WEATHERING AND ABRASION RESISTANCE
OF SYNTHETIC TURF

by

ANDREA TIMM NISLEY

B.S., University of Nebraska, 1974

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Clothing, Textiles, and Interior Design

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1978

Approved by:

Barbara M. Reagan
Major Professor

ACKNOWLEDGMENTS

It is with great pleasure that I express my sincere gratitude and appreciation to those whose contributions have made this research project possible:

Dr. Barbara Reagan, my major professor and Dr. Theresa Perenich, for their guidance, enthusiasm, and encouragement throughout this research project and my graduate program.

Mr. Ludwig Villasi and Dr. William Fateley, my committee members, for their assistance in this study.

Mr. Ed M. Milner, Director, Products Technology Consumer and Recreational Products Division of the Monsanto Company, for sharing information on artifical turf surfaces and for providing the AstroTurf® stadium surface utilized in this study.

Dr. Constance M. Chiasson and Mrs. Mary Ann Rounds, Laboratory Technician, Purdue University, for the instrumental reflectance measurements of the weathered synthetic turf samples.

Mr. John Krchma, Scanning Electron Microscope Technician, for his assistance in using the scanning electron microscope.

Mr. David Culp for his assistance with the statistical analysis of data and his suggestions for its presentation.

Miss Ann Moore for her assistance in running the carbon-arc Weather-Ometer.

Mrs. Peggy Harrison for her typing of this thesis.

My husband, Fred Nisley, and my parents, Mr. and Mrs. Clarence

Timm, for their encouragement and interest throughout my graduate work.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Over the past few years there has been a significant increase in the use of synthetic sports surfaces in playing fields. This has been attributed to both the low maintenance cost of synthetic turfs and the needs of athletes and sportsmen for greater consistency in playing surfaces. In addition the increased emphasis on leisure time activities has resulted in the construction of more versatile sports surfaces. (2, 20) The production of synthetic recreational surfaces by fiber companies was an outgrowth of the industry's interest in synthetic polymers. Recreational surfaces are used for two purposes. The first is for competitive sports (i.e., football, baseball, soccer, etc.) and the other is for personal leisure activities (i.e., golf, miniature golf, playgrounds, etc.). In both instances, players and fans in the past have accepted the ever-changing characteristics of natural playing fields. In addition to providing more uniform recreational surfaces, the turf-like materials are engineered to have durability, functionality, similarity to natural turf, and esthetic appeal. (47)

The major justification for the use of synthetic turf is the increase in usage it permits on a playing field. A natural turf field will withstand only 35 to 50 hours per year of hard play in most climates, and even then, requires constant maintenance if it is to retain its quality. In comparison, there are many synthetic turf fields which are used 1800 to 2000 hours per year in all climates. (30)

The costs for covering a typical football field may range from

$250,000 to $800,000, depending upon the amount of subsurface work required. The initial cost of the synthetic turf fields often is justified by the thousands of dollars that will be saved on maintenance costs, such as for permanent ground crews, sodding, seeding, and laundry bills for grass-stained, mud-splattered uniforms. (2)

The Monsanto Company has pioneered research in the development of synthetic recreational surfaces. Nearly seventy installations of a synthetic turf athletic field were completed for professional, college, and high school athletics through 1970 by Monsanto. AstroTurf®, manufactured by the Monsanto Company, is used in four out of every five synthetic turf stadium installations. (44)

Synthetic recreational surfaces were widely installed during the late fall and winter of 1968-69, but as flaws were observed, enthusiasm for stadium turf slackened noticeably. Midway through the 1968 football season, darkspots appeared on the University of Tennessee's artifical turf. It was found that the predominant green fibers of the turf had suffered extensive breakage in areas where play had been heavy. The breakage was attributed to low denier (fiber weight per length) of the nylon fibers which may be peculiarly susceptible to ultraviolet rays. (49)

Although there are many advantages with artifical turf, heavy criticism has occurred related to the incidence of athletic injuries. (48) The Monsanto Company has had AstroTurf® fields in use since 1964, and has surveyed 185 schools on the incidence of knee and ankle injuries of players. It has been reported that teams playing on real sod surfaces suffer a substantially greater number of injuries each year than those teams playing on AstroTurf®. (25)

Other complaints about artificial turf included the incidence of skid burns and abrasions, and problems with the artifical turf being slick when wet. Some athletes such as football players have had initial difficulty adjusting to falls on artifical surface. (25) Another aspect of artifical turf that has evoked concern is the buildup of heat on sunny days. There have been instances reported where playing field temperatures were as much as 30^{0} higher than adjacent areas. The high temperature conditions have been attributed to the asphalt that is under the turf, which does not give off cooling evaporating moisture as do grass and dirt fields. (11, 48)

The three major factors that affect the life of a synthetic turf installation are (1) exposure to ultraviolet radiation, (2) exposure to severe air pollution, and (3) wear from traffic. (30) Limited literature is available on the durability of synthetic turf. Milner (33) states that Monsanto has conducted extensive studies on the durability of AstroTurf® surfaces both in the laboratory and in the field. Most of this research, however, has been proprietary providing the basis for the company's product formulation, design, and installation techniques.

The proposed study was undertaken to evaluate the durability of synthetic turf after weathering and abrading. The objectives of this study were

(1) to evaluate the effects of accelerated weathering on the abrasion resistance of synthetic turf,

(2) to evaluate the amount of color change which occurred on the unexposed and exposed synthetic turf after abrasion,

(3) to determine the weight loss of the specimens abraded at varying exposure hours,

(4) to determine the thickness of abraded specimens after each 1,000 cycles of abrasion at varying exposure hours, and

(5) to examine representative areas from the unabraded and abraded specimens using scanning electron microscopy to determine the type and extent of surface damage.

