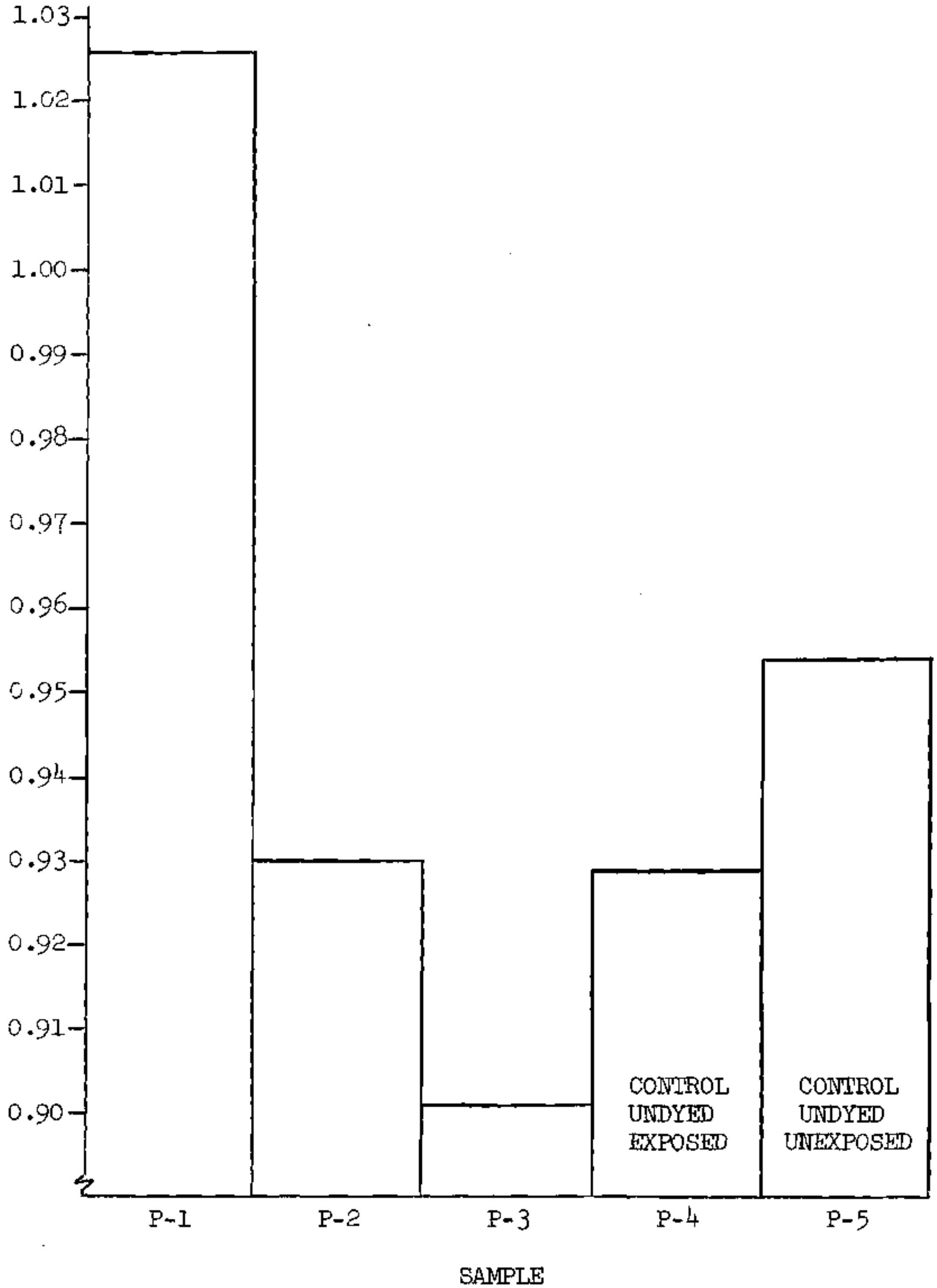


Figure 1. Polyester Strengths

