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THE PHOTODEGRADATION OF WOVEN POLYPROPYLENE
USING ACCELERATED WEATHERING MACHINES WITH
FLUORESCENT ULTRAVIOLET TUBES: CORRELATING
THE QUV AND THE UVCON

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By

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ABSTRACT

THE PHOTODEGRADATION OF WOVEN POLYPROPYLENE USING ACCELERATED WEATHERING MACHINES WITH FLUORESCENT ULTRAVIOLET TUBES: CORRELATING THE QUV AND THE UVCON

By

David M. Powers

This study explores the photodegradation that polymers experience when they are exposed to sunlight. Four different woven polypropylene fabrics used for bags were tested. The harmful ultraviolet rays were simulated using two different fluorescent weathering machines, under two different exposure conditions: a continuous ultraviolet light cycle without condensation, and a cycle consisting of 8 hours of ultraviolet light and 4 hours of condensation.

After the fabrics were exposed to the harmful rays, tensile tests were performed to determine load strength. Correlation of the fabrics, machines, and test conditions was then established using linear regression.

Positive correlation was determined between the machines, and test conditions. Overall, the amount of degradation was directly proportional to the length of ultraviolet exposure. The affect of a dark condensation cycle was determined to be statistically insignificant.

Dedicated to my loving wife, **Cindi**, and daughter, **Colleen**.

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KEY TO ABBREVIATIONS AND NOMENCLATURE

QUV	Accelerated weathering machine: made by The Q-Panel Company (Cleveland, Ohio)
UVCON	Accelerated weathering machine: made by Atlas Electric Devices Company (Chicago, Illinois)
AVG	average
STD	standard deviation
lbf	force (in pounds)
UV	ultraviolet light
NA	not applicable
Warp (W)	Parallel yarns, strung onto the loom first
Fill (F)	Interwoven perpendicular yarns
mil	1/1000 of an inch
% Retention	Amount of original strength after tests
Cond	Condensation (water cycle)
Load	measurement of force (in pounds)
Ext	extension (in inches)
° C	degrees celsius
irrad	irradiance

CHAPTER 1

INTRODUCTION

The purpose of this study was to compare two accelerated weathering machines using fluorescent ultraviolet (uv) tubes, under two different ultraviolet exposure conditions. The results were used to determine if either machine may be utilized to produce similar results, for a United States Department of Agriculture (USDA) specification for ultraviolet degradation resistance due to accelerated weathering. Four different woven polypropylene fabrics containing various stabilizers were used.

The current USDA standard for degradation due to accelerated weathering, states that the fabric must maintain at least 70% of its original tensile strength after 200 hours of exposure to a carbon arc. However, carbon arc testing is costly and rarely performed. Most USDA fabric suppliers simply request that their resin be treated with enough ultraviolet stabilizer to meet the requirement. The USDA would like a less expensive quality control test.

One objective of this study was to determine the amount of hours necessary to produce comparable results (e.g. how many hours would it take to reach 70% retention level with the QUV), for a new standard using fluorescent uv tubes.

The study investigated the photodegradation of woven polypropylene bags used by the USDA. The USDA is concerned with the stability of woven polypropylene bags, used to ship food, that may be stored outdoors.

The USDA buys 40-60 million bags per year for use in its overseas food aid programs like those established under Public Law 480, Title II (U.S. Department of Agriculture 1954). One out of every seven Americans receive food assistance. The USDA is the world's largest food buyer with over 70 million recipients overseas. This is the largest ongoing food assistance program that the world has ever known (Miteff 1993).

Numerous studies have shown that ultraviolet light is the major cause of the degradation of polymers exposed to outdoor conditions. Heat, oxygen, humidity, and wetness can also contribute to degradation of polymeric fabrics.

This study investigated the effects of continuous exposure of woven polypropylene fabrics to ultraviolet light (24 hour ultraviolet, no condensation cycle). This was done to establish correlation between continuous exposure to ultraviolet light, and a more common cycle used for testing (8 hour ultraviolet, 4 hour condensation) to enable a decrease in testing time. In addition, results from the two ultraviolet test machines (QUV supplied by Q-Panel and UVCON supplied by Altas Electric Devices Company) were compared.

This study was requested by the USDA, and The Textile

Bag Manufacturers' Association. The study was performed at Michigan State University (MSU), School of Packaging.

The objectives of this study were to:

1. Compare the results for four different woven polypropylene fabrics.
2. Compare two accelerated weathering machines.
3. Compare two different exposure conditions.
4. Determine correlations between methods and machines.

The major objective of this study was to determine whether there is a correlation between the two fluorescent accelerated weather machines and to recommend whether either machine could be used for quality control tests.

Chapter 2 of this paper provides information pertaining to degradation of polymers, ultraviolet radiation, test methods, polypropylene, and stabilization methods. Chapter 3 describes the materials and test methods used in this study. Chapter 4 covers the results of the study. Conclusions and recommendations for further research can be found in Chapter 5. The appendix contains the experimental data.

CHAPTER 2

LITERATURE REVIEW

The use of polypropylene and other polymers in outdoor environments is increasing. However, when these polymers are exposed to harmful ultraviolet rays they will deteriorate rapidly unless stabilizers are added to prolong their lifetimes. Degradation can be affected by a number of circumstances; the primary factors are the wavelength of light, heat and moisture. The major mechanisms involved in polymer degradation are random chain scission and cross-linking. The ultraviolet rays in the 290-400 nanometer region have been shown to be the most energetic and damaging wavelengths of light. The damaging effects of photodegradation on a polymer's mechanical and physical properties have lead to improved test methods in the area of photodegradation. Advances in polymer stabilization have also been a result of improved knowledge of the damaging effects of ultraviolet rays.

This section reviews the literature pertaining to degradation, uv radiation, test methods, polypropylene, and stabilization.

DEGRADATION

Degradation that polymers experience while being used in outdoor environments leads to the loss of desired properties. "Photodegradation refers to the degradation of polymeric substances and other organic compounds when exposed to sunlight and other intense sources of light. The ultraviolet wavelengths are primarily responsible for the observed damage." (Plastics, Environmentally Degradable 1984) Oxidative degradation, which nearly all polymers undergo, is the degradation of polymeric chains through attack by oxygen and ozone. Oxidative degradation may be catalyzed by ultraviolet light, catalyst residues, or both (Plastics, Environmentally Degradable 1984). Nomenclature used to describe photosensitized reactions can be applied as follows:

> Photoinitiator is a compound which absorbs light and is excited by it to a higher energy state having a total energy content in excess of that required to effect a homolytic scission of some bonds in polymer molecule to form free radicals, which promote secondary reactions.
>
> Photosensitizer is a compound which by absorption of light is transferred to excited states and then donates the energy to another compound by inter- or intramolecular energy transfer.
>
> Photosensitized reactions are strictly speaking such reactions which are activated by photoinitiators or photosensitizers. (Rabek 1976)

A chemical may behave as a photoinitiator or a photosensitizer, depending on the conditions of a particular reaction.

A major concern when using plastics is premature failure and possible product contamination (Johnson 1988). Unstabilized polyolefins are destroyed rapidly in sunlight which has limited their long-term use out-of-doors (Scott 1976b). Plastics must be able to provide their desired properties throughout their expected lifetime. These properties include chemical resistance, impact strength, tensile strength, modulus of elasticity, and other mechanical properties. Plastics must also be stable in order to eliminate package-to-product migration, which could result in product contamination.

Photodegradation of polymers has become a concern because of their increased use in outdoor applications, including bags for agricultural commodities, carpeting, synthetic turf, agricultural film, and ring connectors for beverages. The United States Department of Agriculture, is concerned about the durability of woven polypropylene bags used to ship food to famine and disaster areas, where bags may be stored outdoors for a short period of time (Miteff 1993).

In some cases, degradable plastics have become popular because plastic products are among some of the most visible forms of trash (Klemchuk 1989). Degradable plastics are plastics that deteriorate at a rate which is more rapid than normal while maintaining indoor stability for long time periods. Plastic ring connectors for beverage bottles are now required to be degradable by law in some states. This law was developed to help prevent wildlife from being entrapped in the ring connectors. Other applications of degradable plastics that have been developed or proposed include shopping bags, trash bags, garbage bags, produce and fruit bags, snack bags, bread bags and frozen food bags. The problem with these applications is that if the packaging material is disposed of properly, for example, by being incinerated or buried in a landfill, the benefit of being photodegradable is not utilized. The photodegradability of the material is only a societal benefit if the packaging material is improperly discarded as litter (Plastics, Environmentally Degradable 1984).

All synthetic polymers deteriorate upon exposure to ultraviolet light (Carlsson and Wiles 1976; Guillet 1972; Seppala, et al 1991; Wiles 1978; Tirrell 1981). These polymers can be classified into two groups with respect to their changes upon absorption of the harmful rays. The first category includes polymers such as polyvinyl chloride and polyacrylonitrile which tend to retain their physical properties but discolor rapidly. The discoloration is mainly a result of changes in the chemical structure of the polymer, but scission does not occur in the backbone of the polymer chain. The second category includes polymers such as polypropylene, polyethylene, and polystyrene which tend to embrittle after the absorption of ultraviolet light.

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Embrittlement can be caused by any one or a combination of the following (i) scission of the main chain, (ii) photoinduced crystallization, and (iii) crosslinking (Guillet 1972).

Some of the effects of photodegradation include yellowing, bleaching, bond cleavage, destructive oxidation, charring, crazing, chalking and the loss of physical properties. Sunlight causes yellowing and weakening of fibers, which results in brittleness and loss of strength (Hardy 1983a). Bleaching is most common in the long wavelength region and in thick specimens; yellowing is more common in the short wavelength region. Yellowing, which is the result of short wavelength irradiation, tends to be destroyed by energy in the long wavelength region (Hirt and Searle 1967). Long wavelength radiation penetrates the bulk of the polymer, while short wavelength radiation will have a greater effect on surface properties (Searle 1984). Greying or whitening of the surface is an occurrence generally referred to as chalking. Chalking is independent of the degraded upper layer depth; this phenomenon depends on the concentration of exposed filler particles that reflect the incident light (Rysavy and Tkadleckova 1992). The excellent properties of plastics result from their long molecular chains. When photodegradable plastics are exposed to sunlight their molecular chains are cleaved and the plastic articles lose desired properties. Discoloration and surface cracking are visible indications of degradation (Hawkins 1984b, Johnson 1988).

Environmental stress cracking is a special type of degradation which occurs in polymers at a stress concentration lower than the polymer's ultimate strength. This phenomenon occurs at critical stress levels with certain surface-active agents (Hawkins 1984a).

Factors influencing the degradation of polymers include natural weather conditions, thermal history, and the physical form of the polymer. The major factor responsible for the degradation of plastics is ultraviolet radiation. Heat is primarily responsible for secondary reactions. Measurement of degradative effects at high temperatures does not always reflect the conditions found at lower temperatures. Oxygen, humidity, and wetness can also influence reactions (Hirt and Searle 1967, Freedman 1976, Swasey 1980). Atmospheric contaminants, including oxides of sulfur and nitrogen, have been suggested to catalyze oxidation (Hawkins 1984a). Geography can influence degradation because of variations in weather conditions. For example, exposure in Arizona, where there are more sunlight-hours per year, would be more destructive than exposure in New Hampshire (Swasey 1980).

A polymer's thermal history has been shown to have a marked effect on its subsequent photostability (Crewdson 1993, Rabek 1976). If processing periods are extended, substantial amounts of hydroperoxides may develop which can serve as initiators in the degradation of polypropylene (Hardy 1982). Therefore, while processing plastics it is critical to minimize the formation of radicals that may serve as photoinitiation sites. Drawing of polymers under high shear conditions (high draw speeds and low temperatures) produces appreciable amounts of hydroperoxide groups, which increases the rate of degradation. These hydroperoxide groups result from mechanically induced thermal oxidation (Carlsson, Garton and Wiles 1979).

The physical form and chemical makeup of the specimen can influence the degradation of a polymer. The rate of hydrogen abstraction from hydrogen chains increases in the order of primary < secondary < tertiary bonded. This order is the same regardless if the attack is by singlet oxygen or a free radical process because it is due to the strength of the C-H bond being broken (Ranby and Rabek 1976). Primary bonds occur when a carbon atom is attached to one other carbon atom; these bonds appear at the end of a polymer chain, secondary bonds occur when a carbon atom is attached to two other carbon atoms, and tertiary bonds occur when a carbon atom is attached to three other carbon atoms. Polypropylene's structure contains many tertiary carbon atoms and linear polyethylene contains primarily secondary carbon atoms; this results in polypropylene being more susceptible to degradation than polyethylene.

Experimental results have shown that the wavelength having the maximum effect on a polymer is dependent on the sample thickness, decreasing as the sample thickness decreases (Hirt and Searle 1964). Since the degradation of polypropylene proceeds from the exposed surface inward, it is expected that thicker samples will survive longer than thin samples (Hardy 1982, McTigue and Blumberg 1967). The shape of a polymer may also influence degradation. "Curved surfaces are much more susceptible to initiation of degradation and cracking than flat surfaces." (Swasey 1980)

Polymer morphology (i.e. crystallinity, orientation, etc.) can effect the photodegradation of polymers. Improvement in light resistance due to orientation is not completely understood, but it may be attributed to a combination of increased transparency, more uniform crystalline order, and reduced oxygen permeability (Carlsson and Wiles 1976, McTigue and Blumberg 1967). The number of degradation reactions that will result from a single quantum of ultraviolet radiation is a function of the chain length, which is an attribute of each respective polymer.

The major mechanisms involved in the photodegradation of polymers are cross-linking and chain scission reactions. Most degradation processes begin with cross-linking reactions. However, chain scission (C-C bond destruction) becomes more prevalent as sites for C-H scission decrease (Bremer 1982). "Chain-scission reactions generate free radicals, hydroperoxide groups form, and volatile products such as aldehydes, esters, ketones, alcohols, and hydrocarbons are produced in addition to cellulosic monomers and oligomers" (Plastics, Environmentally Degradable 1984). Chain-scission reactions shorten molecular chains rapidly, while cross-linking lengthens the molecular chains. When photodegradable polymers are exposed to sunlight, bond cleavage and destructive oxidation occur, resulting in decreases in molecular weight and consequently a shortened service life of the plastic (Hardy 1983a). For polypropylene, the primary photoinitiation steps all involve backbone scission. However, in the absence of oxygen, polypropylene's mechanical properties do not deteriorate appreciably (Carlsson and Wiles 1976). Free-radicals are formed in many reactions and are then responsible for the initiation of degradation and cross-linking of polymers. Some of the major free-radicals that have been studied include aliphatic ketones, ethers and peroxides (Rabek 1976).

The main mechanisms in the photodegradation of polymers are Norrish Type I and Norrish Type II reactions. Norrish Type I reactions involve free radical production, which lead to further reactions, and random chain scission. There is also cleavage of molecular chains which results in very rapid reduction of molecular weight. In Norrish Type II reactions there are not any free radicals produced, but there is random chain scission, leading to a rapid reduction in molecular weight. Ketone carbonyl is the main product formed in the initial stages by Norrish II photolysis (Scott 1976a). The quantum yield for Norrish type II reactions depends on the polymer's chain length and whether the ketone carbonyl group is in a side chain or in the main chain of the polymer (Plastics, Environmentally Degradable 1984). Cross-linking is possible in both types of reactions.

Degradation may be initiated in some polymers by the absorption of ultraviolet radiation through their normal structure, but frequently it is the presence of structural irregularities or associated impurities that are the primary ultraviolet absorbers (Hawkins 1984a). Degradation is the result of energy that is absorbed by chromophoric groups in polymers. This energy is then available for cleaving bonds. Unsaturated structures (structures containing double bonds) are more susceptible to degradation than saturated structures. Chromophoric groups may be introduced during manufacture, processing, or environmental exposure. Catalyst residues (e.g. titanium, aluminum, and chlorine) and carbonyl groups are common chromophores that may be introduced during the manufacturing of polymers to enhance degradation. Carbonyl groups absorb energy in the 270 to 360 nanometer range, (Hutson and Scott 1974, Johnson 1988). In polyolefin films the percent of carbonyl formation can be used to predict brittleness.

Hydroperoxides, peroxides, reactive forms of oxygen (ozone and singlet oxygen), and polynuclear aromatic compounds (PNA) may also be introduced during processing and environmental exposure. Charge transfer complexes (CTC), which are formed between oxygen and polymeric substrates, have been considered as possible sources of photoinitiation for polypropylene (Gugumus 1979, Wiles 1978). Energy transfer reactions are believed to have an important role in the formation of singlet oxygen. This occurs because energy is added to the molecule enabling it to change its molecular configuration (Ranby and Rabek 1976). Van der Waals interactions and quinones are also capable of sensitizing reactions important in polymer degradation mechanisms.

All commercially important polymers undergo reactions with oxygen, eventually leading to changes in molecular structure (Guillet 1972, Hawkins 1984a). The mechanism for photo-oxidation begins with the formation of a polymer-chain radical. This is initiated by ultraviolet exposure, mechanical shear, or chemicals such as peroxides, singlet oxygen, or ozone. The radical then forms polymer peroxides and hydroperoxides by reaction with oxygen (Carlsson, et al 1981; Cicchetti 1970; Gabriele, et al 1984; Plastics, Environmentally Degradable 1984). As with photodegradation, intensive photo-oxidation takes place mainly on the surface of the polymer, in a boundary region between a completely degraded upper layer and the unexposed polymer (Rysavy and

Tkadleckova 1992). The effects of photo-oxidation are similar to those of photodegradation, for example, loss of mechanical properties and embrittlement.

ULTRAVIOLET RADIATION

As stated earlier, ultraviolet radiation is responsible for most of the damage to photodegradable plastics. The extent of damage is influenced by contaminants and the activation spectrum for the specific polymer. Energy in the 290-400 nm region consists of only about five percent of the total energy reaching the earth, but it is responsible for most of the damage caused by sunlight (Guillet 1972, Hardy 1983a, Swasey 1980, Tobin and Vigeant 1981). However, these wavelengths do not appreciably penetrate window glass (Johnson 1988).

The only requirement involved in the degradation process is that the energy absorbed must be great enough to break the chemical bonds. Therefore, if the energy absorbed is greater than the bond dissociation energy for a specific polymer, degradation will be initiated. Sunlight induced changes in plastics may very well include chemical alterations in side groups (Cooney and Wiles 1973, Hawkins 1984a). The intensity of ultraviolet radiation being absorbed by the material will determine the rate at which chemical bonds are broken.

Some variables that will influence the intensity of ultraviolet light include altitude, latitude, seasons of the year, and atmospheric contaminants. Local weather conditions, including smoke, dust, fog, haze, and clouds may affect ultraviolet intensity (Hirt and Searle 1967, Zerlant 1982). Finally, atmospheric contaminants, such as air pollution and oxides of sulfur and nitrogen, may influence the intensity of ultraviolet wavelengths.

An activation spectrum represents the direct response of a material to the wavelengths emitted from the source, for a specific degradation measurement (e.g. yellowing, carbonyl formation, cross-linking, or bond scission). The absorption properties of the material are very important in determining the activation spectrum (Searle 1984). An activation spectrum can also be defined as the "wavelength sensitivity" of a polymer may be described as the extent of photodegradation as a function of incident wavelength (Hirt and Searle 1964). Another factor in determining the activation spectrum is the relationship between the bond strength of the material and wavelengths absorbed. The type of degradation being measured (i.e. yellowing, carbonyl formation, crosslinking, or scission) will also influence the activation spectrum of a material (Searle 1984).

Activation spectrums can be useful in the determination of appropriate light absorption requirements. This can be especially useful in the selection of proper stabilizers for photodegradable polymers. The relative effectiveness of stabilizers may be estimated based on the match of their spectral characteristics with the activation spectrum. An activation spectrum can also be useful in the selection of accelerated weathering devices and in monitoring actinic radiation. This helps in establishing better correlation among tests as well as predicting lifetimes (Searle 1984). Polypropylene's activation spectra maxima is approximately 310, and 370 nanometers (Hawkins 1984a, Hsuan and Koerner 1993, Searle 1987).

It should also be noted that in no case is there a complete understanding of how photons interact with a polymer. This is due to the complex physics and chemistry involved and because of the fact that polymers are not pure compounds (Wiles 1978). The effects of ultraviolet radiation on polymers were previously discussed in the degradation of polymers section, for example: discoloration/fading (yellowing), weakening of fibers (embrittlement), bond cleavage, charring, crazing, etc.

TEST METHODS

The fundamental parameters of weathering tests are light, heat and moisture. Materials will respond differently depending on the intensity and combination of these parameters (Crewdson 1993). The major test methods for photodegradation of polypropylene include indoor tests using accelerated conditions and outdoor exposure tests.

Tests may be classified as either design or materials tests. Design tests are used to measure the useful life of polymers as they function in an actual device or design. These are the types of tests used to provide information for design engineers. Design tests take all external environmental factors into account as well as all other components that may have an adverse (or beneficial) effect on a polymers stability. Materials tests evaluate only the stability of polymer test samples without consideration of how the polymer samples will perform in a final product (Hawkins 1984b).

Accelerated testing is necessary for estimating the useful life of polymers because testing under use conditions is time consuming and natural weathering involves many variables. Accelerated testing has the advantage of much closer control over variables and reduced time of testing (Freedman 1976). Testing is really the only way to determine how stabilizers will improve a polymer's performance under the damaging effects of ultraviolet light.

There are four instruments used to produce artificial sunshine; these include carbon arcs, fluorescent lamps, xenon arcs, and mercury arcs.

Carbon arcs give a close approximation to sunlight at short wavelengths (Hirt and Searle 1967). Carbon arcs generate a considerable amount of heat. Therefore, their design may include a baffle that will shield the test samples, or a water spraying device to reduce the effects of this heat. However, carbon arcs have strong emission peaks in the actinic region (violet and ultraviolet parts of the spectrum which are photochemically effective) that are not present in sunlight and may distort results (Hardy 1983b, Hirt and Searle 1967, Searle 1987). These emission peaks in the long wavelength region, of the ultraviolet spectrum, (350-396 nm) will be responsible for most of the degradative effects (e.g. color change and embrittlement) when testing polymers with a carbon arc light source (Searle 1987).

Fluorescent lamps are more intense than sunlight in the short wavelength region (below 313 nanometers), but are less intense than sunlight in the long wavelength region (above 313 nanometers). Ultraviolet absorption of clear plastics increases gradually with decreasing wavelengths. As a result, degradation should increase as the short wavelength energy increases. Therefore, fluorescent lamps will have a stronger effect on clear plastics than either sunlight or carbon arcs (Hirt and Searle 1967).

The xenon arc's spectral distribution comes closest to matching natural sunlight in the ultraviolet region (Freedman and Diamond 1976, Hardy 1983b, Hirt and Searle 1967). Xenon arcs are normally preferred over carbon arcs in lightfastness tests. Xenon arcs utilize water for cooling test samples, and filters to reduce the short wavelength emission of the arc.

Mercury arcs are comparable to fluorescent lamps in the short wavelength region (below 320 nanometers), but in the long wavelength region they are stronger than fluorescent lamps (Hirt and Searle 1967).

Wetting of samples during ultraviolet tests may have two effects. First, wetting can accelerate degradation if the material is sensitive to the synergistic effects of temperature, moisture and sunlight. Second, wetting can cause thermal shock, reducing surface temperatures as much as 25 °C, resulting in physical stresses which can also contribute to accelerating the degradative process. The advantages of wetting include enhanced ability to repeat test, and thermal shock to test samples at peak temperature periods (Searle 1987).

The ultraviolet spectrum can be divided into three regions: (i) UV-A region (315 to 400 nanometers), (ii) UV-B region (280 to 315 nanometers), and (iii) UV-C region (below 280 nanometers).

Fluorescent lamps are usually categorized depending on the region where most of their output falls. UV-B lamps include the shortest wavelengths found in sunlight at the earth's surface. Most of their output is in the UV-B region, but they do have some output in the UV-A and visible regions. UV-A lamps include the longer wavelength spectrum and are especially useful for tests comparing generically different types of polymers. These lamps give enhanced correlation with actual outdoor weathering but they do not emit radiation below the normal solar cutoff of 295 nm. Therefore, they usually do not degrade materials as fast as UV-B lamps. The majority of UV-A lamps' energy is in the UV-A region, with a small amount in the UV-B and visible regions (A Choice of Lamps for the Q-U-V). The choice of lamps used in lightfastness tests is critical because differences in lamp energy output or wavelength spectrum can cause significant differences in test results.

Most weathering tests call for machines to be operated at irradiance levels comparable to average optimum sunlight (Crewdson 1991). But, artificial sunlight can be used to accelerate degradation in two ways; first, the intensity of the wavelengths found in sunlight can be increased; and second, wavelengths of shorter frequencies than those found in sunlight can be used. However, raising the irradiance level and changing the spectral power distribution of the radiation source will cause variation in test results (Crewdson 1993).

Correlation of test results has been performed a number of ways. Pearson's method of correlation can be used as a measure of the linear relationship between test samples. Alternatively, "Spearman's method assigns a rank to each material, based on the amount of degradation, and compares ranks between the test methods under consideration" (Crewdson 1993).

After initial polymer degradation studies have been completed using accelerated testing indoors, outdoor testing may be performed to give a more accurate prediction of polymer performance. The purpose of outdoor weathering tests is to determine any one or a combination of the following: to provide statistical data for prediction of the influence of weathering on material properties, as a quality control technique, or to ascertain the weathering characteristics of materials (Zerlant 1982). Outdoor weathering is important because it is estimated that at least 25% of all plastics are exposed to weathering in outdoor environments (Freedman 1976). Outdoor weathering environments should match the conditions of end use, and diagnostic tests should be selected for the most accurate measurement and assessment of the degradation effects which most significantly affect the choice of materials for utilization in a specific environment (Zerlant 1982).

Outdoor exposure tests are normally performed in either Florida or Arizona. Samples are exposed to two different sets of conditions at these sites: humidity is high in Florida and low in Arizona. Both of these locations provide high amounts of incident radiant energy from the sun (Hardy 1983b, Hawkins 1984b).

Data obtained from outdoor tests includes amount of energy (langleys or ultraviolet sun hours), relative humidity, temperature, and hours of exposure to sunlight.

The main disadvantages of outdoor testing are that the time required for initial studies is too long, and the interruption of solar radiation during the night hours makes reaching the failure point in well-stabilized polymers difficult. Ultraviolet radiation is more intense in the summer months than in the winter months. This is due to the fact that there are more daylight hours, latitudes are lower, and ozone concentration is lower, which results in more intense radiation. Even at a constant level of total incident radiation, degradation proceeds faster in the summer than in the winter. Tests that begin in the winter will have about two times the life expectancy as those started in the summer (Zerlant 1982).

Variations in exposure conditions may be material dependent. For example, black samples get hotter than white samples and fabrics will remain wetter longer than coatings (South Florida Test Service).

There are a lot of uncontrollable variables in outdoor exposure tests, which makes accelerated testing necessary to provide initial degradation results.

After polymeric samples have been exposed to harmful rays (real light, fluorescent, xenon, etc.), a method is needed to judge degradation. Methods include: infrared spectrophotoscopy, tensile tests, and colorness tests. Other tests, such as gel permeation chromatography, melt flow index, electron spin resonance, differential scanning calorimetry, thermal gravimetric analysis, and thermal volatization analysis may also be useful.

Infrared spectrophotometers are used to monitor chemical changes, such as carbonyl content, ultraviolet absorption, and yellowing (Freedman and Diamond 1976; Allen, et al 1991; Subowo, et al 1986). Infrared spectrophotoscopy is especially useful in studying hydrocarbon polymers because they do not contain interfering oxygen compounds (Freedman and Diamond 1976). Infrared spectrophotoscopy is commonly used to measure increase of carbonyl content for a polymer in a given region (e.g. the carbonyl region is approximately 1750-1690 cm^{-1}).

Tensile tests can be performed to determine the tensile properties of a polymeric material. These stretchiness tests and tests to determine elongation at break can be used to determine the effects of sunlight on the polymer's mechanical properties (Gonzalez, et al 1989; Hardy 1982, Love 1984, Pouncy 1985). The major property that is evaluated when tensile tests are performed is the force (in pounds = lbf) required to reach a polymers yield point.

Colorimeters can be used to determine the yellowness index for a polymer (Searle, et al 1989). Color changes can also be determined by comparison with color standards.

Electron Spin Resonance (ESR) spectroscopy may be used to give an indication of stabilizer changes (Bauer, et al 1992; Carlsson, et al 1978).

Gel Permeation Chromatography (GPC) can be used to determine changes in a polymer's molecular weight and molecular weight distribution. Knowledge of a polymer's molecular weight can be useful in determining mechanical properties (e.g. elongation and tensile strength). Molecular weight averages are beneficial because they allow packaging engineers to determine properties such as flex life, stiffness, brittleness, flow properties, extrudability and molding properties.

A polymer's melt flow index can be measured and used to indicate thermal oxidative stability (Amin and Scott 1974, Bremer 1982). Melt flow index values are normally reported in grams/10 minutes.

Differential Scanning Calorimetry (DSC) can be used to determine the melting point and heat of fusion for a polymer, which is useful in determining percent crystallinity. Crystallinity can be used to determine a polymer's structural/ stereochemical regularity. Properties affected by crystallinity include: modulus, impact strength, tensile strength, orientability, and brittleness.

Thermal gravimetric analysis (TGA), which measures weight loss, may also be used to analyze degradative effects. TGA is conducted in a high vacuum or in an inert atmosphere and is widely used as a test to determine a polymer's stability to heat (Hawkins 1984b).

Thermal volatization analysis (TVA) measures pressure developed by volatile products. A Pirani gauge is used to indicate small pressure changes (Hawkins 1984b).

Pyrheliometers can be used to measure the intensity of sunlight in many outdoor locations. The intensity of light is usually reported in either langleys (g-cal/cm^2) or "ultraviolet sun hours." Ultraviolet sun hours are measured as the number of hours for which the intensity is greater than a value of 0.823 langleys/min on the samples (Hirt and Searle 1967).

When using accelerated tests to evaluate a polymer's stability, interpretation of results must proceed with caution. The intensity of sunlight expressed in units such as langleys or "ultraviolet sun hours" does not truly measure the actinic radiation. For successful correlations of exposure test data, continuous monitoring and integrating of the activation spectrum is desirable (Hirt and Searle 1967). In the evaluation of test results, it is very important to realize that the results obtained in accelerated tests may be different than the results occurring in the environment in which the plastic will be used. Acceleration of only the primary process by increasing irradiation intensity alone can distort results even if the spectral distribution is maintained constant (Hardy 1982, Hirt and Searle 1967). Accelerated tests should take into account every factor that contributes to degradation under use conditions. The applicable factors should also be present proportional to their existence in the real environment (Hawkins 1984b).

Problems associated with accelerated testing are believed to result from changes in light intensity (I_o) of photo-oxidation process for different ultraviolet stabilizer mechanisms. For example, the light intensity for a ultraviolet absorber may be $I_o^{0.5}$, whereas the light intensity of a radical scavenger may be $I_o^{1.0}$ (Carlsson, et al 1979). Other problems include varying ratios of wavelengths emitted from light sources, and the fact that UV irradiation is a surface phenomenon, while classic mechanical tests such as tensile strength and elongation at break are essentially bulk measurements (Gonzalez, et al 1989).

POLYPROPYLENE

Pure polypropylene, if saturated, should be transparent to terrestrial sunlight. Therefore, photodegradation must be the result of impurities in the polymer. Hydroperoxide groups which form during the manufacturing process are the main absorbing groups in polypropylene (Hardy 1983b). Aromatic ketones have also been reported to accelerate the photo-oxidation of polypropylene. Other species believed to accelerate the photodegradation of polypropylene include carbonyl groups, transition metals (iron nickel, copper, and chromium), charge transfer complexes, endoperoxides, ozone and singlet oxygen (Gugumus 1979).

The major reactions in the photodegradation of polypropylene are surface reactions. Photo-oxidative changes are confined largely on or near the surfaces of the polypropylene film up to the stage of brittleness (Cooney, et al 1973). The depth of the reactions and degradation depends on the structure of the polymer, the wavelength of light, and additives that may be introduced into the polymer.

Polypropylene degradation is primarily a result of a free-radical reaction. Initiation occurs by random scission in the main chain. Radicals that are formed undergo transfer reactions most readily at tertiary carbon atoms (Grassie and Leeming 1976).

Polypropylene does not show any significant evidence of optical deterioration. Long before the material yellows, it deteriorates physically showing cracks and scratches due to ultraviolet irradiation (Hirt and Searle 1964). When evaluating the degradation of polypropylene, one must be careful because before physical changes are evident, changes in ultraviolet absorption can be detected. Polypropylene degradation can be measured by examining carbonyl content, using infrared spectrophotometry.

Changes in physical properties can be evaluated by doing tensile tests, most commonly with an Instron machine. Degradation can also be determined by measurement of UV spectra, phosphorescence, color change, or physical properties such as impact strength (Hardy 1983b).

Polypropylene is one of the easiest polymers to make photodegradable because its molecular structure makes it susceptible to oxidative attack. Polypropylene can be made to degrade in days outdoors, while showing negligible physical changes after many months indoors (Cooney, et al 1973).

Polypropylene's crystalline nature leads to complex morphology or microstructure in fabricated articles. Crystallite size, degree of orientation, and density can be influenced by temperature, rate of cooling, and rate of filling the mold. Orientation apparently reduces the loss of ultraviolet stabilizers. Improvement in light resistance due to orientation is not completely understood, but it may be the result of increased transparency, more uniform crystalline order, and reduced oxygen permeability (McTigue and Blumberg 1967).

Polypropylene is used in the packaging industry because it has excellent physical properties, chemical resistance, good processability, and low cost. Some of the uses for polypropylene include indoor-outdoor carpeting, stretch tapes, rope, twine, bag fabric, chain webbing, and artificial grass (Hardy 1982). The major problem in using polypropylene outdoors is that it is susceptible to photo-oxidative attack. However, the excellent properties can be utilized outdoors by the addition of effective stabilizers. For example, woven polypropylene is stabilized for use in sandbags.

STABILIZATION

In order to properly stabilize polymers, their mechanisms of photodegradation must be understood at the molecular level. In short, the purpose of stabilization is to allow polymers to be useful for their desired lifetime under adverse conditions.

The basic categories of stabilization are preventive and arrestive. A preventive measure results in the production of a more stable polymer. In order to produce a more stable material (internal stabilization), monomers that are higher in purity can be used.

Arrestive stabilization can be achieved by the removal, neutralization, or inactivation of potential degradation sources that accumulate in a polymer. The primary method is to introduce reactive species into the polymer (external stabilization). However, stabilizers may also be built-in to the polymer chain (Klein 1983).

The major factor in selecting a stabilizer is the initiation mechanism for the degradation of a specific polymer. This can be a problem because synthetic polymers break down by a variety of mechanisms and the reactions frequently involve the presence of moisture, oxygen and/or pollutants (Guillet 1972).

The selection of ultraviolet stabilizers should also take into account the activation spectra maxima in order to provide the greatest level of protection. This will allow protection against the most damaging frequencies for the polymer.

Some of the desirable stabilizer characteristics include high light stability, high thermal stability, diffusability, resistance to extraction by water, low color, low toxicity, minimal adverse effects on the polymer's properties, and low costs (Hardy 1983b).

The early approaches to achieve stabilization can be characterized as using coatings opaque to harmful radiation. This was not a good approach because of adhesion problems and coating and application costs (Hardy 1982).

Today stabilization is achieved, in several different ways, by incorporating additives into the bulk of the polymer. Advances in surface treatment and/or primer coats have solved the adhesion problems with surface coatings, enabling them to adhere to the top coat of polypropylene and provide exceptional protection against damaging ultraviolet rays. For example, polypropylene that was coated with a white pigmented nitrocellulose-acrylic lacquer, showed no evidence of surface damage after a full year of exposure in Florida (McTigue and Blumberg 1967).

The general types of photostabilizers can be classified

as ultraviolet screeners, ultraviolet absorbers, excited state quenchers, free radical scavengers and/or hydroperoxide decomposers.

Ultraviolet light screeners are opaque additives or pigments that reflect or absorb radiation before it reaches the polymer surface, limiting penetration into the bulk of the polymer material (Hardy 1982). Carbon black is the most common ultraviolet screener. The effectiveness of ultraviolet screeners strongly depends on their dispersion in the polymer matrix (Klein 1983). Some white pigments, such as titanium dioxide, are also used as ultraviolet screeners. Sometimes colored pigments are used, but they are not as powerful as white pigments. However, ultraviolet screeners have been limited in use because of their adverse effect on other additives, contribution of color, or opacity (Hardy 1983a).

Ultraviolet light absorbers are stabilizers that function by preventing the light from being absorbed by the photoactive impurities or structural units in the polymer (Hardy 1982). The ultraviolet radiation is absorbed and harmlessly dissipated. 2-hydroxybenzophenones and 2-(2-hydroxyphenyl)-benzotriazoles are the most widely used ultraviolet absorbers. These stabilizers exhibit excellent performance in thick sections. Their efficiency as ultraviolet stabilizers has been attributed to an extremely fast non-radiative decay from the first excited singlet state to the ground state (Gugumus 1979). In the selection of absorbers for photodegradable polymers it is important to note that the effectiveness of the absorber is predictable and should change as a function of the concentration. Experimental results have shown that the effectiveness of the absorber varied as the square root of the change in concentration. For example, to double the life, the absorber concentration should be quadrupled (McTigue and Blumberg 1967).

Excited state quenchers function by the abstraction of excited state energy from a polymer molecule through energy transfer (Hardy 1982). These stabilizers deactivate excited chromophores before degradation occurs. Quenchers are effective in thin or thick materials; nickel complexes and benzoates are most common. The effectiveness of nickel complexes can be attributed to quenching carbonyl triplet states or oxygen singlet states (Amin, et al 1974).

Free radical scavengers and/or hydroperoxide decomposers function by radical scavenging or by decomposing hydroperoxides. The stabilizers used for this type of stabilization must be stable to ultraviolet light (Hardy 1982). Metal complexes, such as nickel oxime chelates, transition metal dithiocarbamates, and transition metal phosphates are most common. Some of these chelates are more effective as light stabilizers than the 2-hydroxybenzophenones. Peroxide decomposing stabilizers produce a minimal amount of photosensitizers during processing, which makes them effective ultraviolet stabilizers (Scott 1976b). Free radical scavenging is the main step used by phenolic antioxidants in protecting polymers against thermooxidative degradation (Gugumus 1979).

Antioxidants can be classified into two main groups which are distinguished according to their mode of action: primary or chain-breaking, and secondary or preventive antioxidants (Klein 1983). Chain breaking antioxidants interfere with the chain propagation steps of photooxidation. Hydrogen donors are the most common chain breaking antioxidants, they function by donating hydrogen atoms to polymer radicals. Preventive antioxidants interfere with the initiation steps of oxidation. Antioxidants can be added to polyolefins to help provide melt stability during processing (Scott 1976b).

Hindered amine light stabilizers (HALS) are new antioxidants which have displayed exceptional performance. Many of the HALS are based on 2,2,6,6-tetramethylpiperidine, but they do not exhibit near ultraviolet absorption or excited state quenching (Carlsson, et al 1984). HALS are believed to function similarly to ultraviolet stable antioxidants and are effective in either thick or thin materials. They are oxidized to the appropriate radicals, and function by scavenging free radicals. HALS performance may be improved by the addition of antioxidants, creating a synergistic effect. In most cases, HALS outperform other light stabilizers, such as ultraviolet absorbers and excited state quenchers (Gugumus 1989). However, HALS have been shown to be effective only after a certain level of hydroperoxide concentration has been achieved.

In the stabilization of polypropylene, systems may contain one or more UV light stabilizers, an antioxidant (hindered phenol), and a hydroperoxide decomposer (phosphite or thioester) (Hardy 1982).

A stabilizer's performance depends upon the polymer that it is being used in, the polymer's form, and any other additives that may be present. Combinations of antioxidants with light stabilizers can lead to synergistic or antagonistic effects. Copolymers have also been used to attain synergistic effects and improve processing characteristics (Grassie and Leeming 1976). Some of the problems that occur in the stabilization of polymers are leaching and migration of the stabilizer to the polymer's surface. Ultraviolet screening agents may be lost by evaporation or leached out (Gupta, et al 1981). "The solubility of the stabilizer in the matrix is often less than the minimum effective concentration, leading to stabilizer migration, and exposure to solvents and/or high temperatures in processing or in use can accelerate stabilizer loss." (Tirrell 1981). In the future, stabilizer systems will become more complex in order to maximize polymer lifetimes.

Polypropylene is a very useful polymer for the packaging industry. The fact that polypropylene deteriorates very quickly when exposed to ultraviolet light has lead to the development of stabilizers. When stabilizers are added to polypropylene, and other polymers, their desired properties can be maintained as needed in outdoor environments. In the future, better and more efficient stabilizer systems will emerge as more studies are performed on the photodegradation of polymers. Stabilization of polymers will be enhanced because the initiation mechanisms that lead to photodegradation will be better understood.

CHAPTER 3

MATERIALS AND TEST METHODS

The materials and test methods section of this paper will be divided into four parts: materials, ultraviolet test methods, tensile test, and statistical analysis of data.

MATERIALS

There were four different woven polypropylene fabrics used in the study. Fabric A, fabric B, and fabric C are currently used by the USDA. The three resins were certified by their manufacturers to have adequate ultraviolet stabilizers to meet the 200 hour carbon arc test requirement. The fourth fabric (fabric D) did not contain any uv stabilizer.

The yarns per inch for each fabric was obtained by taking three measures in both the warp and fill directions at different locations along each roll of fabric. Each measure counted five inches of fabric and these were averaged together and divided by five to determine the calculated yarns/inch. The results were as follows: fabric A had 9.8 yarns per inch in the warp direction and 10.6 yarns per inch in the fill direction. Fabric B had 10.8

yarns per inch in the warp direction and 7 yarns per inch in the fill direction. Fabric C had 9 yarns per inch in both directions. Finally, fabric D had 9.9 yarns per inch in the warp direction and 6.8 yarns per inch in the fill direction. (see Table 1).

The fabric weight was determined by cutting six 1 ft^2 samples out of each fabric. The samples for each fabric were averaged together to find the average weight per square foot. This weight was then multiplied by nine to obtain the calculated bag weight in oz/yard^2. The results were as follows: fabric A weighted 2.73 oz/yd^2, fabric B weighted 2.86 oz/yd^2, fabric C weighted 2.43 oz/yd^2, and fabric D weighted 2.25 oz/yd^2. (see Table 1).

Fabric thickness measurements were obtained by taking ten measurements (of individual yarns) in both the warp and fill directions at different locations along each roll of fabric. The measurements were determined using a Micrometer Model 549 M, manufactured by Testing Machines, Inc. accuracy of the micrometer was 0.1 mils. Averages of the ten measurements were then calculated to determine the fabric thickness results. The results were as follows: fabric A was 13.99 mils thick in the warp direction and 11.11 mils thick in the fill direction. Fabric B was 8.81 mils thick in the warp direction and 9.99 mills thick in the fill direction. Fabric C was 7.95 mils thick in the warp

Table 1: Fabric weight and yarns per inch

Fabric	Measured Fabric Weight	Data Sheet Fabric Weight	Measured Yarns/inch (warp x fill)	Data Sheet Yarns/inch (warp x fill)
A	2.73	2.6	9.8 x 10.6	10 x 10
B	2.86	2.7	10.8 x 7	10.8 x 6.9
C	2.43	2.6	9 x 9	9 x 9
D	2.25	----	9.9 x 6.8	----

note: fabric weight = oz/square yard
fabric D data sheet was not available

Table 2: Fabric thickness results

Thickness measurements (mils)								
	AW	AF	BW	BF	CW	CF	DW	DF
1	13.2	11.1	9.3	8.1	7.9	7.7	5.9	7.2
2	14.0	14.6	7.6	7.4	8.1	7.2	5.8	5.5
3	14.3	10.6	8.8	10.1	7.4	10.4	7.7	7.1
4	14.1	11.2	7.4	11.6	7.8	9.1	6.9	5.6
5	14.1	10.5	9.3	9.7	8.0	9.8	6.2	7.0
6	14.2	10.7	9.4	7.6	8.0	11.2	5.9	5.8
7	14.5	9.8	9.2	11.9	7.7	9.7	6.5	5.7
8	13.1	12.4	9.7	10.4	7.2	7.8	6.7	5.4
9	13.8	10.2	8.2	11.4	8.8	8.0	7.4	7.4
10	14.6	10.0	9.2	11.7	8.6	12.0	5.6	5.3
AVG	13.99	11.11	8.81	9.99	7.95	9.29	6.46	6.20
STD	0.50	1.43	0.80	1.75	0.49	1.61	0.71	0.86

direction and 9.29 mils thick in the fill direction. Fabric D was 6.46 mils thick in the warp direction and 6.20 mils thick in the fill direction. (see Table 2)

ULTRAVIOLET TEST METHODS

There were four different sets of tests performed. Samples were prepared for testing, and then tests were performed under two different exposure conditions. First, tests were performed using a continuous uv cycle (no condensation), on all four fabrics (A, B, C, and D). Second, tests were performed using a 8 hour UV (4 hour condensation) cycle, on all four fabrics. Third, replicate tests were performed on fabrics A, B, and C for the continuous uv cycle. Finally, replicate tests were performed on fabrics A, B, and C for the 8 UV (4 hour condensation) cycle.