REVIEW OF LITERATURE

Synthetic Turf Surfaces

The newness of the first synthetic recreational surfaces precluded the existance of many competitive products. Leaders in the industry are the Monsanto Company; Minnesota, Mining, and Manufacturing Company (3M); and American Biltrite Rubber Company. Monsanto's main product is AstroTurf®, a fine-bladed turf employing 500 denier nylon ribbon pile over a synthetic elastomeric energy-absorbing foam underpad. (5, 25, 43, 47) 3M's main product is Tartan Brand Turf®, a carpet-like turf employing 50 denier fiber pile, with an elastomeric pour-in-place substrate containing fine globular inorganic particles. (25, 43, 57) American Biltrite produces Polyturf®, which is a soft pile turf manufactured from green 500 denier polypropylene ribbon filaments. (7, 47) Numerous indoor and outdoor installation have already been completed. The first was an AstroTurf® surface that was installed in the Houston Astrodome in August 1966 as a last minute solution after the lack of direct sunlight killed the natural grass there. (2, 34)

Construction Characteristics of Synthetic Playing Surfaces

The turf system can be divided into three parts as follows: (1) The surface, which consists of the pile, the primary backing (yarns interlacing with the pile), and the latex or back coating used to seal turfs in place. (2) The substrate, which consists of the material or combination of materials placed between the fabric and the ground or subsurface. The substrate may be laminated, sandwiched, or adhered to the fabric or subsurface. If more than one material is used, e.g. a foam pad and a nonwoven pad, it is designated as a "straticulate" substrate. (3) The subsurface on which the surface and substrate rest consists of a specially prepared ground containing soil, concrete or asphalt. (47)

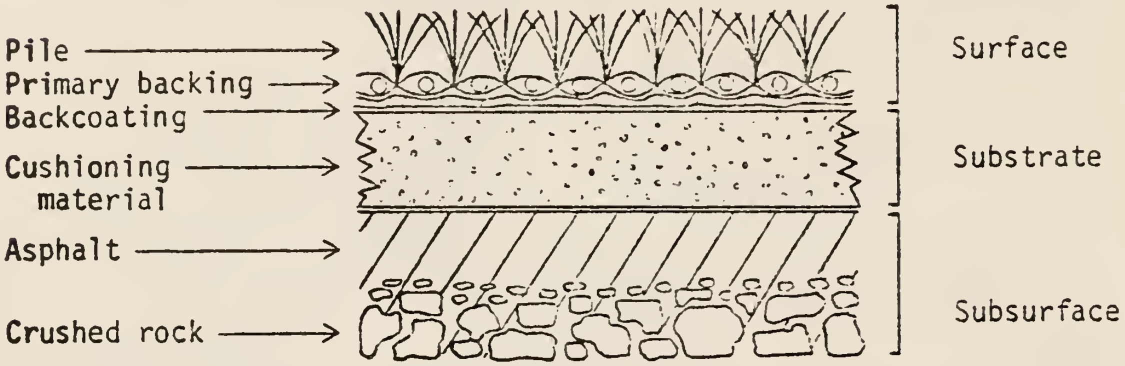

Figure 1: Cross Section of Synthetic Turf System

Pigmented Fiber-Forming Nylon Composition

Polyamides, such as nylon 6, nylon 66, nylon 4, nylon 610, and nylon 11 are used in producing synthetic turf monofilaments. The polyamide compositions are prepared by thoroughly admixing the pigmenting mixture with heat and light stabilized nylon composition. The mixture is melted and mixed in an extruder to form a uniform pigmented molten nylon composition. The mixture is subsequently extruded into ribbon-like monofilaments, which are monofilaments used in making synthetic grass turf on carpet tufting machines. (15, 16)

Various means are known for stabilizing polyamides against heat and light deterioration. United States Patent 3,565,910 (16), for example, discloses a pigmented, heat and light stabilized polyamide composition suitable for formation into fibers that is useful in producing synthetic turf simulating living grass.

A variety of pigments and polyamide compositions (embodiments) are used in producing synthetic turf that is suitable for use as an outdoor athletic field. Mixtures of copper phthalocyanine and chrome yellow pigment frequently are used as the coloring component. Chlorinated copper phthalocycanine is frequently used because of its good fastness to light. In general the phthalocyanine pigment is employed in an amount which varies from about 0.1 to about 2% by weight of the entire polyamide composition. The amount of the phthalocyanine pigment used will depend upon the particular polyamide composition desired in the end product. The amount of the chrome yellow pigment employed also depends upon the specific polyamide composition to be pigmented as well as the particular shade desired. In general the amount will be from about 0.5 to about 2% by weight of the composition. The total pigment present in the composition will generally range from about 1 to about 3%. These amounts may vary according to desired color and weathering properties of the compositions. (16)

In addition to the phthalocyanine green and chrome yellow pigment, a small amount (up to 0.1% of the pigmenting mixture) of carbon black may be added to obtain the desired shade of color. A dispersing agent is frequently used to assist in the thorough dispersion of coloring additives into the nylon. (16)

Surface Fiber

Filament deniers suitable for use in synthetic surfaces range from 300 to 1200. Deniers from 500 to 900 produce the most durable and grass-like characteristics in the finished product. The filaments are generally flat and ribbon-like to simulate natural grass and to obtain suitable bending properties. Methods employed to reduce the sheen produced by the flat surfaces of the ribbons include the addition of delustering agents and the introduction of longitudinal striations to the ribbons during the extrusion process. Ribbons having a thickness of between 0.001 and 0.003 inch and a width of between 0.01 and 0.20 inch possess flexing and bending characteristics that are best suited for synthetic turf surfaces. They are treated with surfactants or other means for roughing the surface to aid manufacture and prevent footwear slippage. (15)

Manufacturing Technology

Textile processes used in manufacturing synthetic turf include velvet and/or Wilton weaving, flat-bed knitting, tufting, and silver knitting. All of these manufacturing processes produce pile fabrics, but they differ in the method by which the pile is fastened to the backing. (47) The velvet or Wilton process is a warp-pile technique which interlaces three sets of yarns. The pile is formed by using an extra set of warp yarns. The wire-cut pile method is frequently used to make warp pile synthetic turf fabrics. During wire-cut weaving process the pile yarns are raised over flat wires, lowered down and then interlaced with the filling yarns. The process is repeated and the wires are subsequently pulled out, cutting the loops and forming the pile. (15, 47) The flat-bed knitting technique also interlaces three sets of yarns, which consists of the lay-in yarn that serves as the backing, the stitch yarn which fastens the pile to the backing, and the pile yarn which is made into loops and cut to form the pile. (15, 43, 47) The tufting technique utilizes the sewing machine principle. Holes are punched in the base fabric through which tufts are inserted. (15, 47) The silver knitting technique interlaces a backing yarn with bunches of individual fibers. It is a common technique used in the production of simulated fur fabrics and paint-roller covers. The technique forms a base fabric similar to that use for men's T-shirts (jersey stitch) and deposits fibers in the interstices to form a pile. The three principal techniques currently utilized by producers of simulated turf are flat-bed knitting, tufting, and silver knitting. (47)