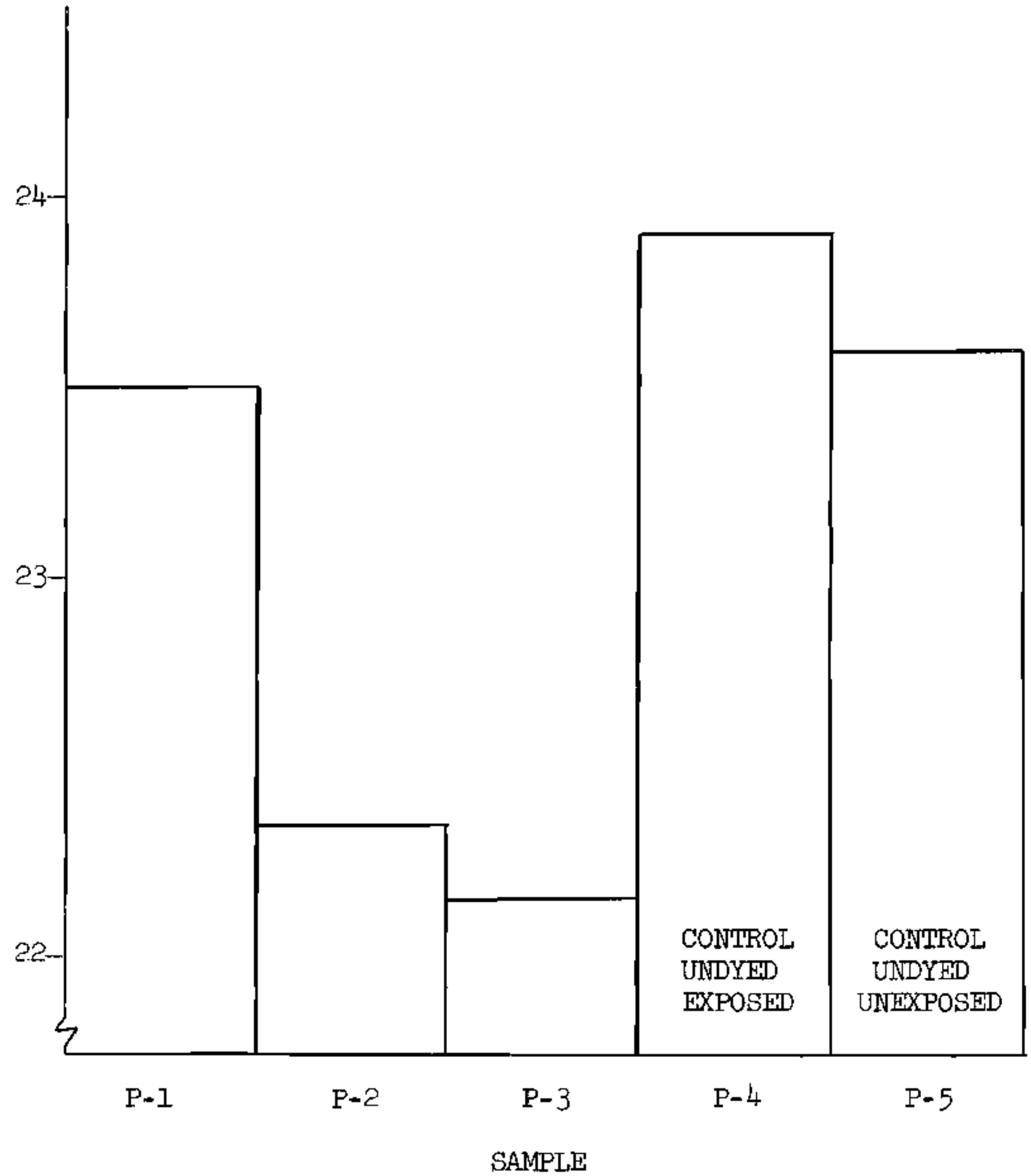


Figure 2. Polyester Elongations

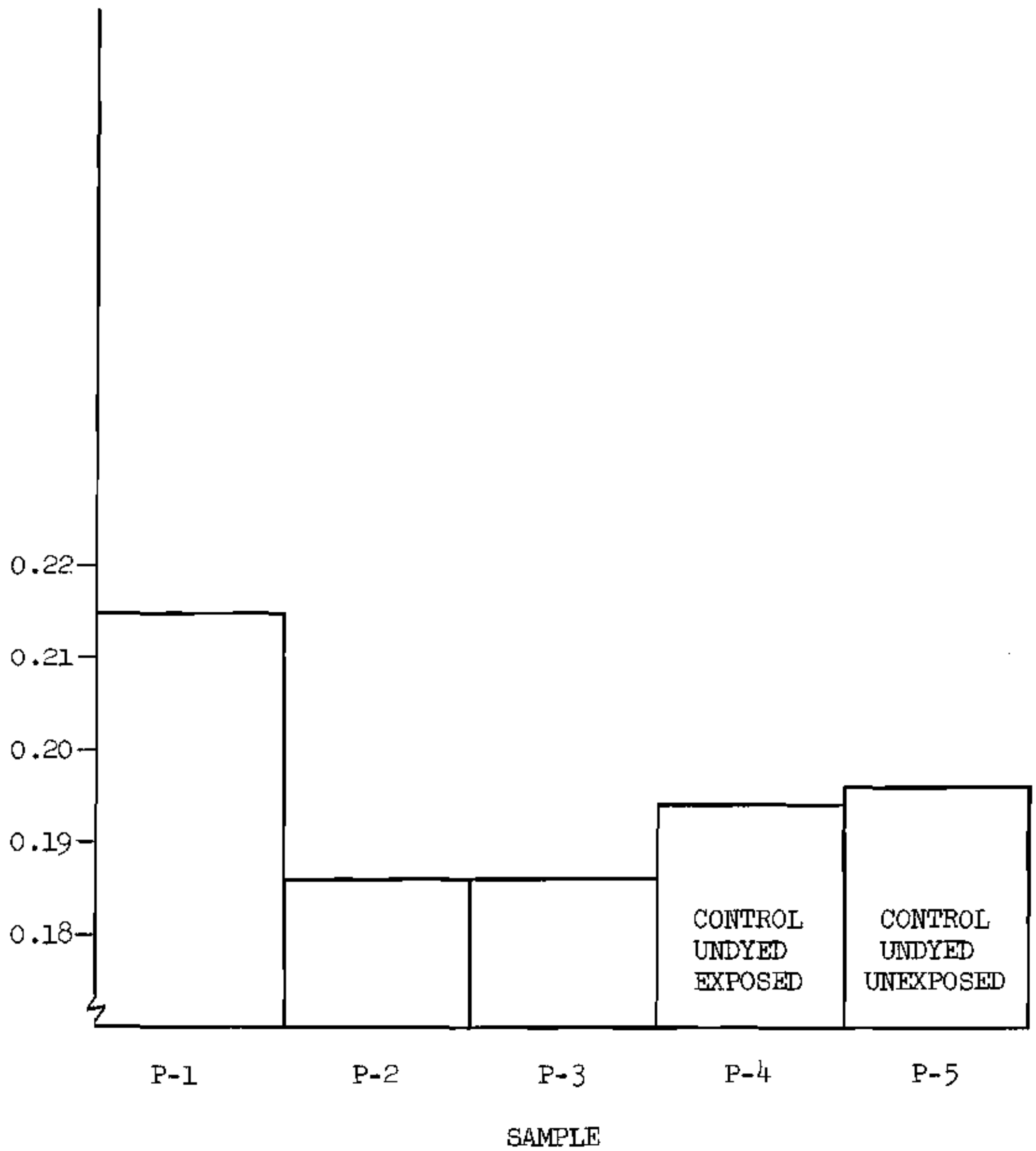