The ultraviolet light was simulated using two different accelerated weathering test machines (ASTM D 5208 1991, ASTM G 53 1988, ASTM D 4329 1984). Tensile tests were performed on all samples to determined their strength (in lbf) after being exposed to uv light.

Sample Preparation

Samples were prepared for testing from rolls of woven polypropylene fabric. The samples were cut to be tested in two different directions, warp and fill. In weaving, the warp direction parallel yarns are strung onto a loom first, and the fill yarns are interwoven in the perpendicular direction (thus filling the fabric). To compare to other packaging material terminology, the warp direction is equivalent to the "machine" direction.

The three fabrics (A, B, and C) used by the USDA are circular woven, into a tube, which facilitates bag making. In circular woven fabric, the warp yarns are strung the length of a tube and the fill yarns encircle the tube. Fabric D is regular flat woven fabric.

A 7¼" by 4¼" pattern was traced on the fabric with a permanent marker. The pattern was positioned so the 7¼" side was in the vertical direction with respect to the fabric coming off the roll for the warp direction. The 7¼" side was in the horizontal direction with respect to the fabric coming off the roll for the fill direction.

The traced patterns on the fabric were than cut out with scissors. After the samples were cut they were labelled with a permanent marker on the inside of the bag material. The inside of the fabric was labelled for fabrics A, B, and C, since the outside was exposed to uv light.

While the samples were being prepared for testing it was critical to handle them as little as possible to reduce unravelling and premature damage. Fabric D was very hard to work with because the yarns moved very easily, making it difficult to cut the rectangular pattern. Fabric D was flat woven fabric, the inside of the material, with respect to the fabric coming off the roll, was labelled, and the reverse side was exposed to the uv light.

Accelerated Weathering Tests

After the samples were prepared for testing they were placed in the accelerated weathering machines (UVCON and QUV) for testing.

The UVCON (model number UC-327-2) was supplied by Atlas Electric Devices Company in Chicago, Illinois. The dimensions for the UVCON were as follows: 61" (155 cm) * 53" (135 cm) * 20" (51 cm), height * width * depth. The UVCON weighted 285 lbs (129 kg). The UVCON had 26 positions for specimen racks (one position was used for a black panel sensor), resulting in a maximum capacity of 50 samples measuring 3" * 6" (75 * 150 mm). The samples were placed on metal plates (with a solid backing to prevent condensation evaporation), and secured in the specimen holder with snap-in rings.

The QUV (model number QUV/SER) was supplied by The Q-Panel Company in Cleveland, Ohio. The dimensions for the QUV were as follows: 53" (135 cm) * 54" (137 cm) * 21" (53 cm), height * width * depth. The QUV weighted 300 lbs (136 kg). The QUV had 26 positions for specimen racks (two positions were used for uv sensors), resulting in a maximum capacity of 48 samples measuring 3" * 6" (75 * 150 mm). The samples were placed on metal plates (with a solid backing to prevent condensation evaporation), and secured in the specimen holder with snap-in rings.

When putting the samples in the machines it was very important to make sure that the correct (outside) side of the fabrics would be exposed to the ultraviolet lights.

Test initiation and completion dates and times were calculated and recorded on a calendar. The machines also had timers on them that were used to double check exposure durations. There were two different test conditions used in this study. The duration of testing was different depending on the test conditions used.

Condensation occurred because of the temperature change in the test chamber between the ultraviolet cycle and condensation cycle. The temperature in the test chamber was 70 °C in the ultraviolet cycle and 50 °C in the condensation cycle. This condition was meant to simulate a day and night cycle.

The first set of tests consisted of a continuous ultraviolet cycle, with no condensation cycle. This test condition did not have a condensation cycle but their was water in the machines. For this cycle, samples were tested at intervals of 66, 100, 166, 200, 233, 266, and 333 hours. These times represent two-thirds of the 8-hour ultraviolet exposure length times. This was done to compare results of the two conditions based on the equivalent length of ultraviolet exposure (e.g. 8 hours UV for 12 hours is ⅔ of 12 hours UV for 12 hours) and to determine if water, and a dark period had any effect on the severity of degradation.

The second set of tests consisted of an 8 hour ultraviolet and 4 hour condensation cycle every 12 hours. During the condensation cycle, the uv lamps are not on. For this condition, samples were tested at intervals of 100, 150, 200, 250, 300, 400, and 500 hours. During this test there was one 8 hour delay because the UVCON overheated due to a lack of water for one condensation cycle.

The temperature setting for the first set of tests (continuous uv and no condensation) was 70 °C. The second set of tests (8 hour ultraviolet and 4 hour condensation) used a temperature of 70 °C for the ultraviolet cycle, and 50 °C for the condensation cycle.

UVA340 fluorescent uv tubes were used as the source of ultraviolet light. Most of the energy emitted by these lights falls in the UV-A region (315-400 nm), with a small amount in the UV-B region (280-315 nm).

The QUV was calibrated when the tests began, at 70 °C, with an irradiance level of 0.72. The QUV was also calibrated when the "calibrate" light flashed, showing that it was time to recalibrate the system (this occurred approximately every 400 hours). The calibration was performed using the CR-10 Calibration Radiometer that came with the QUV. This instrument had a calibration connection cable with two jacks. One end was inserted into the calibration instrument and the other end was inserted into the UV sensors in the QUV (there were four different sensors, each sensor monitors two lamps). This calibrated the irradiance level at the desired setting.

The fluorescent uv tubes in the UVCON were rotated approximately every 400 hours, as shown in Figure 3 of ASTM G 53, Standard Practice for Operating Light- and Water-Exposure Apparatus (Fluorescent UV-Condensation Type) for Exposure of Nonmetallic Materials. In this rotation procedure, two light tubes are discarded and the remaining six tubes are rotated every 400 to 450 hours. Therefore, tubes are rotated approximately every 400 hours and replaced every 1600 hours.

Once a day (approximately every 24 hours), the extreme left hand and extreme right hand samples were rotated into the center. This was done for both the UVCON and the QUV in accordance with the procedure suggested in ASTM G 53, section 9.5.1 for horizontal rotation.

Data recorded included the irradiance level and temperature (approximately three times a day), time of sample rotation, and anything unusual that was observed.

After the samples had been exposed to test conditions for the desired time interval, they were removed from the QUV and UVCON, and placed in wax paper. Pictures were taken of samples that were determined to be too brittle for tensile tests. The criteria for a sample to be too brittle for testing was deterioration visible to the naked eye.

After the continuous uv (no condensation) cycle was completed, the 8 hour ultraviolet (4 hour condensation) cycle was initiated. Then repeat tests were done for fabric A, fabric B, and fabric C for both ultraviolet conditions (continuous ultraviolet, no condensation, and 8 hour ultraviolet, 4 hour condensation).

For the initial tests, two samples were tested for each material (fabrics A,B,C, and D), for each condition. Two samples were also tested for the replicate tests (fabrics A,B, and C). Variability in data may make it difficult to distinguish between tests results. Therefore, replication of testing was necessary (Crewdson 1993).

Machine Comparison

The UVCON had the following advantages over the QUV: the temperature was maintained very well and was easy to set, chart recorder for machine temperature was beneficial, machine had a safety control device "equalizing cycle" that shut off the harmful ultraviolet rays if the test chamber was accidently opened, and the machine warmed up quickly.

Disadvantages were as follows: uv tubes must be rotated every 400 to 450 hours, and a specific device (called a "cam") was necessary to set the UVCON for a specific condition. For example, one "cam" was used for the

8 hour uv (4 hour condensation cycle) and a different "cam" was used in the continuous uv cycle. These "cams" had smooth sections for the uv cycle and notches for the condensation cycle. The "cams" made one revolution every twenty four hours.

The QUV had the following advantages over the UVCON: rotating light tubes was not necessary because the solar eye controlled the irradiance level; sensors were located in the middle of the test chamber, making daily rotation of samples easier; the machine had "tabs" that were placed in or out depending on the desired cycle setting (which allowed the user to modify cycle settings easily, without ordering additional "cams").

Disadvantages were as follows: machine warmed up slowly and temperature settings were difficult, the machine did not have a safety control device to protect the user from accidently opening the test chamber, and the machine did not have a chart recorder to monitor the temperature in the test chamber.

TENSILE TESTING

Tensile tests were performed to determine the strength of samples that had been exposed to ultraviolet light. The USDA requires 70% strength retention after 200 hours of exposure to a carbon arc.

Sample Preparation

Exposed samples were cut in half in the vertical direction; the new dimensions were 2⅛" by 7¼". Four samples were prepared for each variable being tested. Variables included: fabric (A,B,C, and D), time (Continuous UV Cycle = 66, 100, 166, 200, 233, 266,and 333 hours; 8 Hour UV Cycle = 100, 150, 200, 250, 300, 400, and 500 hours), direction (warp and fill), and machine (UVCON and QUV). Replicate tests were performed on fabrics ABC. Therefore, for the initial tests, 896 samples were prepared. The second set of tests (replicate tests) required 672 samples.

Next, samples were prepared for testing in accordance with ASTM D 5035 Strip test ravel type, any yarns on the samples that were not full length (7¼" in the vertical direction) were removed, by unravelling. Ten full yarns were counted from the middle (point that the samples were cut at) to the outside edge, and the rest of the lengthwise yarns were removed. Ten lengthwise yarns, with all crosswoven yarns intact, were determined to be the number of yarns necessary for tensile testing purposes.

Samples were then placed back in wax paper and manila envelopes until tensile tests were performed to avoid sample mix-up. Samples that were determined to be too brittle for tensile tests were saved.

Tensile Tests

Tensile tests were performed with an Instron Machine (Model number 4201). The procedure followed was performed in accordance with ASTM D 5035-90 Strip test ravel type. The Instron Machine was set up with a load cell of 5 kN, air pressure of 90 psi, jaw separation of three inches, and grip separation speed of 12 in/min.

The dimensions of the grippers on the Instron machine were 2" by 1½". As the grippers held the samples, the 2" side was parallel to the width of the sample. The grabbers for ravel test are identical, except they have rubber on them. Peak load and extension were recorded.

Ten unexposed samples for each fabric and direction were tested as controls.

STATISTICAL ANALYSIS OF DATA

Averages and standard deviations were calculated for all of the samples. T-tests were performed to determine if the tests are repeatable. Correlation between test methods was determined using linear regression. A multifactor analysis of variance (ANOVA) was also performed.

CHAPTER 4

RESULTS

As a control, 10 unexposed samples were tested for each fabric, for each direction. It is important to note that there was variation in these tests from 6.5- 13.7% in peak load measurements (see Table 3). Therefore, variation after the uv exposure tests had been completed, was expected.

There were four separate tests performed in this study. They were set up as follows: 8 hour ultraviolet (4 hour condensation) cycle for fabrics A, B, C, and D (8 Hour UV - Test 1), 8 hour ultraviolet (4 hour condensation) cycle replicate test for fabrics A, B, and C (8 Hour UV - Test 2), continuous ultraviolet (no condensation) for fabrics A, B, C, and D (Continuous UV - Test 1), and continuous ultraviolet (no condensation) replicate test for fabrics A, B, and C (Continuous UV - Test 2).

Four samples were tested for each variable; fabric (A,B,C, and D), time (Continuous UV Cycle = 66, 100, 166, 200, 233, 266,and 333 hours; 8 UV Cycle = 100, 150, 200, 250, 300, 400, and 500 hours), direction (warp and fill), and machine (UVCON and QUV). Replicate tests were performed on fabrics ABC. Therefore, for the initial tests, 896 samples were tested. The second set of tests (replicate

Table 3: Test Control (Original Fabrics)

Control (Unexposed Fabrics)								
		Fabric A				Fabric B		
	Warp		Fill		Warp		Fill	
	Load	Ext	Load	Ext	Load	Ext	Load	Ext
1	102.8	0.764	67.6	0.6	87.57	0.863	98.63	0.843
2	109.2	0.762	72.62	0.503	101.8	0.821	114.8	0.8
3	103.9	0.851	69.88	0.613	96.7	0.793	102.6	0.87
4	117.7	0.851	71.62	0.614	96.54	0.848	107.1	0.95
5	118.1	0.715	76.81	0.649	105.2	0.644	110.2	0.711
6	88.81	0.786	66.71	0.695	104.2	0.841	99.38	0.803
7	103.1	0.754	69.5	0.587	76.99	0.893	121	0.833
8	95.74	0.807	68.57	0.616	109.5	0.797	112.4	0.911
9	100.1	0.603	63.03	0.483	73.93	0.717	93.66	0.865
10	100.3	0.776	61.53	0.608	100.2	0.785	92.03	1.187
AVG	104	0.767	68.79	0.597	95.26	0.8	105.2	0.877
STD	9.09	0.071	4.477	0.063	12.02	0.073	9.502	0.127
		Fabric C				Fabric D		
	Warp		Fill		Warp		Fill	
	Load	Ext	Load	Ext	Load	Ext	Load	Ext
1	92.35	0.758	96.75	0.825	89.58	0.871	87.06	1.038
2	98.9	0.884	73.74	1.072	68.27	0.785	81.05	0.749
3	95.47	0.786	76.3	0.803	93.69	0.785	85.05	0.852
4	84.08	0.899	72.4	0.832	73.64	1.24	79.57	0.836
5	101.4	0.806	62.71	0.857	77.23	0.659	72.7	0.836
6	95.68	0.841	71.17	0.73	86.79	0.9	75.33	0.97
7	97.07	0.961	83.57	1.015	85.23	0.667	77.21	0.92
8	105.8	0.866	76.38	0.885	98.47	0.934	57.61	0.906
9	101.6	0.819	66.98	0.719	76.11	0.808	79.36	1.048
10	104.1	0.927	91.17	0.832	70.31	0.862	59.34	0.995
AVG	97.65	0.855	77.12	0.857	81.93	0.851	75.43	0.915
STD	6.329	0.064	10.57	0.112	10.28	0.164	9.883	0.098

tests) required 672 samples.

Statistical T-tests were performed comparing the results of the two tests (results of 8 UV - Test 1 vs. 8 UV - Test 2 and continuous UV - Test 1 vs. continuous UV - Test 2) for each variable (time, machine, direction, and fabric) to determine if the results of the replicate tests were similar to the original tests.

Correlation between fabrics, machines and test conditions was established using linear regression. Equivalent test times were established for machines and test conditions.

A multifactor analysis of variance was then performed on all four test conditions.

8 HOUR UV - TEST 1

In this test, fabrics experienced slightly more degradation in the UVCON than in the QUV. Fabric B and fabric D showed visible signs of degradation (turned white and small holes), in both the warp and fill directions, after 400 hours of exposure in the UVCON, and after 500 hours of exposure in the QUV. Fabric A and fabric C did not show any visible signs of degradation.

All four fabrics exhibited a decrease in load strength during tensile tests. However, some of the fabrics showed an increase in load strength at certain time intervals (see Table 4). For example, fabric B showed an increase (of

Table 4: 8 Hour UV, Test 1 – Averages

8 Hour UV (4 hour Condensation) 1st Test								
	WARP				FILL			
	QUV		UVCON		QUV		UVCON	
HOURS	LOAD	% RET	LOAD	% RET	LOAD	% RET	LOAD	% RET
A								
0	103.98	100.00	103.98	100.00	68.79	100.00	68.79	100.00
100	92.98	89.42	91.88	88.36	66.19	96.22	80.11	116.46
150	91.94	88.42	84.65	81.41	58.71	85.35	58.02	84.34
200	93.97	90.37	73.26	70.46	61.76	89.78	61.72	89.72
250	76.64	73.71	64.72	62.24	53.66	78.01	48.92	71.11
300	78.71	75.70	65.81	63.29	50.51	73.43	46.45	67.52
400	65.43	62.93	63.01	60.60	44.41	64.56	39.51	57.44
500	60.46	58.15	47.62	45.80	34.77	50.55	33.45	48.63
B								
0	95.26	100.00	95.26	100.00	105.20	100.00	105.20	100.00
100	82.91	87.04	84.32	88.52	90.66	86.18	90.48	86.01
150	82.33	86.43	90.31	94.80	87.96	83.61	85.45	81.23
200	79.33	83.28	82.46	86.56	77.62	73.78	74.36	70.68
250	73.48	77.14	77.95	81.83	73.52	69.89	45.89	43.62
300	40.83	42.86	64.34	67.54	63.64	60.49	30.29	28.79
400	64.92	68.15	0.00	0.00	18.96	18.02	0.00	0.00
500	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C								
0	97.65	100.00	97.65	100.00	77.12	100.00	77.12	100.00
100	81.99	83.96	90.88	93.07	72.15	93.56	74.20	96.21
150	75.52	77.34	78.20	80.08	68.50	88.82	64.03	83.03
200	76.79	78.64	79.70	81.62	64.84	84.08	62.44	80.96
250	70.71	72.41	77.95	79.83	58.50	75.86	58.01	75.22
300	74.29	76.08	71.82	73.55	59.43	77.06	67.70	87.79
400	69.52	71.19	57.82	59.21	53.50	69.37	57.70	74.82
500	66.21	67.80	47.60	48.75	54.16	70.23	45.81	59.40
D								
0	81.93	100.00	81.93	100.00	75.43	100.00	75.43	100.00
100	74.84	91.35	63.52	77.53	64.14	85.03	63.23	83.83
150	74.71	91.19	66.58	81.26	60.83	80.64	60.12	79.70
200	61.99	75.66	53.69	65.53	60.38	80.05	57.55	76.30
250	56.13	68.51	51.38	62.71	51.42	68.17	54.47	72.21
300	50.82	62.03	56.68	69.18	48.48	64.27	44.29	58.72
400	22.90	27.95	0.00	0.00	17.72	23.49	0.00	0.00
500	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

approximately 24 lbf) in load strength at 400 hours (compared to 300 hours) in the warp direction, in the QUV.

Fabric B and fabric D were too brittle for tensile tests after 400 hours of exposure in the UVCON and 500 hours of exposure in the QUV (the fabrics fell apart while being prepared for the tests).

After 500 hours of exposure, fabric C showed the greatest retention of load strength, followed by fabric A, fabric D and fabric B, respectively, for all conditions except 8 UV - Test 1, in the QUV (where fabric B was stronger than fabric D).

8 HOUR UV - TEST 2

Fabrics experienced slightly more degradation in the UVCON, than in the QUV, for the warp direction in this test also. However, results were similar between the two machines for the fill direction. Fabric B turned white and developed small holes after 500 hours of exposure in both machines, in both the warp and fill directions. Fabric A and fabric C did not show any visible signs of degradation.

All three fabrics showed a decrease in load strength during tensile tests (note that replicate tests were not performed on fabric D). However, as in the first test, some of the fabrics exhibited an increase in load strength at certain intervals (see Table 5). For example, fabric C had an increase (of approximately 7 lbf) in load strength at 300

Table 5: 8 Hour UV, Test 2 – Averages

8 Hour UV (4 hour Condensation) 2nd Test								
	WARP				FILL			
	QUV		UVCON		QUV		UVCON	
HOURS	LOAD	% RET	LOAD	% RET	LOAD	% RET	LOAD	% RET
A								
0	103.98	100.00	103.98	100.00	68.79	100.00	68.79	100.00
100	83.54	80.34	100.50	96.65	50.90	73.99	63.90	92.89
150	91.89	88.37	85.48	82.21	54.38	79.05	64.08	93.15
200	82.97	79.79	81.93	78.79	61.02	88.70	57.28	83.27
250	78.48	75.48	69.70	67.03	52.80	76.76	49.48	71.93
300	68.60	65.97	75.69	72.79	50.29	73.11	47.15	68.54
400	75.94	73.03	67.63	65.04	44.76	65.07	47.87	69.59
500	63.57	61.14	52.06	50.07	34.40	50.01	33.44	48.61
B								
0	95.26	100.00	95.26	100.00	105.20	100.00	105.20	100.00
100	99.82	104.79	88.69	93.10	102.80	97.72	94.48	89.81
150	82.74	86.86	75.22	78.96	86.70	82.41	85.44	81.22
200	86.12	90.41	82.35	86.45	79.26	75.34	83.73	79.59
250	71.44	74.99	69.42	72.87	47.01	44.69	46.68	44.37
300	70.94	74.47	74.31	78.01	46.24	43.95	31.77	30.20
400	58.09	60.98	58.53	61.44	14.16	13.46	13.29	12.63
500	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C								
0	97.65	100.00	97.65	100.00	77.12	100.00	77.12	100.00
100	84.76	86.80	92.05	94.27	70.35	91.22	67.94	88.10
150	73.59	75.36	80.40	82.33	73.26	94.99	64.52	83.66
200	69.15	70.81	79.99	81.92	58.59	75.97	67.90	88.04
250	70.76	72.46	92.50	94.73	54.76	71.01	55.11	71.46
300	60.86	62.32	78.89	80.79	54.31	70.42	60.33	78.23
400	69.63	71.31	65.75	67.33	48.23	62.54	55.56	72.04
500	63.90	65.44	53.05	54.33	44.97	58.31	48.55	62.95

hours (compared to 250 hours) in the fill direction, in the UVCON.

Fabric B was too brittle for tensile tests after 500 hours of exposure in both the QUV and the UVCON during this test. After 500 hours of exposure, both of the machines and sample directions ranked the fabrics the same (C, A, B).

CONTINUOUS UV - TEST 1

Fabrics experienced more degradation in the UVCON, than in the QUV, for both the warp and fill directions in this test as well. Fabric D showed visible signs of degradation (white, brittle and holes) at 200 hours of exposure in the UVCON. At 266 hours of exposure, in both the QUV and the UVCON, fabrics B and D showed visible signs of degradation (small holes and white in color). As in the 8 hour UV tests, fabric A and fabric C did not show any visible signs of degradation.

All four fabrics showed an overall decrease in load strength during tensile tests, as in the 8 hour UV tests (see Table 6). Certain time intervals showed an unexpected increase in load strength (as found in some 8 hour UV tests). For example, the load strength of fabric C (warp) increased (approximately 13 lbf) at 200 hours (compared to 166 hours), in the UVCON.

Fabric D was too brittle for tensile tests in both machines at 266 hours, in the warp direction. In the fill

Table 6: Continuous UV, Test 1 – Averages

Continuous UV (No Condensation) 1st Test								
	WARP				FILL			
	QUV		UVCON		QUV		UVCON	
HOURS	LOAD	% RET	LOAD	% RET	LOAD	% RET	LOAD	% RET
A								
0	103.98	100.00	103.98	100.00	68.79	100.00	68.79	100.00
66	90.83	87.35	92.97	89.41	67.32	97.86	62.95	91.51
100	90.43	86.97	91.27	87.78	66.28	96.35	63.96	92.98
133	75.97	73.06	84.19	80.97	60.13	87.41	58.51	85.06
166	76.84	73.90	77.56	74.59	57.71	83.89	51.88	75.42
200	85.17	81.91	70.84	68.13	61.98	90.10	48.22	70.10
266	66.41	63.87	53.67	51.62	48.46	70.45	40.75	59.24
333	53.84	51.78	46.11	44.35	38.22	55.56	28.41	41.30
B								
0	95.26	100.00	95.26	100.00	105.20	100.00	105.20	100.00
66	87.91	92.28	97.11	101.94	99.20	94.30	100.00	95.06
100	91.88	96.45	90.35	94.85	90.61	86.13	87.57	83.24
133	86.62	90.93	86.70	91.01	73.64	70.00	69.74	66.29
166	81.00	85.03	67.54	70.90	42.87	40.75	32.06	30.48
200	71.79	75.36	68.86	72.29	25.54	24.28	24.79	23.56
266	48.80	51.23	51.63	54.20	14.76	14.03	14.62	13.90
333	50.78	53.31	0.00	0.00	0.00	0.00	0.00	0.00
C								
0	97.65	100.00	97.65	100.00	77.12	100.00	77.12	100.00
66	100.97	103.40	93.30	95.55	71.51	92.73	83.59	108.39
100	98.53	100.90	70.51	72.21	70.85	91.87	65.33	84.71
133	87.81	89.92	83.67	85.68	65.03	84.32	62.84	81.48
166	63.98	65.52	68.89	70.55	72.25	93.69	59.77	77.50
200	73.52	75.29	81.59	83.55	70.56	91.49	53.22	69.01
266	82.20	84.18	65.22	66.79	61.34	79.54	49.36	64.00
333	57.15	58.53	57.61	59.00	54.71	70.94	45.27	58.70
D								
0	81.93	100.00	81.93	100.00	75.43	100.00	75.43	100.00
66	80.00	97.64	84.67	103.34	72.63	96.29	65.23	86.48
100	73.21	89.36	89.25	108.93	70.99	94.11	68.35	90.61
133	71.17	86.87	67.30	82.14	60.58	80.31	46.53	61.69
166	71.08	86.76	46.39	56.62	59.79	79.27	43.83	58.11
200	47.91	58.48	33.79	41.24	40.46	53.64	14.82	19.65
266	0.00	0.00	0.00	0.00	37.59	49.83	0.00	0.00
333	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

direction, fabric D was too brittle for tensile tests at 266 hours in the UVCON, and 333 hours in the QUV. Fabric B was too brittle for tensile tests in both the warp and fill directions at 333 hours in the UVCON, and too brittle for tensile tests in the fill direction in the QUV at 333 hours.

The fabric ranks after 333 hours were as follows: UVCON - Fill (C, A, B, D), UVCON - Warp (C, A, D, B), QUV - Fill (C, A, D ,B), and QUV - Warp (C, B, A, D).

CONTINUOUS UV - TEST 2

Fabric degradation was similar for both of the machines, in both directions for this test. Fabric B started to show visible signs of degradation after 266 hours of exposure in both the QUV and the UVCON. Fabric A and fabric C did not show any visible signs of degradation, as in all other tests.

However, as with all of the other tests, there were unexpected increases in load strength during certain time intervals (see Table 7), for all three fabrics (note that replicate tests were not performed on fabric D).

Fabric B was too brittle for tensile tests for both directions, in both machines, at 333 hours.

Retention strength after 333 hours ranked the fabrics similarly in this test. Fabric rank was C, A, B for both machines (QUV and UVCON), and directions (warp and fill). (see Table 8).

Table 7: Continuous UV, Test 2 – Averages

Continuous UV (No Condensation) 2nd Test								
	WARP				FILL			
	QUV		UVCON		QUV		UVCON	
HOURS	LOAD	% RET	LOAD	% RET	LOAD	% RET	LOAD	% RET
A								
0	103.98	100.00	103.98	100.00	68.79	100.00	68.79	100.00
66	93.09	89.53	89.64	86.21	73.64	107.05	67.43	98.02
100	86.51	83.20	84.54	81.30	61.62	89.58	64.53	93.81
133	81.79	78.66	68.96	66.32	49.61	72.12	60.43	87.85
166	76.17	73.25	82.52	79.36	55.63	80.87	47.11	68.48
200	73.68	70.86	69.09	66.45	46.11	67.03	49.10	71.38
266	60.70	58.38	75.90	72.99	39.03	56.74	44.46	64.63
333	47.54	45.72	55.93	53.79	31.33	45.54	24.22	35.21
B								
0	95.26	100.00	95.26	100.00	105.20	100.00	105.20	100.00
66	89.37	93.82	93.70	98.36	83.46	79.33	81.56	77.53
100	91.76	96.33	79.78	83.75	89.80	85.36	80.88	76.88
133	59.07	62.01	78.47	82.37	80.16	76.20	71.64	68.10
166	89.58	94.04	68.12	71.51	61.29	58.26	50.14	47.66
200	56.43	59.24	58.03	60.92	44.01	41.83	47.26	44.92
266	58.16	61.05	55.32	58.07	25.14	23.90	20.58	19.56
333	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C								
0	97.65	100.00	97.65	100.00	77.12	100.00	77.12	100.00
66	86.84	88.93	94.02	96.28	75.05	97.32	61.68	79.98
100	84.41	86.44	72.92	74.67	62.33	80.82	67.35	87.33
133	69.20	70.87	81.52	83.48	70.10	90.90	63.58	82.44
166	66.10	67.69	61.45	62.93	61.34	79.54	64.48	83.61
200	79.26	81.17	76.81	78.66	58.37	75.69	58.10	75.34
266	69.74	71.42	64.15	65.69	56.66	73.47	46.67	60.52
333	48.07	49.23	58.21	59.61	49.03	63.58	50.28	65.20

Table 8: Fabric Rank by Retention

			Best			Worst
Condition	Direction	Machine	1	2	3	4
8 UV – Test 1	Warp	QUV	C	A	B	D
8 UV – Test 1	Warp	UVCON	C	A	D	B
8 UV – Test 1	Fill	QUV	C	A	D	B
8 UV – Test 1	Fill	UVCON	C	A	D	B
8 UV – Test 2	Warp	QUV	C	A	B	NA
8 UV – Test 2	Warp	UVCON	C	A	B	NA
8 UV – Test 2	Fill	QUV	C	A	B	NA
8 UV – Test 2	Fill	UVCON	C	A	B	NA
Continuous UV–Test 1	Warp	QUV	C	B	A	D
Continuous UV–Test 1	Warp	UVCON	C	A	D	B
Continuous UV–Test 1	Fill	QUV	C	A	D	B
Continuous UV–Test 1	Fill	UVCON	C	A	B	D
Continuous UV–Test 2	Warp	QUV	C	A	B	NA
Continuous UV–Test 2	Warp	UVCON	C	A	B	NA
Continuous UV–Test 2	Fill	QUV	C	A	B	NA
Continuous UV–Test 2	Fill	UVCON	C	A	B	NA

note: 8 UV, after 500 hours of exposure
Continuous UV, after 333 hours of exposure

RESULTS VS. CURRENT SPECIFICATION

The USDA's current specification for uv degradation resistance due to accelerated weathering, states that a fabric must retain 70% of its original tensile strength after 200 hours of exposure to a carbon arc.

The results of the 8 hour UV (4 hour condensation) tests showed that all four fabrics (A, B, C, and D) meet this criteria for both machines (QUV and UVCON) and directions (warp and fill), except one condition (fabric D, warp, UVCON, test 1). (see Table 4 and Table 5).

Fabric A and fabric C passed the 200 hour specification for most of the conditions (machine and direction) under the continuous UV tests. Fabric B, warp direction, passed the 200 hour specification in the first continuous UV test. Fabric B, fill direction, and fabric D (warp and fill), failed to pass the 200 hour specification in the first continuous UV test. Fabric B failed to pass the 200 hour specification (for both machines and directions) in the second continuous UV test. (see Table 6 and Table 7).

It is important to note that the continuous UV condition was more severe than the 8 hour UV (4 hour condensation) cycle. The results for the continuous UV condition at 133 hours should be equivalent to the results of the 8 hour UV (4 hour condensation) cycle at 200 hours. Therefore, when analyzing the continuous UV results with respect to the 200 hour specification, one should see if fabrics had 70 percent retention at 133 hours.

At 133 hours, continuous UV, most of the fabrics passed the 70% retention criteria for both machines (QUV and UVCON) and directions (warp and fill). The fabrics and conditions that did not pass specification were as follows: fabric B - fill, UVCON, test 1 (66% retention); fabric D - fill, UVCON (62% retention); fabric A - warp, QUV (66% retention), note: this fabric passed at 166 hours (79% retention); fabric B - warp, QUV (62% retention), note: this fabric passed at 166 hours (94% retention); and fabric B - fill, UVCON (68% retention).

T-TESTS

One hundred and sixty-eight T-tests were performed comparing the results of the first test, with the results of the second replication test, for all four variables (machine, direction, time, and fabric). This was done to determine the confidence interval for (μ_1 - μ_2) and to determine the probability of getting a value as, or more extreme than, the computed t-value.

The results of the T-tests showed that only 11 of the 168 conditions had evidence to conclude a statistically significant difference, at the 0.05 level of significance. (see Tables 9-12). Therefore, the results from the two tests were combined for further analysis.

Table 9: T–test Results – QUV (8 Hour UV)

QUV – 8 Hour UV (4 hour Condensation)						
	Fabric A		Fabric B		Fabric C	
Hours	Warp	Fill	Warp	Fill	Warp	Fill
100	0.26	0.13	0.26	0.29	0.51	0.8
150	0.99	0.6	0.97	0.9	0.84	0.21
200	0.23	0.86	0.47	0.86	0.48	0.56
250	0.87	0.83	0.85	0.056	0.99	0.58
300	0.32	0.96	0.03	0.062	0.17	0.23
400	0.11	0.95	0.28	0.089	0.99	0.47
500	0.6	0.92	NA	NA	0.66	0.18

Table 10: T–test Results – QUV (Continuous UV)

QUV – Continuous UV (No Condensation)						
	Fabric A		Fabric B		Fabric C	
Hours	Warp	Fill	Warp	Fill	Warp	Fill
66	0.7	0.46	0.85	0.26	0.084	0.54
100	0.6	0.32	0.98	0.94	0.016	0.32
133	0.5	0.12	0.11	0.65	0.026	0.54
166	0.96	0.76	0.39	0.051	0.084	0.22
200	0.1	0.036	0.31	0.002	0.32	0.068
266	0.52	0.032	0.44	0.097	0.026	0.68
333	0.25	0.32	NA	NA	0.31	0.32

note: 1. NA = fabrics were not able to be tested, load of 0 created error message.

2. Fabric D was not replicated. Therefore, T–tests could not be performed.

3. Values are probabilities.

Table 11: T–test Results – UVCON (8 Hour UV)

UVCON – 8 Hour UV (4 hour Condensation)						
	Fabric A		Fabric B		Fabric C	
Hours	Warp	Fill	Warp	Fill	Warp	Fill
100	0.31	0.061	0.7	0.72	0.9	0.35
150	0.91	0.41	0.2	1	0.8	0.95
200	0.35	0.44	0.99	0.3	0.97	0.48
250	0.51	0.92	0.4	0.93	0.006	0.57
300	0.16	0.85	0.29	0.71	0.32	0.36
400	0.48	0.21	NA	NA	0.36	0.16
500	0.19	1	NA	NA	0.53	0.56

Table 12: T–test Results – UVCON (Continuous UV)

UVCON – Continuous UV (No Condensation)						
	Fabric A		Fabric B		Fabric C	
Hours	Warp	Fill	Warp	Fill	Warp	Fill
66	0.47	0.53	0.8	0.11	0.92	0.033
100	0.48	0.88	0.25	0.69	0.79	0.76
133	0.23	0.66	0.49	0.88	0.79	0.92
166	0.26	0.38	0.96	0.049	0.37	0.38
200	0.83	0.88	0.28	0.082	0.54	0.46
266	0.007	0.44	0.43	0.27	0.88	0.32
333	0.32	0.22	NA	NA	0.92	0.092

note: 1. NA = fabrics were not able to be tested,
load of 0 created error message.

2. Fabric D was not replicated. Therefore,
T–tests could not be performed.

3. Values are probabilities.

COMBINED TESTS

The results of the first test and second replication test were combined and the peak loads (lbf) versus time were plotted to determine the best straight line fit for all the fabrics and test conditions (see Figures 1-32).

These graphs were than superimposed to determine fabric rank by percent retention. The results of this analysis showed that the fabrics rank as follows: C, A, B, D, with fabric C displaying the best retention and fabric D displaying the worst retention.

The fabric ranks are supported by the actual data also, indicating that the linear regression did not distort test results. The fabric rank was also evident in observing the fabrics after tests were completed, tensile tests could be performed on fabric A and fabric C over the entire test duration. On the other hand, tensile tests could not be performed on the later time periods (e.g 400 and 500 hours for the 8 UV condition, and 266 and 333 hours for the continuous UV condition) for fabric B and fabric D.

CORRELATION

Linear regression was used to determine correlation between fabrics, machines, and test conditions (condensation and no condensation). Equivalent test duration times were then calculated. To determine correlation the following steps were performed: first, the peak loads versus time were plotted to determine a best straight line fit for all of the fabrics and test conditions(see Figures 1-32).

Second, the equation of the line from each graph, was used to calculate a time value (X), using 50%, 60%, 70%, 80%, and 90% of the initial load strength for a fabric as Y (see Table 13). Third, the time values (X's) for each test method were graphed against each other, to produce a best straight line fit (see Figures 33-40).

Finally, from the last set of graphs (figures 33-40), equivalent times were calculated for the machines (QUV and UVCON) and test conditions (condensation and no condensation).

Correlation coefficient

The strength of a linear relation is measured by

$$r^2=\frac{S_{xy}^2}{S_{xx}S_{yy}}$$

where:

$$S_{xy}=\Sigma(x-\overline{x})(y-\overline{y})$$

$$S_{xx}=\Sigma(x-\overline{x})^2$$

$$S_{yy}=\Sigma(y-\overline{y})^2$$

The value for r^2 gives the variability in y that is explained by the linear regression model. The linear model is normally considered to be satisfactory if r^2 is 0.8 or greater. The correlation coefficient has a range from -1 to

Table 13: Load as a Function of Time (X)

	INITIAL	WARP	Y	Y	Y	Y	Y
	LOAD		0.5	0.6	0.7	0.8	0.9
	A	103.98	51.99	62.388	72.786	83.184	93.582
	B	95.26	47.63	57.156	66.682	76.208	85.734
	C	97.65	48.825	58.59	68.355	78.12	87.885
	D	81.93	40.965	49.158	57.351	65.544	73.737
		FILL					
	A	68.79	34.395	41.274	48.153	55.032	61.911
	B	105.2	52.6	63.12	73.64	84.16	94.68
	C	77.12	38.56	46.272	53.984	61.696	69.408
	D	75.43	37.715	45.258	52.801	60.344	67.887

Y = LOAD Y=Mx + B X = (Y−B)/ M

8 UV – QUV (warp)						
	B	M	X	X	X	X	X
A	101.52	−0.0816	606.896	479.488	352.081	224.673	97.2651
B	106.7	−0.1657	356.595	299.088	241.582	184.075	126.568
C	89.534	−0.0594	685.903	521.373	356.843	192.314	27.7839
D	88.647	−0.1558	306.144	253.541	200.937	148.334	95.7303
FILL							
	B	M	X	X	X	X	X
A	68.411	−0.0627	542.485	432.779	323.073	213.368	103.662
B	115.57	−0.2251	279.693	232.966	186.24	139.513	92.7867
C	76.285	−0.0606	622.268	495.06	367.852	240.643	113.435
D	80.138	−0.142	298.775	245.651	192.528	139.404	86.2807
UVCON WARP							
	B	M	X	X	X	X	X
A	102.16	−0.1057	474.645	376.272	277.9	179.527	81.1542
B	108.5	−0.1853	328.423	277.026	225.629	174.231	122.834
C	99.02	−0.0903	555.863	447.725	339.586	231.448	123.31
D	84.971	−0.1611	273.126	222.275	171.425	120.575	69.7244
FILL							
	B	M	X	X	X	X	X
A	72.508	−0.0771	494.114	404.932	315.749	226.567	137.384
B	112.59	−0.2396	250.407	206.495	162.583	118.671	74.7589
C	75.654	−0.0541	685.2	542.744	400.288	257.832	115.376
D	80.007	−0.1513	279.487	229.639	179.791	129.943	80.0952

Table 13 (cont'd)

Continuous UV							
QUV WARP							
	B	M	X	X	X	X	X
A	103.13	−0.1514	337.825	269.137	200.449	131.761	63.0731
B	103.67	−0.2015	278.142	230.862	183.581	136.301	89.0212
C	98.595	−0.1246	399.502	321.119	242.736	164.352	85.9689
D	91.075	−0.2427	206.477	172.718	138.959	105.2	71.4409
FILL							
	B	M	X	X	X	X	X
A	72.736	−0.1073	357.492	293.352	229.212	165.072	100.932
B	112.7	−0.3433	175.091	144.443	113.795	83.1464	52.4982
C	77.056	−0.071	542.159	433.547	324.935	216.323	107.711
D	82.486	−0.2002	223.665	185.982	148.299	110.616	72.933
UVCON WARP							
	B	M	X	X	X	X	X
A	102.29	−0.1521	330.617	262.272	193.927	125.582	57.2368
B	105.98	−0.2318	251.682	210.594	169.505	128.416	87.3275
C	94.893	−0.1154	399.134	314.53	229.925	145.321	60.7174
D	93.485	−0.2883	182.171	153.753	125.335	96.9164	68.4981
FILL							
	B	M	X	X	X	X	X
A	72.872	−0.126	305.421	250.818	196.214	141.61	87.0059
B	109.79	−0.3453	165.629	135.162	104.695	74.2275	43.7603
C	76.962	−0.0971	395.31	315.923	236.535	157.148	77.7608
D	81.085	−0.2813	154.177	127.362	100.547	73.7327	46.9179

1. A value of positive 1 indicates that all values (for x and y) lie exactly on a straight line with a positive slope (perfect positive linear relation). A value of negative 1 indicates that all values (for x and y) lie exactly on a straight line with a negative slope (perfect negative linear correlation) (Johnson and Bhattacharyya 1992). Therefore, if r^2 is closer to 1, the strength of the linear relation is greater.

Fabrics

The four fabrics were analyzed to determine correlation between peak load and length of uv light exposure (see Figures 1-32 and Table 14). In the warp direction, the results were as follows: fabric D had a 0.722 correlation; fabric A had a 0.682 correlation; fabric B had a 0.656 correlation; and fabric C had a 0.556 correlation.

In the fill direction, fabric B had a 0.863 correlation; fabric D had a 0.796 correlation; fabric A had a 0.691 correlation; and fabric C had a 0.490 correlation.

These results show that in the warp direction, fabric D supports the linear model greatest, followed by fabric A, fabric B, and fabric C. In the fill direction, fabric B supports the linear model greatest, followed by fabric D, fabric A, and fabric C.

Results were not greater than 0.800 for most of the individual fabrics (both warp and fill directions), which

Table 14: Linear Regression Correlations–Fabrics

	8 Hour UV		Continuous UV		
Fabric	QUV	UVCON	QUV	UVCON	AVG
A–Warp	0.586	0.745	0.715	0.681	0.682
A–Fill	0.629	0.704	0.638	0.793	0.691
B–Warp	0.673	0.703	0.573	0.673	0.656
B–Fill	0.880	0.897	0.845	0.831	0.863
C–Warp	0.462	0.662	0.552	0.548	0.556
C–Fill	0.524	0.498	0.360	0.579	0.490
D–Warp	0.844	0.703	0.630	0.709	0.722
D–Fill	0.856	0.721	0.788	0.819	0.796
AVG	0.682	0.704	0.638	0.704	NA

Table 15: Linear Regression Correlations – Machines

Test Condition	Warp	Fill
UVCON (8UV) vs. QUV (8UV)	0.957	0.972
UVCON (Continuous UV) vs. QUV (Continuous UV)	0.993	0.967
QUV (Continuous UV) vs. QUV (8UV)	0.943	0.936
UVCON (Continuous UV) vs. UVCON (8UV)	0.985	0.993
Average	0.9695	0.967

means that correlation using linear regression did not support the model. Variance amongst the fabrics load measurements is the major reason for the low correlation. The reasons for variation among samples will be discussed in Chapter 5.

Machines

The QUV and the UVCON were plotted against each other for both test conditions, and sample directions. (see Table 15 and Figures 33-36).

Correlation between the machines (QUV vs. UVCON) was as follows: 8 hour UV (4 hour condensation), 0.957 in the warp direction, and 0.972 in the fill direction. Continuous UV, 0.993 in the warp direction, and 0.967 in the fill direction.

All of these correlation values are very high, representing almost perfect positive correlation, between machines. Therefore, I propose that either machine may be used to achieve similar test results.

Test Condition

Results of the test with condensation (8 UV) were plotted against the test without condensation (continuous UV) for each machine to determine if water would affect strength retention (see Table 15 and Figures 37-40). The length of uv exposure was the variable in this comparison.