Characteristics of Synthetic Turf Surfaces

The general characteristics of synthetic turf system claimed by the manufacturers are: (1) the pile fiber contains light-resistant pigments and is stabilized for resistance to outdoor exposure, (2) the entire surface system is resistant to weather, insects, rot, mildew, and fungus growth, (3) the pile surface is non-allergenic and non-toxic, (4) the pile surface has good abrasion resistant to normal athletic and recreational traffic, (5) the stadium surface system is shock resistant and has good energy absorption characteristics, (6) the surface system presents a uniform playing surface without irregular changes in contour or elevation, (7) the pile surface provides excellent traction with use of conventional sneaker-type, composition soled soccer, or football shoes, (8) the configuration of pile surface permits good water drainage from the field, and (9) the pile surface is suitable for both temporary and permanent line markings using line marking paint systems specified by the turf supplier. (5)

The three major factors which affect the longevity of a synthetic turf installation are exposure to ultraviolet radiation, exposure to severe air pollution, and wear from traffic. (30)

The intensity of ultraviolet radiation is largely determined by the geographical location of the installation site, temperature, and relative humidity. In high, dry, equatorial areas ultraviolet exposure, for example, is most severe. In cool, moist, extreme northern or southern areas it is least severe. The ultraviolet exposure of indoor installations usually is minimal. In general nylon fibers may be degraded by strong acids or alkalis. Reduced serviceability of synthetic turf playing fields has been attributed to high concentrations of certain air pollutants such as atmospheric sulfur dioxide in certain geographical locations. Of perhaps greater significance is the abrasive wear that may result from heavy deposits of air borne dust and grit particles on installations in dusty areas. In either case, keeping fields clean is the best protection against excessive wear, and the best cleaning medium is plenty of water. Rainfall also can assist in removing dirt and dust deposits. (30)

The wear that results from use of the field is the least significant factor in its longevity. Indoor installations made in 1964 through 1966 shows little evidence of wear after ten or more years of heavy usuage. (30)

Uses of Synthetic Sports Surfaces

Large scale stadium installations represents only a portion of the potential uses for artifical sport surfaces. Already in use are artifical ski surfaces, toboggan slides, ice skating surfaces, and race tracks. (12) Sorbo-Ski is an artifical ski slope made from moulded plastic, with an underlay of heavy woven polypropylene fabric. (20) At the 19th Olympic Games at Mexico City in October 12, 1968 the six Olympic tracks, and all runways, circles, and aprons for field events, were topped with a specially compounded resin developed in 1961 by 3M of St. Paul. In addition to its rapid development as the track surface, new surfacing materials are widely used to convert the floors of school and municipal fieldhouses into all-purpose gymnasiums, on playgrounds and ship decks, in hallways and locker rooms, as flooring for veterinary barns, and for truck beds. (49) Any place where a good looking ground cover is needed, but heavy wear and high maintenance costs make natural surfaces impractical, may be suitable for synthetic surfaces. (12)

The following includes the designed uses for Monsanto's AstorTurf® stadium surface: football, soccer, lacrosse, field hockey, rugby, baseball, gymnastics, physical exercises, playground surface, marching band, military drills, and other uses with similar surface activities. (5) Monsanto produces eight variations of a synthetic surface, usually bright green, that may be used to surface playgrounds, golf tees and greens, lawns, tennis courts, field houses, poolsides, playing fields for football and baseball, doormats, highway medians, around gas stations, motels, shopping centers, cemetary plots, and to line a baby jaguar's cage at the Philadelphia Zoo. (7, 49)

According to Milner (45), director of Product Technology for

AstroTurf®, Monsanto's AstroTurf® athletic and commercial synthetic surfaces, which have been around for a few years, are taking on new uses each day. A Missouri turkey farmer, for example, buys AstroTurf® scraps from Monsanto for use in chicken hatcheries. Egg breakage was reduced when AstroTurf® was substituted for the conventional materials used in the bottom of chicken pens. At the Bureau of Fisheries in Alaska, experiments have shown an increase from 70 to 98 percent in hatchery rates at salmon hatcheries. The salmon hatcheries are much easier to clean, and fish find places to hide while maturing. At Ohio State University, AstroTurf® is being used in stalls of dairy cattle to cut down on infection of hocks thereby increasing milk production.

Weathering

Variables Affecting Light and Weather Resistance

The most important factors affecting the light and weather resistance of fibers are the wavelength and intensity of the light rays, the general conditions of exposure, and the characteristics of the fiber product. (28)

The primary cause of the photodegradation of fibers by exposure either to solar radiation or to artifical light sources is the ultraviolet portion of the electromagnetic spectrum (wavelengths of 290 to 400 nanometer). (14, 28) Studies (28) have indicated that different rates during outdoor exposure. The rate of fiber degradation can be affected by the exposure site since geographical location determines the amount and spectral distribution of radiant energy from the sun that reaches the exposure site. Location determines the general weather conditions (rainfall, cloud cover, temperature, relative humidity, wind velocity, and atmospheric contaminants), which influences the rate of degradation. The extent of fiber deterioration also is affected by the season of the year in which it is exposed, as solar radiation and weather conditions at a particular site vary with the time of the year. Another factor influencing decomposition rate for a given time of exposure is whether or not the sample is exposed directly to sunlight or is exposed under window glass, as window glass will filter out shorter wavelengths of ultraviolet radiation. (28, 41)

The characteristics of fibers that are most likely to influence light and weather resistance are: (1) chemical composition and internal structure of the fiber, (2) colored pigments, delustrants, and other additives or impurities in the polymer, (3) size or thickness of the fiber structure, and (4) dyes, finishes, impurities, ultraviolet absorbers, and other agents applied to the fiber product during processing or use. The physical characteristics of the fiber also will affect its light resistance. For example, light resistance will increase as the denier or size of the fiber increases, probably because less radiation penetrates into the interior. In addition, the cross-sectional shape of a fiber can influence the reflection, refraction, and transmission of radiation striking the fiber. Thus, yarns of different cross-sectional shapes of the same fiber may have different degrees of light resistance. (28)

Different types of fiber from the same generic class may differ in their resistance to light and weather. Such differences could result from modifications of the fiber polymer or structure, or from the presence of additives. Pigments also affect the rate of degradation of fibers. The light resistance of polyester and nylon 66 fibers, for example, is greatly improved when carbon black is dispersed in the polymer during fiber manufacture. Conversely, the light resistance of many fibers decreases when the amount of delustrant added during fiber manufacture is increased; thus, bright fibers usually are more durable than semi-dull fibers which, in turn, are more durable than dull fibers. Dyes can either adversely influence the light resistance of fibers or can increase the resistance. (3, 10, 28)

Light Sources

Giles and McKay (19) discussed six principal sources of illumination which have been used for photodegradation studies on textiles. These are (1) natural daylight, (2) carbon-arcs, (3) mercury vapor lamps, (4) tungsten filament lamps, (5) the xenon arc lamp, and (6) fluorescent tubes.