Figure 3. Polyester Toughness

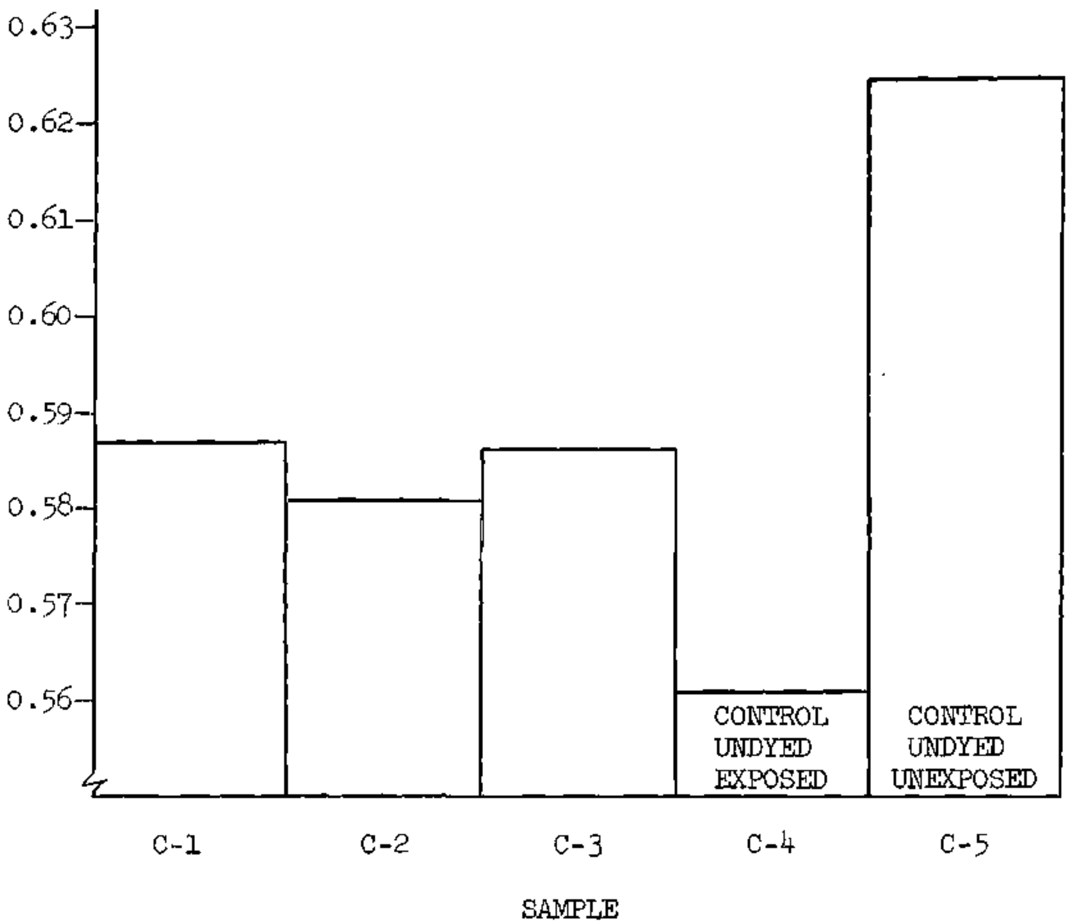


Figure 4. Cotton Strengths