For the QUV, correlation was 0.943 in the warp direction, and in the fill direction, correlation was 0.936. The UVCON, had correlation of 0.985 in the warp direction and 0.993 in the fill direction.

These correlation values are very high, illustrating almost perfect positive correlation, between test conditions. Therefore, I propose that either test condition may be used to achieve similar test results.

Equivalent Times

In analyzing the test data, equivalent test times for the QUV and the UVCON were similar, but the degradation was more severe in the UVCON. For example, 150 hours in the QUV, for the 8 hour UV test was equivalent to 150 hours in the UVCON. However, overall the values for the UVCON were lower than the values for the QUV, indicating quicker degradation in the UVCON (see Table 16).

In comparing the 8 Hour UV (4 hour condensation) cycle to the continuous uv condition, 100 hours for the 8 hour UV test, should be equivalent to 66 hours in the continuous UV test, based on the length of UV exposure. The results showed that most of the conditions were close to the expected value. For example, at 250 hours in the QUV, warp direction, the equivalent value for the continuous uv condition was 172 hours, which is very close to the expected value of 166 hours (see Table 16).

Table 16: Equivalent test times

			Time (hours)				
Condition	Y−int	Slope	100	150	200	250	QUV
8 UV − Warp	38.13	0.749	113	150	188	225	UVCON
8 UV − Fill	−15.9	1.049	89	141	194	246	UVCON
Cont. UV − Warp	−12.3	1.003	88	138	188	238	UVCON
Cont. UV − Fill	8.631	0.739	82.6	120	156	193	UVCON
QUV vs. QUV			Time (hours)				
Condition	Y−int	Slope	100	150	200	250	8 Hour− UV
Warp	40.97	0.523	93.2	119	146	172	Cont −UV
Fill	−10.3	0.802	69.8	110	150	190	Cont −UV
Expected time			66	100	133	166	
UVCON vs. UVCON			Time (hours)				
Condition	Y−int	Slope	100	150	200	250	8 Hour− UV
Warp	1.486	0.703	71.7	107	142	177	Cont −UV
Fill	5.167	0.583	63.5	92.7	122	151	Cont −UV
Expected time			66	100	133	166	

note: 1. The expected times are the values for a perfect correlation between the two variables.

e.g. QUV vs. UVCON (100 hours QUV should equal 100 hours UVCON)

8 UV vs. Cont. UV (100 hours 8 UV should equal 66 hours Cont. UV)

Cont. = Continuous

*based on length of uv exposure

Based on these findings, I propose that either machine (the QUV or the UVCON) may be used for accelerated weathering tests to provide similar results, with equal lengths of exposure in each machine. The results also show that the dark condensation cycle did not have a statistically significant effect on test results. Therefore, either a continuous uv condition or a 8 hour UV (4 hour condensation) cycle, may be used to produce similar results. I propose the use of a continuous uv condition to reduce test time, based on the length of uv exposure.

ANOVA

The ANOVA table displays the following information: Sum of Squares, degrees of freedom, mean square, F-ratio, and the significance level. The Sum of Squares is the observed value minus the mean, squared. Degrees of freedom are the number of elements whose squares are summed minus the number of linear constraints satisfied by the elements. The mean square is equal to the Sum of Squares divided by the degrees of freedom. The F-ratio is the treatment mean square divided by the error mean square. The observed F-ratio can be compared with the tabulated value for F (given in statistical tables), with the respective degrees of freedom, to determine if there is a significant difference between the effects in question.

Statgraphics, version 6.0, was used to compute the

ANOVA tables for this analysis. In analyzing the tables, if 0.05 exceeds the significance level given by the table, there is evidence to conclude statistical significance between the elements, at 0.05 level of significance.

The ANOVA tables, for the first tests of each condition (8 UV - Test 1 and Continuous UV - Test 1) show that the difference between all of the main effects (fabric, time, machine, and direction) are statistically significant at the 0.05 level of significance (see Tables 17 and 18). Almost all of the interactions between the main effects are statistically significant also. One reason that there is a statistically significant difference between machines for this test is that fabric B and fabric D have zeros at 400 hours for the UVCON, but were able to be tested and have values for the QUV. Separate ANOVA tables were generated to support this fact (see Tables 19-22), when the last two time periods are omitted from the data, there is not a statistically significant difference between the machines (for both conditions in the warp direction and for the 8 hour UV - 4 hour condensation cycle, in the fill direction).

The significance level for the warp direction was 0.2110 for the 8 Hour UV (4 hour condensation) cycle, and 0.1858 for the continuous uv condition. (see Table 19 and Table 20).

In the fill direction, the significance level was 0.1009 for the 8 Hour UV (4 hour condensation) cycle, and

0.0117 for the continuous uv condition. (see Table 21 and Table 22).

These results illustrate, that for the first set of tests, the difference between machines is not statistically significant at the 0.05 level of significance for both test conditions in the warp direction and for the 8 Hour UV (4 hour condensation) cycle in the fill direction. However, the difference between machines was statistically significant at the 0.05 level of significance for the continuous uv condition, for the fill direction in the first set of tests.

The ANOVA tables, for the second tests (8 UV - Test 2 and Continuous UV - Test 2) show that the difference between fabric, time, and direction are statistically significant at the 0.05 level of significance, but the difference between machines is not statistically significant (see Table 23 and Table 24).

CHAPTER 5

SUMMARY AND CONCLUSIONS

Photodegradation of polymers is a very complex phenomenon. In order to prevent photodegradation, the reactions which polymers undergo due to ultraviolet light absorption must be understood at the molecular level. The initial steps in the photodegradation of polymers are not totally understood today. Possible initiation mechanisms are believed to involve cross-linking and chain scission reactions, which result in the formation of free-radicals.

In this study, the photostabilizer concentrations used were not available, which made it impossible to break down the reactions at the molecular level.

Most of the tests resulted in a steady decrease in load strength over time of exposure to the ultraviolet lights. However, there were unexpected increases in load strength observed at certain time intervals, for the tensile tests (see Figures 41 - 56).

These increases can possibly be explained by a number of factors. First, cross-linking and photo-induced crystallization may have occurred due to the ultraviolet rays. Second, variation of results may have been due to the time interval between when the samples were removed from the accelerated weathering machines and when tensile tests were performed (this was probably a minimal effect, the time between tests was usually less than 50 hours), because once degradation is initiated the reaction may continue whether there is UV light or not.

Third, preparing the samples for tensile tests after being exposed in the machines was a destructive process that could have resulted in test variation. This process (cutting samples in half and removing yarns) was not likely to increase strength, but could have decreased strength. Fourth, variation can possibly be explained by the fact that photodegradation is a surface phenomenon and tensile tests are mechanical tests that measure bulk properties (Gonzalez, et al 1989). Fifth, it is important to remember that some variation can be explained by the tensile testing procedure, due to the fact that there was variation in the unexposed fabrics (control group). Finally, increases at certain time intervals may be explained by the fact that there were large standard deviations (up to 20% in some cases) among some of the samples that were tested (see Tables 25-32).

The study did show favorable correlation results between the machines (QUV and UVCON) and conditions (condensation and no condensation). The correlation between fabrics was not supportive of the linear regression model in most cases, due mainly to variation between samples tested for each fabric.

Correlation between the two machines (QUV and UVCON), and the two different test conditions (condensation and no condensation) supported the linear model, the results were greater than 0.900 for both test conditions and fabric directions.

The results of the analysis of variance showed that the difference between all of the elements (machine, direction, fabric, and time) was statistically significant, for the first set of tests. There was not a statistical significance between the machines for the second set of tests. The difference between fabrics, directions, and time are to be expected because the fabrics are different in strength (e.g. fabric A was stronger than fabric D originally), the warp direction was stronger than the fill direction originally (except for fabric B), and a decrease in strength over time is expected due to UV exposure. However, the machines should ideally show identical results.

There are differences between the machines that may explain these results, in the first set of tests. First, the QUV was set at an irradiance level of 0.72 (the UVCON did not have an adjustable irradiance level). Second, the QUV had a "solar eye", which made rotation of light tubes unnecessary (the light tubes in the UVCON were rotated every 400-450 hours). Finally, the UVCON warmed up quicker than the QUV (the UV temperature of 70° C was reached in approximately 10-15 minutes in the UVCON and approximately

30 minutes in the QUV), after cycle changes (condensation to ultraviolet). This would not have been a factor in the 24 hour UV test, because there was not a cycle change.

This does not mean that the UVCON is better than the QUV, or vice versa. Both machines show favorable results in correlation analysis and both machines ranked the fabrics similarly under most exposure conditions (from best to worst C, A, B). I feel that either machine could be used for accelerated weathering tests. However, results must be analyzed with caution, and more testing is needed.

RECOMMENDATIONS

Further research is needed to provide additional support to these conclusions. I propose the following:

1. Perform a different test, ASTM D 5034 "Breaking Force and Elongation of Textile Fabrics (Grab Test)." This may minimize tensile result variation and would make it possible to immediately perform the tensile tests upon exposure completion.
2. Perform test under different exposure conditions. For example, using UV-B light tubes and different irradiance levels.
3. Perform tests with solid polymers instead of woven material and try different polymers, possibly polyethylene or polystyrene.
4. Use infrared spectrophotometers to monitor

chemical changes, such as carbonyl content.

5. Test more samples and critical time intervals.

I believe the critical time intervals are between 100 and 300 hours, with continuous uv exposure.

Based on the results of this study, I would recommend the USDA uses a specification of 70% retention after 150 hours, with a continuous uv exposure condition, in either the QUV or UVCON.

The continuous uv exposure condition is more severe than the 8 hour UV (4 hour condensation) cycle, which decreases test time. However, comparing tests results between the two conditions, based on the length of uv exposure, gave similar results for both machines (QUV and UVCON) and conditions (condensation and no condensation).

Therefore, I believe that either machine may be used to produce similar results for uv degradation resistance due to accelerated weathering studies. The results also showed that there was not a significant difference between the test condition with water (8 hour UV, 4 hour condensation cycle) and the test condition without water (continuous uv). Therefore, I propose that studies can be done with a continuous uv condition, reducing testing time.

APPENDIX

```
           Analysis of Variance for load8 - Type III Sums of Squares
--------------------------------------------------------------------------------
Source of variation   Sum of Squares   d.f.   Mean square    F-ratio  Sig. level
--------------------------------------------------------------------------------
MAIN EFFECTS
  A:fabric                 37522.98      3     12507.662     134.099     0.0000
  B:time8                 159029.28      6     26504.881     284.169     0.0000
  C:machine                 2535.65      1      2535.652      27.186     0.0000
  D:direction              13111.03      1     13111.027     140.568     0.0000
INTERACTIONS
  AB                      45974.305     18     2554.1281      27.384     0.0000
  AC                        702.882      3      234.2940       2.512     0.0585
  AD                       5825.115      3     1941.7051      20.818     0.0000
  BC                       3466.763      6      577.7939       6.195     0.0000
  BD                        726.770      6      121.1283       1.299     0.2571
  CD                         62.910      1       62.9100       0.674     0.4208
  ABC                      5465.308     18      303.6282       3.255     0.0000
  ABD                      2849.842     18      158.3246       1.697     0.0381
  ACD                      1236.958      3      412.3194       4.421     0.0046
  BCD                      1939.917      6      323.3195       3.466     0.0024
  ABCD                     5294.980     18      294.1655       3.154     0.0000

RESIDUAL                  31339.242    336     93.271552
-------------------------------------------------------------------------------
TOTAL (CORRECTED)         317083.94    447
-------------------------------------------------------------------------------
0 missing values have been excluded.
All F-ratios are based on the residual mean square error.
```

Table 17: ANOVA - 8 UV (Test 1)

```
          Analysis of Variance for load24 - Type III Sums of Squares
--------------------------------------------------------------------------------
Source of variation   Sum of Squares   d.f.   Mean square    F-ratio  Sig. level
--------------------------------------------------------------------------------
MAIN EFFECTS
  A:fabric                 41502.60       3     13834.201    133.814     0.0000
  B:time24                169701.23       6     28283.539    273.577     0.0000
  C:machine                 4582.82       1      4582.817     44.328     0.0000
  D:direction              28301.76       1     28301.763    273.754     0.0000
INTERACTIONS
  AB                      40455.153      18     2247.5085     21.739     0.0000
  AC                        279.363       3       93.1210      0.901     0.4410
  AD                       4692.238       3     1564.0794     15.129     0.0000
  BC                       2135.613       6      355.9355      3.443     0.0026
  BD                       1765.197       6      294.1995      2.846     0.0102
  CD                        168.027       1      168.0271      1.625     0.2032
  ABC                      5320.833      18      295.6018      2.859     0.0001
  ABD                     12572.030      18      698.4461      6.756     0.0000
  ACD                      1064.990       3      354.9967      3.434     0.0172
  BCD                       907.734       6      151.2890      1.463     0.1900
  ABCD                     4959.402      18      275.5224      2.665     0.0003

RESIDUAL                  34737.031     336     103.38402
--------------------------------------------------------------------------------
TOTAL (CORRECTED)         353146.02     447
--------------------------------------------------------------------------------
0 missing values have been excluded.
All F-ratios are based on the residual mean square error.
```

Table 18: ANOVA - Continuous UV (Test 1)

```
Analysis of Variance for cload8 SELECT(ctime8 LE 300)AND(cdirection EQ 1) - Type
--------------------------------------------------------------------------------
Source of variation   Sum of Squares   d.f.   Mean square    F-ratio  Sig. level
--------------------------------------------------------------------------------
MAIN EFFECTS
  A:cfabric                  716.807      2      358.4037      2.580      0.0786
  B:ctime8                 12110.316      4     3027.5791     21.795      0.0000
  C:cmachine                 218.886      1      218.8860      1.576      0.2110
  D:expt                     180.856      1      180.8565      1.302      0.2554
INTERACTIONS
  AB                       2195.1515      8     274.39394      1.975      0.0519
  AC                       1690.6153      2     845.30765      6.085      0.0028
  AD                        193.8629      2      96.93145      0.698      0.4990
  BC                        462.3421      4     115.58552      0.832      0.5064
  BD                        495.2198      4     123.80495      0.891      0.4704
  CD                        139.0499      1     139.04993      1.001      0.3184
  ABC                      1448.8729      8     181.10911      1.304      0.2442
  ABD                      1937.7616      8     242.22020      1.744      0.0912
  ACD                      1795.6268      2     897.81339      6.463      0.0019
  BCD                       225.2964      4      56.32409      0.405      0.8046
  ABCD                      569.9144      8      71.23930      0.513      0.8458

RESIDUAL                   25004.360    180     138.91311
-----------------------------------------------------------------------------
TOTAL (CORRECTED)          49384.940    239
-----------------------------------------------------------------------------
432 missing values have been excluded.
All F-ratios are based on the residual mean square error.
```

Table 19: ANOVA - 8 UV (Test 1), Warp

```
Analysis of Variance for cload24 SELECT (ctime24 LE '00)AND(cdirection EQ 1)    T
-----------------------------------------------------------------------------
Source of variation   Sum of Squares   d.f.   Mean square    F-ratio  Sig. level
--------------------------------------------------------------------------------
MAIN EFFECTS
  A:cfabric                299.415       2       149.7074      1.044    0.3541
  B:ctime8               14416.329       4      3604.0823     25.141    0.0000
  C:cmachine               252.868       1       252.8680      1.764    0.1858
  D:expt                  1416.739       1      1416.7386      9.883    0.0020
INTERACTIONS
  AB                     3685.3062       8      460.66327      3.213    0.0019
  AC                        9.2508       2        4.62539      0.032    0.9683
  AD                      126.0010       2       63.00048      0.439    0.6451
  BC                     1271.9603       4      317.99009      2.218    0.0688
  BD                     1003.0492       4      250.76229      1.749    0.1411
  CD                       13.4758       1       13.47582      0.094    0.7628
  ABC                    2523.1474       8      315.39342      2.200    0.0294
  ABD                     796.7657       8       99.59571      0.695    0.6959
  ACD                     180.4133       2       90.20664      0.629    0.5342
  BCD                     120.9968       4       30.24919      0.211    0.9321
  ABCD                   1851.3897       8      231.42371      1.614    0.1234

RESIDUAL                 25804.314     180      143.35730
------------------------------------------------------------------------------
TOTAL (CORRECTED)        53771.421     239
------------------------------------------------------------------------------
432 missing values have been excluded.
All F-ratios are based on the residual mean square error.
```

Table 20: ANOVA - Continuous UV (Test 1), Warp

```
Analysis of Variance for cload8 SELECT(ctime8 LE 300)AND(cdirection EQ 2) - Type
--------------------------------------------------------------------------------
Source of variation   Sum of Squares   d.f.   Mean square    F-ratio  Sig. level
--------------------------------------------------------------------------------
MAIN EFFECTS
  A:cfabric                 8217.725      2     4108.8627     42.971      0.0000
  B:ctime8                 24652.696      4     6163.1740     64.455      0.0000
  C:cmachine                 259.979      1      259.9794      2.719      0.1009
  D:expt                     357.582      1      357.5821      3.740      0.0547
INTERACTIONS
  AB                       11703.795      8     1462.9744     15.300      0.0000
  AC                        1316.117      2      658.0584      6.882      0.0013
  AD                          37.049      2       18.5244      0.194      0.8241
  BC                         864.995      4      216.2487      2.262      0.0643
  BD                         460.010      4      115.0025      1.203      0.3113
  CD                         214.799      1      214.7988      2.246      0.1357
  ABC                       2078.411      8      259.8014      2.717      0.0075
  ABD                       1759.875      8      219.9843      2.301      0.0227
  ACD                        241.448      2      120.7239      1.263      0.2854
  BCD                        341.439      4       85.3599      0.893      0.4695
  ABCD                       738.919      8       92.3649      0.966      0.4642

RESIDUAL                   17211.474    180     95.619298
--------------------------------------------------------------------------------
TOTAL (CORRECTED)          70456.313    239
--------------------------------------------------------------------------------
432 missing values have been excluded.
All F-ratios are based on the residual mean square error.
```

Table 21: ANOVA - 8 UV (Test 1), Fill

```
Analysis of Variance for cload24 SELECT (ctime24 LE 200)AND(cdirection EQ 2) - T
--------------------------------------------------------------------------------
Source of variation  Sum of Squares   d.f.   Mean square    F-ratio  Sig. level
--------------------------------------------------------------------------------
MAIN EFFECTS
  A:cfabric               3141.508      2      1570.7538     13.035     0.0000
  B:ctime8               27133.077      4      6783.2692     56.292     0.0000
  C:cmachine               782.034      1       782.0343      6.490     0.0117
  D:expt                     9.821      1         9.8213      0.082     0.7786
INTERACTIONS
  AB                     16634.839      8      2079.3548     17.256     0.0000
  AC                        36.785      2        18.3923      0.153     0.8586
  AD                       705.556      2       352.7780      2.928     0.0561
  BC                       286.588      4        71.6471      0.595     0.6670
  BD                       990.233      4       247.5583      2.054     0.0887
  CD                        76.084      1        76.0838      0.631     0.4364
  ABC                      675.830      8        84.4787      0.701     0.6904
  ABD                     3584.024      8       448.0030      3.718     0.0005
  ACD                      156.897      2        78.4485      0.651     0.5227
  BCD                      790.199      4       197.5498      1.639     0.1663
  ABCD                     842.681      8       105.3351      0.874     0.5394

RESIDUAL                 21690.405    180      120.50225
--------------------------------------------------------------------------------
TOTAL (CORRECTED)        77536.561    239
--------------------------------------------------------------------------------
432 missing values have been excluded.
All F-ratios are based on the residual mean square error.
```

Table 22: ANOVA - Continuous UV (Test 1), Fill

```
            Analysis of Variance for load2nd8 - Type III Sums of Squares
--------------------------------------------------------------------------------
Source of variation   Sum of Squares   d.f.   Mean square    F-ratio  Sig. level
--------------------------------------------------------------------------------
MAIN EFFECTS
  A:fabric2nd               3281.213      2      1640.607     17.568     0.0000
  B:time2nd8               84889.289      6     14148.215    151.499     0.0000
  C:machine2nd                34.053      1        34.053      0.365     0.5529
  D:direct2nd              27737.468      1     27737.468    297.013     0.0000
INTERACTIONS
  AB                       37029.663     12     3085.8053     33.043     0.0000
  AC                         823.634      2      411.8170      4.410     0.0131
  AD                        2723.763      2     1361.8815     14.583     0.0000
  BC                         395.726      6       65.9543      0.706     0.6449
  BD                        3753.811      6      625.6352      6.699     0.0000
  CD                           3.054      1        3.0539      0.033     0.8586
  ABC                       2173.594     12      181.1328      1.940     0.0304
  ABD                       7696.029     12      641.3358      6.867     0.0000
  ACD                        268.833      2      134.4166      1.439     0.2390
  BCD                       1019.764      6      169.9607      1.820     0.0956
  ABCD                      1078.429     12       89.8691      0.962     0.4855

RESIDUAL                   23533.802    252     93.388103
--------------------------------------------------------------------------------
TOTAL (CORRECTED)          196442.13    335
--------------------------------------------------------------------------------
0 missing values have been excluded.
All F-ratios are based on the residual mean square error.
```

Table 23: ANOVA - 8 UV (Test 2)

```
        Analysis of Variance for load2nd24 - Type III Sums of Squares
--------------------------------------------------------------------------------
Source of variation  Sum of Squares  d.f.  Mean square   F-ratio  Sig. level
--------------------------------------------------------------------------------
MAIN EFFECTS
  A:fabric2nd              4309.750     2     2154.875    18.268    0.0000
  B:time2nd24             88068.792     6    14678.132   124.435    0.0000
  C:machine2nd              122.032     1      122.032     1.035    0.3101
  D:direct2nd             19589.746     1    19589.746   166.074    0.0000
INTERACTIONS
  AB                      27360.555    12    2280.0462    19.329    0.0000
  AC                        180.130     2      90.0652     0.764    0.4671
  AD                       3032.544     2    1516.2722    12.854    0.0000
  BC                        736.871     6     122.8118     1.041    0.3991
  BD                       2743.085     6     457.1809     3.876    0.0010
  CD                        138.127     1     138.1265     1.171    0.2802
  ABC                      1692.282    12     141.0235     1.196    0.2864
  ABD                      3912.501    12     326.0418     2.764    0.0015
  ACD                        28.787     2      14.3936     0.122    0.8852
  BCD                       859.319     6     143.2198     1.214    0.2994
  ABCD                     2332.139    12     194.3449     1.648    0.0792

RESIDUAL                  29725.360   252    117.95778
--------------------------------------------------------------------------------
TOTAL (CORRECTED)         184832.02   335
--------------------------------------------------------------------------------
0 missing values have been excluded.
All F-ratios are based on the residual mean square error.
```

Table 24: ANOVA - Continuous UV (Test 2)

Table 25: 8 Hour UV, Test 1 – QUV

A Warp	1	2	3	4	AVG	STD
100 Hours						
Load	98.95	97.19	82.07	93.7	92.98	7.59
Ext	0.801	0.62	0.601	0.817	0.71	0.12
150 Hours						
Load	100.9	86.6	81.53	98.74	91.94	9.37
Ext	0.77	0.745	0.726	0.67	0.73	0.04
200 Hours						
Load	88.56	95.68	98.09	93.53	93.97	4.06
Ext	0.719	0.736	0.736	0.712	0.73	0.01
250 Hours						
Load	60.43	80.4	78.44	87.29	76.64	11.45
Ext	0.563	0.785	0.582	0.541	0.62	0.11
300 Hours						
Load	73.66	88.78	63.62	88.78	78.71	12.33
Ext	0.608	0.64	0.55	0.581	0.59	0.04
400 Hours						
Load	57.66	65.23	66.79	72.03	65.43	5.94
Ext	0.49	0.509	0.519	0.47	0.50	0.02
500 Hours						
Load	63.3	53.53	71.87	53.15	60.46	8.94
Ext	0.539	0.556	0.454	0.328	0.47	0.10
A Fill						
100 Hours						
Load	58.71	74.17	67.84	64.05	66.19	6.50
Ext	0.844	0.675	0.705	0.605	0.71	0.10
150 Hours						
Load	56.03	58.98	59.97	59.87	58.71	1.84
Ext	0.621	0.578	0.614	0.587	0.60	0.02
200 Hours						
Load	65.4	53.23	58.87	69.53	61.76	7.18
Ext	0.639	0.434	0.433	0.756	0.57	0.16
250 Hours						
Load	52.75	59.17	47.97	54.76	53.66	4.65
Ext	0.407	0.65	0.395	0.508	0.49	0.12
300 Hours						
Load	45.26	59.19	46.98	50.6	50.51	6.20
Ext	0.534	0.664	0.337	0.385	0.48	0.15
400 Hours						
Load	56.43	45.61	35.89	39.7	44.41	8.96
Ext	0.509	0.483	0.458	0.407	0.46	0.04
500 Hours						
Load	31.52	42.6	30.2	34.74	34.77	5.56
Ext	0.391	0.349	0.52	0.419	0.42	0.07

Table 25 (cont'd)

B Warp	1	2	3	4	AVG	STD
100 Hours						
Load	78.52	114.1	61.48	77.53	82.91	22.21
Ext	0.893	0.724	0.712	0.835	0.79	0.09
150 Hours						
Load	87.41	92.99	73.37	75.54	82.33	9.41
Ext	0.657	0.691	0.625	0.734	0.68	0.05
200 Hours						
Load	70.95	84.35	75.85	86.17	79.33	7.17
Ext	0.592	0.645	0.824	0.76	0.71	0.11
250 Hours						
Load	73.88	66.5	71.17	82.36	73.48	6.66
Ext	0.469	0.482	0.719	0.605	0.57	0.12
300 Hours						
Load	29.99	60.97	45.69	26.68	40.83	15.78
Ext	0.323	0.39	0.426	0.38	0.38	0.04
400 Hours						
Load	62.42	69.1	73.83	54.31	64.92	8.48
Ext	0.587	0.557	0.529	0.487	0.54	0.04
500 Hours						
Load		Too brittle for tensile tests				
Ext						
B Fill						
100 Hours						
Load	100.8	93.53	85.21	83.09	90.66	8.13
Ext	0.88	0.95	0.794	0.872	0.87	0.06
150 Hours						
Load	73.8	84.67	94.32	99.04	87.96	11.17
Ext	0.498	0.679	0.837	0.735	0.69	0.14
200 Hours						
Load	56.97	77.48	88.54	87.49	77.62	14.64
Ext	0.619	0.899	0.6	0.695	0.70	0.14
250 Hours						
Load	89.53	49.21	78.32	77.02	73.52	17.15
Ext	0.403	0.565	0.333	0.537	0.46	0.11
300 Hours						
Load	71.36	75.65	49.83	57.7	63.64	11.97
Ext	0.613	0.671	0.588	0.568	0.61	0.04
400 Hours						
Load	14.63	21.83	19.41	19.97	18.96	3.07
Ext	0.379	0.271	0.446	0.44	0.38	0.08
500 Hours						
		Too brittle for tensile tests				

Table 25 (cont'd)

C Warp	1	2	3	4	AVG	STD
100 Hours						
Load	79.19	74.9	83.25	90.63	81.99	6.69
Ext	0.598	0.698	0.672	0.506	0.62	0.09
150 Hours						
Load	95.57	72.94	72.81	60.75	75.52	14.54
Ext	0.668	0.61	0.584	0.724	0.65	0.06
200 Hours						
Load	73.18	73.1	74.66	86.2	76.79	6.32
Ext	0.51	0.5	0.587	0.704	0.58	0.09
250 Hours						
Load	72.81	74.36	68.08	67.6	70.71	3.38
Ext	0.618	0.544	0.577	0.499	0.56	0.05
300 Hours						
Load	85.58	59.68	88.11	63.8	74.29	14.63
Ext	0.577	0.385	0.587	0.56	0.53	0.10
400 Hours						
Load	76.43	72.05	71.25	58.36	69.52	7.78
Ext	0.593	0.558	0.555	0.439	0.54	0.07
500 Hours						
Load	71.92	72.86	63.52	56.55	66.21	7.69
Ext	0.503	0.525	0.503	0.39	0.48	0.06
C Fill						
100 Hours						
Load	79.33	83.89	58.28	67.11	72.15	11.65
Ext	0.529	0.586	0.551	0.584	0.56	0.03
150 Hours						
Load	69.88	69.72	61.4	72.99	68.50	4.97
Ext	0.461	0.587	0.446	0.583	0.52	0.08
200 Hours						
Load	42.76	85.34	73.74	57.53	64.84	18.62
Ext	0.413	0.663	0.58	0.463	0.53	0.11
250 Hours						
Load	71.25	53.4	58.25	51.11	58.50	9.00
Ext	0.663	0.635	0.646	0.369	0.58	0.14
300 Hours						
Load	66.39	62.04	51.6	57.69	59.43	6.31
Ext	0.689	0.466	0.566	0.393	0.53	0.13
400 Hours						
Load	38.17	50.36	58.98	66.5	53.50	12.16
Ext	0.729	0.524	0.499	0.551	0.58	0.10
500 Hours						
Load	61.77	58.74	51.22	44.91	54.16	7.60
Ext	0.402	0.453	0.396	0.597	0.46	0.09

Table 25 (cont'd)

D Warp	1	2	3	4	AVG	STD
100 Hours						
Load	65.61	70.2	74.42	89.13	74.84	10.18
Ext	0.82	0.693	0.979	0.843	0.83	0.12
150 Hours						
Load	79.76	80.81	69.83	68.43	74.71	6.48
Ext	0.68	0.849	0.93	0.689	0.79	0.12
200 Hours						
Load	69.02	47.97	67.89	63.09	61.99	9.70
Ext	0.843	0.773	0.859	0.855	0.83	0.04
250 Hours						
Load	66.15	47.87	46.55	63.95	56.13	10.35
Ext	0.695	0.431	0.557	0.463	0.54	0.12
300 Hours						
Load	36.11	42.17	58.12	66.87	50.82	14.17
Ext	0.554	0.605	0.633	0.579	0.59	0.03
400 Hours						
Load	31.22	20.11	21.83	18.44	22.90	5.72
Ext	0.48	0.375	0.423	0.305	0.40	0.07
500 Hours						
		Too brittle for tensile tests				
D Fill						
100 Hours						
Load	70.98	55.3	57.88	72.4	64.14	8.80
Ext	0.877	0.746	0.667	0.703	0.75	0.09
150 Hours						
Load	54.85	58.87	62.87	66.74	60.83	5.12
Ext	0.678	0.639	0.566	0.683	0.64	0.05
200 Hours						
Load	53.15	53.45	65.45	69.45	60.38	8.33
Ext	0.723	0.757	0.623	0.653	0.69	0.06
250 Hours						
Load	48.67	55.11	47.44	54.47	51.42	3.93
Ext	0.554	0.616	0.529	0.417	0.53	0.08
300 Hours						
Load	50.15	46.74	38.68	58.34	48.48	8.15
Ext	0.519	0.486	0.846	0.94	0.70	0.23
400 Hours						
Load	13.44	10.95	20	26.47	17.72	6.97
Ext	0.381	0.27	0.307	0.339	0.32	0.05
500 Hours						
		Too brittle for tensile tests				

Table 26: 8 Hour UV, Test 1 – UVCON

A Warp	1	2	3	4	AVG	STD
100 Hours						
Load	97.56	75.89	107.8	86.28	91.883	13.817
Ext	0.751	0.552	0.896	0.66	0.7148	0.1457
150 Hours						
Load	94.58	89.5	81.07	73.45	84.65	9.3164
Ext	0.682	0.711	0.758	0.857	0.752	0.0767
200 Hours						
Load	76.91	69.37	82.44	64.3	73.26	8.021
Ext	0.56	0.536	0.573	0.689	0.5895	0.0681
250 Hours						
Load	51.54	65.26	70.52	71.54	64.715	9.2043
Ext	0.597	0.558	0.564	0.656	0.5938	0.0449
300 Hours						
Load	53.32	66.36	67.41	76.16	65.813	9.416
Ext	0.63	0.474	0.618	0.691	0.6033	0.0919
400 Hours						
Load	51.6	60.97	77.53	61.96	63.015	10.744
Ext	0.532	0.373	0.602	0.415	0.4805	0.1053
500 Hours						
Load	45.69	49.15	42.76	52.87	47.618	4.3684
Ext	0.343	0.365	0.34	0.374	0.3555	0.0166
A Fill						
100 Hours						
Load	80.24	83.54	81.13	75.54	80.113	3.352
Ext	0.628	0.611	0.655	0.652	0.6365	0.0209
150 Hours						
Load	55.7	52.11	66.09	58.17	58.018	5.929
Ext	0.572	0.529	0.591	0.585	0.5693	0.028
200 Hours						
Load	71.14	54.68	64.54	56.51	61.718	7.6025
Ext	0.551	0.481	0.594	0.513	0.5348	0.0488
250 Hours						
Load	50.07	50.2	46.44	48.97	48.92	1.743
Ext	0.389	0.716	0.416	0.379	0.475	0.1614
300 Hours						
Load	48.3	52.62	47.28	37.58	46.445	6.3471
Ext	0.399	0.418	0.457	0.341	0.4038	0.0483
400 Hours						
Load	39.57	30.55	53.21	34.71	39.51	9.8491
Ext	0.473	0.31	0.607	0.467	0.4643	0.1215
500 Hours						
Load	38.04	37.99	24.62	33.15	33.45	6.3177
Ext	0.313	0.392	0.315	0.344	0.341	0.0368

Table 26 (cont'd)

B Warp	1	2	3	4	AVG	STD
100 Hours						
Load	93.02	64.54	101	78.71	84.318	16.09
Ext	0.769	0.723	0.823	0.795	0.7775	0.0425
150 Hours						
Load	94.23	90.15	106	70.85	90.308	14.609
Ext	0.793	0.669	0.745	0.513	0.68	0.1225
200 Hours						
Load	90.63	95.73	73.45	70.01	82.455	12.636
Ext	0.539	0.728	0.743	0.728	0.6845	0.0973
250 Hours						
Load	85.23	95.78	57.73	73.07	77.953	16.366
Ext	0.585	0.749	0.545	0.629	0.627	0.0883
300 Hours						
Load	64.08	69.32	74.68	49.26	64.335	10.942
Ext	0.614	0.508	0.69	0.471	0.5708	0.1
400 Hours						
Load		Too brittle for tensile tests				
Ext						
500 Hours						
Load		Too brittle for tensile tests				
Ext						
B Fill						
100 Hours						
Load	72.97	111.5	99.33	78.12	90.48	18.07
Ext	0.87	0.741	0.743	0.946	0.825	0.1007
150 Hours						
Load	90.82	82.5	97.83	70.63	85.445	11.697
Ext	0.666	0.667	0.751	0.612	0.674	0.0574
200 Hours						
Load	66.95	84.72	60.56	85.21	74.36	12.522
Ext	0.571	0.623	0.661	0.644	0.6248	0.0391
250 Hours						
Load	46.34	56.46	24.94	55.81	45.888	14.711
Ext	0.435	0.369	0.393	0.381	0.3945	0.0287
300 Hours						
Load	39.36	28.94	30.34	22.5	30.285	6.9468
Ext	0.309	0.231	0.254	0.399	0.2983	0.0747
400 Hours						
Load		Too brittle for tensile tests				
Ext						
500 Hours						
		Too brittle for tensile tests				

Table 26 (cont'd)

C Warp	1	2	3	4	AVG	STD
100 Hours						
Load	76	102.9	98.85	85.77	90.88	12.322
Ext	0.718	0.823	0.792	0.635	0.742	0.0838
150 Hours						
Load	73.21	59.79	86.55	93.23	78.195	14.826
Ext	0.495	0.401	0.714	0.656	0.5665	0.1441
200 Hours						
Load	92.05	65.74	78.71	82.31	79.703	10.881
Ext	0.609	0.781	0.603	0.614	0.6518	0.0863
250 Hours						
Load	78.52	76.46	83.7	73.1	77.945	4.4396
Ext	0.537	0.456	0.521	0.601	0.5288	0.0596
300 Hours						
Load	57.72	85.4	74.25	69.91	71.82	11.442
Ext	0.376	0.535	0.58	0.588	0.5198	0.0986
400 Hours						
Load	72.11	55.3	40.94	62.93	57.82	13.186
Ext	0.596	0.5	0.319	0.439	0.4635	0.116
500 Hours						
Load	48.4	46.71	56.81	38.47	47.598	7.5192
Ext	0.42	0.396	0.449	0.239	0.376	0.0939
C Fill						
100 Hours						
Load	75.79	75.73	82.04	63.25	74.203	7.879
Ext	0.513	0.589	0.707	0.595	0.601	0.0799
150 Hours						
Load	79.62	49.02	58.12	69.34	64.025	13.31
Ext	0.622	0.513	0.67	0.797	0.6505	0.1177
200 Hours						
Load	73.23	71.27	48.91	56.35	62.44	11.755
Ext	0.683	0.499	0.41	0.471	0.5158	0.1175
250 Hours						
Load	59.6	68.59	53.5	50.34	58.008	8.034
Ext	0.425	0.556	0.588	0.569	0.5345	0.0742
300 Hours						
Load	71.89	67.68	68.72	62.5	67.698	3.9003
Ext	0.527	0.498	0.451	0.509	0.4963	0.0324
400 Hours						
Load	59.09	55.28	58.15	58.28	57.7	1.6661
Ext	0.419	0.403	0.463	0.554	0.4598	0.0678
500 Hours						
Load	46.2	40.59	53.42	43.03	45.81	5.569
Ext	0.404	0.373	0.501	0.571	0.4623	0.0907

Table 26 (cont'd)

D Warp	1	2	3	4	AVG	STD
100 Hours						
Load	60.24	67.03	45.21	81.58	63.515	15.105
Ext	0.619	0.951	0.634	0.667	0.7178	0.1568
150 Hours						
Load	49.32	68.99	67.11	80.91	66.583	13.03
Ext	0.519	0.752	0.649	0.643	0.6408	0.0953
200 Hours						
Load	57.26	39.09	52.43	65.97	53.688	11.229
Ext	0.802	0.656	0.853	0.867	0.7945	0.0965
250 Hours						
Load	43.44	61.45	58.47	42.17	51.383	9.9923
Ext	0.495	0.523	0.762	0.521	0.5753	0.1252
300 Hours						
Load	64.55	54.31	48.3	59.57	56.683	6.9793
Ext	0.748	0.479	0.522	0.548	0.5743	0.1193
400 Hours						
Load		Too brittle for tensile tests				
Ext						
500 Hours						
Load		Too brittle for tensile tests				
Ext						
D Fill						
100 Hours						
Load	76.54	64	55.25	57.13	63.23	9.6374
Ext	0.648	0.73	0.707	0.675	0.69	0.036
150 Hours						
Load	55.87	70.09	52.3	62.2	60.115	7.809
Ext	0.761	0.715	0.561	0.624	0.6653	0.0898
200 Hours						
Load	65.13	56.03	48.86	60.16	57.545	6.8822
Ext	0.74	0.582	0.482	0.609	0.6033	0.1063
250 Hours						
Load	70.12	44.27	37.61	65.88	54.47	15.952
Ext	0.675	0.838	0.395	0.622	0.6325	0.1831
300 Hours						
Load	46.93	31.6	46.28	52.35	44.29	8.8869
Ext	0.619	0.597	0.599	0.439	0.5635	0.0836
400 Hours						
Load		Too brittle for tensile tests				
Ext						
500 Hours						
		Too brittle for tensile tests				

Table 27: 8 UV, Test 2 – QUV

A Warp	1	2	3	4	AVG	STD
100 Hours						
Load	83.7	69.05	82.17	99.22	83.54	12.35
Ext	0.744	0.837	0.726	0.805	0.78	0.05
150 Hours						
Load	111.5	83.49	81.53	91.03	91.89	13.70
Ext	0.921	0.779	0.794	0.84	0.83	0.06
200 Hours						
Load	103	75.22	81.91	71.73	82.97	14.01
Ext	0.721	0.631	0.793	0.835	0.75	0.09
250 Hours						
Load	80.91	52.78	93.85	86.36	78.48	17.93
Ext	0.561	0.34	0.63	0.721	0.56	0.16
300 Hours						
Load	80.59	66.36	50.6	76.85	68.60	13.43
Ext	0.735	0.616	0.387	0.561	0.57	0.14
400 Hours						
Load	79.76	84.97	64.13	74.9	75.94	8.88
Ext	0.512	0.526	0.535	0.459	0.51	0.03
500 Hours						
Load	68.19	54.04	67.44	64.62	63.57	6.54
Ext	0.42	0.495	0.38	0.386	0.42	0.05
A Fill						
100 Hours						
Load	67.7	35.62	58.2	42.07	50.90	14.69
Ext	0.702	0.573	0.529	0.663	0.62	0.08
150 Hours						
Load	49.85	73.64	55.68	38.34	54.38	14.72
Ext	0.593	0.618	0.603	0.49	0.58	0.06
200 Hours						
Load	64.19	62.42	57.07	60.4	61.02	3.05
Ext	0.473	0.54	0.528	0.503	0.51	0.03
250 Hours						
Load	48	60.64	48.72	53.83	52.80	5.84
Ext	0.465	0.502	0.58	0.434	0.50	0.06
300 Hours						
Load	45.91	43.89	57.72	53.64	50.29	6.50
Ext	0.436	0.519	0.433	0.456	0.46	0.04
400 Hours						
Load	38.25	49.74	48.78	42.25	44.76	5.47
Ext	0.391	0.579	0.385	0.329	0.42	0.11
500 Hours						
Load	28.99	34.71	33.5	40.38	34.40	4.69
Ext	0.429	0.298	0.293	0.51	0.38	0.11

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Table 27 (cont'd)

B Warp	1	2	3	4	AVG	STD
100 Hours						
Load	92.67	82.2	114.3	110.1	99.82	15.02
Ext	0.67	0.717	0.769	0.753	0.73	0.04
150 Hours						
Load	72.32	106.1	78.68	73.85	82.74	15.81
Ext	0.803	0.797	0.8	0.756	0.79	0.02
200 Hours						
Load	101.1	79.33	96.38	67.65	86.12	15.46
Ext	0.681	0.663	0.647	0.683	0.67	0.02
250 Hours						
Load	49.05	89.15	63.36	84.19	71.44	18.64
Ext	0.535	0.661	0.579	0.73	0.63	0.09
300 Hours						
Load	57.32	78.01	74.5	73.93	70.94	9.26
Ext	0.62	0.613	0.785	0.576	0.65	0.09
400 Hours						
Load	50.9	57.21	55.7	68.56	58.09	7.48
Ext	0.492	0.429	0.521	0.445	0.47	0.04
500 Hours						
Load		Samples were too brittle for tensile tests				
Ext						
B Fill						
100 Hours						
Load	90.12	126.4	87.52	107.2	102.81	17.99
Ext	0.718	0.965	0.671	0.729	0.77	0.13
150 Hours						
Load	86.09	88.7	103.8	68.19	86.70	14.60
Ext	0.723	0.56	0.714	0.72	0.68	0.08
200 Hours						
Load	74.71	72.67	95.44	74.2	79.26	10.82
Ext	0.481	0.533	0.658	0.463	0.53	0.09
250 Hours						
Load	51.03	43.52	45.18	48.3	47.01	3.33
Ext	0.362	0.491	0.45	0.419	0.43	0.05
300 Hours						
Load	53.53	46.44	46.85	38.12	46.24	6.31
Ext	0.321	0.272	0.301	0.363	0.31	0.04
400 Hours						
Load	11.6	14.63	11.62	18.77	14.16	3.39
Ext	0.57	0.169	0.115	0.134	0.25	0.22
500 Hours						
Load		Samples were too brittle for tensile tests				
Ext						

Table 27 (cont'd)