Natural daylight is often the preferred light source for photodegradation studies, but more time is required to conduct specific tests and daylight varies in intensity depending on geographical conditions, time of year, and weather conditions. The spectral distribution of sunlight at the earth's surface is about 5% in the ultraviolet region, 40% in the visible region, and 55% in the infrared region. At the earth's surface sunlight contains no ultraviolet radiation below 290 nm. (14, 19, 28)

Carbon-arc sources (i.e., Atlas carbon-arc Fade-Ometers and carbon-arc Weather-Ometers) are widely used for laboratory weathering and colorfastness to light studies. (19, 37, 46) The main differences in the spectral energy distribution between the enclosed carbon-arc and natural daylight is that the former has two high energy peaks within the 350-390 nm range, and is much weaker than sunlight elsewhere in the ultraviolet down to about 305 nm and also above 425 nm in the visible range. (31, 46) Between 305 and 290 nm it is stronger than noon summer sunlight. (46)

The mercury vapor lamp's spectral range is only 180 to 1400 nm with an especially strong distribution in the ultraviolet range. A considerable disadvantage of the mercury vapor lamp is that the radiation is not predictable because it tends to change in quality and intensity with continued use of the lamp. (3, 37) In tungsten lamps the radiation emitted consists of visible light and large amounts of infrared radiation. (37) This type of illumination is said to be very slow for routine testing. (19)

The ultraviolet spectral distribution of the fluorescent tubes is approximately 290 to 390 nm. (37) The fluorescent lamp emits less ultraviolet radiation than either the sun or the carbon-arc lamp; nevertheless, the unprotected fibers will deteriorate if they are stored in close adjacency to fluorescent lamps for prolonged periods of time. (28)

The resistance of fibers to deterioration from general weathering usually is determined by outdoor exposure tests or accelerated weathering tests. It is believed, however, that accelerated laboratory tests are not an acceptable substitute for outdoor exposure since no consistent correlation either with outdoor exposure tests or with actual weathering performances has been observed. When correlations are being made between outdoor exposures and accelerated light sources, consideration must be given to the fact that accelerated light sources do not duplicate natural sunlight, and differ greatly among themselves in spectral energy distribution. (28)

Abrasion

Serviceability of a fabric is defined by Skinkle (42) as its length of life up to its end of usefulness, which is when one or more necessary properties become deficient. Wear often is an important consideration when evaluating the serviceability of textiles. (9, 42) According to Booth (9) wear is the result of a number of agencies which reduce the serviceability of an article. It is the deterioration of a fabric due to the breaking, cutting, or the wearing out or removal of the fibers or yarns. (29, 42) The components responsible for wear include (1) a direct force applied to the fabric, (2) the impact effect, (3) flexing, and (4) abrasion. (42)

Abrasion, the most important factor in wear, (3, 5) is defined as the wearing away of any part of a material by rubbing against another surface. (4, 9, 42, 39, 52) Abrasion may be classified as plane or flat abrasion, edge abrasion, and flex abrasion. (9)

The evaluation of the abrasion resistance of textile and other materials is very complex. The resistance to abrasion is affected by many such factors as the inherent mechanical properties of the fibers, the dimensions of the fibers, the structure of the yarns, the construction of the fabrics, and the type, kind, and amount of finishing material added to the fibers, yarns, or fabric. (4, 39)

The American Society for Testing and Materials (ASTM) Test Method D-1175 (4) gives abrasion testing procedures for the following six instruments: Accelerotor, Schiefer, Stoll (inflated diaphragm and flex), Taber, and Wyzenbeek. All six testers differ in the types of abradants used, the loads under which the abradants are applied, the levels of tensile stress applied to the fabric before the abrasion is started, the degree of fabric flexing and bending that occurs during abrasion, and the uniformity of stress application across the specimen surface. Because they differ greatly in the relative amounts of frictional, cutting, and plucking forces which they apply to fabrics, the results obtained with one instrument do not always correlate well with those obtained with another. (39)

Booth and Skinkle (9, 42) give a number of important factors that require consideration before abrasion tests can be carried out: (1) condition of specimen, (2) choice of testing instrument, (3) choice of abrasive motion, (4) direction of abrasion, (5) choice of abradant, (6) backing the specimen, (7) cleanliness of the specimen and instrument, (8) tension on the specimen, (9) pressure between abradant and specimen, (10) the end-point of the test, (11) assessment of abrasion damage, and (12) dimensional changes in the specimen.

Many researchers wish that abrasion tests could be developed which would predict the durability or serviceability of a fabric during use. Such expectations have never been realized because no one abrasion instrument has been formed which will either simulate or correlate with all the various types of abrasive stresses, and actual wear usually involves mechanical stresses other than rubbing plus the action of various chemical agents on the fabric during laundering, weathering, etc. Abrasion may also contribute to changes in fabric appearance and performance properties long before actual fabric rupture occurs. The consumer is often concerned about these less drastic changes in fabric structure that occur with progressive wear as well as with the final failure of the fabric. (39)

The criteria used most often for measuring the effects of abrasion are: (1) visual evaluation of yarn breakage, formation of a hole, or change in surface appearance or color, (2) changes in mechanical properties of the fabric such as weight, thickness, stiffness, air permeability, or breaking strength and elongation, and (3) microscopic study of changed in fabric, yarn, and fiber structures. Of these, the number of abrasion cycles needed to cause a fabric hole or rupture and loss in breaking strength are most frequently used. (39)

When the number of abrasion cycles needed to cause yarn or fabric rupture is used as the measure of abrasion resistance, a high degree of variability in the data is obtained, especially in inter-laboratory testing. Most abrasion testing is extremely sensitive to the tension placed on the specimen as it is mounted in the specimen holder. Changes in mechanical properties are often used to measure abrasion damage, but problems arise because consecutive application of equal increments of abrasion does not always cause physical property changes that are directly proportional to the amounts of abrasive stress applied. Fabric weight loss measures the amount of fiber or fiber fragments removed during abrasion but does not measure the degree of damage sustained by the fiber and yarn structures remaining in the fabric. (39)

Many of the recent studies (21, 26, 38) of abrasion have included optical and scanning electron microscope evaluations of fiber, yarn, and fabric structures both before and after abrasion. Types of fiber damage found include bruising, mashing, and chipping of the fiber surface, and transverse or diagonal cracking across the fiber, sometimes with notched or forked ends.