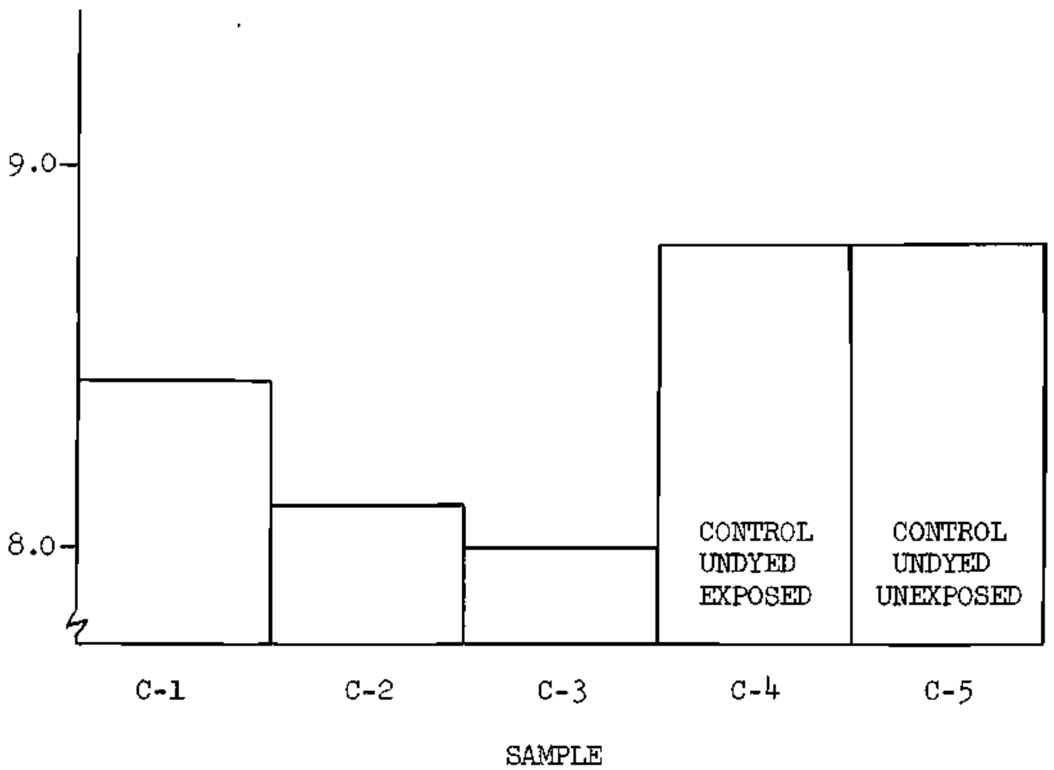


Figure 5. Cotton Elongations