C Warp	1	2	3	4	AVG	STD
100 Hours						
Load	89.74	86.66	81.37	81.26	84.76	4.17
Ext	0.711	0.693	0.685	0.75	0.71	0.03
150 Hours						
Load	61.74	80.43	84.94	67.25	73.59	10.90
Ext	0.489	0.548	0.618	0.49	0.54	0.06
200 Hours						
Load	79.06	89.1	50.01	58.42	69.15	18.05
Ext	0.619	0.606	0.438	0.393	0.51	0.12
250 Hours						
Load	63.54	65.45	74.25	79.79	70.76	7.62
Ext	0.525	0.44	0.527	0.702	0.55	0.11
300 Hours						
Load	54.01	69.88	62.79	56.74	60.86	7.05
Ext	0.359	0.566	0.373	0.633	0.48	0.14
400 Hours						
Load	77.85	72.7	65.64	62.31	69.63	6.99
Ext	0.457	0.506	0.556	0.452	0.49	0.05
500 Hours						
Load	56.64	61.93	65.56	71.46	63.90	6.23
Ext	0.398	0.41	0.406	0.446	0.42	0.02
C Fill						
100 Hours						
Load	71.25	79.25	64.64	66.25	70.35	6.57
Ext	0.68	0.604	0.617	0.492	0.60	0.08
150 Hours						
Load	67.68	75.65	77.4	72.3	73.26	4.28
Ext	0.605	0.524	0.617	0.697	0.61	0.07
200 Hours						
Load	52.56	58.55	62.98	60.27	58.59	4.41
Ext	0.564	0.396	0.617	0.553	0.53	0.10
250 Hours						
Load	53.83	52.35	45.77	67.09	54.76	8.94
Ext	0.449	0.524	0.392	0.689	0.51	0.13
300 Hours						
Load	52.43	53.66	50.82	60.32	54.31	4.17
Ext	0.573	0.453	0.372	0.416	0.45	0.09
400 Hours						
Load	49.99	40.21	49.58	53.13	48.23	5.58
Ext	0.48	0.475	0.484	0.427	0.47	0.03
500 Hours						
Load	40.19	57.29	36.72	45.66	44.97	9.00
Ext	0.28	0.382	0.377	0.39	0.36	0.05

Table 28: 8 Hour UV, Test 2 – UVCON

A Warp	1	2	3	4	AVG	STD
100 Hours						
Load	99.06	98.09	101.5	103.4	100.51	2.40
Ext	0.809	0.694	0.811	0.739	0.76	0.06
150 Hours						
Load	95.01	90.44	85.69	70.79	85.48	10.51
Ext	0.78	0.699	0.785	0.649	0.73	0.07
200 Hours						
Load	86.2	61.26	95.11	85.13	81.93	14.48
Ext	0.682	0.664	0.785	0.71	0.71	0.05
250 Hours						
Load	83.19	71.19	66.2	58.23	69.70	10.46
Ext	0.611	0.594	0.419	0.459	0.52	0.10
300 Hours						
Load	86.47	69.69	73.77	72.83	75.69	7.40
Ext	0.545	0.523	0.583	0.67	0.58	0.06
400 Hours						
Load	71.14	69.15	60.67	69.56	67.63	4.72
Ext	0.56	0.582	0.454	0.453	0.51	0.07
500 Hours						
Load	49.23	48.38	54.23	56.38	52.06	3.87
Ext	0.362	0.323	0.393	0.415	0.37	0.04
A Fill						
100 Hours						
Load	78.9	63.36	58.34	55.01	63.90	10.57
Ext	0.628	0.59	0.493	0.585	0.57	0.06
150 Hours						
Load	75.25	47.52	64.11	69.45	64.08	11.94
Ext	0.81	0.69	0.543	0.6	0.66	0.12
200 Hours						
Load	55.68	50.9	54.87	67.68	57.28	7.24
Ext	0.56	0.509	0.574	0.552	0.55	0.03
250 Hours						
Load	52.27	61.21	47.41	37.02	49.48	10.08
Ext	0.609	0.544	0.487	0.531	0.54	0.05
300 Hours						
Load	49.93	43.17	46.09	49.42	47.15	3.15
Ext	0.63	0.475	0.528	0.441	0.52	0.08
400 Hours						
Load	50.04	51.97	44.4	45.07	47.87	3.71
Ext	0.401	0.434	0.447	0.368	0.41	0.04
500 Hours						
Load	34.52	35.54	30.12	33.58	33.44	2.35
Ext	0.278	0.378	0.28	0.353	0.32	0.05

Table 28 (cont'd)

B Warp	1	2	3	4	AVG	STD
100 Hours						
Load	103.6	97.29	71.17	82.68	88.69	14.60
Ext	0.762	0.857	0.715	0.746	0.77	0.06
150 Hours						
Load	71.73	93.8	59.38	75.95	75.22	14.25
Ext	0.734	0.764	0.716	0.837	0.76	0.05
200 Hours						
Load	89.61	68.97	89.1	81.72	82.35	9.62
Ext	0.677	0.65	0.567	0.657	0.64	0.05
250 Hours						
Load	63.87	69.4	78.39	66.01	69.42	6.40
Ext	0.433	0.611	0.603	0.609	0.56	0.09
300 Hours						
Load	56.62	87.6	75.3	77.7	74.31	12.94
Ext	0.529	0.55	0.531	0.639	0.56	0.05
400 Hours						
Load	43.41	58.82	71.49	60.4	58.53	11.55
Ext	0.32	0.456	0.417	0.351	0.39	0.06
500 Hours						
Load		Samples	were too	brittle for	tensile tests	
Ext						
B Fill						
100 Hours						
Load	85.42	108	95.57	88.94	94.48	9.95
Ext	0.782	0.773	0.981	0.741	0.82	0.11
150 Hours						
Load	79.92	79.65	100.6	81.6	85.44	10.14
Ext	0.615	0.98	0.838	0.797	0.81	0.15
200 Hours						
Load	93.56	89.61	70.6	81.15	83.73	10.17
Ext	0.563	0.463	0.57	0.639	0.56	0.07
250 Hours						
Load	54.82	44.46	54.66	32.78	46.68	10.46
Ext	0.316	0.297	0.337	0.255	0.30	0.03
300 Hours						
Load	28.51	33.72	32.97	31.89	31.77	2.30
Ext	0.16	0.299	0.212	0.267	0.23	0.06
400 Hours						
Load	15.52	15.89	9.557	12.19	13.29	2.99
Ext	0.776	0.117	0.104	0.098	0.27	0.33
500 Hours						
Load		Samples	were too	brittle for	tensile tests	
Ext						

Table 28 (cont'd)

C Warp	1	2	3	4	AVG	STD
100 Hours						
Load	99.38	74.85	100.3	93.66	92.05	11.84
Ext	0.775	0.691	0.766	0.744	0.74	0.04
150 Hours						
Load	78.68	71.76	88.89	82.25	80.40	7.14
Ext	0.71	0.8	0.517	0.57	0.65	0.13
200 Hours						
Load	73.15	71.49	87.52	87.79	79.99	8.88
Ext	0.625	0.63	0.653	0.717	0.66	0.04
250 Hours						
Load	94.6	85.93	96.81	92.67	92.50	4.70
Ext	0.769	0.665	0.683	0.578	0.67	0.08
300 Hours						
Load	80.05	82.39	74.58	78.52	78.89	3.28
Ext	0.615	0.566	0.493	0.594	0.57	0.05
400 Hours						
Load	76.59	65.83	55.19	65.4	65.75	8.74
Ext	0.448	0.432	0.329	0.575	0.45	0.10
500 Hours						
Load	65.66	38.25	44.13	64.16	53.05	13.92
Ext	0.418	0.276	0.305	0.483	0.37	0.10
C Fill						
100 Hours						
Load	75.76	60.67	58.98	76.35	67.94	9.40
Ext	0.54	0.527	0.594	0.577	0.56	0.03
150 Hours						
Load	72.72	65.13	60.32	59.92	64.52	5.96
Ext	0.573	0.609	0.537	0.561	0.57	0.03
200 Hours						
Load	57.53	69.96	76.48	67.62	67.90	7.86
Ext	0.416	0.765	0.64	0.527	0.59	0.15
250 Hours						
Load	50.31	59.76	58.34	52.03	55.11	4.64
Ext	0.638	0.576	0.418	0.576	0.55	0.09
300 Hours						
Load	58.5	42.68	72.78	67.36	60.33	13.16
Ext	0.499	0.443	0.546	0.513	0.50	0.04
400 Hours						
Load	53.99	53.93	58.12	56.19	55.56	2.01
Ext	0.399	0.341	0.51	0.358	0.40	0.08
500 Hours						
Load	38.47	51.01	52	52.72	48.55	6.76
Ext	0.444	0.519	0.476	0.363	0.45	0.07

Table 29: Continuous UV, Test 1 – QUV

A Warp	1	2	3	4	AVG	STD
66 Hours						
Load	95.38	95.6	87.95	84.38	90.83	5.58
Ext	0.638	0.821	0.588	0.75	0.70	0.11
100 Hours						
Load	92.56	89.96	91.36	87.84	90.43	2.03
Ext	0.82	0.798	0.853	0.804	0.82	0.02
133 Hours						
Load	77.18	84.78	68.67	73.23	75.97	6.83
Ext	0.58	0.836	0.626	0.583	0.66	0.12
166 Hours						
Load	47.65	83.7	80.89	95.11	76.84	20.41
Ext	0.657	0.71	0.81	0.616	0.70	0.08
200 Hours						
Load	87.46	88.94	75.38	88.91	85.17	6.56
Ext	0.736	0.611	0.538	0.632	0.63	0.08
266 Hours						
Load	72.3	56.05	67.01	70.28	66.41	7.24
Ext	0.467	0.527	0.425	0.606	0.51	0.08
333 Hours						
Load	50.07	65.72	52.81	46.76	53.84	8.30
Ext	0.408	0.403	0.41	0.39	0.40	0.01
A Fill						
66 Hours						
Load	64.54	83.62	62.12	58.98	67.32	11.11
Ext	0.576	0.593	0.625	0.543	0.58	0.03
100 Hours						
Load	67.11	68.27	65.45	64.27	66.28	1.77
Ext	0.563	0.689	0.573	0.733	0.64	0.08
133 Hours						
Load	64.48	60.72	56.4	58.9	60.13	3.40
Ext	0.6	0.65	0.789	0.724	0.69	0.08
166 Hours						
Load	54.68	67.49	55.36	53.32	57.71	6.57
Ext	0.695	0.547	0.553	0.857	0.66	0.15
200 Hours						
Load	64.27	69.13	60.38	54.15	61.98	6.33
Ext	0.508	0.608	0.524	0.609	0.56	0.05
266 Hours						
Load	49.23	43.62	55.19	45.8	48.46	5.05
Ext	0.434	0.493	0.446	0.435	0.45	0.03
333 Hours						
Load	31.73	32.13	35.95	53.05	38.22	10.07
Ext	0.337	0.375	0.607	0.409	0.43	0.12

Table 29 (cont'd)

B Warp	1	2	3	4	AVG	STD
66 Hours						
Load	95.62	97.02	72.97	86.04	87.91	11.09
Ext	0.953	0.918	0.931	0.841	0.91	0.05
100 Hours						
Load	94.41	100.2	89.53	83.37	91.88	7.15
Ext	0.995	0.867	0.92	0.857	0.91	0.06
133 Hours						
Load	100	69.42	90.36	86.71	86.62	12.77
Ext	0.857	0.945	0.671	1.044	0.88	0.16
166 Hours						
Load	61.99	79.01	80.48	102.5	81.00	16.61
Ext	0.738	1.093	0.805	0.799	0.86	0.16
200 Hours						
Load	69.02	75.36	51.68	91.11	71.79	16.31
Ext	0.553	0.677	0.603	0.707	0.64	0.07
266 Hours						
Load	43.95	56.97	55.95	38.31	48.80	9.15
Ext	0.481	0.667	0.5	0.35	0.50	0.13
333 Hours						
Load	36.05	58.44	55.44	53.18	50.78	10.05
Ext	0.835	0.607	0.361	0.453	0.56	0.21
B Fill						
66 Hours						
Load	87.95	116.4	118.3	74.15	99.20	21.72
Ext	0.739	0.968	0.944	0.66	0.83	0.15
100 Hours						
Load	82.1	94.07	85.45	100.8	90.61	8.46
Ext	1.136	0.821	1.007	0.846	0.95	0.15
133 Hours						
Load	83.73	49.05	68.13	93.66	73.64	19.47
Ext	0.821	0.737	0.374	0.848	0.70	0.22
166 Hours						
Load	35.19	30.66	53.72	51.89	42.87	11.65
Ext	0.283	0.496	0.314	0.383	0.37	0.09
200 Hours						
Load	27.84	23.06	30.6	20.64	25.54	4.51
Ext	0.182	0.154	0.233	0.906	0.37	0.36
266 Hours						
Load	11.25	10.47	19.57	17.74	14.76	4.57
Ext	1.086	0.681	0.853	0.247	0.72	0.35
333 Hours						
Load						
Ext		Samples	were too	brittle for	tensile tests	

Table 29 (cont'd)

C Warp	1	2	3	4	AVG	STD
66 Hours						
Load	106.1	103.5	101.4	92.86	100.97	5.74
Ext	0.805	0.863	0.868	0.872	0.85	0.03
100 Hours						
Load	99.27	101.6	99.33	93.93	98.53	3.25
Ext	0.754	0.815	0.995	0.777	0.84	0.11
133 Hours						
Load	79.09	89.4	96.59	86.17	87.81	7.27
Ext	0.626	0.65	0.769	0.849	0.72	0.10
166 Hours						
Load	62.71	78.95	75.09	39.17	63.98	17.93
Ext	0.554	0.63	0.559	0.561	0.58	0.04
200 Hours						
Load	66.58	80.91	81.58	65.02	73.52	8.94
Ext	0.613	0.726	0.505	0.496	0.59	0.11
266 Hours						
Load	87.65	74.66	81.53	84.94	82.20	5.61
Ext	0.543	0.529	0.619	0.542	0.56	0.04
333 Hours						
Load	54.63	74.42	50.12	49.42	57.15	11.74
Ext	0.447	0.557	0.395	0.365	0.44	0.08
C Fill						
66 Hours						
Load	70.25	71.36	68.83	75.6	71.51	2.92
Ext	0.656	0.941	0.656	0.594	0.71	0.16
100 Hours						
Load	73.32	62.63	74.47	72.99	70.85	5.52
Ext	0.841	0.688	0.487	0.681	0.67	0.15
133 Hours						
Load	58.31	72.67	62.87	66.28	65.03	6.05
Ext	0.689	0.814	0.739	0.786	0.76	0.05
166 Hours						
Load	79.14	85.48	55.36	69.02	72.25	13.14
Ext	0.832	0.719	0.585	0.713	0.71	0.10
200 Hours						
Load	66.47	64.59	72.94	78.25	70.56	6.25
Ext	0.596	0.588	0.863	0.567	0.65	0.14
266 Hours						
Load	45.02	47.62	85.42	67.3	61.34	18.89
Ext	0.409	0.574	0.565	0.54	0.52	0.08
333 Hours						
Load	48.78	50.39	64.21	55.44	54.71	6.94
Ext	0.515	0.529	0.584	0.459	0.52	0.05

Table 29 (cont'd)

D Warp	1	2	3	4	AVG	STD
66 Hours						
Load	87.25	94.71	75.33	62.71	80.00	14.02
Ext	0.926	0.853	0.844	1.337	0.99	0.23
100 Hours						
Load	78.71	65.07	60.19	88.86	73.21	13.05
Ext	0.678	0.685	1.037	0.849	0.81	0.17
133 Hours						
Load	74.07	81.53	69.15	59.92	71.17	9.06
Ext	0.939	0.687	0.828	0.667	0.78	0.13
166 Hours						
Load	81.1	55.68	86.23	61.32	71.08	14.86
Ext	0.855	0.848	0.858	0.692	0.81	0.08
200 Hours						
Load	35.87	49.1	54.66	52	47.91	8.34
Ext	0.648	0.843	0.473	0.749	0.68	0.16
266 Hours						
Load		Samples	were too	brittle for	tensile tests	
Ext						
333 Hours						
Load		Samples	were too	brittle for	tensile tests	
Ext						
D Fill						
66 Hours						
Load	71.6	89.83	74.87	54.2	72.63	14.62
Ext	0.688	0.747	0.67	0.752	0.71	0.04
100 Hours						
Load	74.71	63.52	74.28	71.44	70.99	5.19
Ext	0.817	0.6	0.991	0.701	0.78	0.17
133 Hours						
Load	61.18	67.14	54.04	59.95	60.58	5.37
Ext	0.637	0.729	0.892	0.643	0.73	0.12
166 Hours						
Load	63.7	67.14	48.81	59.52	59.79	7.96
Ext	0.704	0.681	0.709	0.926	0.76	0.11
200 Hours						
Load	43.92	36.54	48.43	32.94	40.46	7.01
Ext	0.418	0.415	0.579	0.441	0.46	0.08
266 Hours						
Load	35.54	47.7	28.19	38.93	37.59	8.09
Ext	0.297	0.45	0.322	0.501	0.39	0.10
333 Hours						
Load		Samples	were too	brittle for	tensile tests	
Ext						

Table 30: Continuous UV, Test 1 – UVCON

A Warp	1	2	3	4	AVG	STD
66 Hours						
Load	95.46	95.78	81.48	99.17	92.97	7.84
Ext	0.854	1.122	0.745	0.777	0.87	0.17
100 Hours						
Load	90.79	102.3	78.01	93.99	91.27	10.08
Ext	0.617	0.706	0.883	0.795	0.75	0.11
133 Hours						
Load	95.44	75.81	86.36	79.14	84.19	8.70
Ext	0.629	0.558	0.924	0.678	0.70	0.16
166 Hours						
Load	79.6	76.11	74.71	79.81	77.56	2.55
Ext	0.661	0.619	0.646	0.609	0.63	0.02
200 Hours						
Load	90.58	67.76	63.79	61.21	70.84	13.44
Ext	0.662	0.547	0.535	0.568	0.58	0.06
266 Hours						
Load	59.81	46.39	58.28	50.2	53.67	6.43
Ext	0.412	0.422	0.489	0.358	0.42	0.05
333 Hours						
Load	34.47	51.38	35.95	62.63	46.11	13.41
Ext	0.383	0.313	0.249	0.374	0.33	0.06
A Fill						
66 Hours						
Load	62.87	58.5	53.21	77.21	62.95	10.30
Ext	0.581	0.609	0.763	0.686	0.66	0.08
100 Hours						
Load	64.08	66.66	56.83	68.27	63.96	5.06
Ext	0.617	0.589	0.65	0.474	0.58	0.08
133 Hours						
Load	64.62	63.19	55.49	50.74	58.51	6.55
Ext	0.567	0.567	0.523	0.65	0.58	0.05
166 Hours						
Load	48.32	57.29	55.41	46.5	51.88	5.27
Ext	0.611	0.465	0.48	0.337	0.47	0.11
200 Hours						
Load	47.79	49.4	42.6	53.1	48.22	4.36
Ext	0.402	0.424	0.357	0.498	0.42	0.06
266 Hours						
Load	42.28	40.97	45.07	34.66	40.75	4.40
Ext	0.394	0.3	0.421	0.308	0.36	0.06
333 Hours						
Load	32.43	21.72	31.6	27.87	28.41	4.88
Ext	0.293	0.323	0.309	0.252	0.29	0.03

Table 30 (cont'd)

B Warp	1	2	3	4	AVG	STD
66 Hours						
Load	114.6	69.02	102.5	102.3	97.11	19.59
Ext	0.965	1.042	0.972	0.91	0.97	0.05
100 Hours						
Load	96.54	81.8	96.21	86.85	90.35	7.26
Ext	0.72	0.729	0.856	0.927	0.81	0.10
133 Hours						
Load	66.07	107.8	92.21	80.72	86.70	17.67
Ext	0.691	0.875	0.863	1.045	0.87	0.14
166 Hours						
Load	41.96	92.94	60.13	75.14	67.54	21.70
Ext	0.6	0.772	0.965	0.809	0.79	0.15
200 Hours						
Load	84.64	52.05	77.37	61.37	68.86	14.83
Ext	0.553	0.834	0.591	0.62	0.65	0.13
266 Hours						
Load	53.64	48.08	56.7	48.11	51.63	4.27
Ext	0.62	0.519	0.584	0.477	0.55	0.06
333 Hours						
Load		Samples were too brittle for tensile tests				
Ext						
B Fill						
66 Hours						
Load	108.1	96.97	91.33	103.6	100.00	7.37
Ext	0.859	0.909	0.722	0.879	0.84	0.08
100 Hours						
Load	56.21	95.22	83.36	115.5	87.57	24.76
Ext	0.61	0.778	0.54	0.846	0.69	0.14
133 Hours						
Load	49.18	54.25	85.56	89.96	69.74	20.99
Ext	0.687	0.571	0.631	0.659	0.64	0.05
166 Hours						
Load	39.19	26.6	40.94	21.5	32.06	9.50
Ext	0.281	0.322	0.487	1.061	0.54	0.36
200 Hours						
Load	24	31.44	30.42	13.29	24.79	8.34
Ext	0.21	0.197	0.42	0.182	0.25	0.11
266 Hours						
Load	20.7	11.92	9.262	16.59	14.62	5.06
Ext	0.223	0.321	0.23	0.308	0.27	0.05
333 Hours						
Load		Samples were too brittle for tensile tests				
Ext						

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Table 30 (cont'd)

C Warp	1	2	3	4	AVG	STD
66 Hours						
Load	84.7	98.79	89.96	99.76	93.30	7.23
Ext	0.637	0.759	0.749	0.624	0.69	0.07
100 Hours						
Load	65.5	80.21	63.7	72.64	70.51	7.53
Ext	0.447	0.599	0.541	0.738	0.58	0.12
133 Hours						
Load	78.44	90.82	80.21	85.21	83.67	5.56
Ext	0.593	0.707	0.961	0.721	0.75	0.15
166 Hours						
Load	71.44	58.5	73.91	71.7	68.89	7.01
Ext	0.583	0.449	0.571	0.569	0.54	0.06
200 Hours						
Load	76.62	89.69	89.85	70.2	81.59	9.80
Ext	0.526	0.619	0.598	0.454	0.55	0.07
266 Hours						
Load	56.11	61.66	60.43	82.66	65.22	11.87
Ext	0.495	0.425	0.464	0.52	0.48	0.04
333 Hours						
Load	54.9	52.11	56.05	67.36	57.61	6.71
Ext	0.516	0.347	0.383	0.415	0.42	0.07
C Fill						
66 Hours						
Load	82.44	92.62	77.83	81.48	83.59	6.34
Ext	0.558	0.846	0.631	0.742	0.69	0.13
100 Hours						
Load	72.59	62.66	59.84	66.23	65.33	5.50
Ext	0.49	0.534	0.681	0.721	0.61	0.11
133 Hours						
Load	57.74	51.01	65.37	77.23	62.84	11.25
Ext	0.687	0.587	0.671	0.688	0.66	0.05
166 Hours						
Load	53.53	51.19	64.21	70.15	59.77	8.94
Ext	0.595	0.773	0.54	0.509	0.60	0.12
200 Hours						
Load	54.39	52.86	60.67	44.94	53.22	6.47
Ext	0.566	0.517	0.427	0.809	0.58	0.16
266 Hours						
Load	49.42	48.05	45.4	54.55	49.36	3.84
Ext	0.439	0.531	0.659	0.525	0.54	0.09
333 Hours						
Load	44	40.13	47.22	49.72	45.27	4.15
Ext	0.403	0.37	0.399	0.375	0.39	0.02

Table 30 (cont'd)

D Warp	1	2	3	4	AVG	STD
66 Hours						
Load	75.11	93.74	101.8	68.03	84.67	15.75
Ext	0.821	0.926	0.889	0.983	0.90	0.07
100 Hours						
Load	88.46	89.26	81.13	98.15	89.25	6.97
Ext	0.933	0.705	0.627	0.907	0.79	0.15
133 Hours						
Load	62.47	81.42	59.49	65.8	67.30	9.76
Ext	0.827	0.671	0.731	0.893	0.78	0.10
166 Hours						
Load	35.97	59.36	23.33	66.9	46.39	20.24
Ext	0.575	0.427	0.531	0.541	0.52	0.06
200 Hours						
Load	29.1	32.46	38.9	34.68	33.79	4.11
Ext	0.565	0.507	0.509	0.292	0.47	0.12
266 Hours						
Load		Samples were too brittle for tensile tests				
Ext						
333 Hours						
Load		Samples were too brittle for tensile tests				
Ext						
D Fill						
66 Hours						
Load	51.09	73.32	66.93	69.58	65.23	9.78
Ext	0.92	0.642	0.669	0.685	0.73	0.13
100 Hours						
Load	62.66	88.67	64.16	57.91	68.35	13.81
Ext	0.633	0.731	0.85	0.647	0.72	0.10
133 Hours						
Load	56.51	38.34	51.36	39.92	46.53	8.83
Ext	0.649	0.457	0.349	0.573	0.51	0.13
166 Hours						
Load	31.76	42.93	56.64	43.97	43.83	10.18
Ext	0.441	0.491	0.473	0.469	0.47	0.02
200 Hours						
Load	7.302	25.4	19.95	6.631	14.82	9.34
Ext	0.258	0.461	0.512	0.273	0.38	0.13
266 Hours						
Load		Samples were too brittle for tensile tests				
Ext						
333 Hours						
		Samples were too brittle for tensile tests				

Table 31: Continuous UV, Test 2 – QUV

A Warp	1	2	3	4	AVG	STD
66 Hours						
Load	95.95	83.95	87.36	105.1	93.09	9.47
Ext	0.665	0.746	0.852	0.846	0.78	0.09
100 Hours						
Load	84.64	71.95	104	85.45	86.51	13.20
Ext	0.64	0.8	0.804	0.779	0.76	0.08
133 Hours						
Load	73.05	71.97	79.54	102.6	81.79	14.27
Ext	0.542	0.53	0.647	0.82	0.63	0.13
166 Hours						
Load	77.66	66.63	72.56	87.84	76.17	8.99
Ext	0.686	0.611	0.66	0.617	0.64	0.04
200 Hours						
Load	67.46	69.58	69.96	87.73	73.68	9.43
Ext	0.535	0.505	0.58	0.55	0.54	0.03
266 Hours						
Load	71.68	63.41	68.48	39.22	60.70	14.72
Ext	0.503	0.457	0.415	0.347	0.43	0.07
333 Hours						
Load	45.48	47.81	51.52	45.34	47.54	2.89
Ext	0.268	0.378	0.359	0.403	0.35	0.06
A Fill						
66 Hours						
Load	68.83	84.38	59.87	81.48	73.64	11.40
Ext	0.508	0.666	0.642	0.732	0.64	0.09
100 Hours						
Load	59.3	55.7	72.72	58.74	61.62	7.57
Ext	0.619	0.582	0.681	0.583	0.62	0.05
133 Hours						
Load	36.94	57.42	55.09	48.99	49.61	9.16
Ext	0.591	0.634	0.526	0.607	0.59	0.05
166 Hours						
Load	70.31	45.21	50.47	56.54	55.63	10.82
Ext	0.543	0.483	0.539	0.406	0.49	0.06
200 Hours						
Load	43.22	40.62	59.81	40.78	46.11	9.21
Ext	0.49	0.465	0.453	0.553	0.49	0.04
266 Hours						
Load	39.84	36.43	35.6	44.24	39.03	3.93
Ext	0.327	0.267	0.297	0.365	0.31	0.04
333 Hours						
Load	36.32	31.11	36.72	21.15	31.33	7.25
Ext	0.324	0.278	0.336	0.304	0.31	0.03

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Table 31 (cont'd)

B Warp	1	2	3	4	AVG	STD
66 Hours						
Load	88.19	89.34	100.8	79.14	89.37	8.88
Ext	0.795	0.601	0.767	0.758	0.73	0.09
100 Hours						
Load	99.27	100.1	81.1	86.55	91.76	9.43
Ext	0.986	0.655	0.763	0.715	0.78	0.14
133 Hours						
Load	75.68	44.46	33.32	82.82	59.07	23.92
Ext	0.921	0.857	1.09	0.771	0.91	0.13
166 Hours						
Load	86.58	99.65	84.13	87.97	89.58	6.90
Ext	0.596	0.704	0.761	0.651	0.68	0.07
200 Hours						
Load	76.86	41.42	34.66	72.78	56.43	21.48
Ext	0.495	0.643	0.405	0.601	0.54	0.11
266 Hours						
Load	53.07	64.56	81.02	33.99	58.16	19.78
Ext	0.357	0.461	0.511	0.541	0.47	0.08
333 Hours						
Load		Samples	were too	brittle for	tensile tests	
Ext						
B Fill						
66 Hours						
Load	69.8	80.54	92.86	90.63	83.46	10.57
Ext	0.794	0.776	0.849	0.909	0.83	0.06
100 Hours						
Load	82.66	111	71.57	93.96	89.80	16.83
Ext	0.599	0.692	0.698	0.801	0.70	0.08
133 Hours						
Load	65.26	79.84	68.64	106.9	80.16	18.88
Ext	0.465	0.964	0.823	0.73	0.75	0.21
166 Hours						
Load	55.19	70.09	62.12	57.74	61.29	6.53
Ext	0.491	0.476	0.404	0.458	0.46	0.04
200 Hours						
Load	46.36	42.52	44.97	42.2	44.01	2.00
Ext	0.336	0.281	0.291	0.307	0.30	0.02
266 Hours						
Load	18.79	19.92	24.62	37.22	25.14	8.44
Ext	0.308	0.145	0.417	0.506	0.34	0.16
333 Hours						
Load		Samples	were too	brittle for	tensile tests	
Ext						

Table 31 (cont'd)

C Warp	1	2	3	4	AVG	STD
66 Hours						
Load	100.2	74.6	82.39	90.17	86.84	10.94
Ext	0.695	0.775	0.603	0.657	0.68	0.07
100 Hours						
Load	82.79	77.66	84.54	92.64	84.41	6.22
Ext	0.714	0.757	0.584	0.691	0.69	0.07
133 Hours						
Load	57.66	79.33	66.17	73.64	69.20	9.39
Ext	0.415	0.564	0.66	0.62	0.56	0.11
166 Hours						
Load	61.05	70.66	76.75	55.92	66.10	9.37
Ext	0.363	0.588	0.56	0.451	0.49	0.10
200 Hours						
Load	74.6	84.89	81.77	75.76	79.26	4.90
Ext	0.562	0.582	0.585	0.553	0.57	0.02
266 Hours						
Load	64.16	70.76	66.9	77.15	69.74	5.63
Ext	0.452	0.547	0.409	0.56	0.49	0.07
333 Hours						
Load	45.05	50.25	35.09	61.88	48.07	11.15
Ext	0.282	0.333	0.269	0.384	0.32	0.05
C Fill						
66 Hours						
Load	61.99	75.65	76.64	85.91	75.05	9.86
Ext	0.571	0.539	0.673	0.801	0.65	0.12
100 Hours						
Load	60.05	61.99	79.84	47.44	62.33	13.34
Ext	0.806	0.494	0.635	0.535	0.62	0.14
133 Hours						
Load	76.78	57.23	59.81	86.58	70.10	14.00
Ext	0.696	0.581	0.651	0.849	0.69	0.11
166 Hours						
Load	54.74	72.64	62.9	55.09	61.34	8.42
Ext	0.483	0.617	0.614	0.344	0.51	0.13
200 Hours						
Load	48.99	69.45	58.2	56.83	58.37	8.43
Ext	0.497	0.572	0.413	0.553	0.51	0.07
266 Hours						
Load	49.58	51.19	61.45	64.43	56.66	7.38
Ext	0.517	0.367	0.558	0.644	0.52	0.12
333 Hours						
Load	54.9	55.01	39.03	47.17	49.03	7.61
Ext	0.571	0.422	0.718	0.346	0.51	0.16

Table 32: Continuous UV, Test 2 – UVCON

A Warp	1	2	3	4	AVG	STD
66 Hours						
Load	89.53	90.85	91.62	86.55	89.64	2.23
Ext	0.625	0.705	0.909	0.797	0.76	0.12
100 Hours						
Load	105.9	77.56	73.02	81.69	84.54	14.67
Ext	0.826	0.767	0.52	0.73	0.71	0.13
133 Hours						
Load	39.46	79.22	75.3	81.85	68.96	19.85
Ext	0.67	0.683	0.728	0.842	0.73	0.08
166 Hours						
Load	76.83	90.23	76.86	86.15	82.52	6.76
Ext	0.632	0.7	0.604	0.842	0.69	0.11
200 Hours						
Load	65.77	64.91	76.72	68.97	69.09	5.38
Ext	0.592	0.476	0.658	0.722	0.61	0.11
266 Hours						
Load	84.75	71.57	67.33	79.95	75.90	7.89
Ext	0.71	0.487	0.52	0.545	0.57	0.10
333 Hours						
Load	59.81	50.44	69.83	43.62	55.93	11.40
Ext	0.42	0.477	0.402	0.465	0.44	0.04
A Fill						
66 Hours						
Load	66.39	70.6	76.24	56.48	67.43	8.34
Ext	0.554	0.589	0.715	0.519	0.59	0.09
100 Hours						
Load	65.5	59.97	60.89	71.76	64.53	5.39
Ext	0.693	0.525	0.601	0.524	0.59	0.08
133 Hours						
Load	64.48	54.01	63.79	59.44	60.43	4.83
Ext	0.664	0.557	0.511	0.508	0.56	0.07
166 Hours						
Load	51.22	46.63	55.03	35.54	47.11	8.44
Ext	0.617	0.413	0.5	0.345	0.47	0.12
200 Hours						
Load	54.82	59.84	38.79	42.95	49.10	9.87
Ext	0.498	0.503	0.351	0.48	0.46	0.07
266 Hours						
Load	35.73	40.75	49.61	51.73	44.46	7.51
Ext	0.36	0.378	0.394	0.416	0.39	0.02
333 Hours						
Load	28.67	20.46	23.97	23.79	24.22	3.38
Ext	0.42	0.289	0.277	0.264	0.31	0.07

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Table 32 (cont'd)

B Warp	1	2	3	4	AVG	STD
66 Hours						
Load	69.61	106.7	102.9	95.6	93.70	16.71
Ext	0.868	0.833	0.739	0.747	0.80	0.06
100 Hours						
Load	91.01	76.83	61.32	89.96	79.78	13.90
Ext	0.73	0.68	0.881	0.679	0.74	0.10
133 Hours						
Load	78.58	60.24	88.21	86.85	78.47	12.88
Ext	0.623	0.667	0.661	0.677	0.66	0.02
166 Hours						
Load	67.79	66.23	78.31	60.16	68.12	7.55
Ext	0.738	0.493	0.764	0.567	0.64	0.13
200 Hours						
Load	66.01	44.89	61.26	59.97	58.03	9.14
Ext	0.56	0.764	0.559	0.482	0.59	0.12
266 Hours						
Load	50.85	59.17	63.62	47.65	55.32	7.36
Ext	0.519	0.591	0.548	0.497	0.54	0.04
333 Hours						
Load		Samples were too brittle for tensile tests				
Ext						
B Fill						
66 Hours						
Load	100.9	70.42	88.94	65.96	81.56	16.29
Ext	0.65	0.677	0.679	0.629	0.66	0.02
100 Hours						
Load	80.05	102.3	85.53	55.65	80.88	19.30
Ext	0.856	0.917	0.753	0.633	0.79	0.12
133 Hours						
Load	55.33	71.17	86.12	73.93	71.64	12.66
Ext	0.793	0.615	0.563	0.497	0.62	0.13
166 Hours						
Load	35.44	50.87	58.04	56.21	50.14	10.26
Ext	0.316	0.416	0.341	0.497	0.39	0.08
200 Hours						
Load	31.49	63.03	61.8	32.7	47.26	17.52
Ext	0.184	0.421	0.396	0.259	0.32	0.11
266 Hours						
Load	27.46	26.23	9.799	18.82	20.58	8.14
Ext	0.91	0.665	0.659	0.204	0.61	0.29
333 Hours						
Load		Samples were too brittle for tensile tests				
Ext						

Table 32 (cont'd)

C Warp	1	2	3	4	AVG	STD
66 Hours						
Load	100.2	100.7	77.77	97.4	94.02	10.93
Ext	0.776	0.805	0.582	0.8	0.74	0.11
100 Hours						
Load	90.23	53.64	75.54	72.27	72.92	15.04
Ext	0.614	0.687	0.888	0.635	0.71	0.13
133 Hours						
Load	88.32	78.6	64.05	95.09	81.52	13.47
Ext	0.806	0.629	0.468	0.551	0.61	0.14
166 Hours						
Load	58.5	46.93	78.79	61.58	61.45	13.17
Ext	0.588	0.452	0.548	0.491	0.52	0.06
200 Hours						
Load	85.07	60.99	83.25	77.91	76.81	10.97
Ext	0.605	0.632	0.539	0.567	0.59	0.04
266 Hours						
Load	66.66	62.28	70.98	56.67	64.15	6.12
Ext	0.557	0.427	0.543	0.653	0.55	0.09
333 Hours						
Load	56.16	47.14	69.74	59.81	58.21	9.35
Ext	0.37	0.482	0.431	0.323	0.40	0.07
C Fill						
66 Hours						
Load	74.25	69.88	53.02	49.56	61.68	12.21
Ext	0.663	0.548	0.49	0.793	0.62	0.13
100 Hours						
Load	53.93	71.89	63.6	79.97	67.35	11.17
Ext	0.474	0.77	0.541	0.811	0.65	0.17
133 Hours						
Load	71.19	55.09	69.42	58.6	63.58	7.94
Ext	0.582	0.524	0.624	0.459	0.55	0.07
166 Hours						
Load	61.77	63.97	66.6	65.58	64.48	2.11
Ext	0.572	0.71	0.441	0.475	0.55	0.12
200 Hours						
Load	71.03	59.6	45.8	55.97	58.10	10.41
Ext	0.703	0.625	0.579	0.628	0.63	0.05
266 Hours						
Load	44.19	47.65	44.48	50.34	46.67	2.91
Ext	0.535	0.476	0.651	0.432	0.52	0.09
333 Hours						
Load	52.4	51.22	48.97	48.54	50.28	1.84
Ext	0.521	0.477	0.451	0.397	0.46	0.05

Table 33: 8 Hour UV, Test 1 (Test dates)

		Fabric A		Fabric B		Fabric C		Fabric D	
Hours	Duty	Warp	Fill	Warp	Fill	Warp	Fill	Warp	Fill
100	Start	2/2/94	2/2/94	2/2/94	2/2/94	2/2/94	2/2/94	2/2/94	2/2/94
	Time	6:30 am	6:30 am	6:30 am	6:30 am	6:30 am	6:30 am	6:30 am	6:30 am
	Finish	2/6/94	2/6/94	2/6/94	2/6/94	2/6/94	2/6/94	2/6/94	2/6/94
	Time	10:00 am	10:00 am	10:00 am	10:00 am	10:00 am	10:00 am	10:00 am	10:00 am
150	Start	2/2/94	2/2/94	2/2/94	2/2/94	2/2/94	2/2/94	2/2/94	2/2/94
	Time	6:30 am	6:30 am	6:30 am	6:30 am	6:30 am	6:30 am	6:30 am	6:30 am
	Finish	2/8/94	2/8/94	2/8/94	2/8/94	2/8/94	2/8/94	2/8/94	2/8/94
	Time	1:30 pm	1:30 pm	1:30 pm	1:30 pm	1:30 pm	1:30 pm	1:30 pm	1:30 pm
200	Start	1/24/94	1/24/94	1/24/94	1/24/94	1/24/94	1/24/94	1/24/94	1/24/94
	Time	7:00 pm	7:00 pm	7:00 pm	7:00 pm	7:00 pm	7:00 pm	7:00 pm	7:00 pm
	Finish	2/2/94	2/2/94	2/2/94	2/2/94	2/2/94	2/2/94	2/2/94	2/2/94
	Time	4:30 am	4:30 am	4:30 am	4:30 am	4:30 am	4:30 am	4:30 am	4:30 am
250	Start	1/29/94	1/29/94	1/29/94	1/29/94	1/29/94	1/29/94	1/29/94	1/29/94
	Time	1:00 am	1:00 am	1:00 am	1:00 am	1:00 am	1:00 am	1:00 am	1:00 am
	Finish	2/8/94	2/8/94	2/8/94	2/8/94	2/8/94	2/8/94	2/8/94	2/8/94
	Time	1:30 pm	1:30 pm	1:30 pm	1:30 pm	1:30 pm	1:30 pm	1:30 pm	1:30 pm
300	Start	1/11/94	1/11/94	1/11/94	1/11/94	1/11/94	1/11/94	1/11/94	1/11/94
	Time	9:00 pm	9:00 pm	9:00 pm	9:00 pm	9:00 pm	9:00 pm	9:00 pm	9:00 pm
	Finish	1/24/94	1/24/94	1/24/94	1/24/94	1/24/94	1/24/94	1/24/94	1/24/94
	Time	5:00 pm	5:00 pm	5:00 pm	5:00 pm	5:00 pm	5:00 pm	5:00 pm	5:00 pm
400	Start	1/11/94	1/11/94	1/11/94	1/11/94	1/11/94	1/11/94	1/11/94	1/11/94
	Time	9:00 pm	9:00 pm	9:00 pm	9:00 pm	9:00 pm	9:00 pm	9:00 pm	9:00 pm
	Finish	1/28/94	1/28/94	1/28/94	1/28/94	1/28/94	1/28/94	1/28/94	1/28/94
	Time	10:30 pm	10:30 pm	10:30 pm	10:30 pm	10:30 pm	10:30 pm	10:30 pm	10:30 pm
500	Start	1/11/94	1/11/94	1/11/94	1/11/94	1/11/94	1/11/94	1/11/94	1/11/94
	Time	9:00 pm	9:00 pm	9:00 pm	9:00 pm	9:00 pm	9:00 pm	9:00 pm	9:00 pm
	Finish	2/2/94	2/2/94	2/2/94	2/2/94	2/2/94	2/2/94	2/2/94	2/2/94
	Time	4:30 am	4:30 am	4:30 am	4:30 am	4:30 am	4:30 am	4:30 am	4:30 am

Table 34: 8 Hour

Table 34: 8 Hour UV, Test 2 (Test dates)

		Fabric A		Fabric B		Fabric C		Fabric D	
Hours	Duty	Warp	Fill	Warp	Fill	Warp	Fill	Warp	Fill
100	Start	4/16/94	4/16/94	4/16/94	4/16/94	4/16/94	4/16/94	NA	NA
	Time	2:00 pm	2:00 pm	2:00 pm	2:00 pm	2:00 pm	2:00 pm	NA	NA
	Finish	4/20/94	4/20/94	4/20/94	4/20/94	4/20/94	4/20/94	NA	NA
	Time	6:00 pm	6:00 pm	6:00 pm	6:00 pm	6:00 pm	6:00 pm	NA	NA
150	Start	4/12/94	4/12/94	4/12/94	4/12/94	4/12/94	4/12/94	NA	NA
	Time	10:00 am	10:00 am	10:00 am	10:00 am	10:00 am	10:00 am	NA	NA
	Finish	4/18/94	4/18/94	4/18/94	4/18/94	4/18/94	4/18/94	NA	NA
	Time	4:00 pm	4:00 pm	4:00 pm	4:00 pm	4:00 pm	4:00 pm	NA	NA
200	Start	4/10/94	4/10/94	4/10/94	4/10/94	4/10/94	4/10/94	NA	NA
	Time	8:00 am	8:00 am	8:00 am	8:00 am	8:00 am	8:00 am	NA	NA
	Finish	4/18/94	4/18/94	4/18/94	4/18/94	4/18/94	4/18/94	NA	NA
	Time	4:00 pm	4:00 pm	4:00 pm	4:00 pm	4:00 pm	4:00 pm	NA	NA
250	Start	3/30/94	3/30/94	3/30/94	3/30/94	3/30/94	3/30/94	NA	NA
	Time	9:00 pm	9:00 pm	9:00 pm	9:00 pm	9:00 pm	9:00 pm	NA	NA
	Finish	4/10/94	4/10/94	4/10/94	4/10/94	4/10/94	4/10/94	NA	NA
	Time	8:00 am	8:00 am	8:00 am	8:00 am	8:00 am	8:00 am	NA	NA
300	Start	3/30/94	3/30/94	3/30/94	3/30/94	3/30/94	3/30/94	NA	NA
	Time	9:00 pm	9:00 pm	9:00 pm	9:00 pm	9:00 pm	9:00 pm	NA	NA
	Finish	4/12/94	4/12/94	4/12/94	4/12/94	4/12/94	4/12/94	NA	NA
	Time	10:00 am	10:00 am	10:00 am	10:00 am	10:00 am	10:00 am	NA	NA
400	Start	3/30/94	3/30/94	3/30/94	3/30/94	3/30/94	3/30/94	NA	NA
	Time	9:00 pm	9:00 pm	9:00 pm	9:00 pm	9:00 pm	9:00 pm	NA	NA
	Finish	4/16/94	4/16/94	4/16/94	4/16/94	4/16/94	4/16/94	NA	NA
	Time	2:00 pm	2:00 pm	2:00 pm	2:00 pm	2:00 pm	2:00 pm	NA	NA
500	Start	3/30/94	3/30/94	3/30/94	3/30/94	3/30/94	3/30/94	NA	NA
	Time	9:00 pm	9:00 pm	9:00 pm	9:00 pm	9:00 pm	9:00 pm	NA	NA
	Finish	4/20/94	4/20/94	4/20/94	4/20/94	4/20/94	4/20/94	NA	NA
	Time	6:00 pm	6:00 pm	6:00 pm	6:00 pm	6:00 pm	6:00 pm	NA	NA