Laboratory tests may be reliable as an indication of relative end-use performance in cases where the difference in abrasion resistance of various materials is large, but they should not be relied upon where differences in laboratory test findings are small. In general, they should not be relied upon for prediction of actual wear-life in specific end-uses unless there is data showing the specific relationship between laboratory abrasion tests and actual wear in the intended end-use. (4)

Cohen (13) discussed the different types and causes of carpet wear complaints. The types of conditions which most commonly cause failure in use are: (1) durability (resistance to abrasive wear), (2) mechanical deterioration of appearance (flattening and loss of surface texture), (3) deterioration of color (fading, bleeding, marking-off, soiling), (4) pile security (tuft loss, pulling and matting of filaments and fibers), and (5) dimensional stability (shrinking and stretching, both before and after wet cleaning). He also reviewed the test methods that can be used for assessing carpet performance and suggested how these can be used to the best advantage.

Scanning Electron Microscope

Because limitations exist with both transmission electron microscopes and optical microscopes, the scanning electron microscope has become widely adopted. When the scanning electron microscope first became available commercially, it was used almost solely for biological and medical research, however, it is being used in textile research. (8) A two-dimensional image is obtained with a light microscope or with a transmission electron microscope. (17)

The scanning electron microscope, however, is able to furnish images of three-dimensional objects because it records not the electrons passing through the specimen but the secondary electrons that are released from the sample by the electron beam impinging on it. The sample can be of any size and thickness that will fit in the instrument's evacuated sample chamber. (17)

Since a reasonably high resolution is combined with a great depth of focus, the scanning electron microscope allows materials to be examined that are unsuitable for replication (which is needed for the transmission electron microscope), or that have too much geometric relief for the optical microscope. (8) The magnification capacity of a scanning electron microscope (SEM) extends from X20 to X50000. (22) The scanning electron microscope does not replace other microscopes but complements them. (8)

Hearle and Cross (22) discussed the advantages of using a scanning electron microscope in studying the fractography of nondegraded thermoplastic fibers. When used at the optimum magnification, the scanning electron microscope is particularly useful for viewing the position and direction of features of fracture. The actual shape of the fracture surface can be made clearer with steropairs, which are several views around the fiber.

Rollins, DeGruy, Hensarling, and Carra (38) reported microscopical observations on the damaged surfaces of cotton fibers which had been abraded under various conditions. They observed the pattern of fiber fracture in cotton fabrics treated by various durable-press procedures (treatments such as wet-fix, poly-set, face-coating, fiber encapsulation, and graft polymerization) and concluded that although the degree of abrasion resistance varied with different treatments the type of damage exhibited by individual fibers differed little from treatment to treatment.

Hearle and Sparrow (24) investigated the fracture morphology of cotton fibers. Cotton fibers were broken under a variety of conditions and the fractures were examined with a scanning electron microscope. From the observations that were made, it was stated that for raw, scoured, and mercerized cotton tensile fractures occurred adjacent to the reversal zone (area in which the change in direction of the spiral angle occurs) and not through it, indicating that the reversal itself is strong, but, because of its existence in the fiber, it is a source of weakness in that it is the cause of fracture in a region adjacent to the reversal.

Hearle (21) used scanning electron microscopy to study various fracture which occurred in different types of fibers resulting from stress, heat, light, and chemical degradation. When stress was applied to polyamide and polyester fibers during a tensile test, the fiber or yarn extended until it broke. The fractured ends of the fibers exhibited a cracked region at an angle followed by a rougher zone of catastrophic failure running across the fiber. The opposite end shows a mirror image of the angular crack and a matting of the catastrophic region. Other types of fibers showed different forms of tensile fracture. Light, chemical or heat degraded polyamide and polyester fibers also resulted in different forms of failure.

Kirkwood (26) compared scanning electron micrographs of Nomex aramid trousers which had been worn by Army helicopter personnel with material which was ultraviolet-irradiated and/or Acceleroter abraded.

She found that samples which were both ultraviolet-irradiated and abraded had greater strength loss and showed more fiber surface damage in the SEM after abrasion than samples which were abraded only. Wear initiated through peeling, either on the fiber surface or along cracks that formed in the depressed center of the "dogbone" shaped fiber. Short fibrillation eventually caused fiber severing. The Accelerotor reproduced the individual fiber damage observed in field worn Nomex aramid, but distribution of wear within damaged yarns was different. Kirkwood stated that the Nomex aramid material in this study had been singed in order to reduce pilling. The tactile discomfort of wearing this fabric was explained by the SEM examination of the ultraviolet-irradiated fabric. In singeing, the Nomex aramid fiber ends had started to decompose, forming gaseous by products. The ultraviolet radiation provoked this, and the continued gas formation caused bubbles in the singed fiber ends to burst open, exposing rough surfaces and jagged edges. Fiber fracture patterns from fabric tensile tests were quite variable, and no distinct trends were observed.

PLAN OF PROCEDURE

Experimental Fabric

Approximately 15 feet of AstroTurf® was supplied for this study by Monsanto Company, St. Louis, Missouri. AstroTurf® is a synthetic surface designed for athletic and recreational use. The artificial turf surface is a carpet-like material made on carpet making machines. The following specifications were obtained from correspondence and literature obtained from Monsanto Company. The S-22 fabric was knitted on 200-inch flat bed Raschel knitting machines in rolls 15 feet wide and normally 200 feet long. The surface fiber was 500 denier green pigmented nylon 6,6 ribbon, having a serrated cross section, and stabilized for resistance to the effects of outdoor weathering. The surface had an average nylon ribbon content of more than 36 ounces per square yard and the pile height of the finished fabric was approximately 1/2 inch. The ribbon was piled before knitting to give the desired pile density. The texture of the pile surface suggests the appearance of freshly mown natural grass. The color of the pile surface was the turf supplier's standard 'stadium green' shade. (32, 33, 35)

Sampling Plan

The synthetic turf fabric was cut into 27 samples, 16.5 X 28 cm, for assessing resistance to degradation under radiant energy exposure conditions with periodic wetting in a carbon-arc Weather-Ometer under conditions simulating unprotected natural sunlight and weather exposure. Two specimens were cut from each of the carbon-arc exposed replicas and prepared for abrasion testing as shown in the specimen layout diagram in Figure 2.