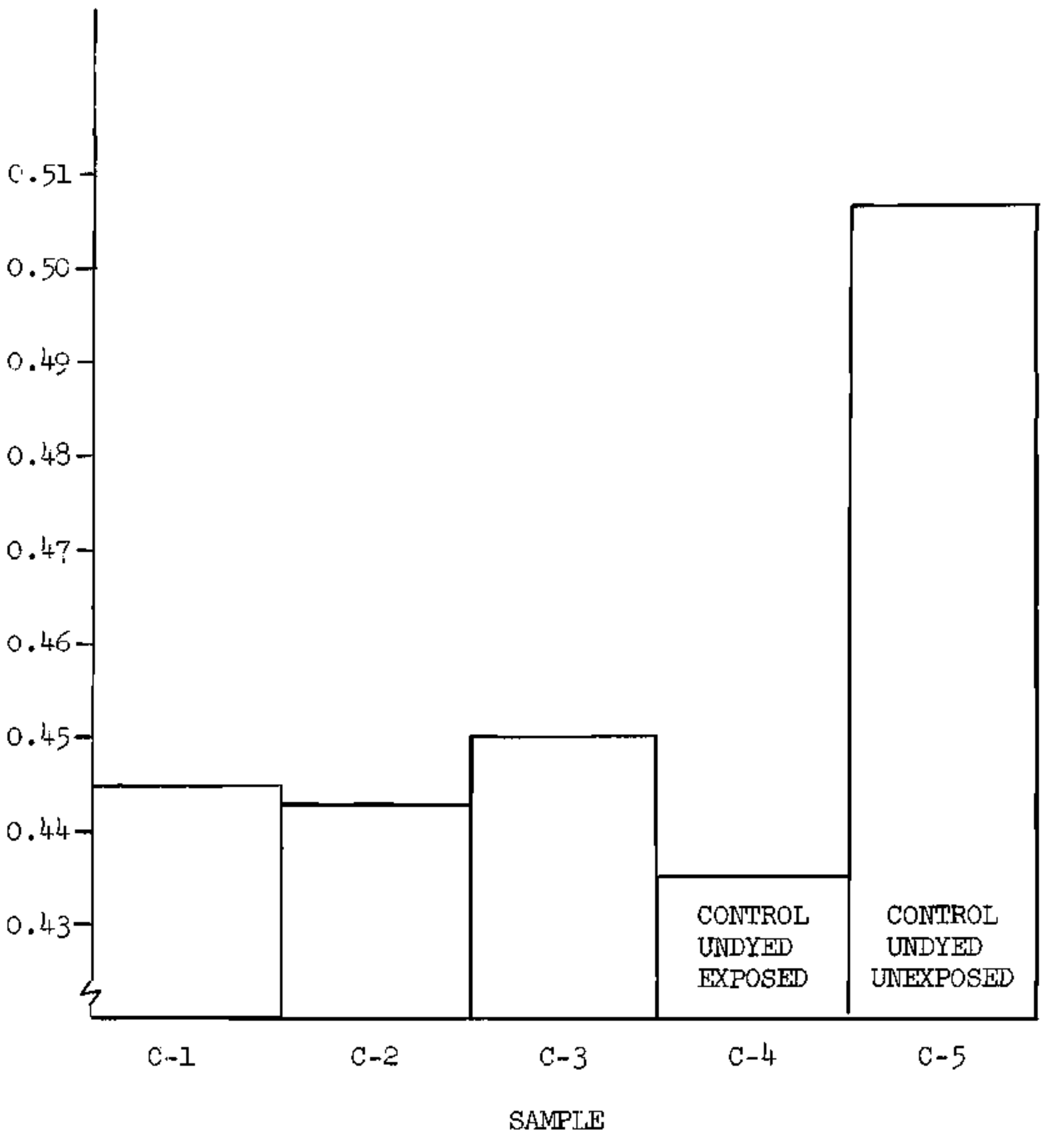


Figure 6. Cotton Toughness

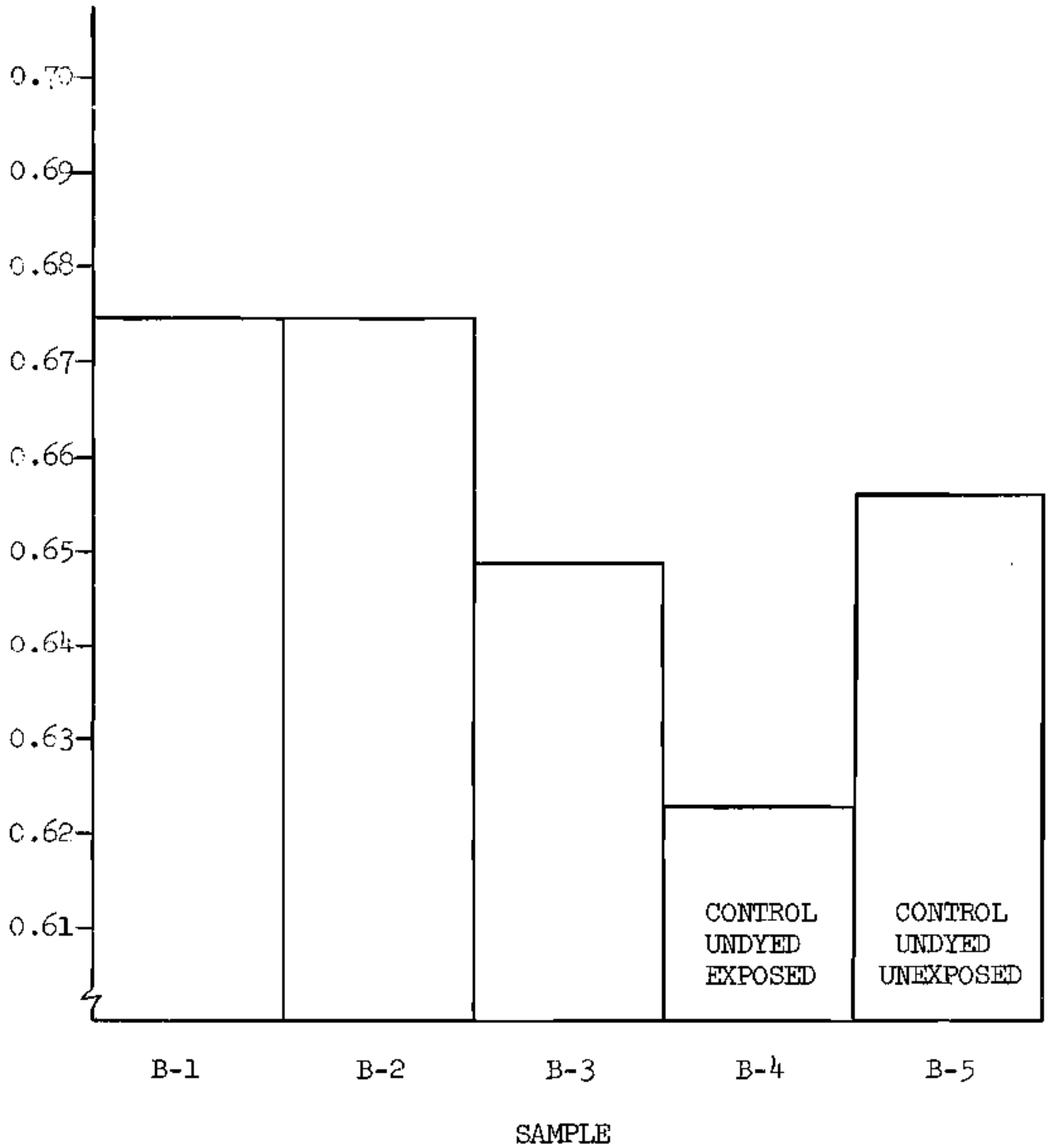