Table 35: Continuous UV, Test 1 (Test dates)

Table 35: Continuous UV, Test 1 (Test dates)

		Fabric A		Fabric B		Fabric C		Fabric D	
Hours	Duty	Warp	Fill	Warp	Fill	Warp	Fill	Warp	Fill
66	Start	12/31/93	12/31/93	12/31/93	12/31/93	12/31/93	12/31/93	12/31/93	12/31/93
	Time	12:05 am	12:05 am	12:05 am	12:05 am	12:05 am	12:05 am	12:05 am	12:05 am
	Finish	1/2/94	1/2/94	1/2/94	1/2/94	1/2/94	1/2/94	1/2/94	1/2/94
	Time	6:05 pm	6:05 pm	6:05 pm	6:05 pm	6:05 pm	6:05 pm	6:05 pm	6:05 pm
100	Start	12/31/93	12/31/93	12/31/93	12/31/93	12/31/93	12/31/93	12/31/93	12/31/93
	Time	12:05 am	12:05 am	12:05 am	12:05 am	12:05 am	12:05 am	12:05 am	12:05 am
	Finish	1/4/94	1/4/94	1/4/94	1/4/94	1/4/94	1/4/94	1/4/94	1/4/94
	Time	5:20 am	5:20 am	5:20 am	5:20 am	5:20 am	5:20 am	5:20 am	5:20 am
133	Start	12/25/93	12/25/93	12/25/93	12/25/93	12/25/93	12/25/93	12/25/93	12/25/93
	Time	7:35 am	7:35 am	7:35 am	7:35 am	7:35 am	7:35 am	7:35 am	7:35 am
	Finish	12/30/93	12/30/93	12/30/93	12/30/93	12/30/93	12/30/93	12/30/93	12/30/93
	Time	10:05 pm	10:05 pm	10:05 pm	10:05 pm	10:05 pm	10:05 pm	10:05 pm	10:05 pm
166	Start	12/28/93	12/28/93	12/28/93	12/28/93	12/28/93	12/28/93	12/28/93	12/28/93
	Time	3:05 am	3:05 am	3:05 am	3:05 am	3:05 am	3:05 am	3:05 am	3:05 am
	Finish	1/4/94	1/4/94	1/4/94	1/4/94	1/4/94	1/4/94	1/4/94	1/4/94
	Time	3:50 am	3:50 am	3:50 am	3:50 am	3:50 am	3:50 am	3:50 am	3:50 am
200	Start	12/16/93	12/16/93	12/16/93	12/16/93	12/16/93	12/16/93	12/16/93	12/16/93
	Time	9:50 pm	9:50 pm	9:50 pm	9:50 pm	9:50 pm	9:50 pm	9:50 pm	9:50 pm
	Finish	12/25/93	12/25/93	12/25/93	12/25/93	12/25/93	12/25/93	12/25/93	12/25/93
	Time	5:50 am	5:50 am	5:50 am	5:50 am	5:50 am	5:50 am	5:50 am	5:50 am
266	Start	12/16/93	12/16/93	12/16/93	12/16/93	12/16/93	12/16/93	12/16/93	12/16/93
	Time	9:50 pm	9:50 pm	9:50 pm	9:50 pm	9:50 pm	9:50 pm	9:50 pm	9:50 pm
	Finish	12/28/93	12/28/93	12/28/93	12/28/93	12/28/93	12/28/93	12/28/93	12/28/93
	Time	1:35 am	1:35 am	1:35 am	1:35 am	1:35 am	1:35 am	1:35 am	1:35 am
333	Start	12/16/93	12/16/93	12/16/93	12/16/93	12/16/93	12/16/93	12/16/93	12/16/93
	Time	9:50 pm	9:50 pm	9:50 pm	9:50 pm	9:50 pm	9:50 pm	9:50 pm	9:50 pm
	Finish	12/30/93	12/30/93	12/30/93	12/30/93	12/30/93	12/30/93	12/30/93	12/30/93
	Time	10:05 pm	10:05 pm	10:05 pm	10:05 pm	10:05 pm	10:05 pm	10:05 pm	10:05 pm

Table 36: Continuous UV, Test 2 (Test dates)

Table 36: Continuous UV, Test 2 (Test dates)

		Fabric A		Fabric B		Fabric C		Fabric D	
Hours	Duty	Warp	Fill	Warp	Fill	Warp	Fill	Warp	Fill
66	Start	3/28/94	3/28/94	3/28/94	3/28/94	3/28/94	3/28/94	NA	NA
	Time	1:00 am	1:00 am	1:00 am	1:00 am	1:00 am	1:00 am	NA	NA
	Finish	3/30/94	3/30/94	3/30/94	3/30/94	3/30/94	3/30/94	NA	NA
	Time	7:00 pm	7:00 pm	7:00 pm	7:00 pm	7:00 pm	7:00 pm	NA	NA
100	Start	3/25/94	3/25/94	3/25/94	3/25/94	3/25/94	3/25/94	NA	NA
	Time	7:00 am	7:00 am	7:00 am	7:00 am	7:00 am	7:00 am	NA	NA
	Finish	3/29/94	3/29/94	3/29/94	3/29/94	3/29/94	3/29/94	NA	NA
	Time	11:00 am	11:00 am	11:00 am	11:00 am	11:00 am	11:00 am	NA	NA
133	Start	3/23/94	3/23/94	3/23/94	3/23/94	3/23/94	3/23/94	NA	NA
	Time	7:45 pm	7:45 pm	7:45 pm	7:45 pm	7:45 pm	7:45 pm	NA	NA
	Finish	3/29/94	3/29/94	3/29/94	3/29/94	3/29/94	3/29/94	NA	NA
	Time	10:00 am	10:00 am	10:00 am	10:00 am	10:00 am	10:00 am	NA	NA
166	Start	3/16/94	3/16/94	3/16/94	3/16/94	3/16/94	3/16/94	NA	NA
	Time	9:00 pm	9:00 pm	9:00 pm	9:00 pm	9:00 pm	9:00 pm	NA	NA
	Finish	3/23/94	3/23/94	3/23/94	3/23/94	3/23/94	3/23/94	NA	NA
	Time	7:00 pm	7:00 pm	7:00 pm	7:00 pm	7:00 pm	7:00 pm	NA	NA
200	Start	3/16/94	3/16/94	3/16/94	3/16/94	3/16/94	3/16/94	NA	NA
	Time	9:00 pm	9:00 pm	9:00 pm	9:00 pm	9:00 pm	9:00 pm	NA	NA
	Finish	3/25/94	3/25/94	3/25/94	3/25/94	3/25/94	3/25/94	NA	NA
	Time	6:35 am	6:35 am	6:35 am	6:35 am	6:35 am	6:35 am	NA	NA
266	Start	3/16/94	3/16/94	3/16/94	3/16/94	3/16/94	3/16/94	NA	NA
	Time	9:00 pm	9:00 pm	9:00 pm	9:00 pm	9:00 pm	9:00 pm	NA	NA
	Finish	3/28/94	3/28/94	3/28/94	3/28/94	3/28/94	3/28/94	NA	NA
	Time	1:00 am	1:00 am	1:00 am	1:00 am	1:00 am	1:00 am	NA	NA
333	Start	3/16/94	3/16/94	3/16/94	3/16/94	3/16/94	3/16/94	NA	NA
	Time	9:00 pm	9:00 pm	9:00 pm	9:00 pm	9:00 pm	9:00 pm	NA	NA
	Finish	3/30/94	3/30/94	3/30/94	3/30/94	3/30/94	3/30/94	NA	NA
	Time	8:00 pm	8:00 pm	8:00 pm	8:00 pm	8:00 pm	8:00 pm	NA	NA

Table 37: Test Temperatures (8 UV - 1st Test)

8 UV (4 Cond)		Rotated Samples		QUV		UVCON
Date	Time	Yes	No	temp °C	irrad	temp °C
1-11	9:00 pm		X	70.2	0.72	70.4
1-12	6:35 am		X	36.3	NA	*28.0
1-12	3:00 pm		X	29.9	NA	33.0
1-12	3:40 pm		X	50.1	NA	47.6
1-12	4:25 pm		X	50.3	NA	50.2
1-12	9:40 pm	X		69.9	0.72	70.4
1-13	2:05 am		X	48.1	NA	50.5
1-13	6:35 am		X	69.7	0.72	70.5
1-13	2:00 pm		X	48.0	NA	50.6
1-13	3:50 pm		X	49.3	NA	50.4
1-13	9:45 pm	X		69.6	0.72	70.4
1-14	6:35 am		X	69.9	0.72	70.5
1-14	2:20 pm		X	49.2	NA	50.6
1-14	8:40 pm	X		70.1	0.72	70.6
1-15	7:00 pm		X	69.6	0.72	70.5
1-15	8:45 pm	X		69.7	0.72	70.5
1-16	2:05 am		X	50.1	NA	50.5
1-16	2:50 pm		X	50.5	NA	50.4
1-16	8:50 pm	X		70.9	0.72	70.4
1-17	1:30 pm		X	49.6	NA	50.4
1-17	9:45 pm	X		69.8	0.72	70.5
1-18	6:35 am		X	70.0	0.72	70.4
1-18	5:15 pm		X	**66.1	0.72	70.4
1-18	8:20 pm	X		69.5	0.72	70.5
1-19	6:35 am		X	69.3	0.72	70.4
1-19	4:00 pm		X	49.6	NA	50.1

Table 37 (cont'd)

1-19	9:50 pm	X		69.2	0.72	70.5
1-20	6:35 am		X	69.2	0.72	70.5
1-20	2:00 pm		X	49.9	NA	50.5
1-20	9:45 pm	X		69.9	0.72	70.4
1-21	6:35 am		X	70.4	0.72	70.5
1-21	4:20 pm		X	50.2	NA	50.6
1-21	8:40 pm	X		70.5	0.72	70.5
1-22	1:05 am		X	49.6	NA	49.0
1-22	8:30 pm	X		70.2	0.72	70.4
1-23	8:00 pm	X		70.2	0.72	70.5
1-24	2:00 pm		X	50.0	NA	50.5
1-24	5:00 pm	X		**62.1	0.72	70.6
1-24	6:30 pm		X	69.5	0.72	70.5
1-25	6:35 am		X	69.0	0.72	70.5
1-25	9:50 pm	X		69.7	0.72	70.4
1-26	6:35 am		X	69.9	0.72	70.6
1-26	1:20 pm		X	**59.8	NA	70.4
1-26	9:55 pm	X		69.6	0.72	70.5
1-27	6:35 am		X	69.9	0.72	70.5
1-27	6:50 pm	X		70.1	0.72	70.4
1-28	6:35 am		X	70.1	0.72	70.5
1-28	1:20 pm		X	**62.1	0.72	70.5
1-28	11:00pm	X		69.7	0.72	70.4
1-29	12:25am		X	70.0	0.72	70.3
1-29	9:45 pm	X		69.3	0.72	70.5
1-30	12:25pm		X	69.7	0.72	70.4
1-30	7:05 pm	X		70.3	0.72	70.5
1-31	1:45 pm		X	70.4	0.72	26.0
1-31	9:45 pm	X		70.2	0.72	50.4

Ta

Table 37 (cont'd)

2-1	6:35 am		X	69.3	0.72	70.4
2-1	2:30 pm		X	52.5	NA	70.5
2-1	9:45	X		70.3	0.72	70.4
2-2	4:35 am	X		49.1	NA	70.5
2-2	6:00 am		X	48.1	NA	47.3
2-2	11:50am		X	69.6	0.72	70.5
2-2	4:30 pm		X	51.3	NA	50.1
2-2	9:00 pm	X		69.7	0.72	70.4
2-3	6:35 am		X	47.5	NA	50.3
2-3	2:00 pm		X	70.3	0.72	70.4
2-3	9:45 pm	X		70.5	0.72	70.5
2-4	6:35 am		X	47.7	NA	50.4
2-4	2:15 pm		X	70.3	0.72	70.4
2-4	8:45 pm	X		70.5	0.72	70.4
2-5	1:05 am		X	70.0	0.72	70.4
2-5	10:40pm	X		69.5	0.72	70.4
2-6	10:00am	X		69.7	0.72	70.5
2-6	11:00am		X	69.1	0.72	71.5
2-6	1:45 pm		X	70.2	0.72	70.4
2-7	1:30 pm	X		69.1	0.72	70.5
2-7	6:10 pm		X	49.6	NA	50.3
2-8	6:35 am		X	49.5	NA	50.4
2-8	1:30 pm		X	69.1	0.72	70.4

* 8 Hour delay

** Machine was still warming from cycle change

Table 38: Test Temperatures (8 UV - 2nd Test)

8 UV(4 Cond) 2nd		**Rotated Samples**		**QUV**		**UVCON**
Date	Time	Yes	No	temp °C	irrad	temp °C
3-30	9:00 pm		X	64.5*	0.72	71.6
3-31	2:05 am		X	70.4	0.72	70.8
3-31	6:35 am		X	50.2	NA	50.4
3-31	7:45 pm	X		50.3	NA	50.4
4-1	2:05 am		X	69.5	0.72	70.4
4-1	12:40pm		X	70.1	0.72	70.4
4-1	8:35 pm	X		49.8	NA	50.3
4-2	1:05 am		X	70.0	0.72	70.4
4-2	8:45 pm	X		50.3	NA	50.4
4-3	6:30 pm	X		50.0	NA	57.3**
4-4	3:15 pm	X		70.4	0.72	83.5?
4-4	9:55 pm		X	49.8	NA	48.3
4-5	2:05 am		X	70.6	0.72	70.4
4-5	6:35 am		X	50.5	NA	50.4
4-5	4:25 pm	X		69.9	0.72	70.4
4-6	2:05 am		X	69.8	0.72	70.4
4-6	6:35 am		X	50.1	NA	50.4
4-6	1:30 pm	X		69.9	0.72	70.5
4-7	2:05 am		X	70.4	0.72	70.5
4-7	6:35 am		X	50.0	NA	50.4
4-7	6:40 pm	X		50.0	NA	50.5
4-8	2:05 am		X	70.2	0.72	70.4
4-8	6:35 am		X	49.8	NA	50.0
4-8	12:45pm		X	69.8	0.72	70.4
4-8	3:15 pm	X		70.0	0.72	70.4
4-8	8:35 pm		X	50.1	NA	50.3

Ta

Table 38 (cont'd)

4-9	1:05 am		X	69.8	0.72	70.4
4-9	3:25	X		69.8	0.72	70.5
4-10	8:00 am	X		50.3	NA	51.1
4-10	8:45 am		X	51.8	NA	49.6
4-11	7:15 am	X		51.7	NA	50.4
4-12	10:00am	X		51.5	NA	50.4
4-12	10:45am		X	68.7	0.72	71.4
4-13	2:10 am		X	69.8	0.72	70.5
4-13	6:35 am		X	50.1	NA	48.2
4-13	1:45 pm	X		70.3	0.72	70.4
4-13	3:30 pm		X	70.4	0.72	70.5
4-14	2:05 am		X	69.9	0.72	70.5
4-14	6:35 am		X	50.1	NA	47.9
4-14	2:00 pm	X		70.0	0.72	70.4
4-15	2:05 am		X	70.1	0.72	70.5
4-15	6:35 am		X	49.9	NA	48.4
4-15	12:40pm		X	69.9	0.72	70.4
4-15	2:15 pm	X		70.1	0.72	70.5
4-15	8:35 pm		X	51.2	NA	50.4
4-16	1:45 pm	X		71.0	0.72	70.6
4-16	2:30 pm		X	69.7	0.72	70.2
4-16	9:50 pm		X	50.7	NA	50.4
4-17	2:00 pm	X		70.9	0.72	70.4
4-17	9:20 pm		X	51.0	NA	50.7
4-18	3:00 pm	X		70.3	0.72	70.5
4-18	4:30 pm		X	69.3	0.72	71.6
4-19	2:05 am		X	69.6	0.72	70.4
4-19	6:35 am		X	51.6	NA	64.8**
4-19	3:05 pm	X		69.7	0.72	70.5

Table 38 (cont'd)

4-20	6:35am		X	51.2	NA	65.3**
4-20	1:30pm		X	70.2	0.72	70.4
4-20	6:05pm		X	70.1	0.72	70.4

* Still warming up ** Cooling from cycle change

Ta

Table 39: Test Temperatures (Continuous UV - 1st Test)

Continuous UV		**Rotated Samples**		**QUV**		**UVCON**
Date	Time	Yes	No	temp °C	irrad	temp °C
12-16	9:50 pm		X	70.0	0.72	70.2
12-17	2:15 am		X	70.2	0.72	70.1
12-17	6:30 am		X	70.0	0.72	70.1
12-17	8:45 pm	X		70.1	0.72	70.1
12-18	8:35 pm	X		70.6	0.72	70.2
12-19	8:35 pm	X		70.3	0.72	70.3
12-20	2:50 pm		X	70.4	0.72	70.3
12-20	9:25 pm	X		70.6	0.72	70.3
12-21	6:35 am		X	69.7	0.72	70.4
12-21	1:25 pm		X	70.0	0.72	70.4
12-21	9:35 pm	X		70.1	0.72	70.5
12-22	6:35 am		X	69.4	0.72	70.4
12-22	9:40 pm	X		69.6	0.72	70.4
12-23	6:35 am		X	69.6	0.72	70.5
12-23	4:10 pm		X	69.3	0.72	70.3
12-23	8:35 pm	X		69.8	0.72	70.4
12-24	1:05 am		X	69.8	0.72	70.4
12-24	8:45 pm	X		70.3	0.72	70.4
12-25	5:50 am		X	70.6	0.72	70.5
12-25	7:35 am		X	70.1	0.72	70.8
12-25	8:25 pm	X		72.4	0.72	70.5
12-26	2:25 pm		X	71.5	0.72	70.5
12-26	8:45 pm	X		70.8	0.72	70.4
12-28	1:05 am		X	70.5	0.72	70.4
12-28	1:35 am	X		70.1	0.72	70.4
12-28	3:05 am		X	69.9	0.72	70.6

Table 39 (cont'd)

12-28	2:40 pm		X	70.4	0.72	70.6
12-28	11:58pm	X		69.9	0.72	70.4
12-29	12:20pm		X	70.6	0.72	70.4
12-29	11:05pm	X		70.2	0.72	70.5
12-30	12:35pm		X	70.3	0.72	70.5
12-30	9:50 pm		X	70.2	0.72	70.4
12-31	12:05am	X		69.4	0.72	70.3
12-31	4:30 pm	X		70.5	0.72	70.5
1-1-94	7:05 pm	X		70.2	0.72	70.4
1-2	6:00 pm		X	69.9	0.72	70.4
1-2	6:50 pm	X		69.7	0.72	70.6
1-3	2:00 pm		X	71.5	0.72	70.4
1-4	3:35 am		X	70.3	0.72	70.5
1-4	3:50 am	X		70.4	0.72	70.5
1-4	4:20 am		X	70.1	0.72	70.6
1-4	5:20 am		X	69.7	0.72	70.4

Table 40: Test Temperatures (Continuous UV - 2nd Test)

Continuous UV (2nd)		**Rotated Samples**		**QUV**		**UVCON**
Date	Time	Yes	No	temp °C	irrad	temp °C
3-16	9:00 pm		X	69.6	0.72	69.7
3-17	2:05 am		X	70.6	0.72	70.4
3-17	6:35 am		X	70.6	0.72	70.4
3-17	6:35 pm	X		70.4	0.72	70.4
3-18	6:35 am		X	69.6	0.72	70.4
3-18	12:40pm		X	70.1	0.72	70.4
3-18	2:00 pm	X		69.8	0.72	70.3
3-19	1:05 am		X	70.0	0.72	70.4
3-19	6:40 pm	X		70.4	0.72	70.3
3-20	12:10pm		X	70.3	0.72	70.4
3-20	5:00 pm	X		70.3	0.72	70.5
3-21	4:00 pm	X		69.9	0.72	70.5
3-21	9:55 pm		X	70.3	0.72	70.4
3-22	6:35 am		X	70.2	0.72	70.3
3-22	5:00 pm	X		70.0	0.72	70.4
3-22	9:55 pm		X	69.0	0.72	70.3
3-23	6:35 am		X	69.6	0.72	70.4
3-23	1:30 pm		X	70.0	0.72	70.5
3-23	7:00 pm	X		70.3	0.72	70.4
3-23	7:45 pm		X	70.5	0.72	70.4
3-24	2:05 am		X	70.6	0.72	70.4
3-24	6:35 am		X	70.2	0.72	70.5
3-24	4:15 pm	X		70.0	0.72	70.4
3-25	2:10 am		X	70.6	0.72	70.4
3-25	6:35 am	X		70.7	0.72	70.5
3-25	7:00 am		X	69.7	0.72	70.2

Table 40 (cont'd)

3-25	4:05 pm	X		70.4	0.72	70.4
3-25	8:40 pm		X	70.8	0.72	70.4
3-26	1:05 am		X	69.0	0.72	70.5
3-26	3:15 pm	X		69.7	0.72	70.4
3-27	1:40 am		X	69.8	0.72	70.5
3-27	4:40 pm	X		69.9	0.72	70.5
3-28	1:00 am		X	70.5	0.72	70.5
3-28	1:30 am		X	69.7	0.72	70.8
3-28	1:35 pm	X		71.4	0.72	70.4
3-29	2:05 am		X	69.9	0.72	70.4
3-29	6:35 am		X	70.6	0.72	70.5
3-29	10:00am		X	70.1	0.72	70.4
3-29	11:00am	X		69.6	0.72	70.6
3-29	9:50 pm		X	69.7	0.72	70.5
3-30	6:35 am		X	70.6	0.72	70.5
3-30	1:35 pm	X		70.3	0.72	70.5
3-30	7:00 pm		X	70.4	0.72	70.4
3-30	8:00 pm	X		70.2	0.72	70.5

QUV Load vs. Time
8 Hour UV (4 hour Condensation)
Fabric A - Warp

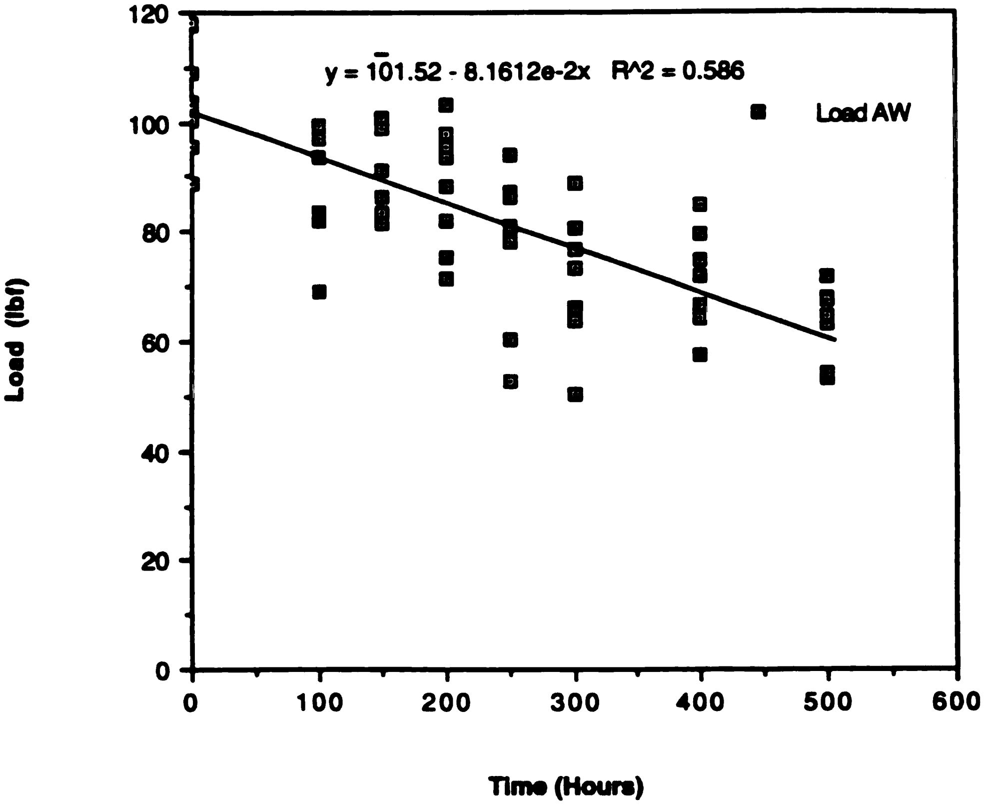


Fig. 1: QUV, 8 Hour UV - Fabric A (Warp)

QUV Load vs. Time
8 Hour UV (4 hour Condensation)
Fabric B - Warp

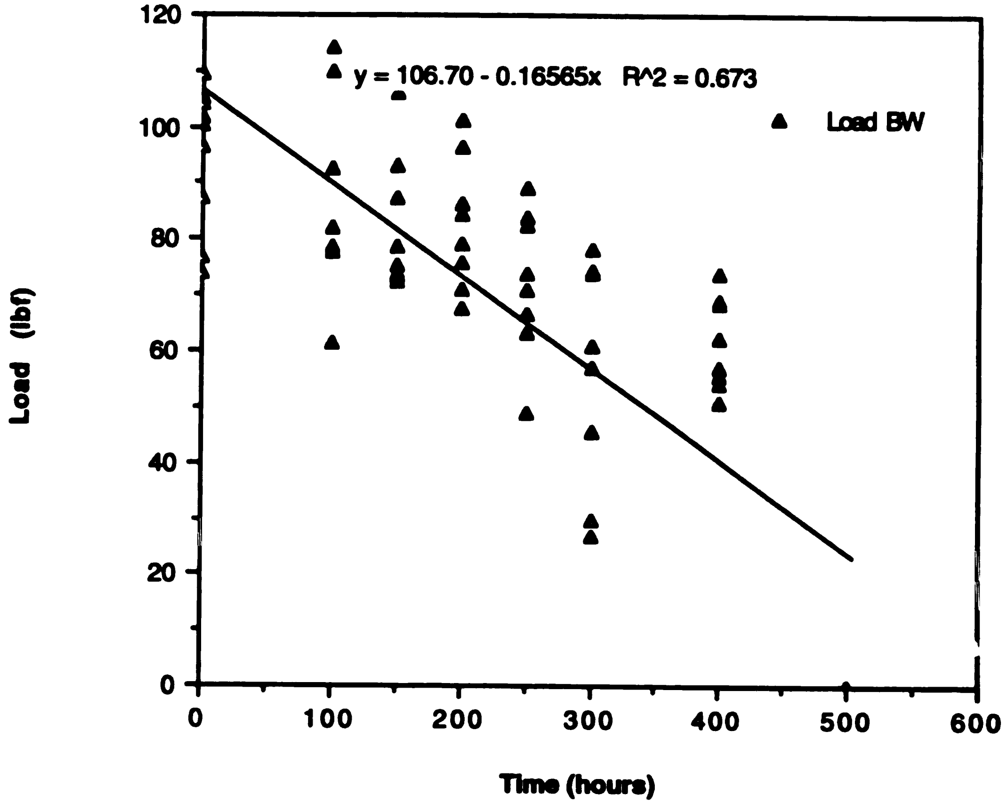


Fig. 2: QUV, 8 Hour UV - Fabric B (Warp)

QUV Load vs. Time
8 Hour UV (4 hour Condensation)
Fabric C - Warp

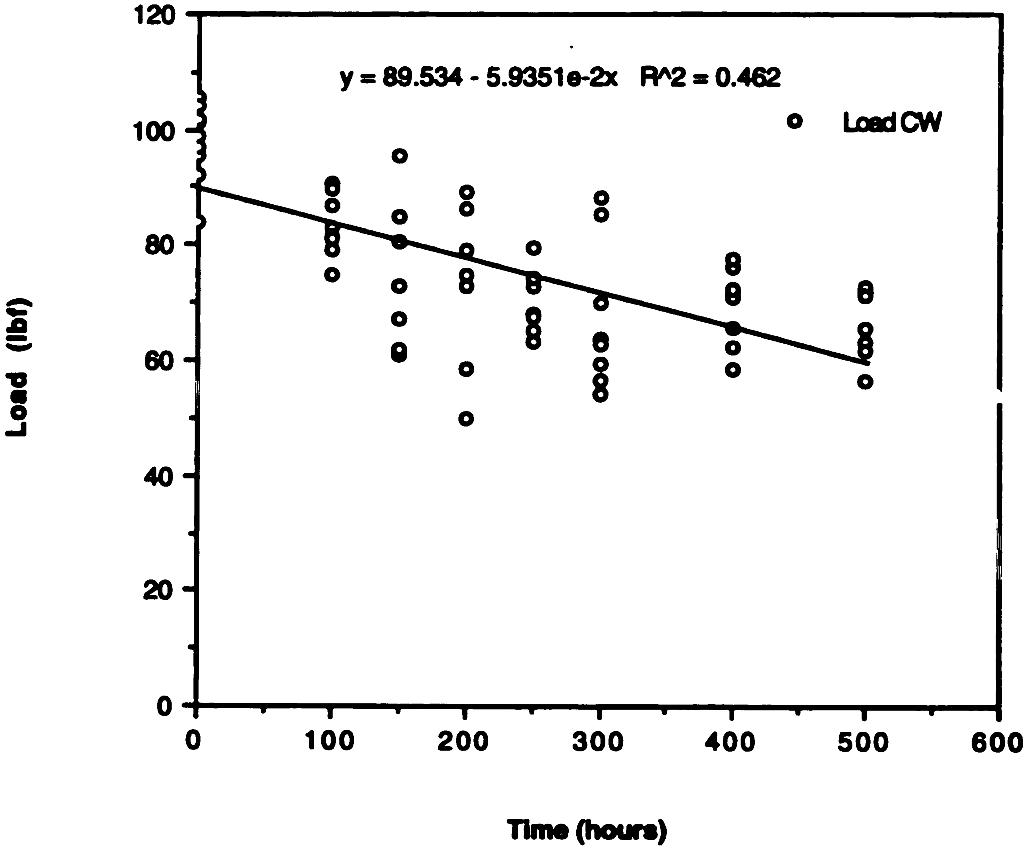


Fig. 3: QUV, 8 Hour UV - Fabric C (Warp)

QUV Load vs. Time
8 Hour UV (4 hour Condensation)
Fabric D - Warp

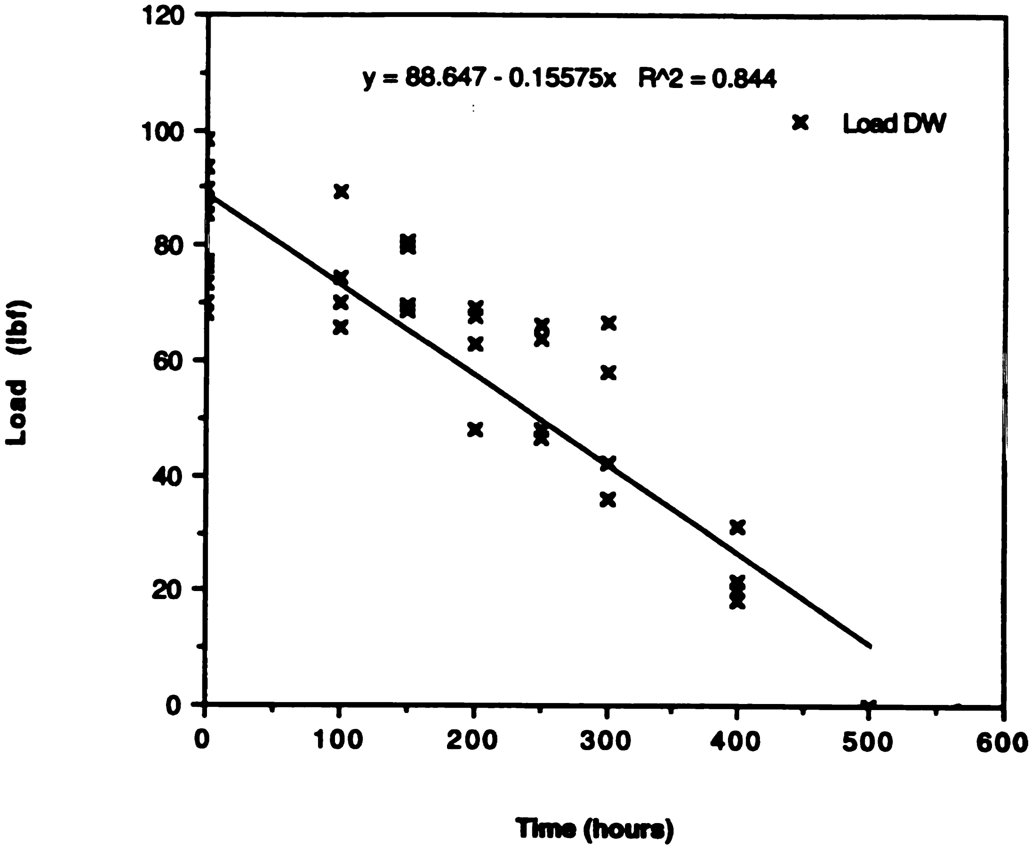
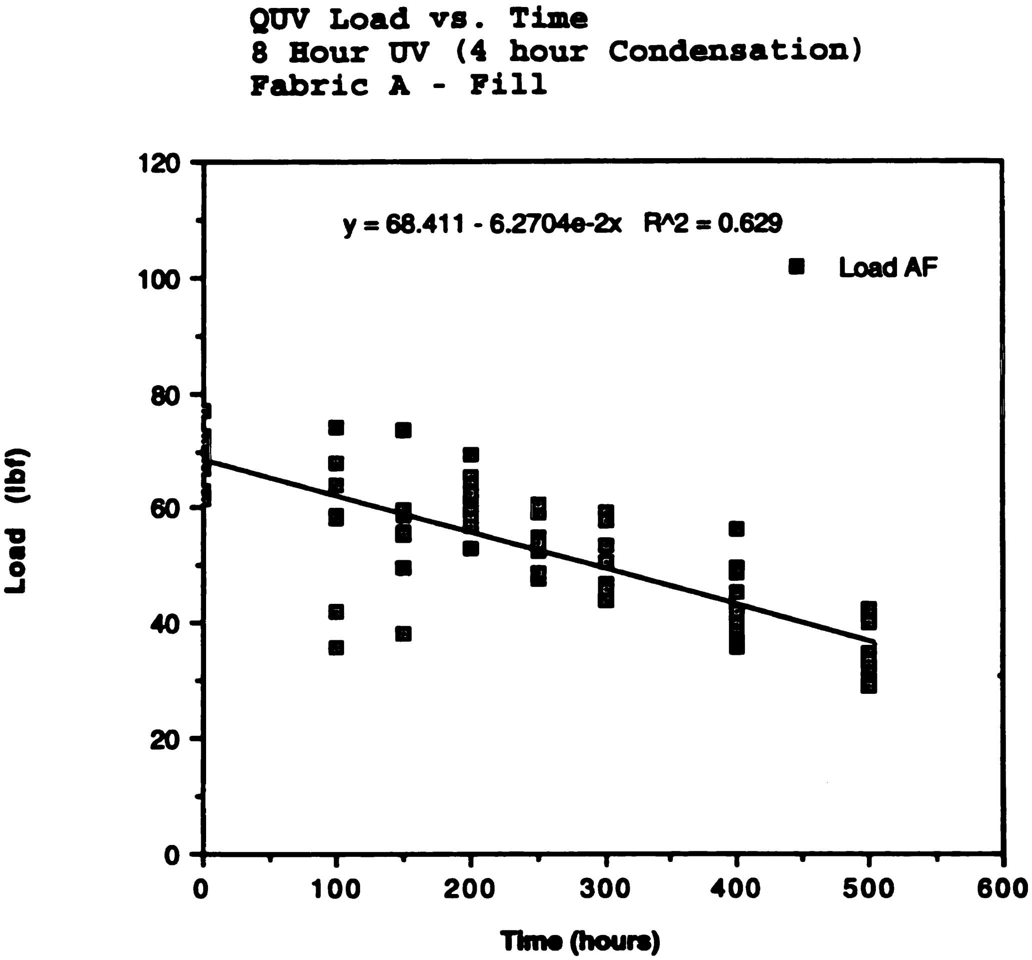


Fig. 4: QUV, 8 Hour UV - Fabric D (Warp)



QUV Load vs. Time
8 Hour UV (4 hour Condensation)
Fabric A - Fill

Fig. 5: QUV, 8 Hour UV - Fabric A (Fill)

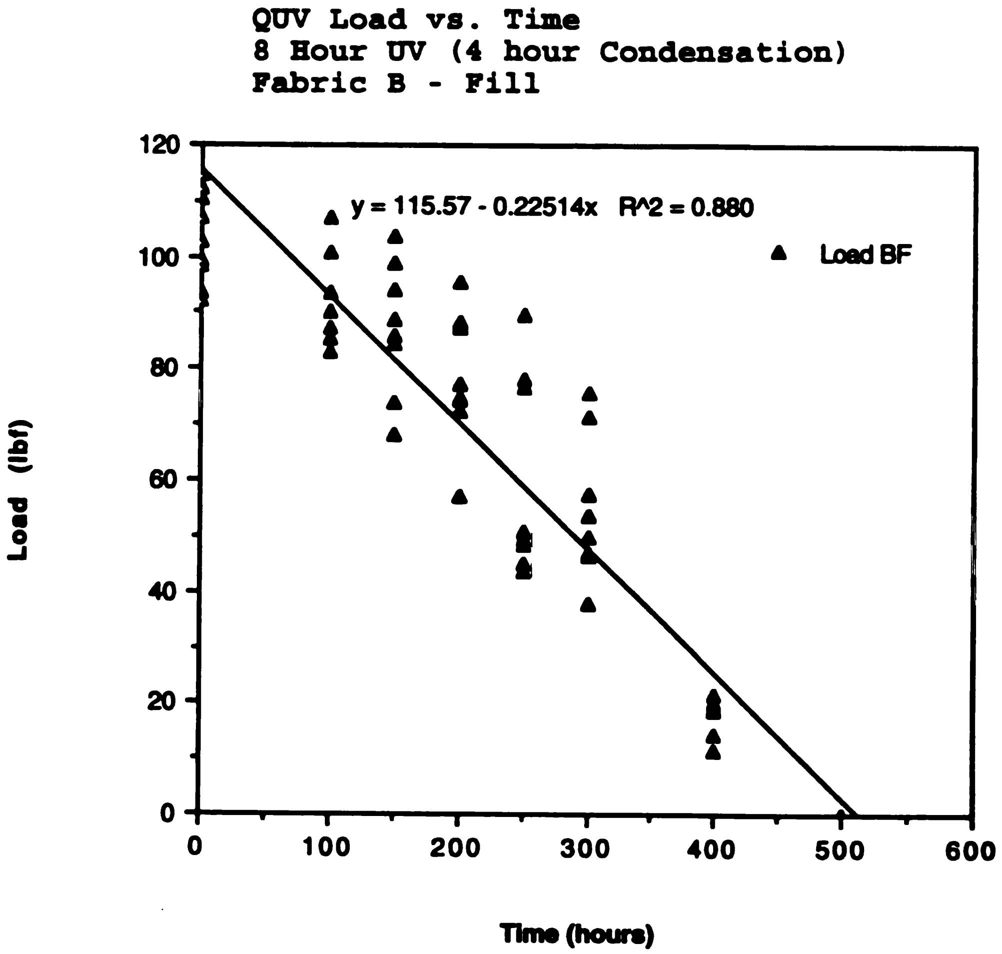


Fig. 6: QUV, 8 Hour UV - Fabric B (Fill)

QUV Load vs. Time
8 Hour UV (4 hour Condensation)
Fabric C - Fill

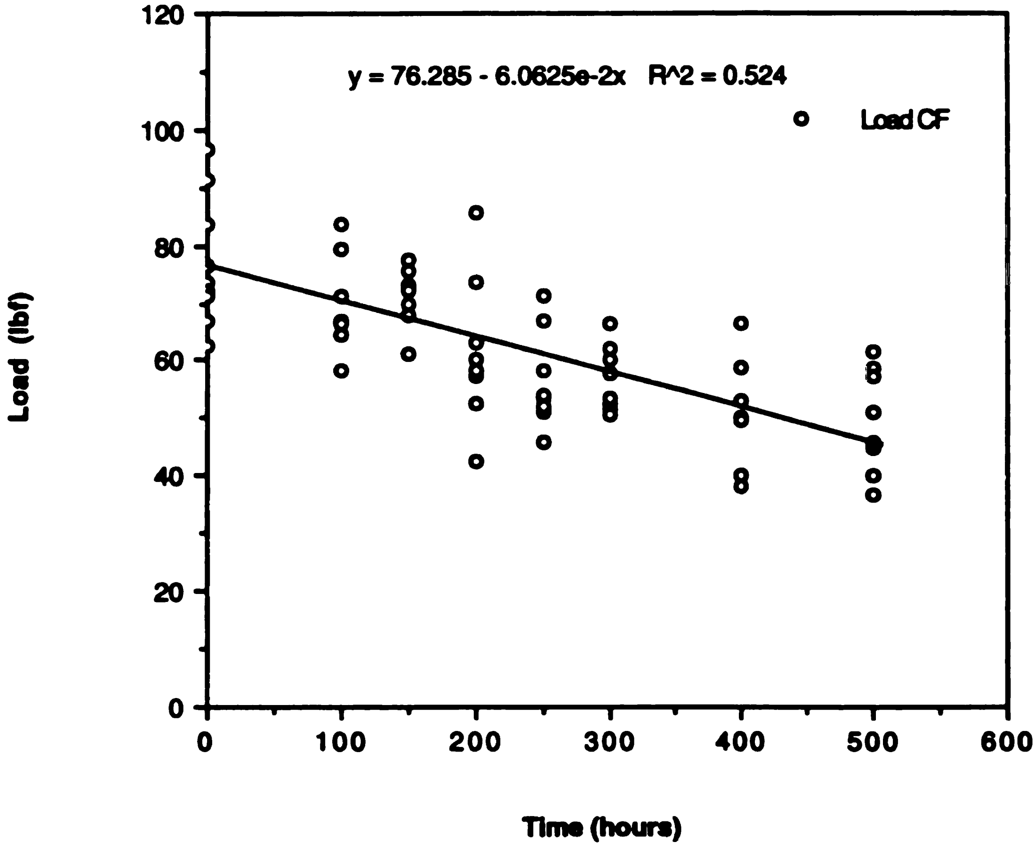


Fig. 7: QUV, 8 Hour UV - Fabric C (Fill)

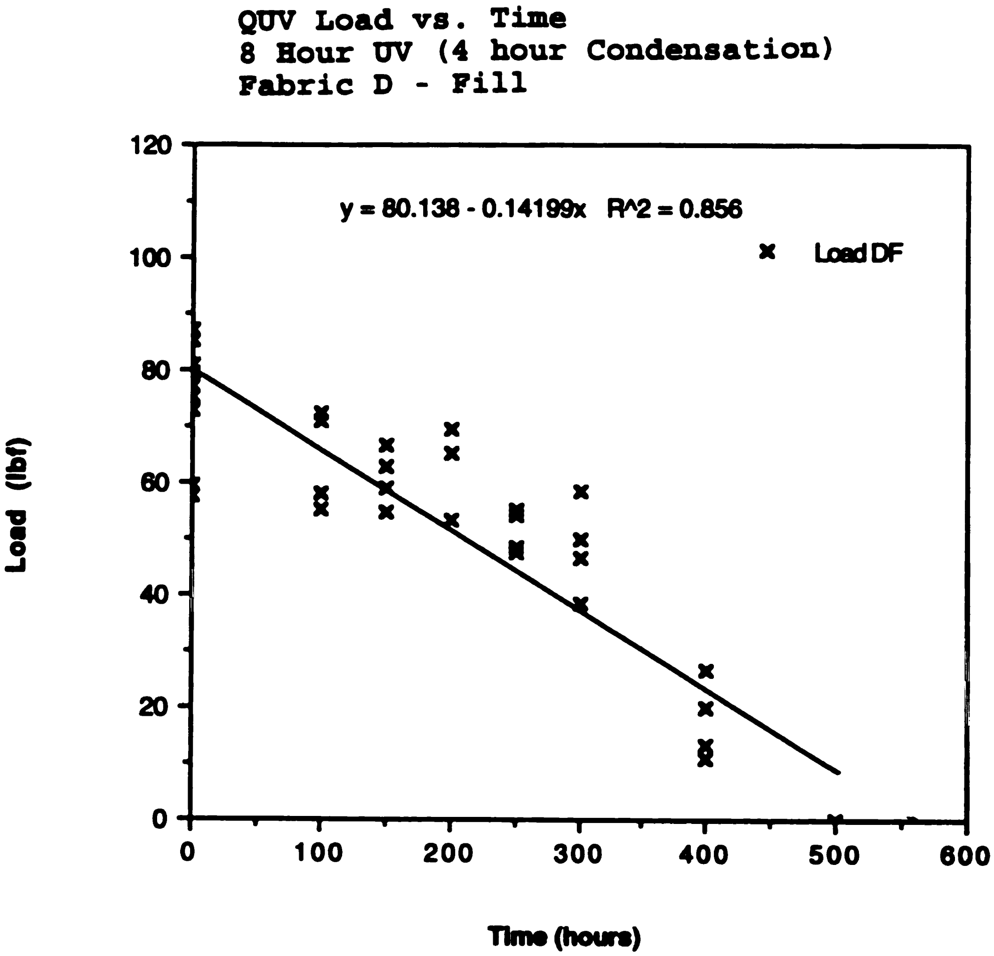


Fig. 8: QUV, 8 Hour UV - Fabric D (Fill)