Exposure of Carbon-Arc Radiation with Wetting

Two replications of randomly selected synthetic turf samples were exposed in an Atlas Model 18-WR carbon-arc Weather-Ometer with continuous light and periodic wetting for 0, 500, 1000, 2000, 3000, 3500, and 4000 clock hours. General operating procedures were followed as specified in AATCC Test Method 111A-1975 (1) and in the Atlas Weather-Ometer Operation Instruction Book No. FW-110WR (6).

The enclosed carbon-arc lamp was operated at a black panel temperature of 63 ± 3°C and at a relative humidity of approximately 30 ± 5% during the 102 minute cycle of light only. The Atlas carbon-arc Weather-Ometer was set with a cycle cam which provided 102 minutes of continuous light and 18 minutes of spray with light for 24 clock hour periods. At the end of each period, the carbons were replaced, and the 9200-PX globe was washed. Six globes were rotated after every 24 clock hours of exposure.

The instrument was calibrated with NBS Light-Sensitive Paper, (NBS Standard Reference Material 700b) and the NBS Booklet of Standard Faded Strips (NBS Standard Reference Material 701b). Samples of the NBS Light-Sensitive Paper were exposed continuously for 20 hours during the initial cycle of the test and thereafter every 500 clock hours of exposure. During the calibration periods, the test specimens were replaced with blanks and exposed to continuous light while maintaining

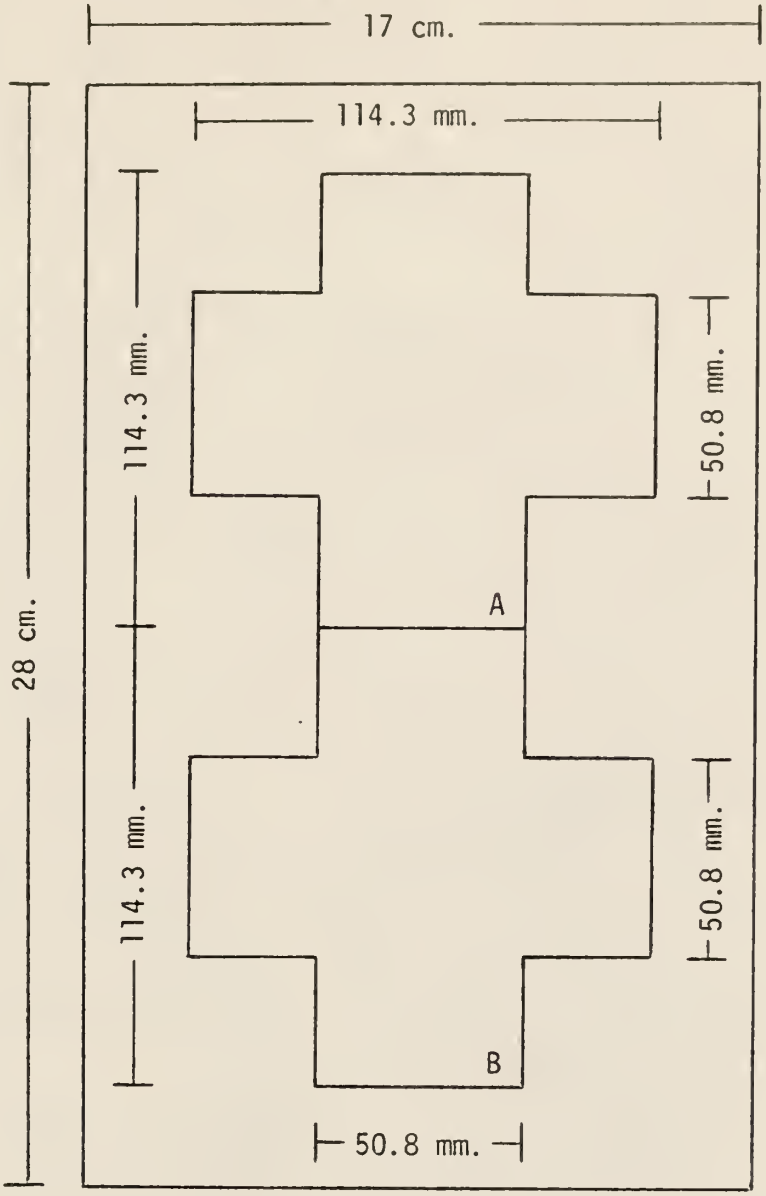

Figure 2: Diagram of Specimen Layout

the same black panel temperature and relative humidity as that used for test specimen exposure. After exposure, the NBS Light-Sensitive Paper was conditioned in the dark for not less than 24 hours in a standard atmosphere for testing (21 ± 1°C and 65% RH), and prepared for instrumental reflectance measurements on a Model 25M-3 Hunterlab Colorimeter. The values obtained for the exposed samples of NBS Light-Sensitive Paper were compared with those readings taken on the NBS Booklet of Standard Faded Strips.

Abrasion Resistance

The abrasion resistance of the turf test specimens was evaluated after 0, 1000, 2000, 3000, 4000, 5000, 6000, 7000, 8000, 9000, and 10,000 abrasion cycles on the Schiefer Abrader using a spring steel blade abradant under a 10 lb load in accordance with ASTM Designation 1175-71 (4). Specimens were mounted in a carpet attachment assembly and initial thickness reading were taken on the Schiefer's dept micrometer. After every 1000 abrasion cycles, thickness and weight loss were determined. Photographs of abraded areas also were taken and a few fibers were removed for subsequent scanning electron photomicrographs. All specimens were conditioned for 24 hours in a standard atmosphere prior to testing.

Color Difference

The differences in color between the unexposed controls and the exposed specimens, after 500, 1000, 2000, 3000, 3500, and 4000 clock hours of weathering, were determined with a Model D25M-3 Hunterlab

Colorimeter.