Figure 7. Polyester/Cotton Blend Strengths

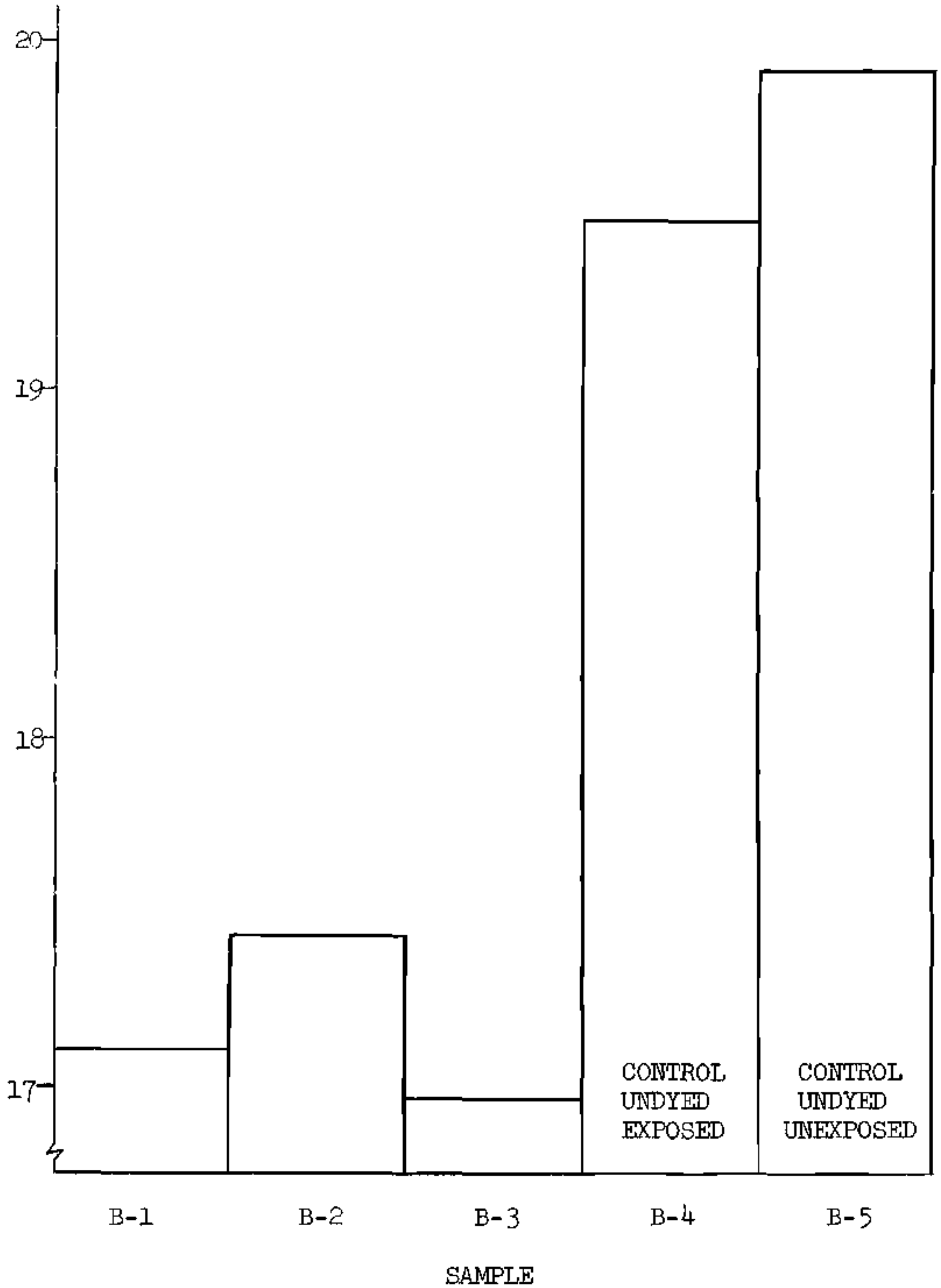