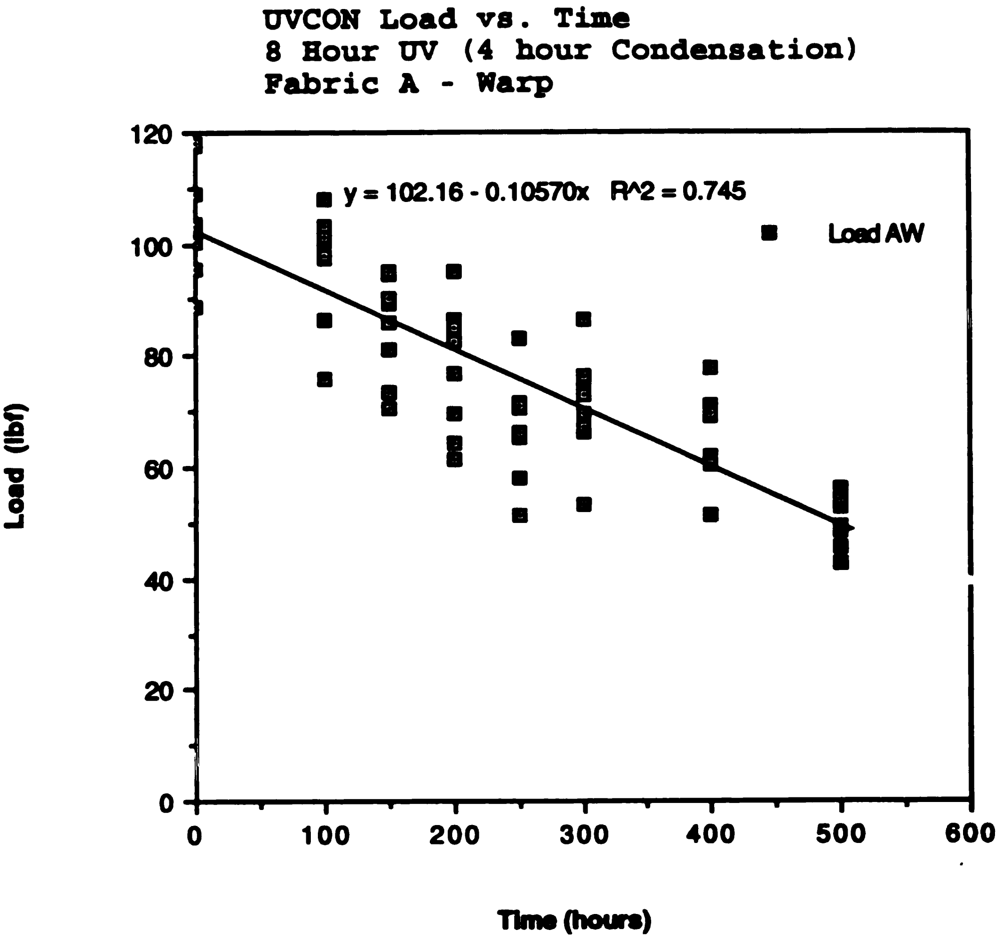


Fig. 9: UVCON, 8 Hour UV - Fabric A (Warp)

Load (lbf)

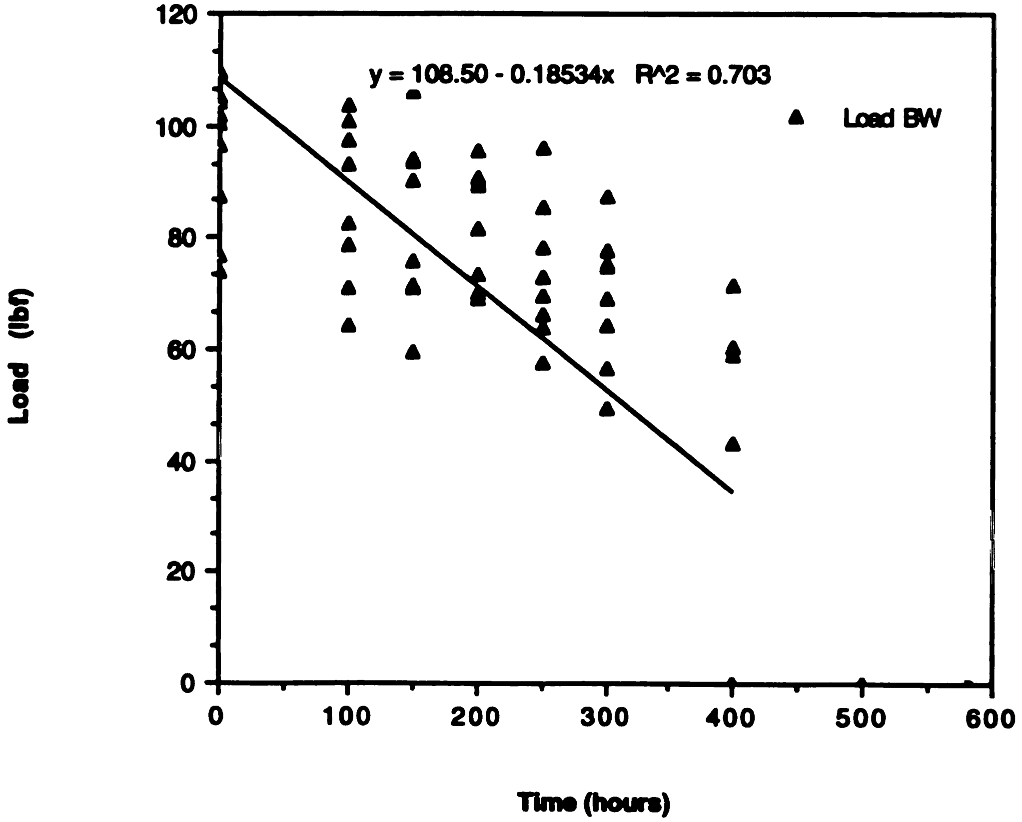

UVCON Load vs. Time
8 Hour UV (4 hour Condensation)
Fabric B - Warp

Fig. 10: UVCON, 8 Hour UV - Fabric B (Warp)

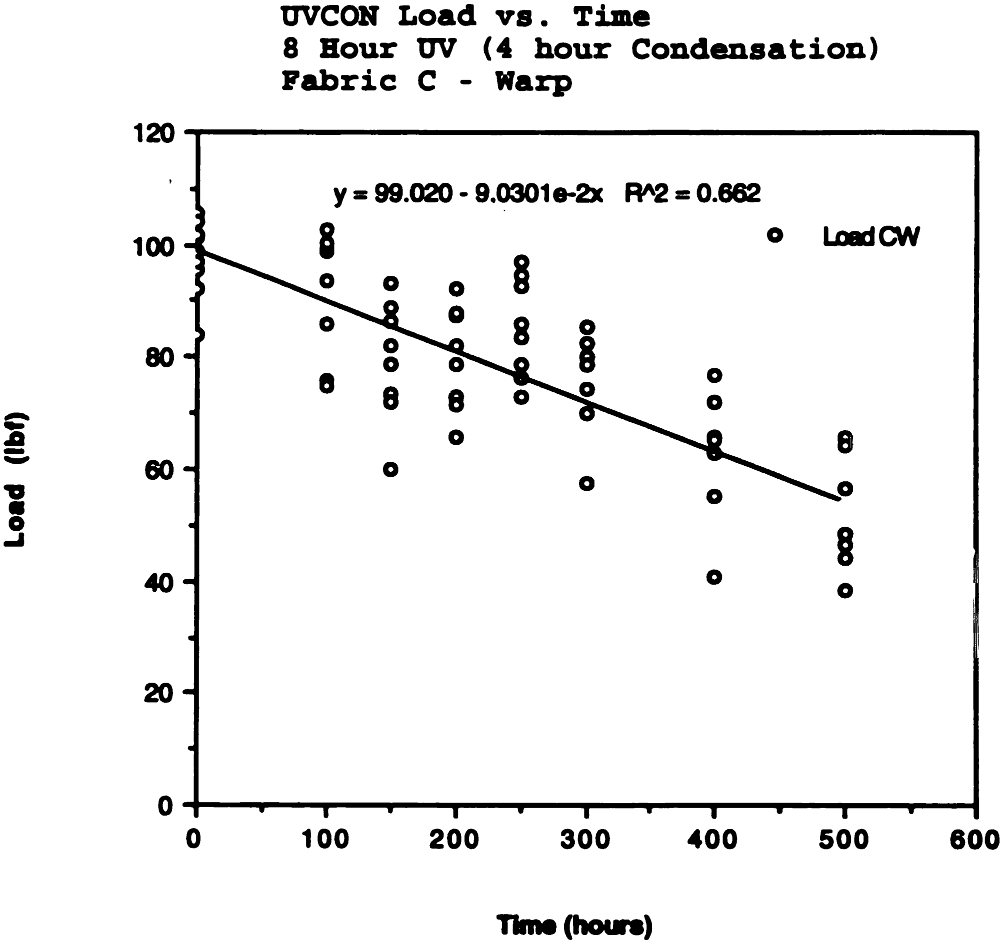
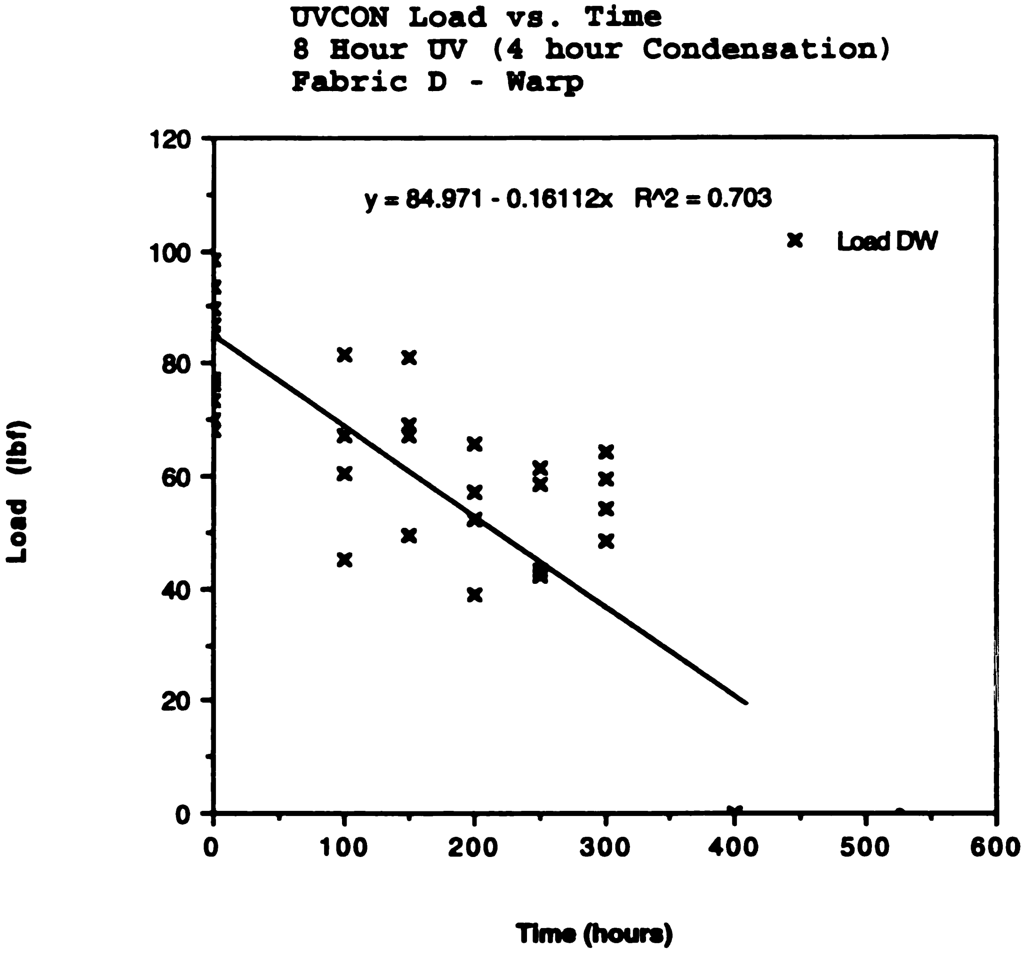


Fig. 11: UVCON, 8 Hour UV - Fabric C (Warp)



UVCON Load vs. Time
8 Hour UV (4 hour Condensation)
Fabric D - Warp

Fig. 12: UVCON, 8 Hour UV - Fabric D (Warp)

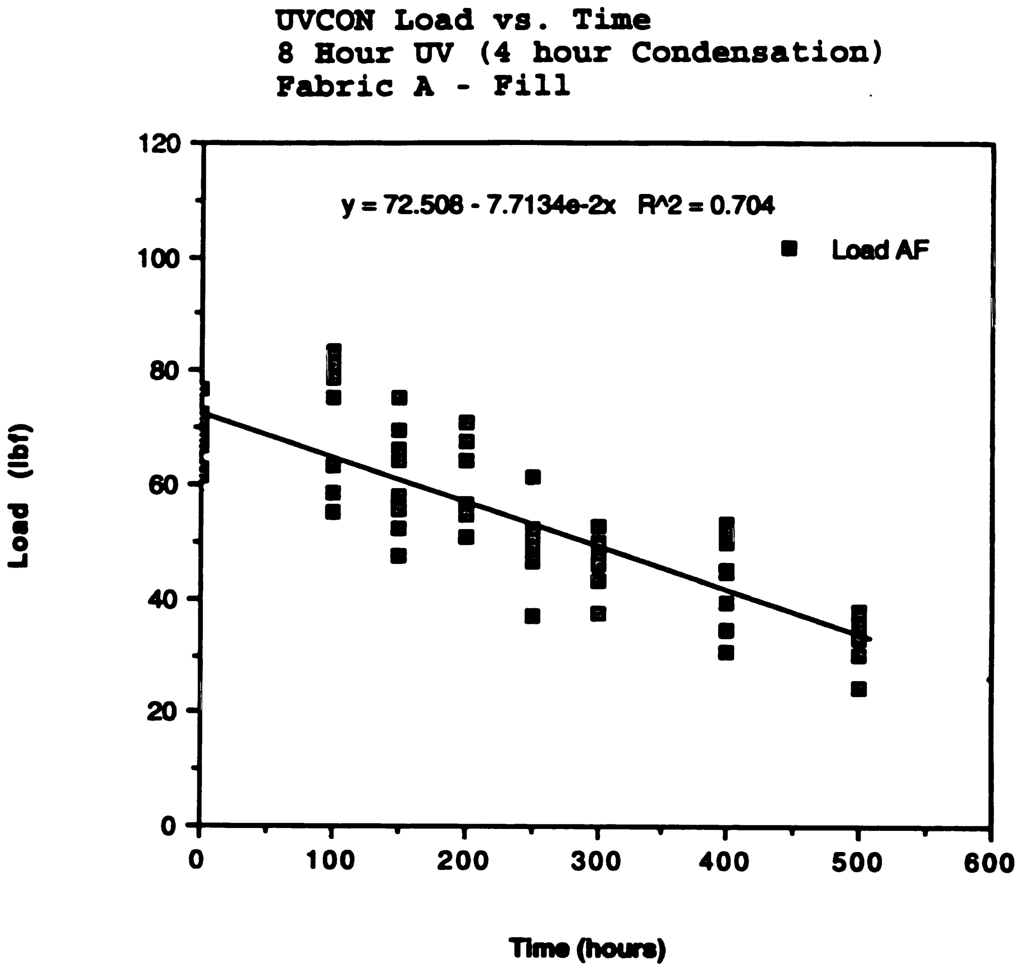


Fig. 13: UVCON, 8 Hour UV - Fabric A (Fill)

UVCON Load vs. Time
8 Hour UV (4 hour Condensation)
Fabric B - Fill

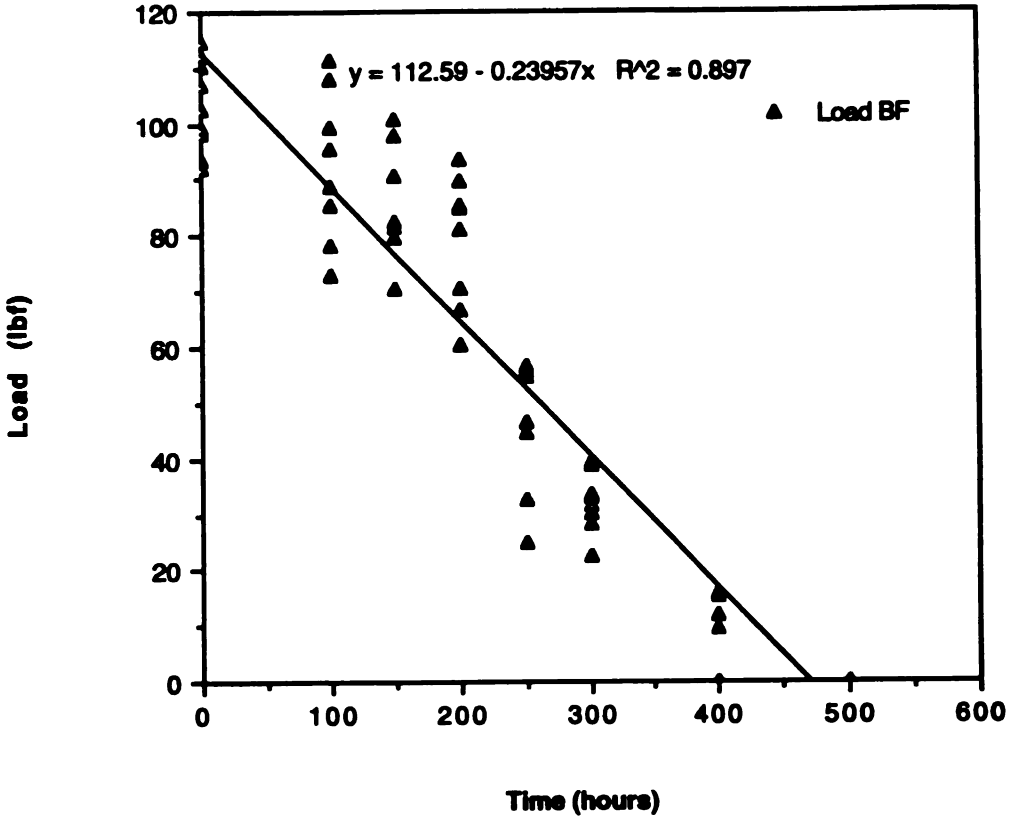
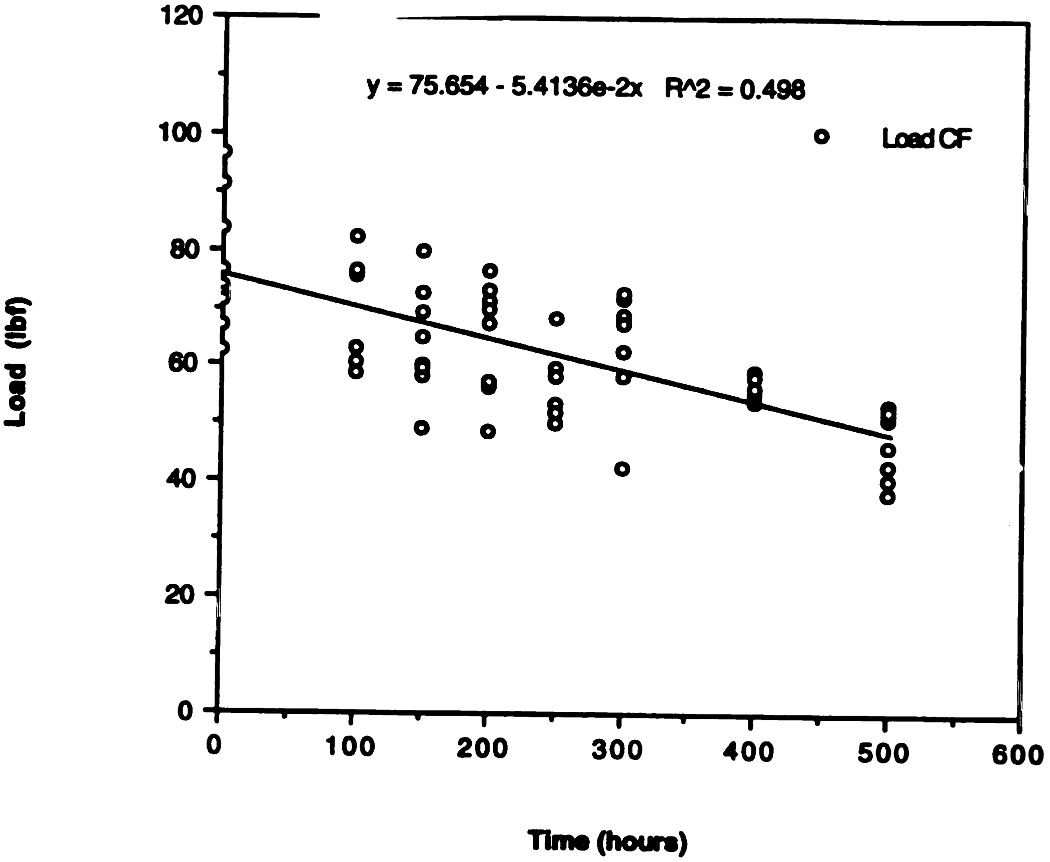


Fig. 14: UVCON, 8 Hour UV - Fabric B (Fill)



UVCON Load vs. Time
8 Hour UV (4 hour Condensation)
Fabric C - Fill

Fig. 15: UVCON, 8 Hour UV - Fabric C (Fill)

UVCON Load vs. Time
8 Hour UV (4 hour Condensation)
Fabric D - Fill

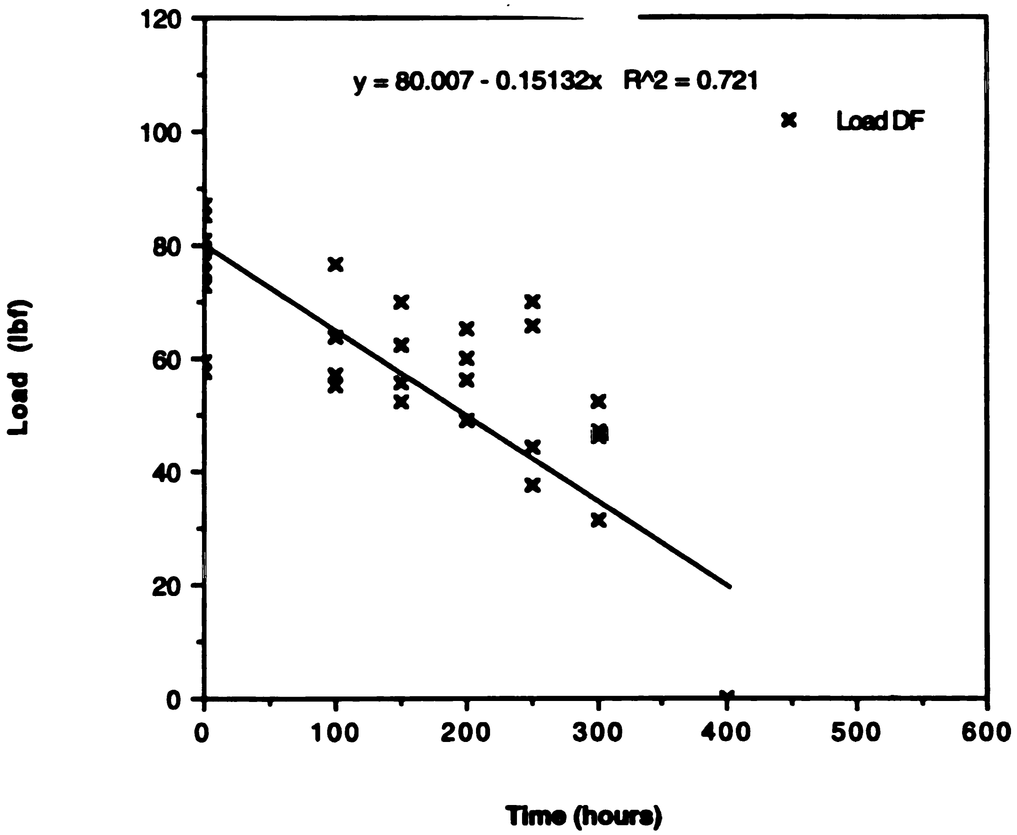


Fig. 16: UVCON, 8 Hour UV - Fabric D (Fill)

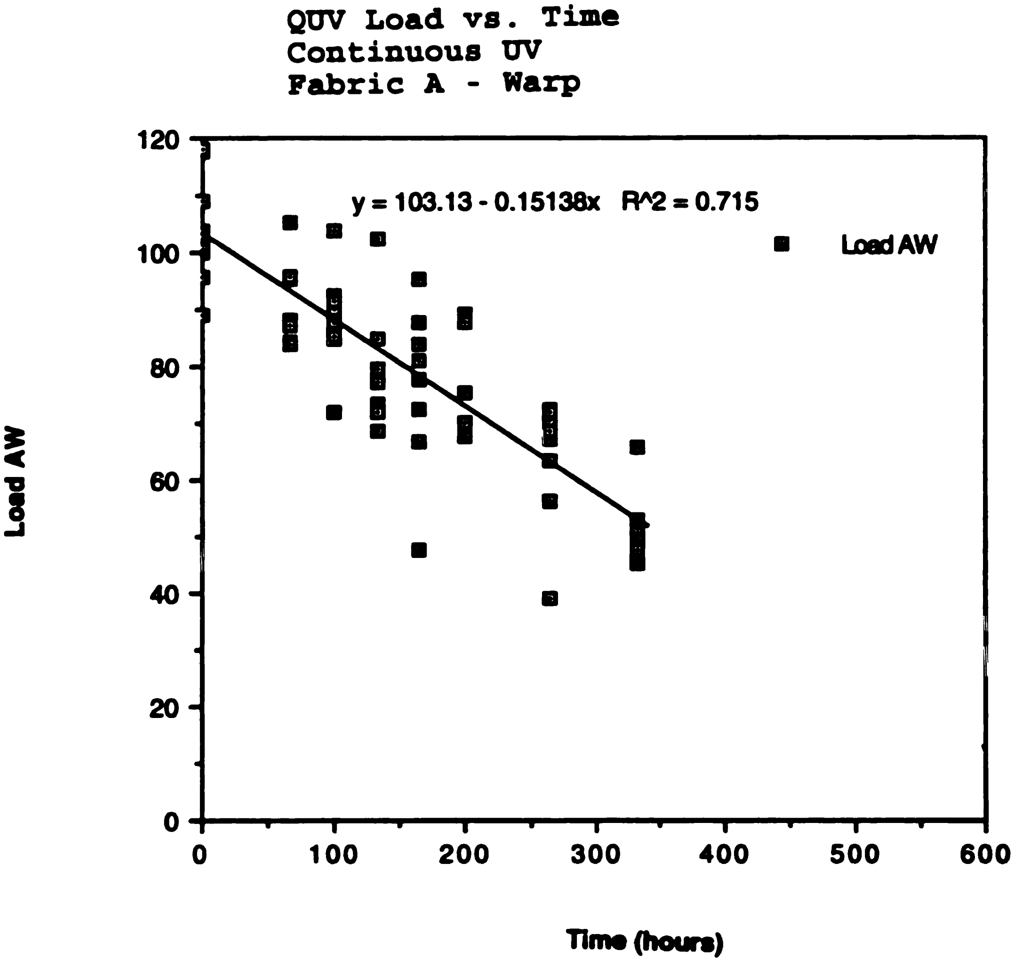


Fig. 17: QUV, Continuous UV - Fabric A (Warp)

Load (lbf)

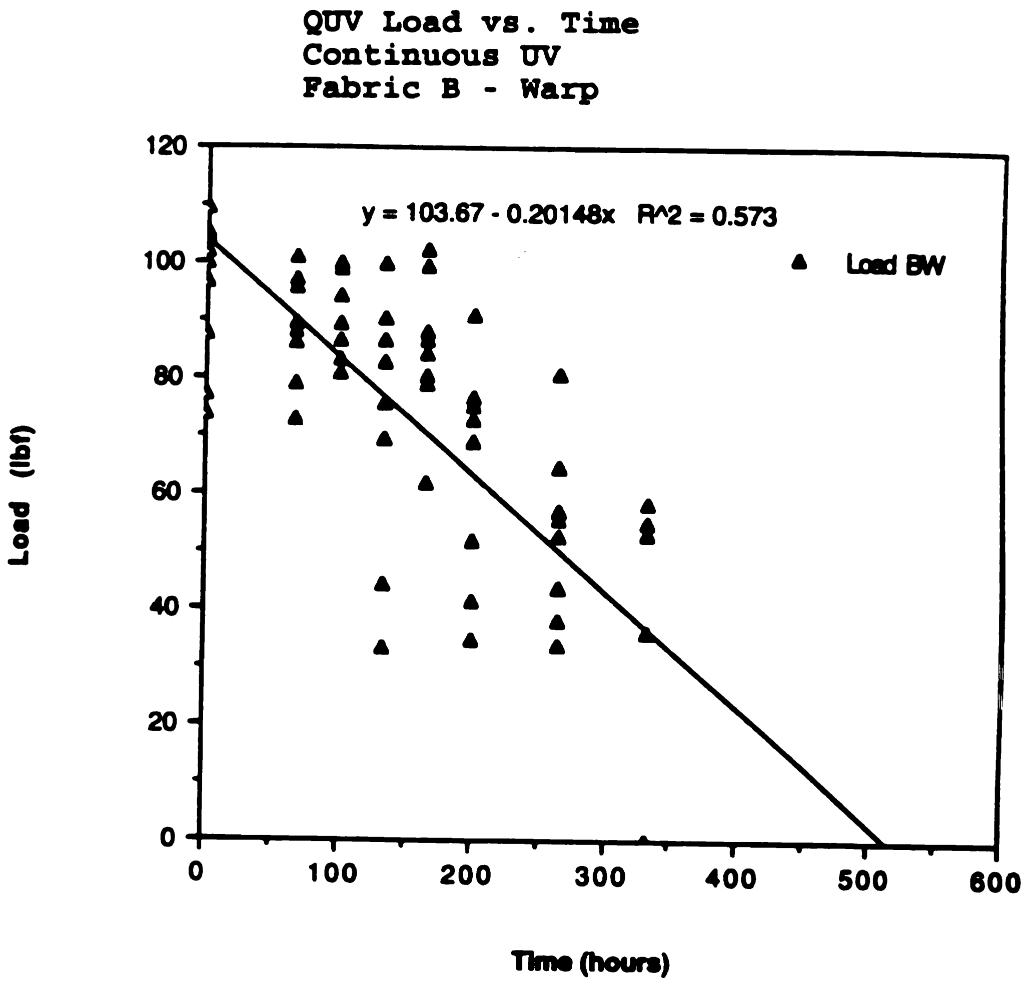


Fig. 18: QUV, Continuous UV - Fabric B (Warp)

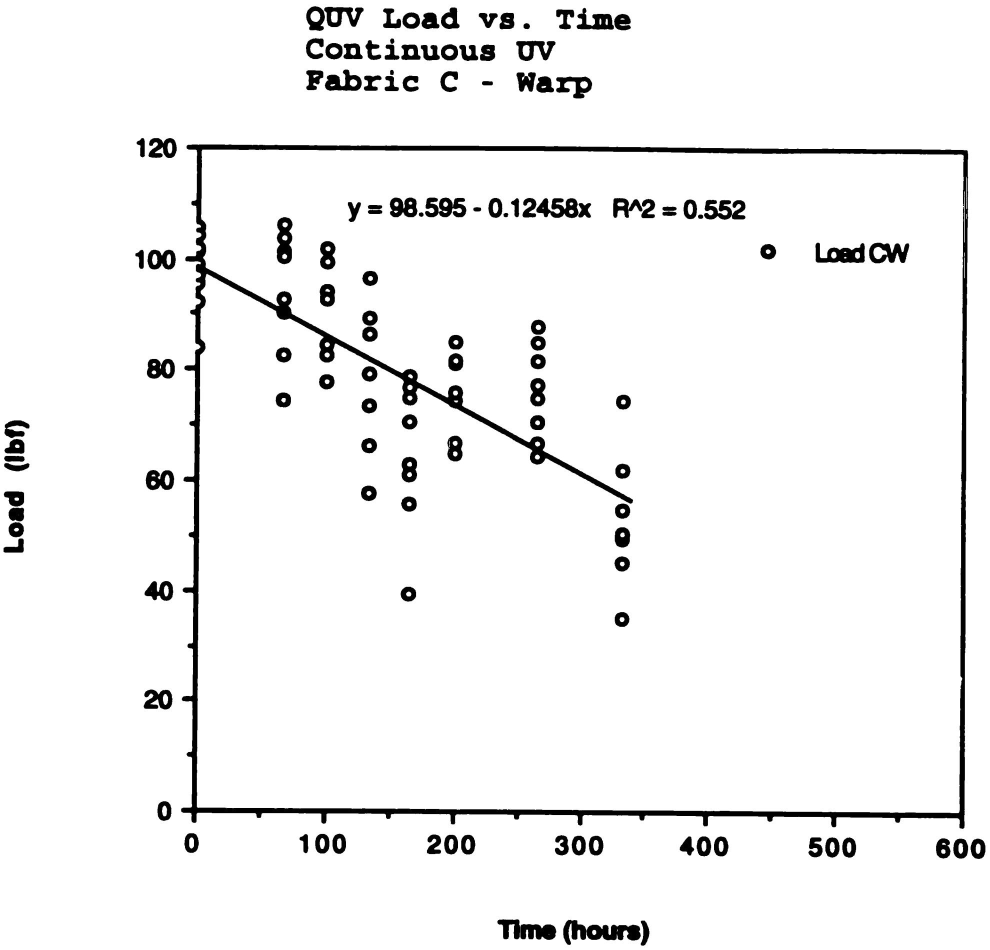


Fig. 19: QUV, Continuous UV - Fabric C (Warp)

QUV Load vs. Time
Continuous UV
Fabric D - Warp

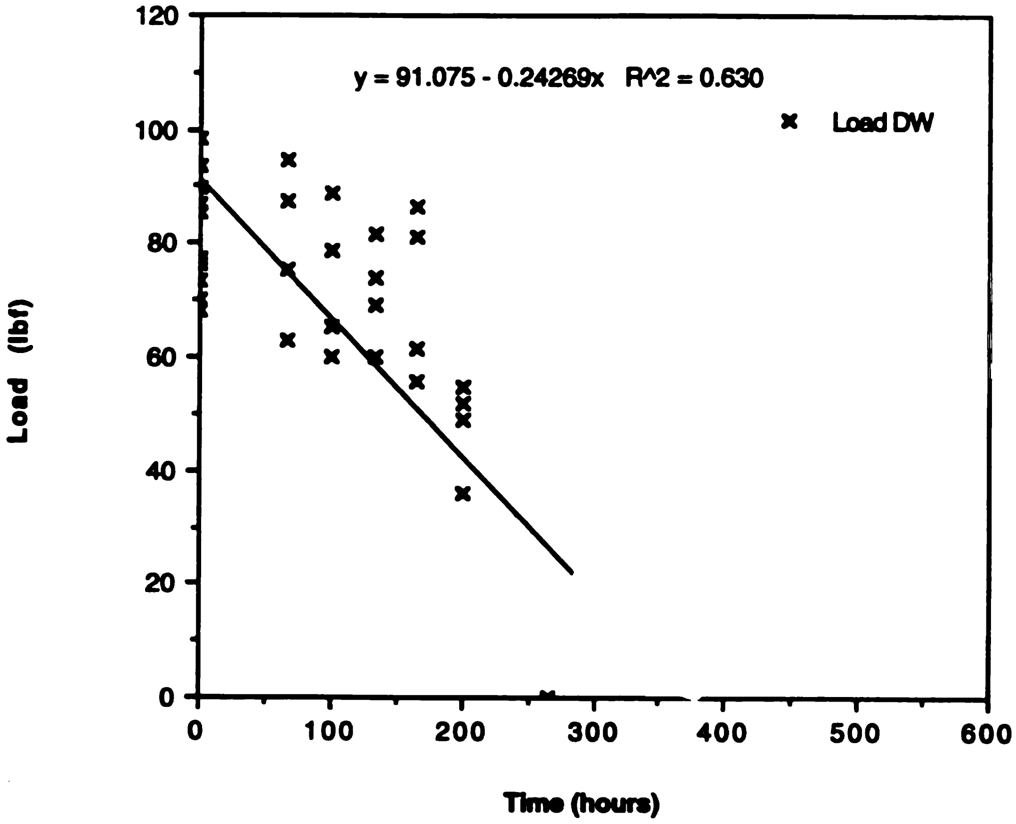


Fig. 20: QUV, Continuous UV - Fabric D (Warp)

Load (lbf)

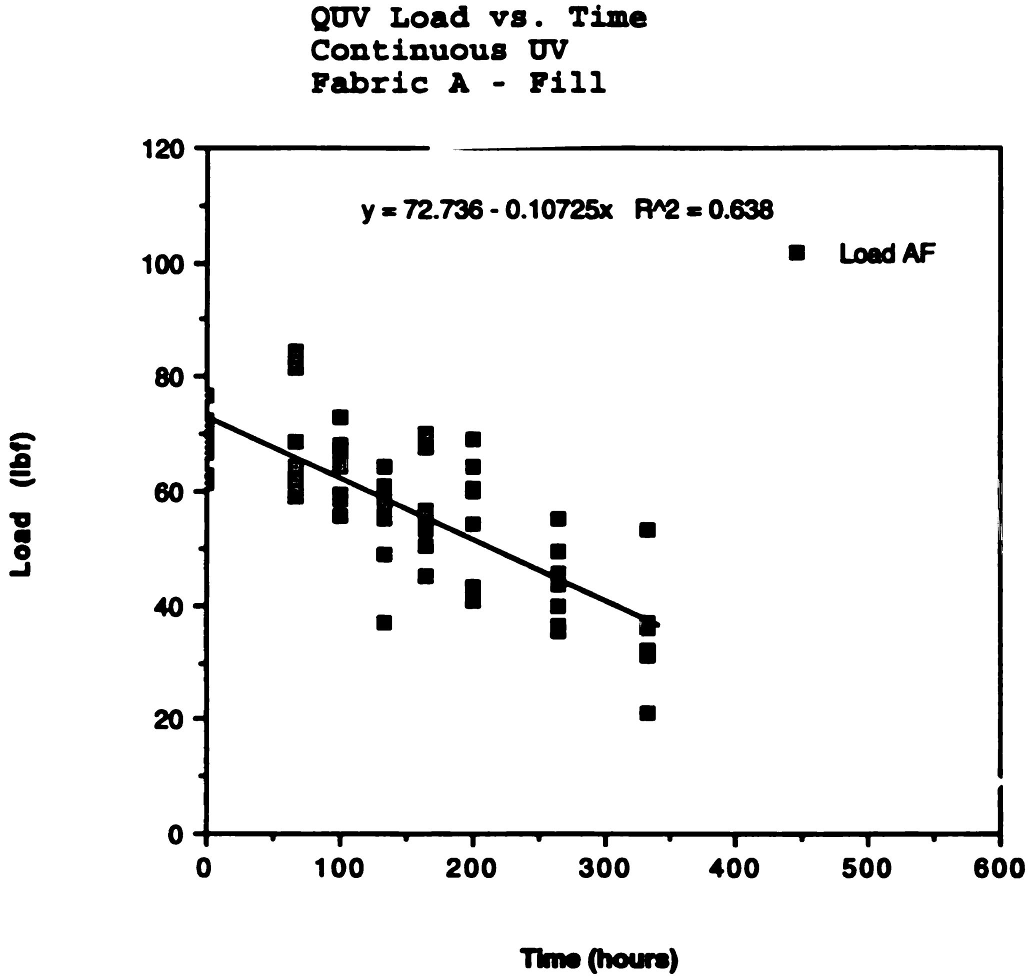


Fig. 21: QUV, Continuous UV - Fabric A (Fill)

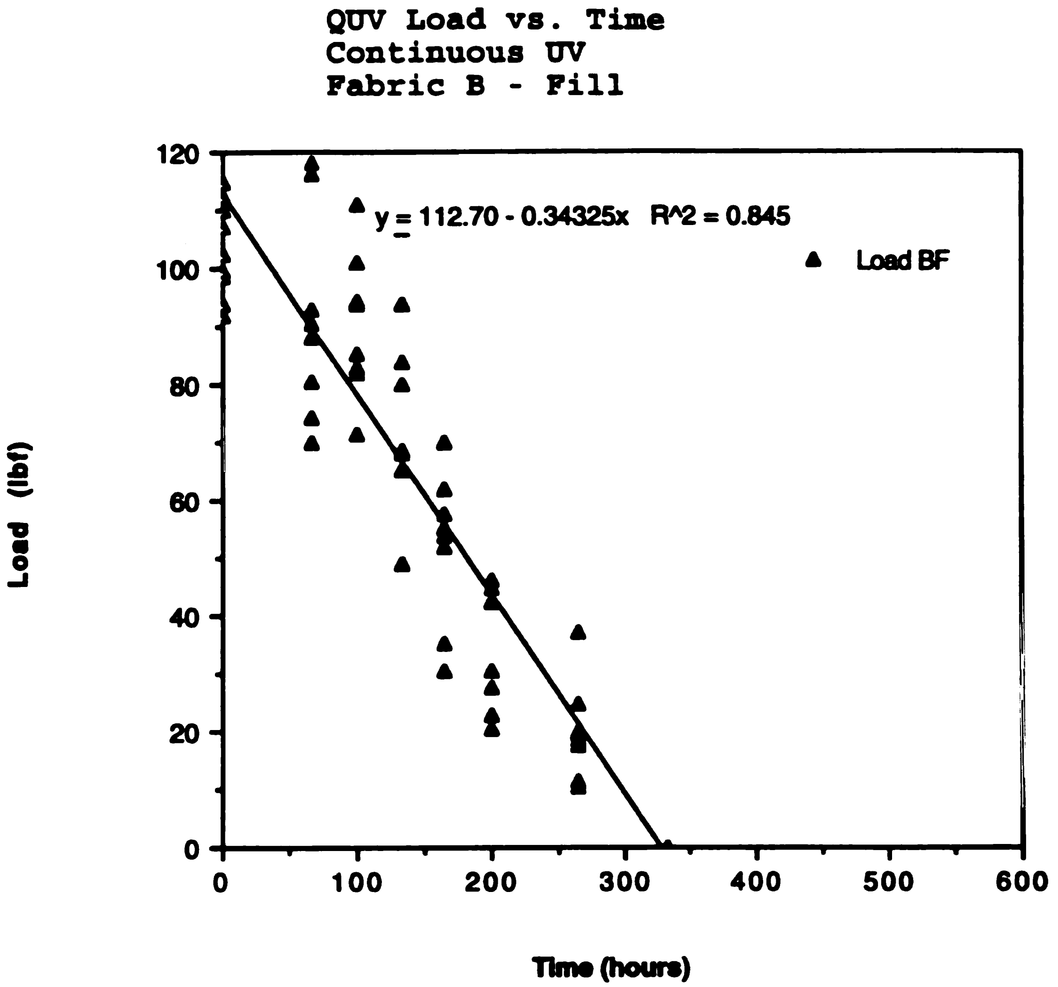


Fig. 22: QUV, Continuous UV - Fabric B (Fill)