Hunter L, a, b uniform color scale coordinates were calculated directly from CIE X, Y, and Z tristimulus values. Total color difference ΔE, was computed using the following equation (18): $\Delta E = ((\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2)^{\frac{1}{2}}$. To indicate the direction of the color change, ΔL, Δa, and Δb also were reported. Four consecutive directional readings were taken for each synthetic turf specimen and averaged.

Because of the small size of the NBS Light-Sensitive Paper and Standard Faded Strip Booklet, a black construction paper mask with a circular opening of one-inch diameter was centered and taped over the two-inch diameter specimen port of the instrument for these measurements. The instrument was first standardized to X, Y, and Z using the white calibrated tile, then the mask was taped into position and the white calibrated tile was reread with the mask in place. Calibration was periodically checked by reading the white calibrated tile with the mask in place, in order to prevent any changes due to removing and replacing the mask during measurement of the NBS standards.

Microscopical Examination

The surface features of the controls and carbon-arc exposed test specimens after abrasion were examined by an ETECH Scanning Electron Microscope. Specimens were mounted on a flat, circular metal with conductive silver paste and coated with a thin layer of carbon followed by gold-palladium to provide a conducting surface for escape of primary electrons to the ground thereby preventing the collection of excess charge on the sample. (38) Photomicrographs were taken at 0, 500, 1000, 2000, 3000, 3500, and 4000 accelerated exposure hours and after 1000, 2000, 3000, 4000, 5000, 6000, 7000, 8000, 9000, and 10,000 abrasion cycles.

Statistical Analysis

The data obtained from the total color difference values of the samples exposed to the enclosed carbon-arc light sources were analyzed using an unequal subclass analysis of variance procedure. The level of confidence established was 0.01.

An analysis of variance procedure of a split-split-plot experiment was performed on the data obtained from thickness and weight loss values after abrasion. The Least Significant Difference (L.S.D.) Test was used to analyze the main effects and interactions only if F was significant in the analysis of variance. The level of confidence established was 0.05.

The IBM 270-158 Calcomp Plotter Program Package developed at Kansas State University was used to fit an arithmetic straight-line trend curve to the data obtained from the reflectance measurements of the NBS Light-Sensitive Papers and Booklet of Standard Faded Strips. All of the statistical computer programs used in this study were obtained from the Kansas State University Computing Center.

PRESENTATION OF DATA WITH DISCUSSION

Evaluation of Total Color Difference

The differences in color between the unexposed controls and the exposed specimens, after 500, 1000, 2000, 3000, 3500, and 4000 clock hours of weathering are presented in Table 1. Hunter L, a, b uniform color scale coordinates were calculated directly from CIE X, Y, and Z tristimulus values, and then total color difference (ΔE) was computed. To indicate the direction of the color change, ΔL, Δa, and Δb also were reported. After exposing the synthetic turf in the carbon-arc Weather-Ometer for 4000 clock hours, which was a year of laboratory time, only a slight change in total color difference resulted. The total color difference values of the weathered synthetic turf were very small from one level of exposure sample to another.

An unequal subclass analysis of variance was performed on the total color difference values obtained for the weathered synthetic turf samples. The results are presented in Table 2. The main sources of variation were weathering and direction of the samples. Weathering had a significant effect on the total color difference of the synthetic turf, but the direction in which the readings were taken had no significant effect on the total color difference. The second order interaction of weathering and direction also had no significant effect on the total color difference.

The significant main effect in this analysis was weathering.

Table 1: Color Measurements on Hunterlab D25M-3 Colorimeter

Clock Hours	Replica	Direction	L	a	b	ΔL	Δa	Δb	ΔE
500	1	01	20.83	-13.75	7.81	0.92	-0.70	0.49	1.256
		02	20.59	-13.84	7.82	1.04	-0.67	0.50	1.334
		03	20.74	-13.99	7.91	1.01	-0.73	0.47	1.332
		04	20.88	-13.89	7.80	0.94	-0.81	0.60	1.378
500	2	01	21.52	-14.18	8.07	0.23	-0.27	0.23	0.423
		02	21.61	-14.44	8.19	0.02	-0.07	0.13	0.149
		03	21.54	-14.49	8.17	0.21	-0.23	0.21	0.376
		04	21.40	-14.35	8.08	0.42	-0.35	0.32	0.633
1000	1	01	22.43	-14.02	8.09	-0.68	-0.43	0.21	0.832
		02	22.36	-14.07	8.10	-0.73	-0.44	0.22	0.880
		03	22.56	-14.40	8.23	-0.81	-0.32	0.15	0.884
		04	22.38	-14.29	8.12	-0.56	-0.41	0.28	0.748
1000	2	01	21.95	-13.62	7.86	-0.20	-0.83	0.44	0.960
		02	21.68	-13.65	7.93	-0.05	-0.86	0.39	0.946
		03	22.11	-13.84	8.00	-0.36	-0.88	0.38	1.024
		04	21.66	-13.75	7.91	0.16	-0.95	0.49	1.081
1000	3	01	21.47	-13.71	7.96	0.28	-0.74	0.34	0.861
		02	21.19	-13.66	7.92	0.44	-0.85	0.40	1.037
		03	21.14	-13.87	7.96	0.61	-0.85	0.42	1.127
		04	21.56	-13.73	7.95	0.26	-0.97	0.45	1.100
2000	1	01	21.68	-12.83	7.60	0.07	-1.62	0.70	1.766
		02	21.59	-12.81	7.59	0.04	-1.70	0.73	1.851
		03	21.77	-12.93	7.70	-0.02	-1.79	0.68	1.915
		04	21.77	-12.93	7.64	0.05	-1.77	0.76	1.927
2000	2	01	21.17	-12.50	7.42	0.58	-1.95	0.88	2.217
		02	21.17	-12.58	7.51	0.46	-1.93	0.81	2.143
		03	21.07	-12.90	7.63	0.68	-1.82	0.75	2.083
		04	20.78	-12.67	7.45	1.04	-2.03	0.95	2.471
3000	1	01	23.04	-12.44	7.51	-1.29	-2.01	0.79	2.516
		02	23.07	-12.58	7.59	-1.44	-1.93	0.73	2.516
		03	22.91	-12.68	7.61	-1.16	-2.04	0.77	2.470
		04	22.96	-12.42	7.52	-1.14	-2.28	0.88	2.697
3000	2	01	23.54	-12.45	7.51	-1.79	-2.00	0.79	2.798
		02	23.62	-12.55	7.60	-1.99	-1.96	0.72	2.884
		03	23.45	-12.73	7.62	-1.70	-1.99	0.76	2.725
		04	23.39	-12.61	7.53	-1.57	-2.09	0.87	2.755
3500	1	01	24.17	-12.60	7.52	-2.42	-1.85	0.78	3.144
		02	23.83	-12.50	7.53	-2.20	-2.01	0.79	3.083
		03	24.04	-12.67	7.61	-2.29	-2.05	0.77	3.169
		04	24.37	-12.77	7.62	-2.55	-1.93	0.78	3.292
3500	2	01	23.75	-12.47	7.44	-2.00	-1.98	0.86	2.943
		02	23.77	-12.54	7.46	-2.14	-1.97	0.86	3.033
		03	23.66	-12.60	7.50	-1.91	-2.12	0.88	2.986
		04	23.28	-12.53	7.36	-1.46	-2.17	1.04	2.815
4000	1	01	24.52	-12.47	7.59	-2.77	-1.98	0.71	3.478
		02	24.70	-12.65	7.64	-3.07	-1.86	0.68	3.653
		03	24.23	-12.56	7.61	-2.48	-2.16	0.77	3.378
		04	24.43	-12.37	7.50	-2.61	-2.33	0.90	3.613
4000	2	01	24.76	-12.33	7.59	-3.01	-2.12	0.71	3.749
		02	24.96	-12.57	7.71	-3.33	-1.94	0.61	3.902
		03	25.04	-12.74	7.78	-3.29	-1.98	0.60	3.886
		04	24.35	-12.49	7.51	-2.53	-2.21	0.89	3.475
4000	3	01	24.31	-12.37	7.41	-2.56	-2.08	0.89	3.416
		02	24.41	-12.53	7.48	-2.78	-1.98	0.84	3.515
		03	24.33	-12.57	7.53	-2.58	-2.15	0.85	3.464
		04	24.45	-12.58	7.45	-2.63	-2.12	0.95	3.509