Figure 8. Polyester/Cotton Blend Elongations

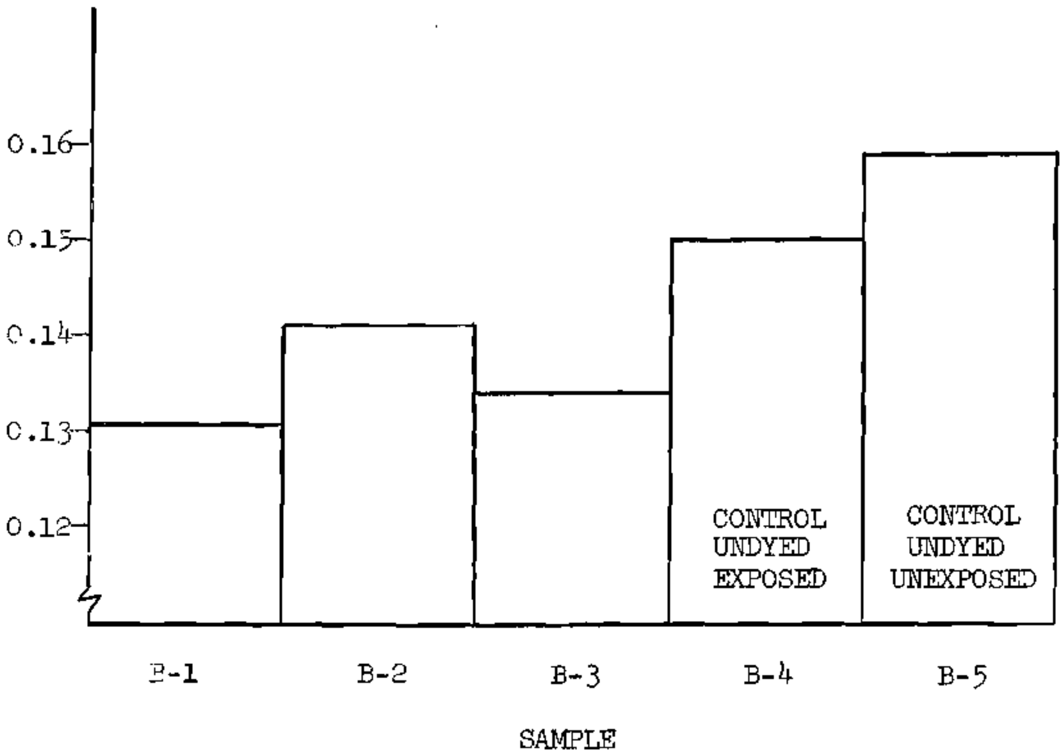


Figure 9. Polyester/Cotton Blend Toughness

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