QUV Load vs. Time
Continuous UV
Fabric C - Fill

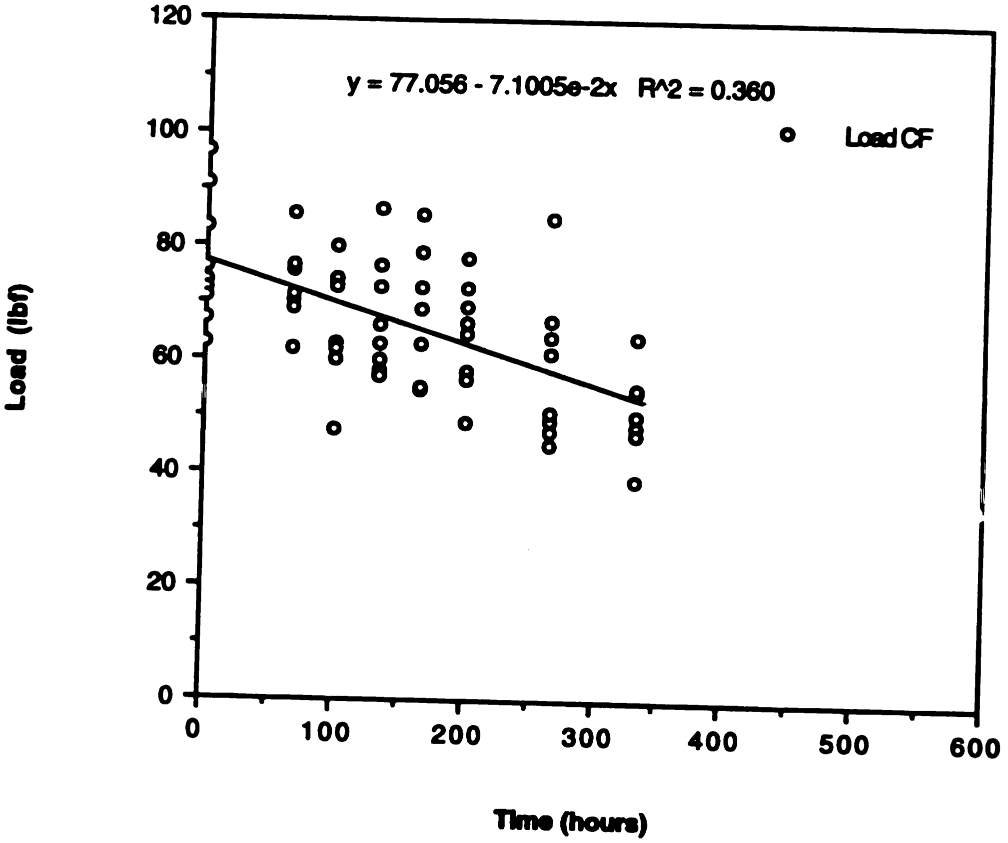


Fig. 23: QUV, Continuous UV - Fabric C (Fill)

Load (lbf)

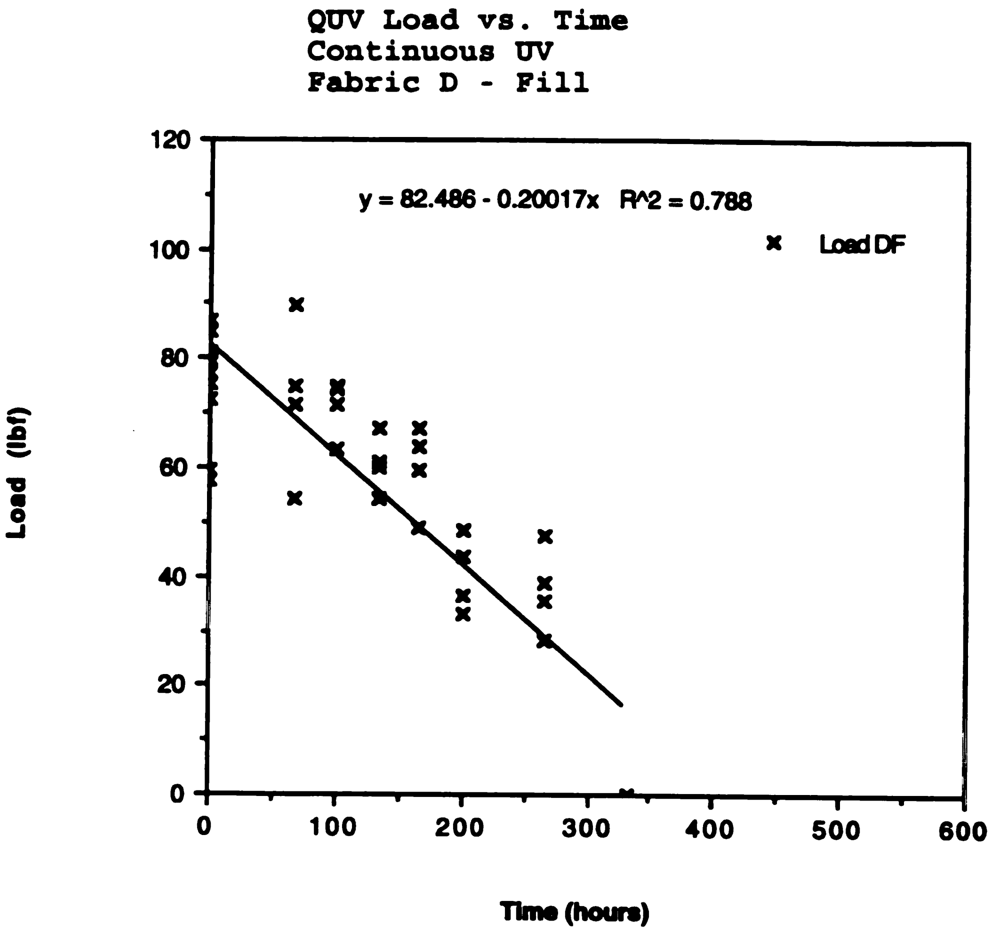


Fig. 24: QUV, Continuous UV - Fabric D (Fill)

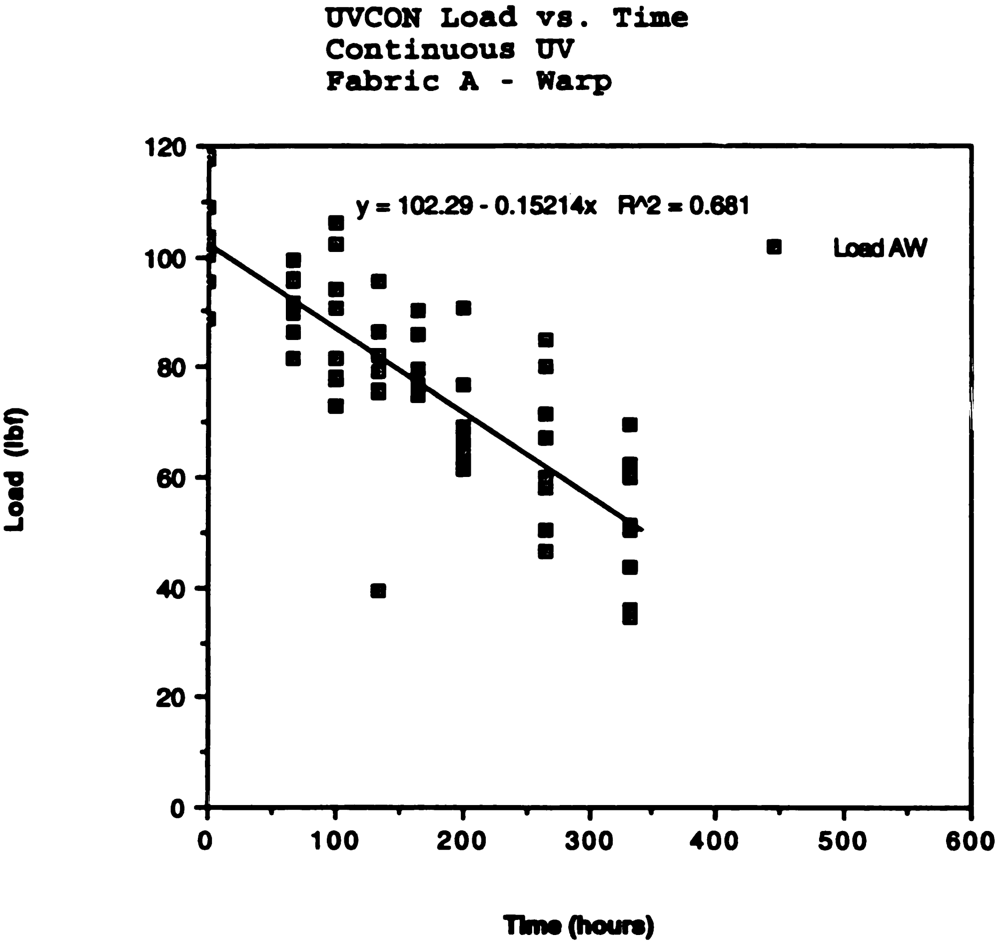


Fig. 25: UVCON, Continuous UV - Fabric A (Warp)

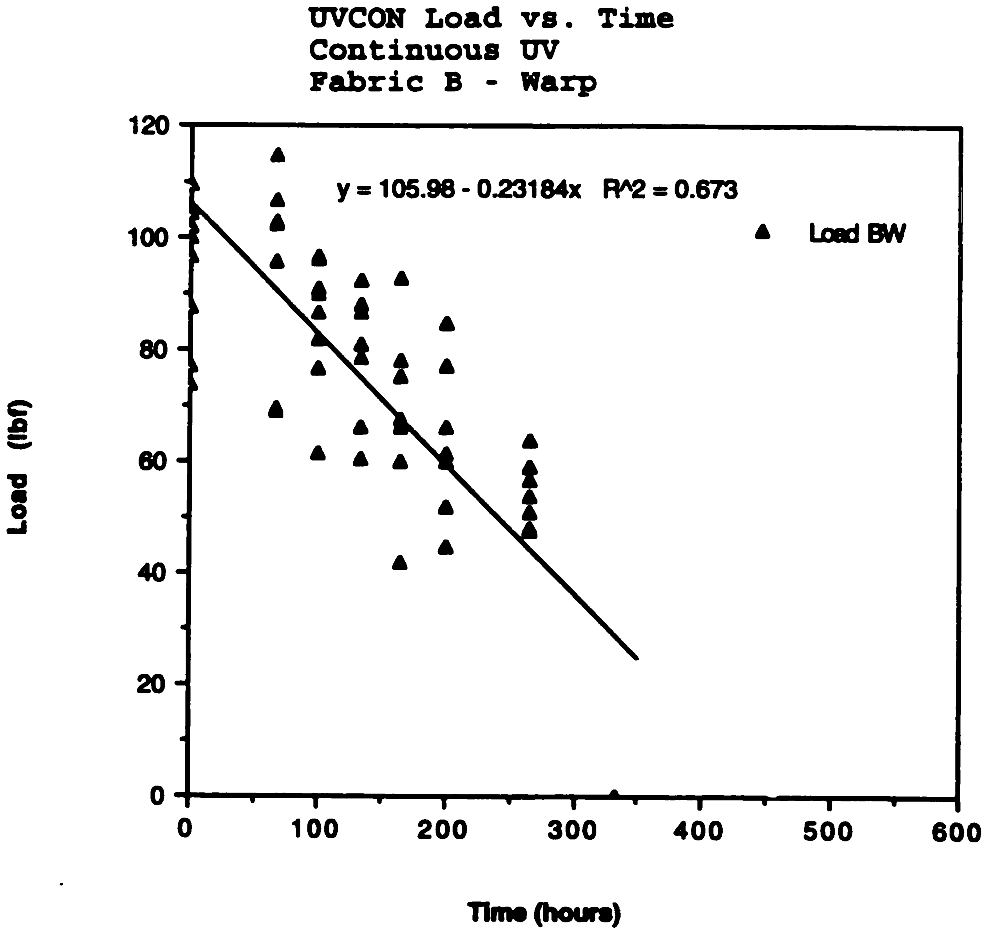


Fig. 26: UVCON, Continuous UV - Fabric B (Warp)

Load (lbf)

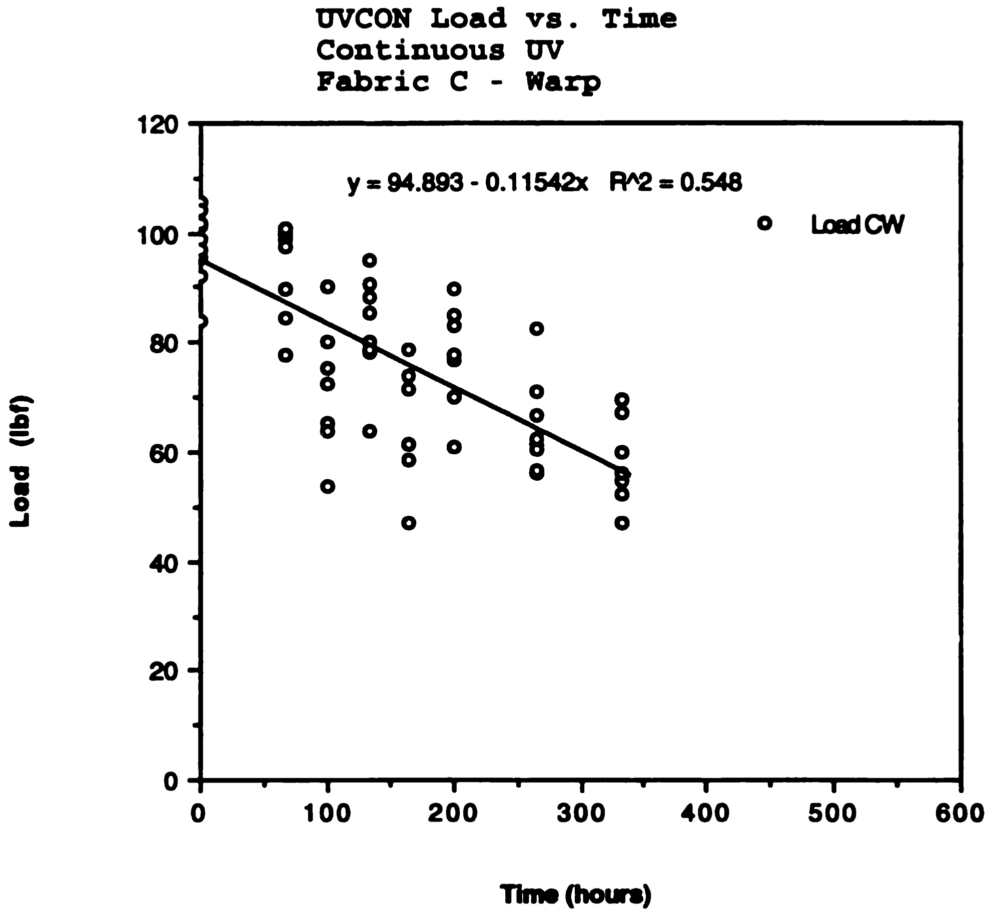


Fig. 27: UVCON, Continuous UV - Fabric C (Warp)

UVCON Load vs. Time
Continuous UV
Fabric D - Warp

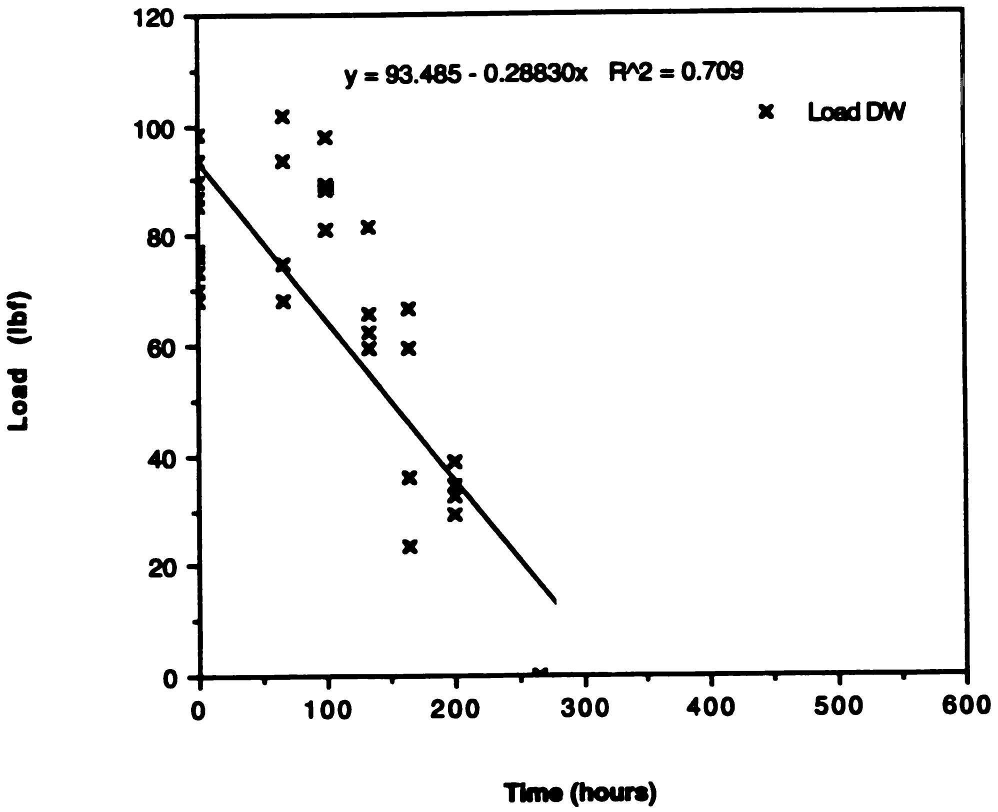


Fig. 28: UVCON, Continuous UV - Fabric D (Warp)

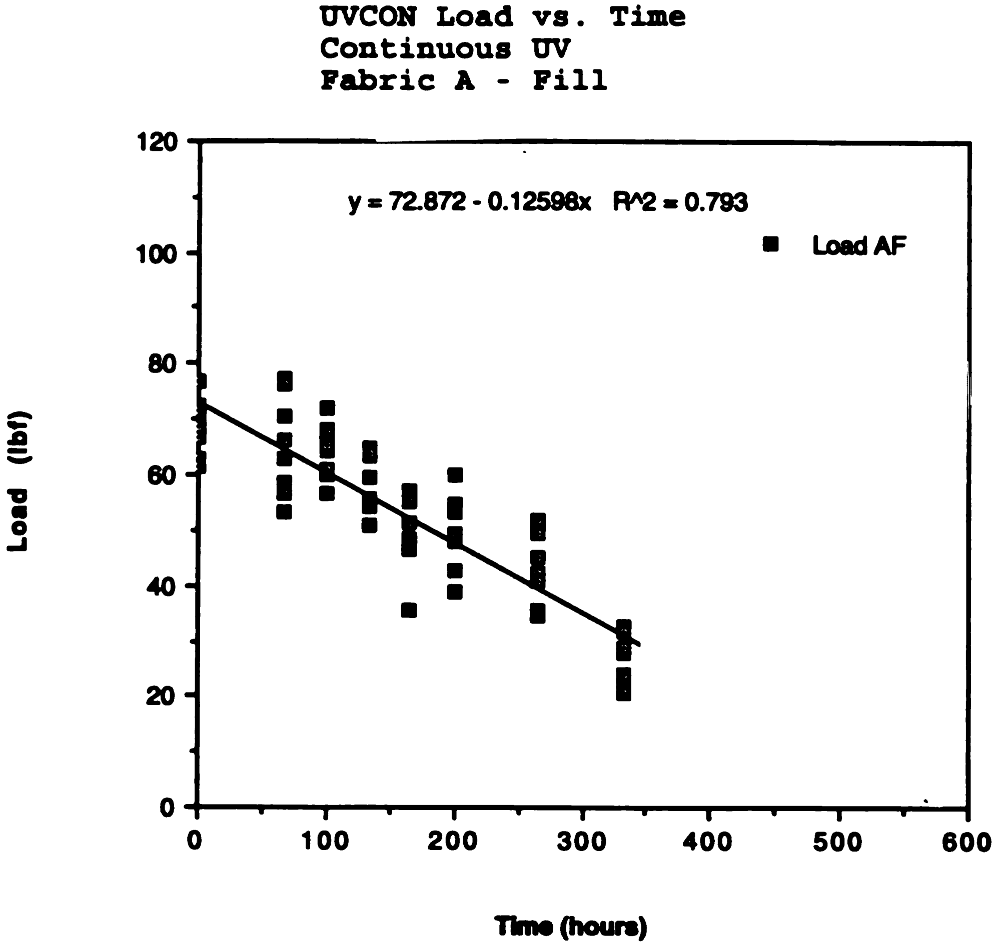


Fig. 29: UVCON, Continuous UV - Fabric A (Fill)

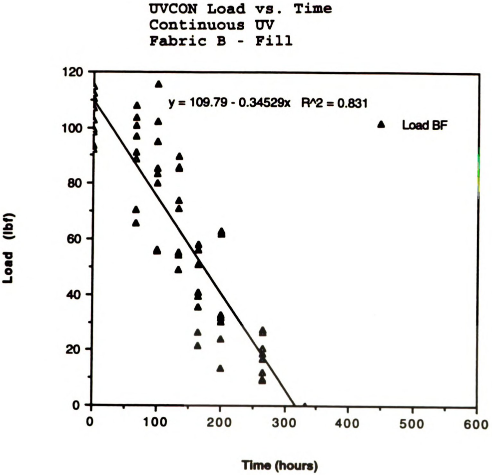


Fig. 30: UVCON, Continuous UV - Fabric B (Fill)

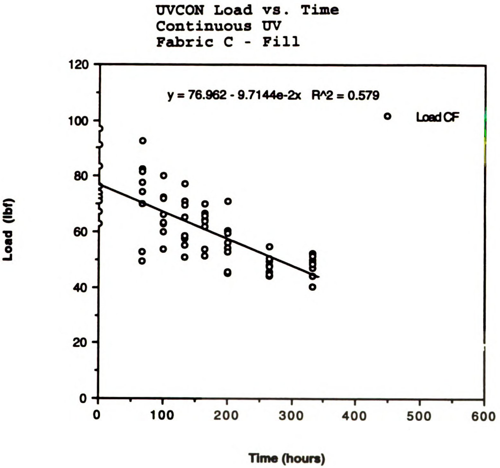


Fig. 31: UVCON, Continuous UV - Fabric C (Fill)

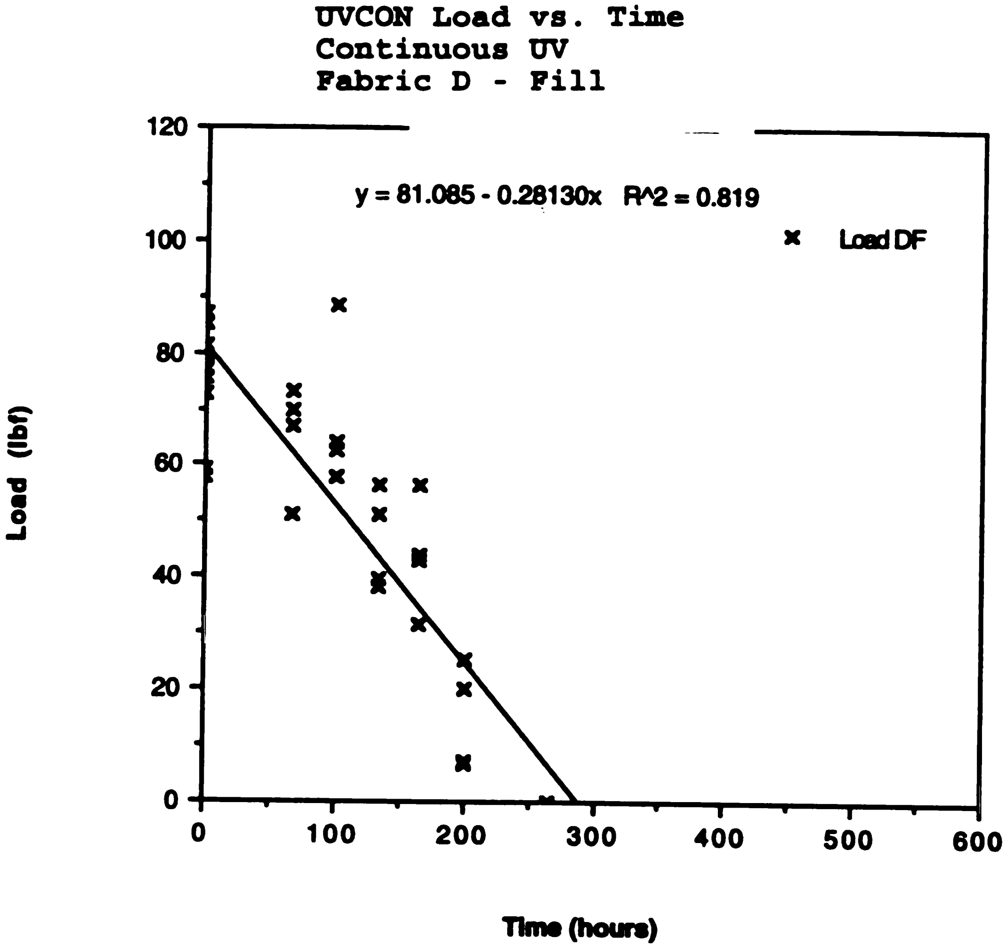


Fig. 32: UVCON, Continuous UV - Fabric D (Fill)

UVCON vs. QUV
8 Hour UV (4 hour Condensation)
Warp

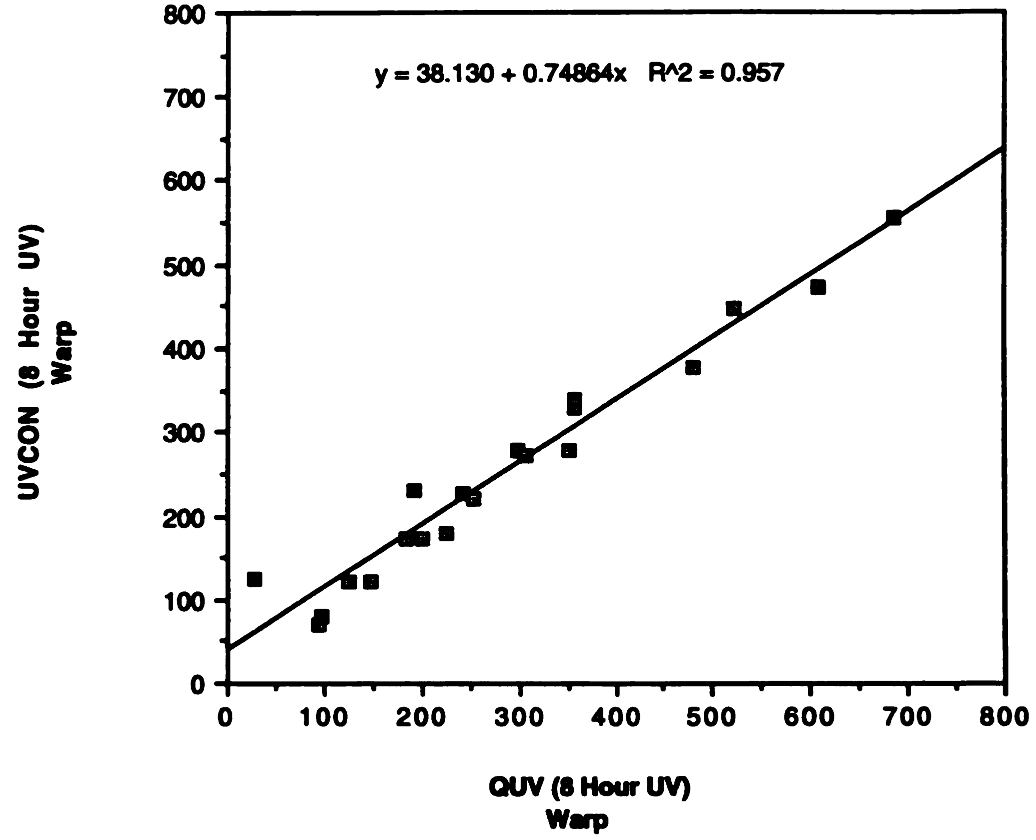


Fig. 33: UVCON vs. QUV, 8 Hour UV - Warp

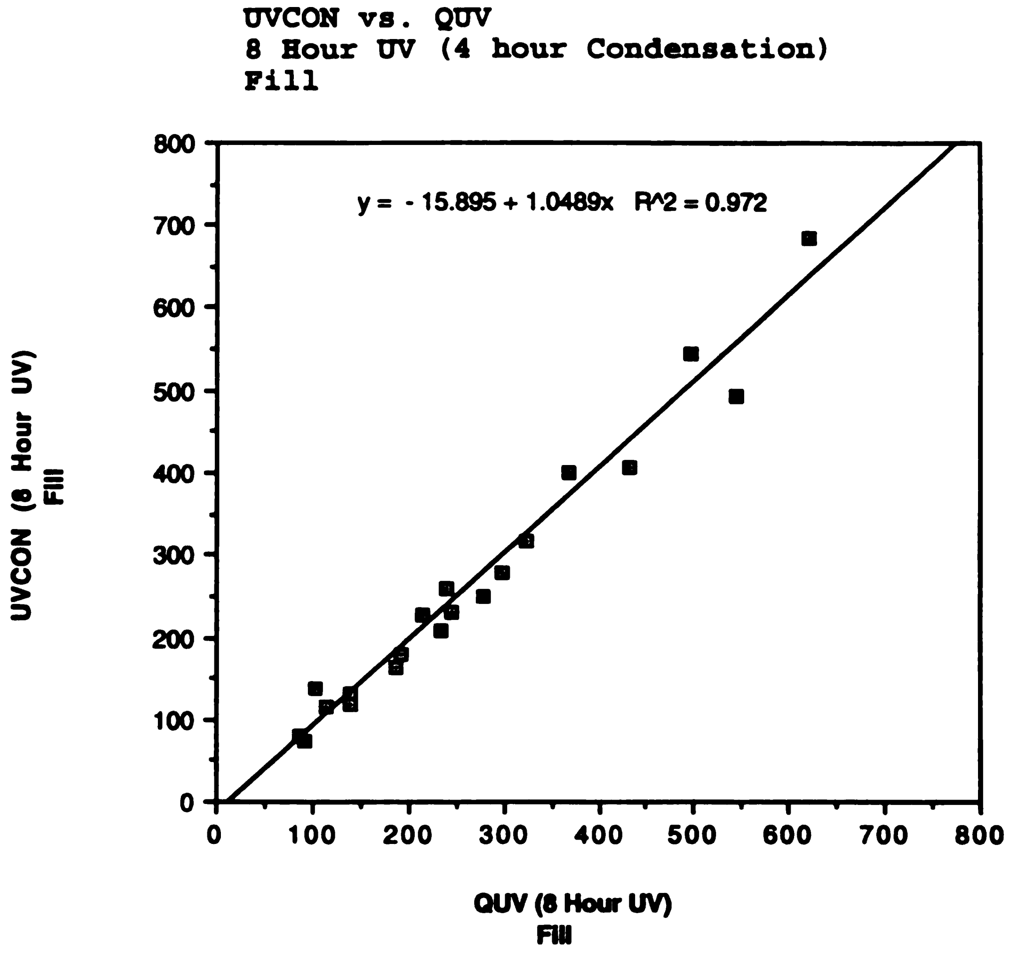


Fig. 34: UVCON vs. QUV, 8 Hour UV - Fill

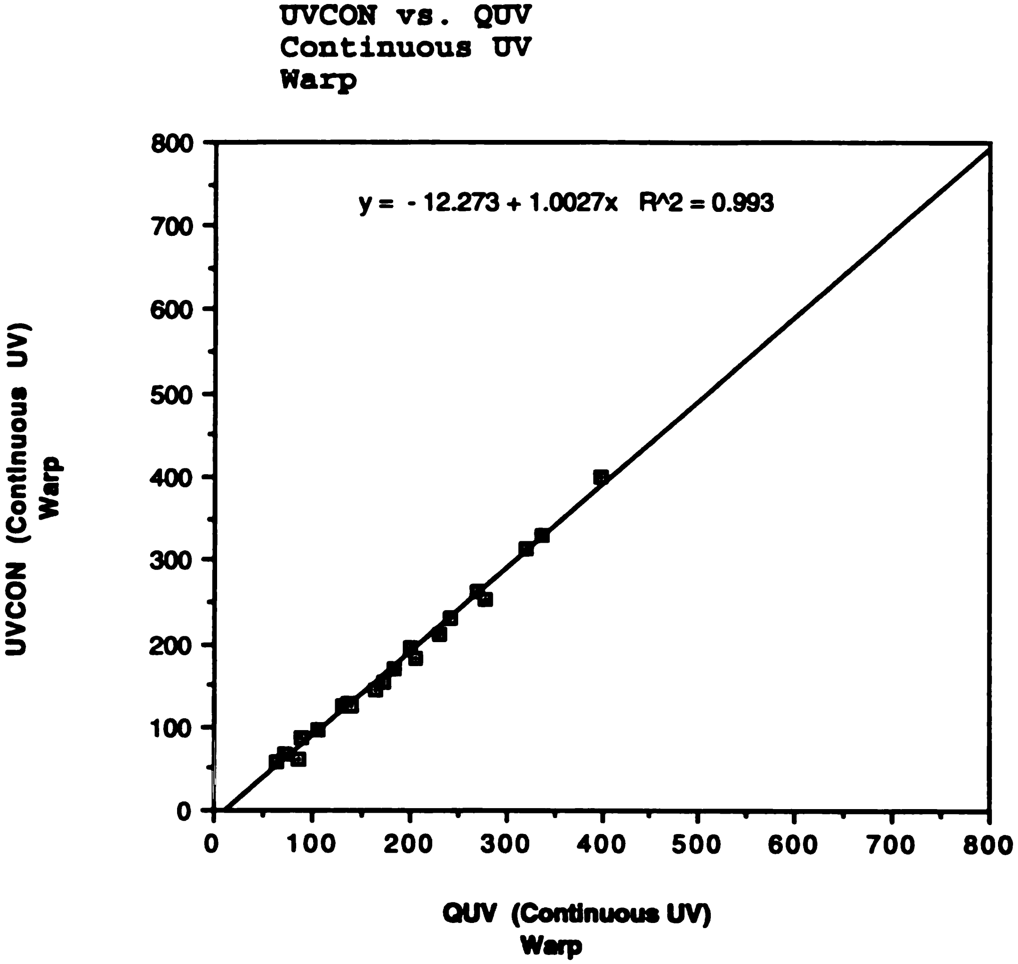


Fig. 35: UVCON vs. QUV, Continuous UV - Warp

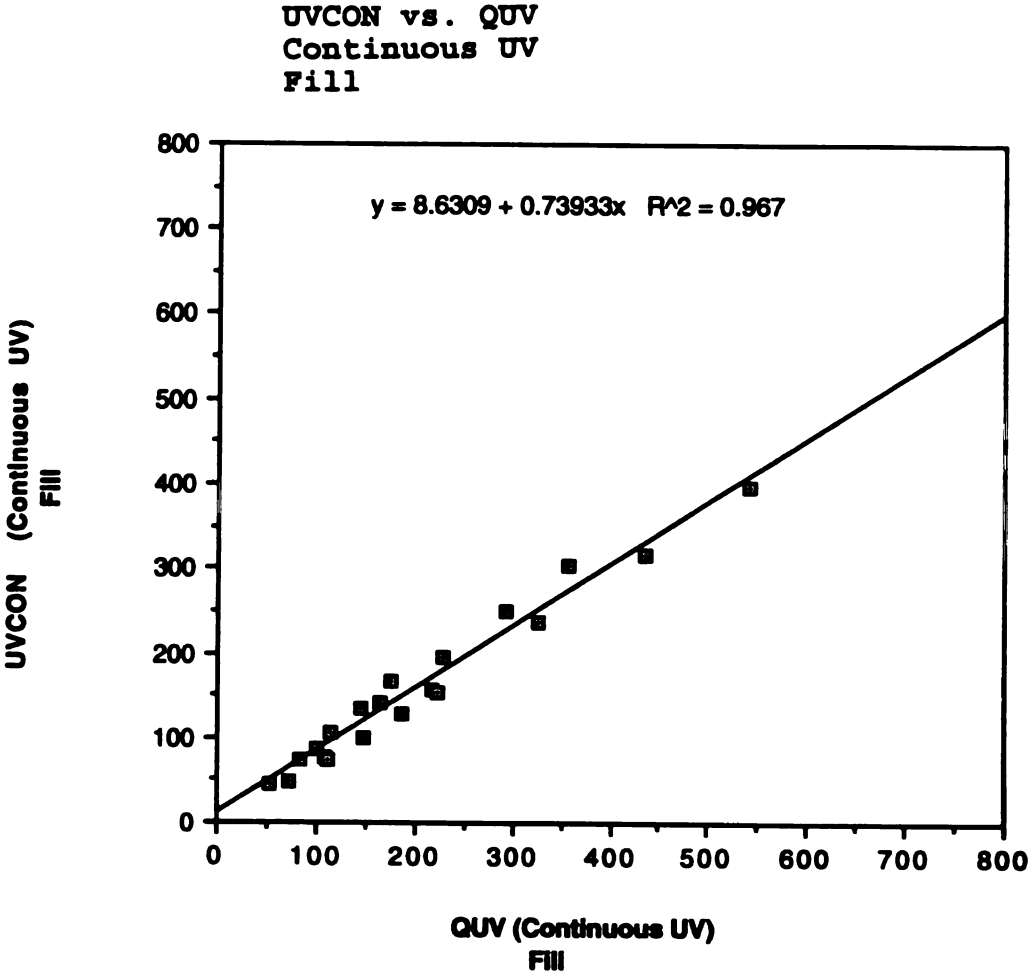


Fig. 36: UVCON vs. QUV, Continuous UV - Fill

QUV vs. QUV
Continuous vs. 8 Hour UV
Warp

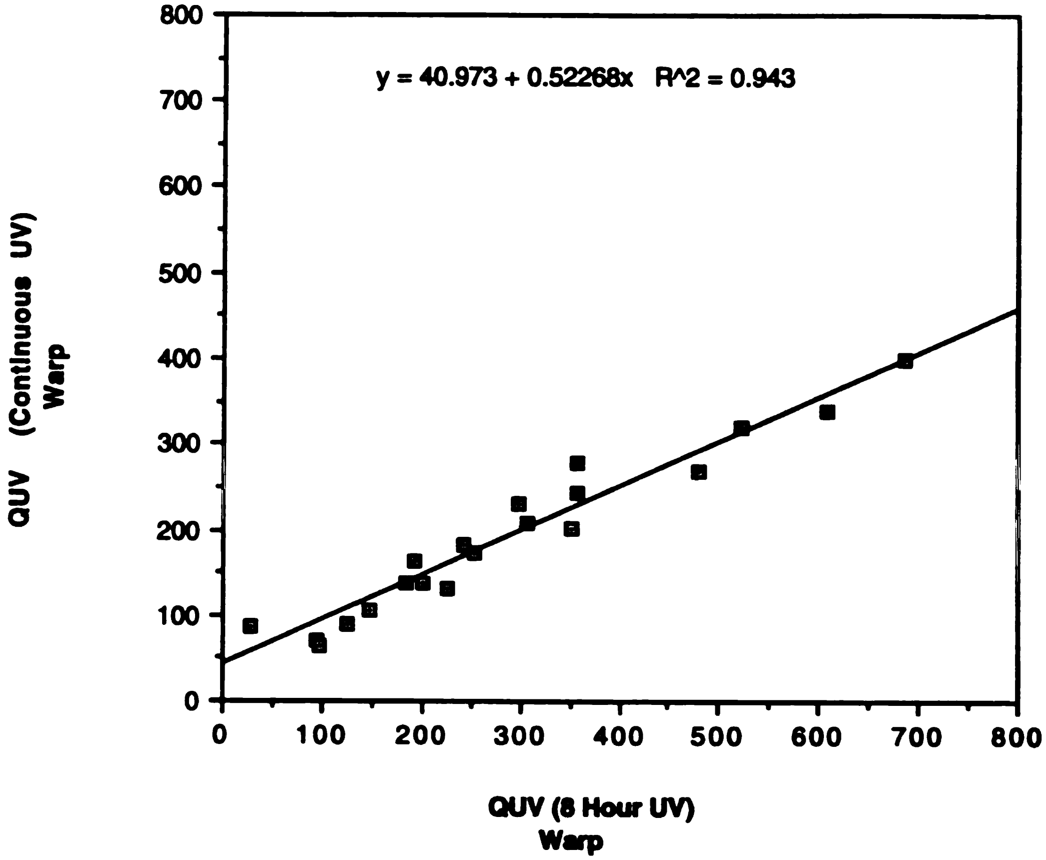


Fig. 37: QUV (Continuous UV) vs. QUV (8 UV) - Warp

QUV vs. QUV
Continuous UV vs. 8 Hour UV
Fill

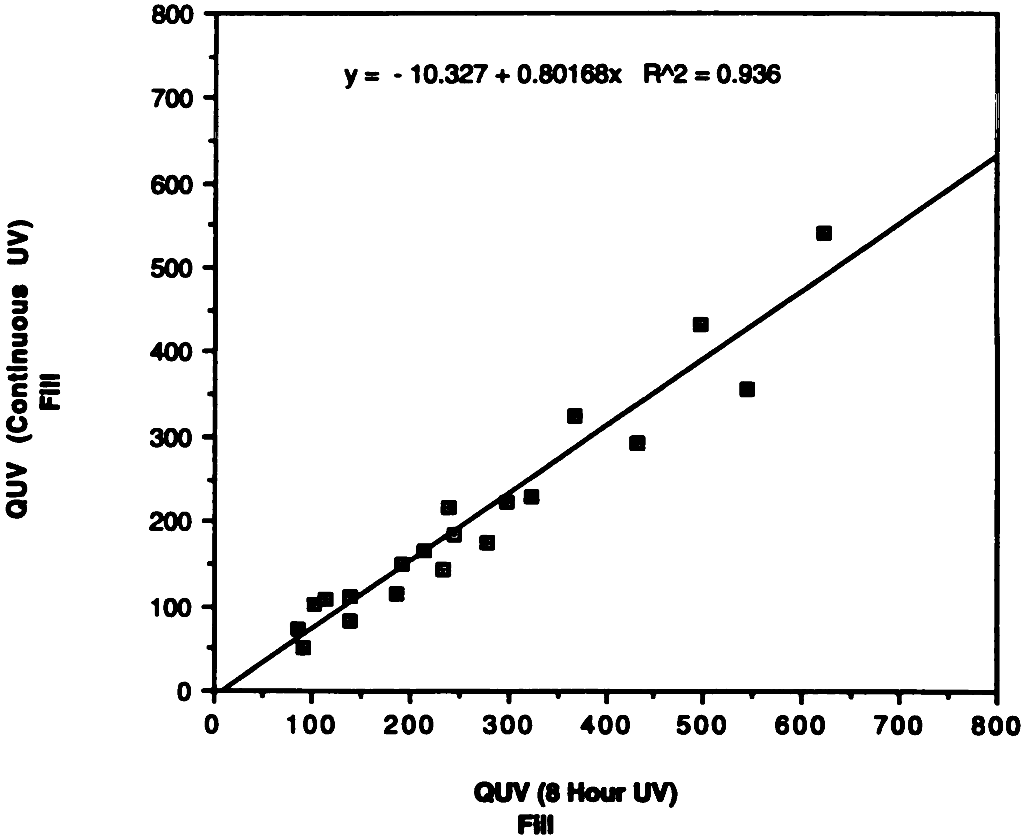


Fig. 38: QUV (Continuous UV) vs. QUV (8 UV) - Fill

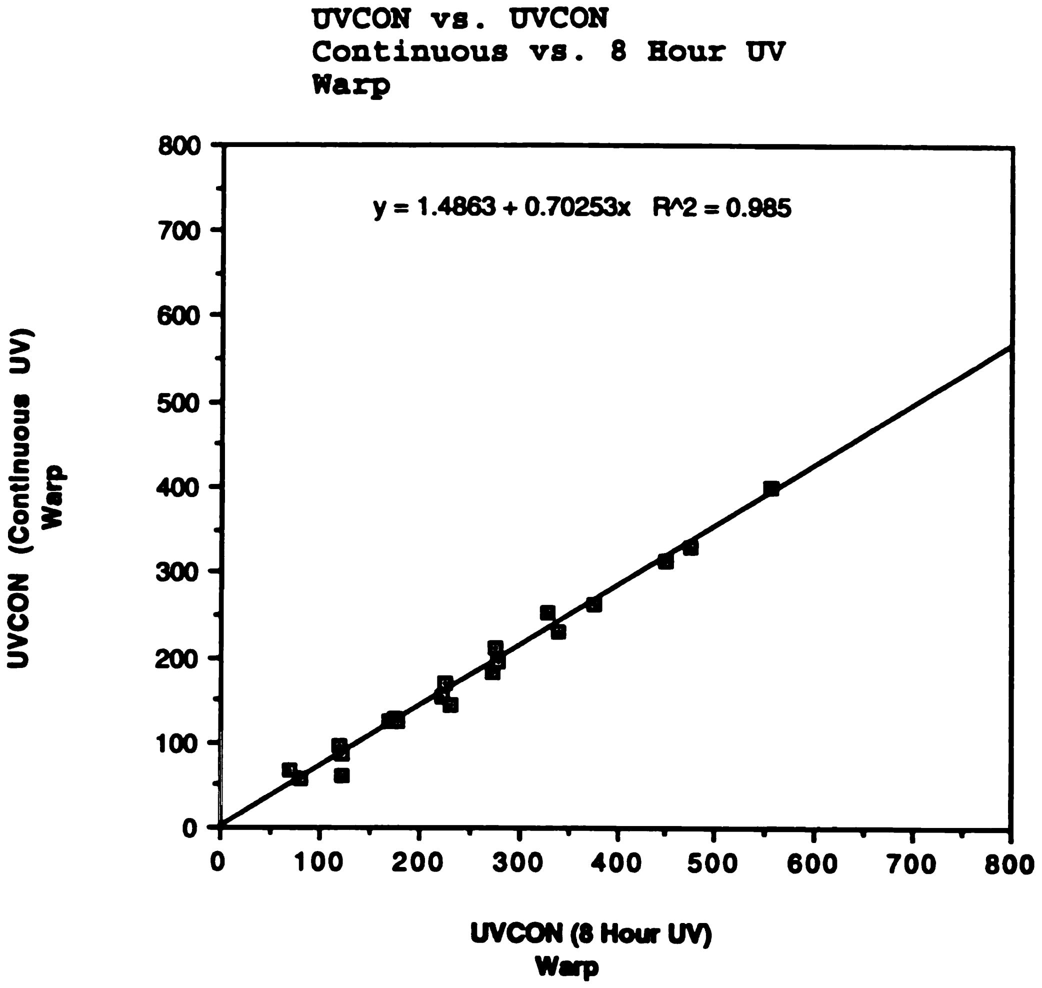


Fig. 39: UVCON (Continuous UV) vs. UVCON (8 UV) - Warp

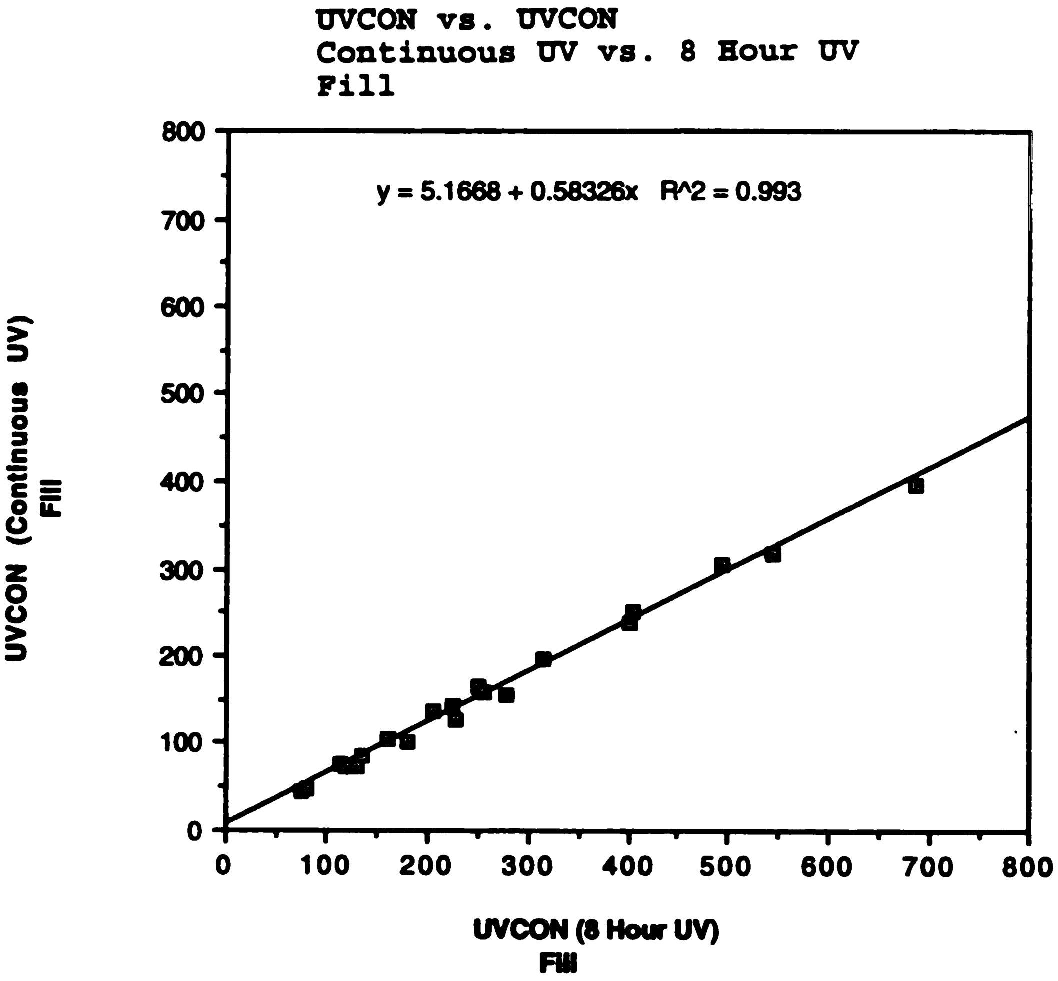


Fig. 40: UVCON (Continuous UV) vs. UVCON (8 UV) - Fill

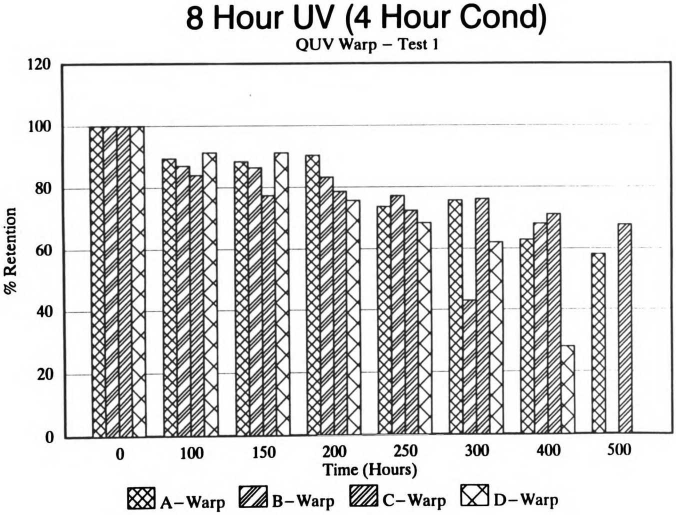


Fig. 41: 8 Hour UV - % Retention, QUV - Test 1 (warp)

UV (1 Hour Cond)

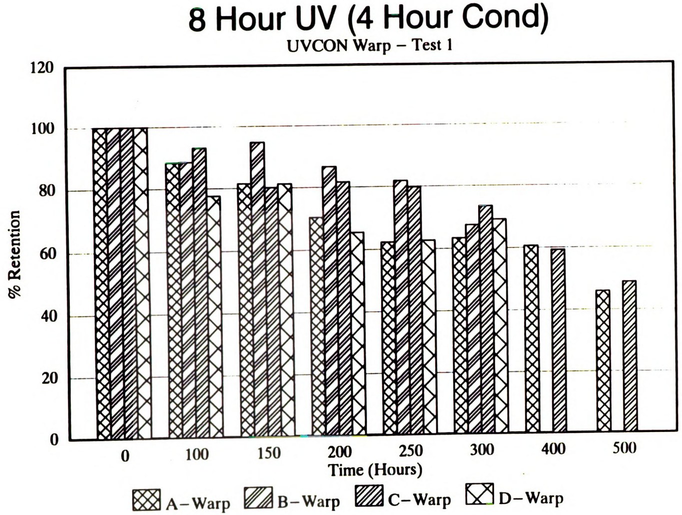


Fig. 42: 8 Hour UV - % Retention, UVCON-Test 1 (warp)

8 Hour UV (4 Hour Cond)

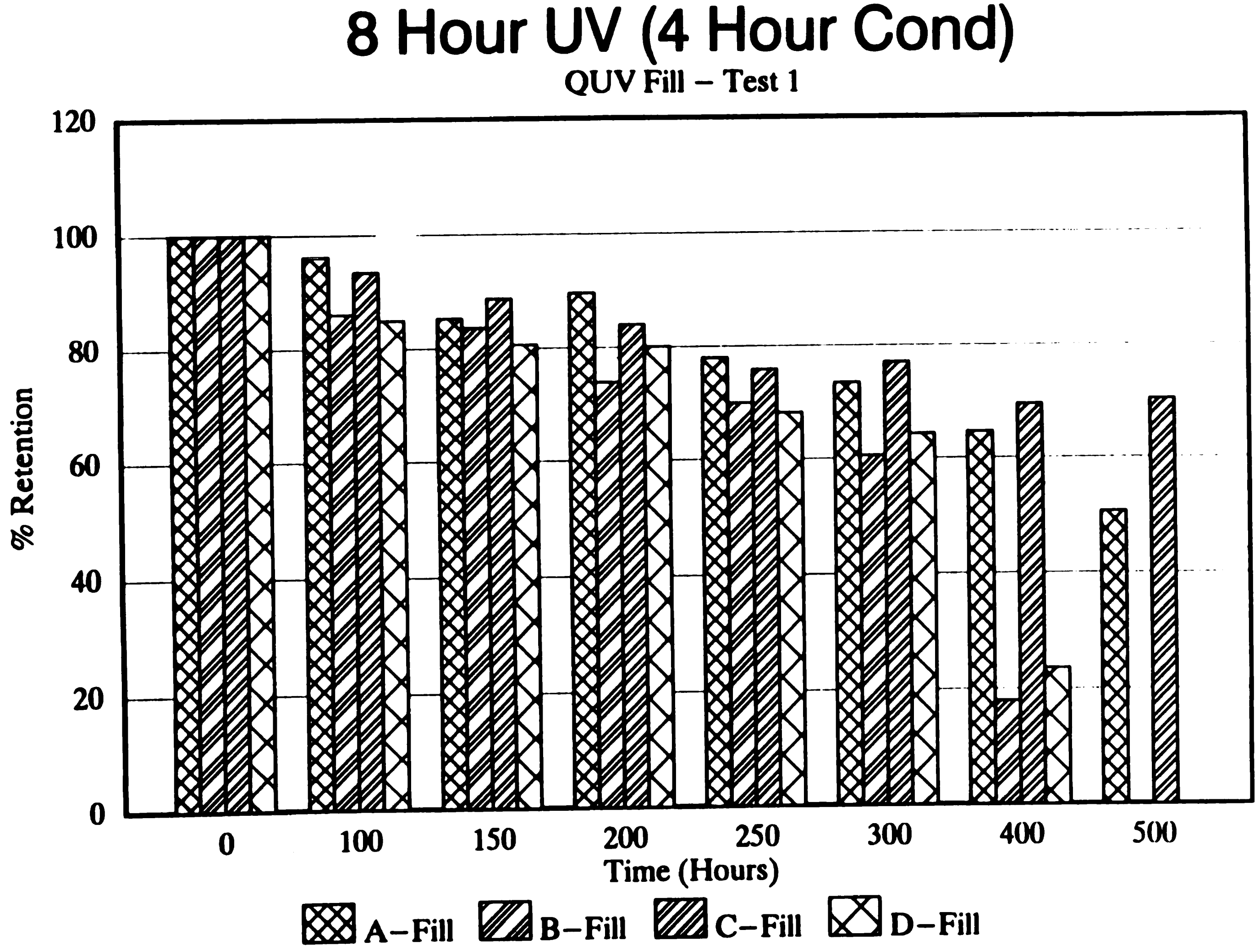


Fig. 43: 8 Hour UV - % Retention, QUV-Test 1 (fill)

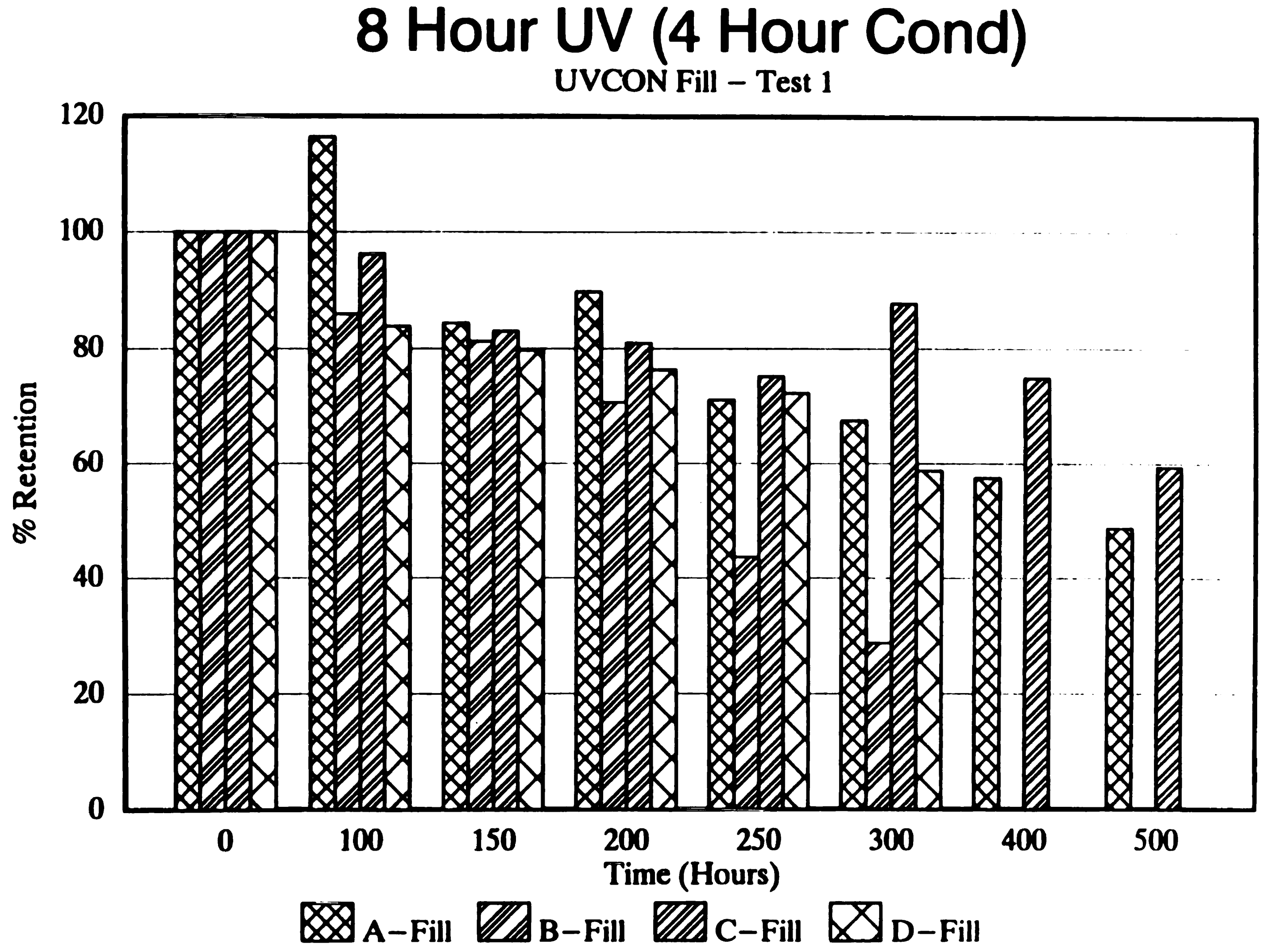


Fig. 44: 8 Hour UV - % Retention, UVCON-Test 1 (fill)

8 Hour UV (4 Hour Cond)

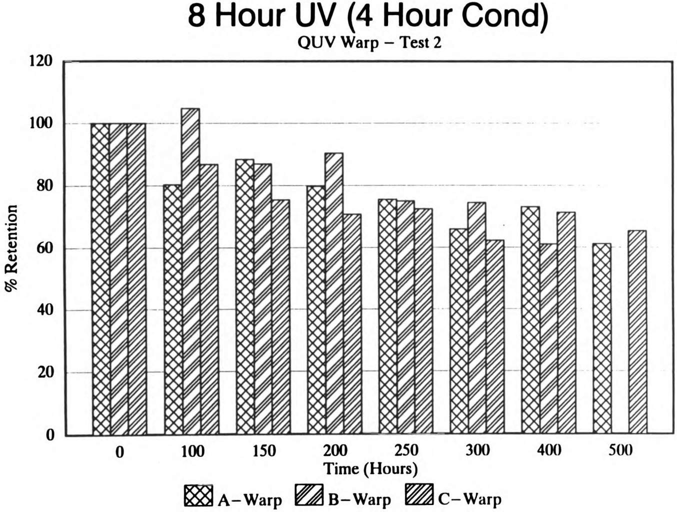


Fig. 45: 8 Hour UV - % Retention, QUV-Test 2 (warp)

8 Hour UV (4 Hour Cond)

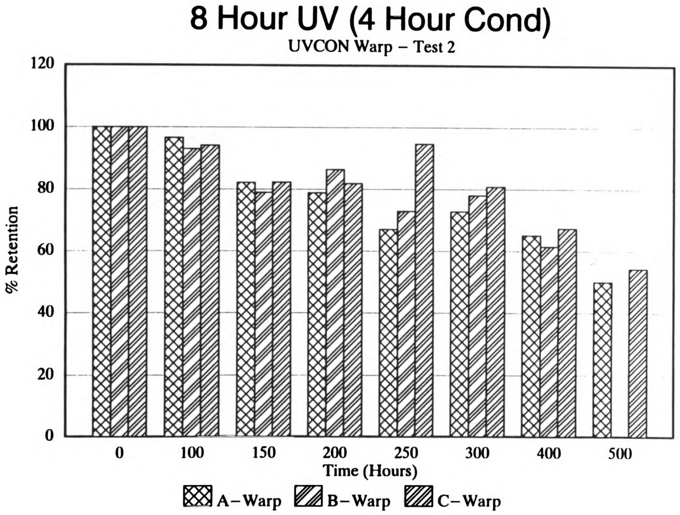


Fig. 46: 8 Hour UV - % Retention, UVCON-Test 2 (warp)

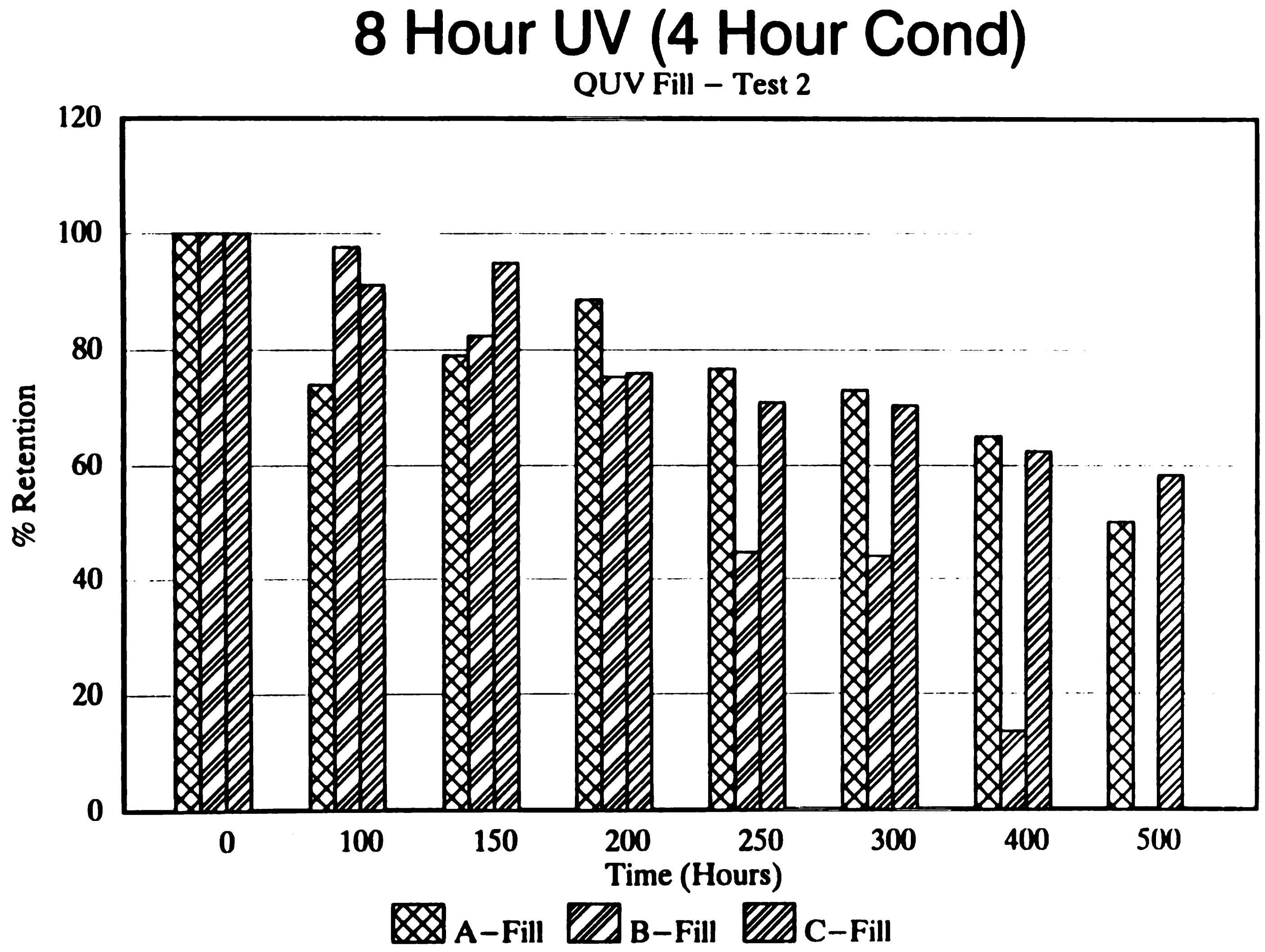


Fig. 47: 8 Hour UV - % Retention, QUV-Test 2 (fill)

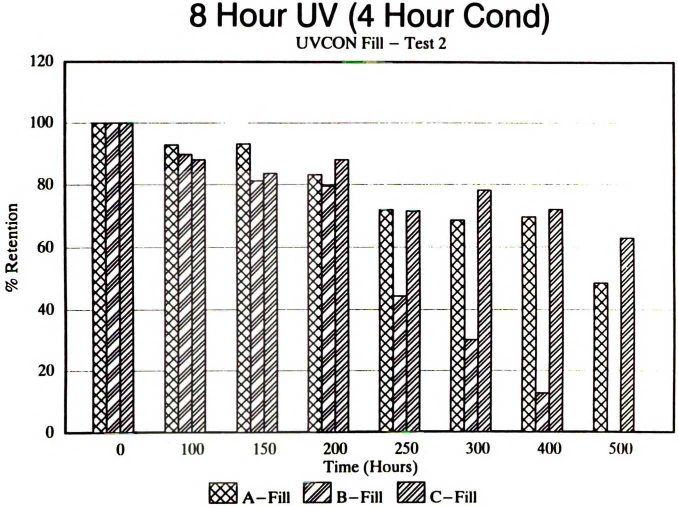


Fig. 48: 8 Hour UV - % Retention, UVCON-Test 2 (fill)

Continuous UV (No Cond)

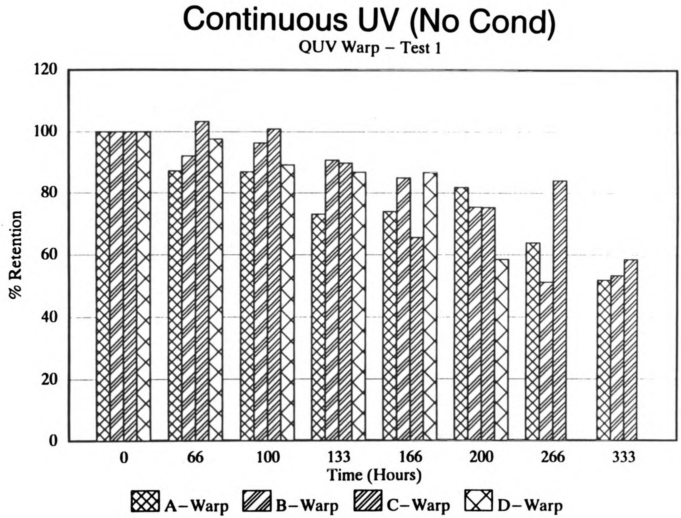


Fig. 49: Continuous UV - % Retention, QUV - Test 1 (warp)

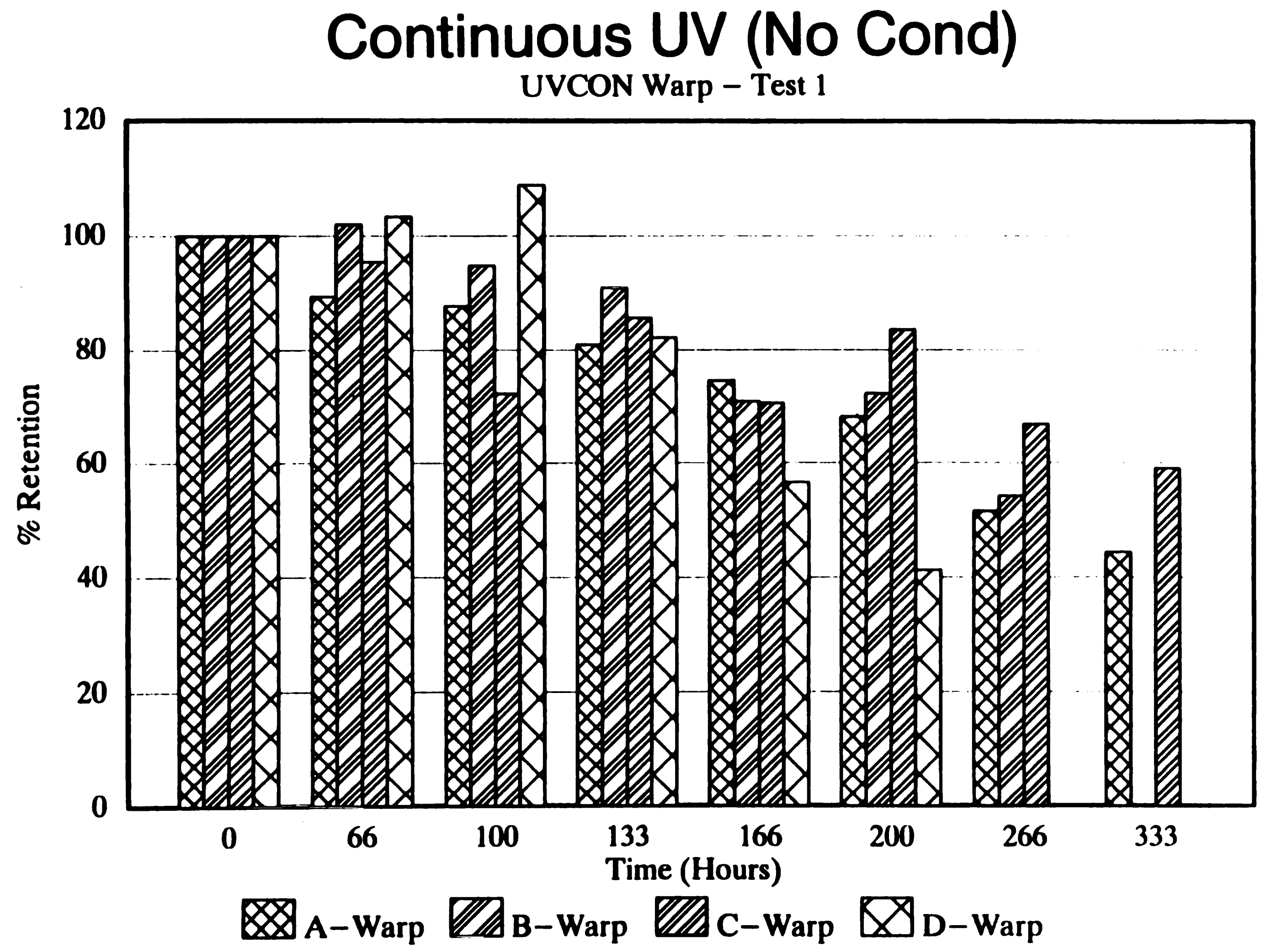


Fig. 50: Continuous UV - % Retention, UVCON - Test 1 (warp)

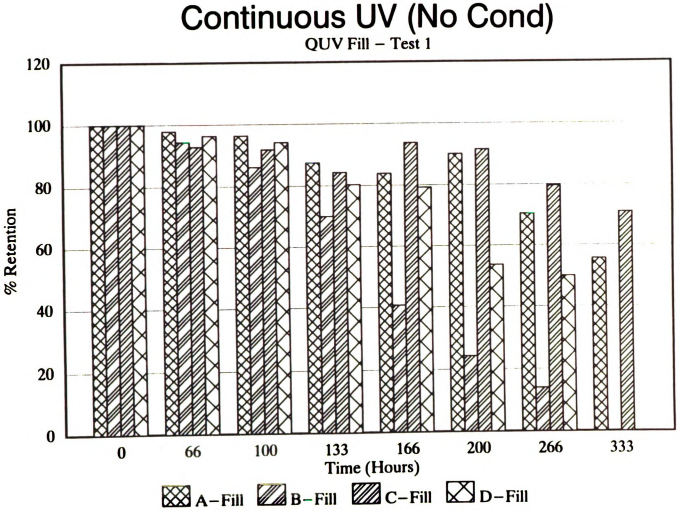


Fig. 51: Continuous UV - % Retention, QUV - Test 1 (fill)

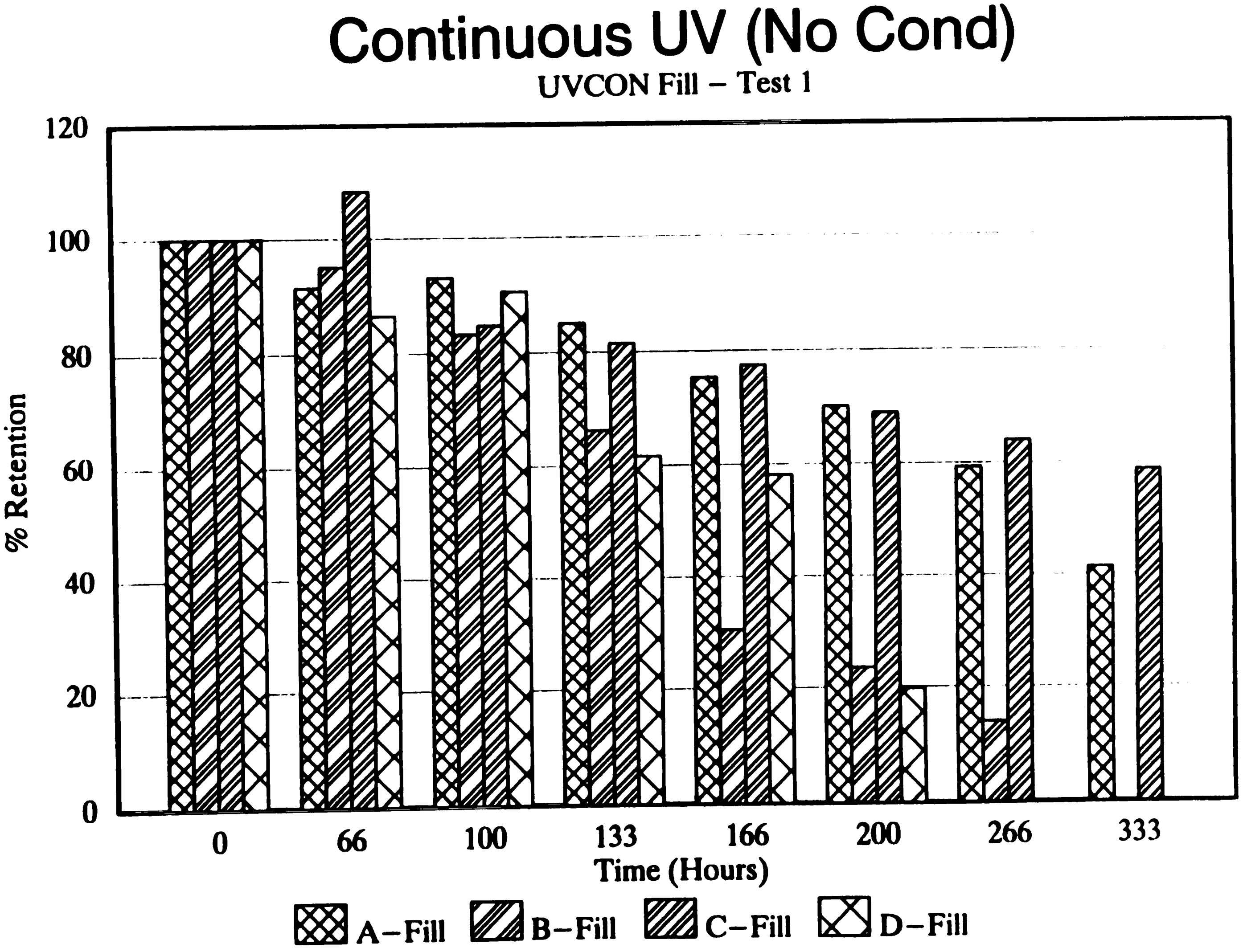


Fig. 52: Continuous UV - % Retention, UVCON - Test 1 (fill)

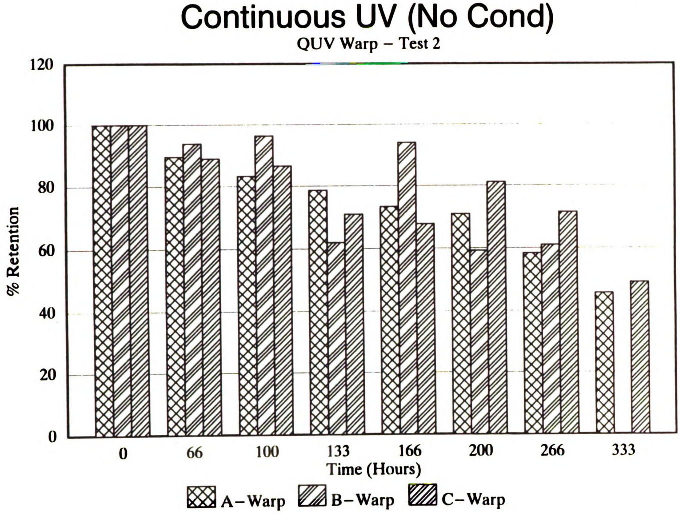


Fig. 53: Continuous UV - % Retention, QUV - Test 2 (warp)

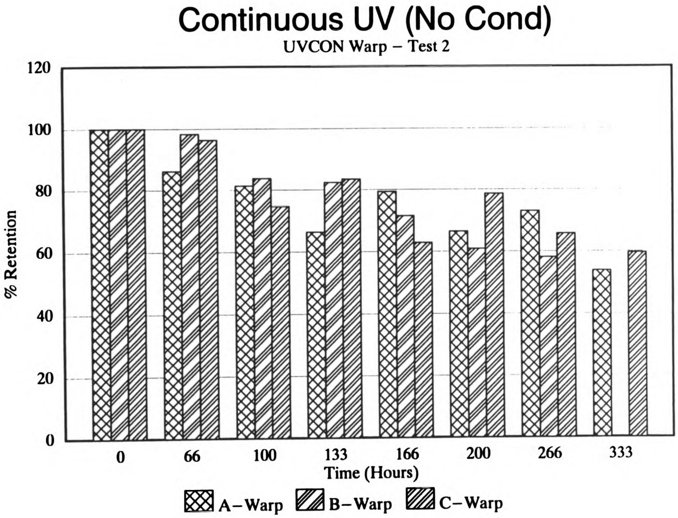


Fig. 54: Continuous UV - % Retention, UVCON - Test 2 (warp)

Continuous UV (No Cond)

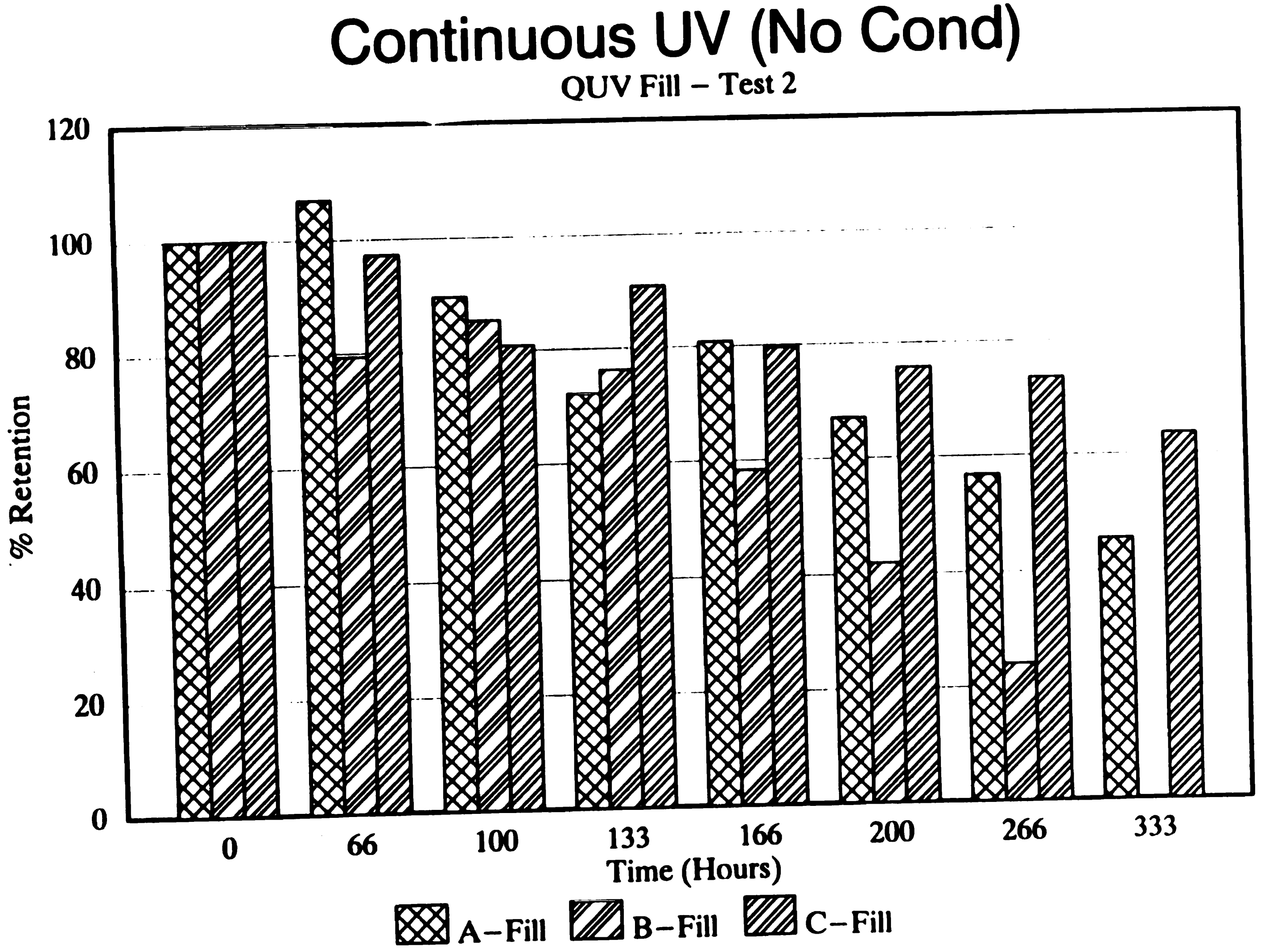


Fig. 55: Continuous UV - % Retention, QUV - Test 2 (fill)

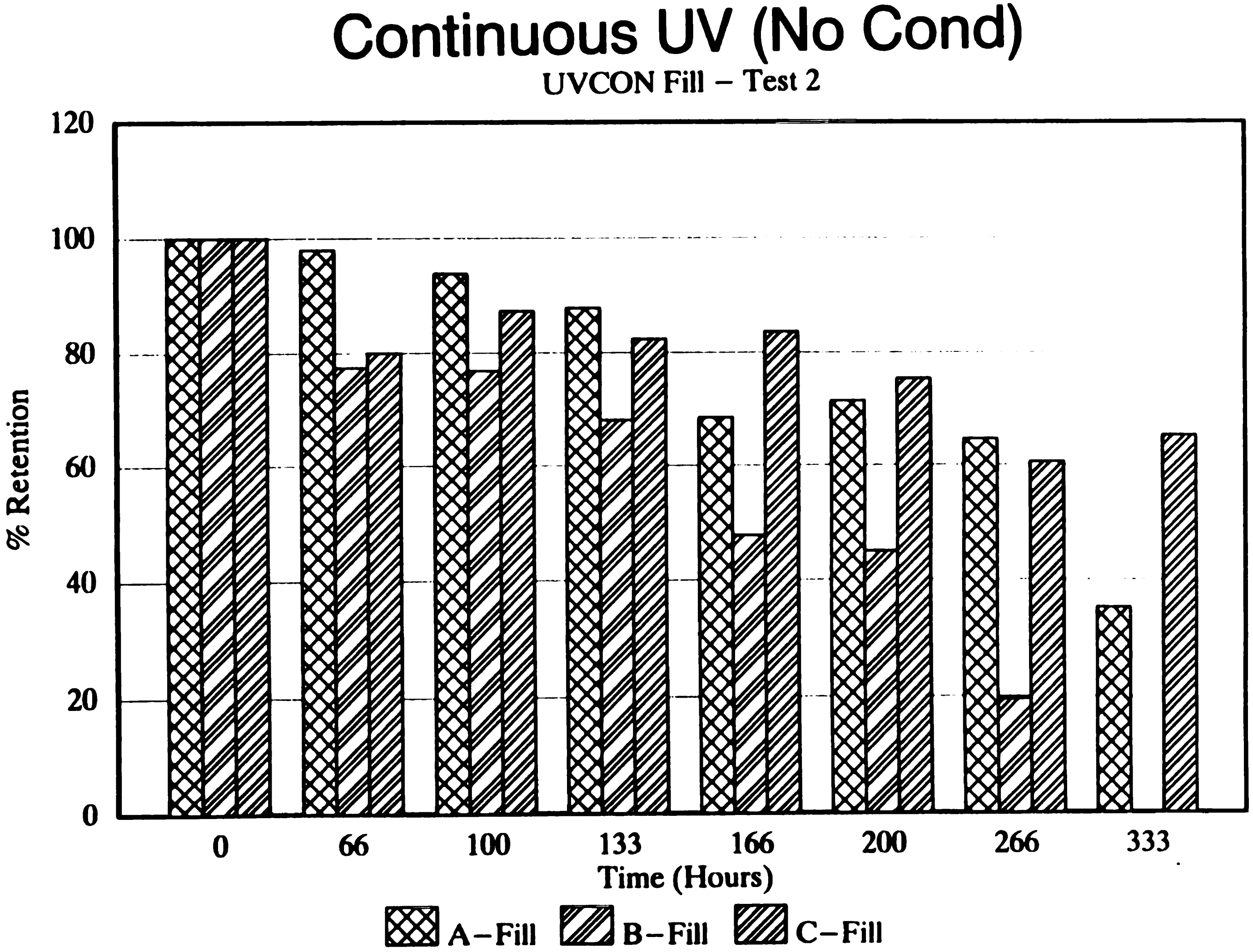


Fig. 56: Continuous UV - % Retention, UVCON - Test 2 (fill)

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