Table 2: Unequal Subclass Analysis of Variance for Total Color Difference

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Weathering (W)	5	63.826	12.765	145.226*
Direction (D)	3	0.056	0.019	0.214
W X D	15	0.179	0.012	0.136
Residual	32	2.813	0.088	
Total	55	66.864		

*Significant at 0.01 level

The significant differences among the levels of the main effect of weathering are presented in Table 3. There was no significant in the amount of color change observed for the samples exposed in the carbon-arc Weather-Ometer for 500 to 1000 clock hours or after 3000 and 3500 clock hours of exposure. In addition, the amount of total color difference among the samples at the other weathering levels was significantly different.

Thus, weathering had a significant effect on the total color difference of the synthetic turf. There was a significant difference in the samples exposed in the carbon-arc Weather-Ometer after every 1000 clock hours of exposure.

Table 3: Least Significant Differences (L.S.D.) For Total Color Difference of Weathered Synthetic Turf

Levels of Weathering Clock Hours		Difference	Standard Error	Least Significant Differences
500	1000	-0.097	0.135	0.372
500	2000	-1.186	0.148	0.408*
500	3000	-1.810	0.148	0.408*
500	3500	-2.198	0.148	0.408*
500	4000	-2.726	0.135	0.372*
1000	2000	-1.090	0.135	0.372*
1000	3000	-1.713	0.135	0.372*
1000	3500	-2.101	0.135	0.372*
1000	4000	-2.630	0.121	0.333*
2000	3000	-0.624	0.148	0.408*
2000	3500	-1.012	0.148	0.408*
2000	4000	-1.540	0.135	0.372*
3000	3500	-0.388	0.148	0.408
3000	4000	-0.916	0.135	0.372*
3500	4000	-0.529	0.135	0.372*

*Significant at 0.01 level

Evaluation of Abrasion

Analysis of Weight Loss

An analysis of variance of split-split-plot experiment was performed on the weight loss values obtained for the abraded samples. The results are presented in Table 4. The main effects in the analysis were replica, sample, weathering, and abrasion. The variables of weathering and abrasion had significant effects on the amount of weight loss. Replica and sample number did not have significant effects on weight loss. All the following two way interactions were significant in the weight loss analysis: sample by weathering, abrasion by weathering, and abrasion by sample. The analysis of variance showed that the third order interaction of abrasion by sample by weathering also was significant at the 0.05 level.

The Least Significant Difference (L.S.D.) Test was performed on the weight loss means which were computed for the variables weathering and abrasion and the results are presented in Tables 5 and 6. An ordered listing of weight loss means Table 5, attributable to the clock hours of exposures and abrasion showed that the highest weight loss mean (1.783 g) occurred after 3500 clock hours and the second highest mean (1.769 g) occurred after 4000 clock hours. Although the mean weight loss was higher after 3500 clock hours than it was after 4000 clock hours, there was no significant difference between these two means. However, with weight loss means of all other exposed and unexposed samples after abrasion were significantly different. In Table 6, the weight loss means for the abraded synthetic turf showed a significant difference for all levels of abrasion. The lowest mean

Table 4: Analysis of Variance of Split-Split-Plot Experiment on Weight Loss of Abraded Synthetic Turf

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F
Main Plots:				
Replica (R)	0.037	1	0.037	2.244
Weathering (W)	28.726	6	4.788	291.503**
Error (R X W)	0.099	6	0.016	
Sub plots:				
Sample (S)	0.000	1	0.000	.016
S X W	2.013	6	0.335	12.445**
Error ((R X S) + (R X S X W))	0.189	7	0.027	
Sub-sub-plots:				
Abrasion (A)	120.343	8	15.043	10468.105**
A X W	1.885	48	0.039	27.327**
A X S	0.003	8	0.000	0.292**
A X S X W	0.811	48	0.017	11.757**
Error	0.161	112	0.001	

**Significant at 0.05 level

(0.350 g) was observed for the 1000 cycles and as the cycles increased, the weight loss means also increased.

Table 5: Weight Loss Means for Weather Synthetic Turf after Abrasion

Clock Hours	Means
3500	1.783 ┐
4000	1.769 ┘
3000	1.706
2000	1.617
1000	1.472
500	1.300
0	0.759

Non-significant groups at 0.05 level connected by brackets

Table 6: Weight Loss Means for Abraded Synthetic Turf

Cycles	Means
9000	2.480
8000	2.266
7000	2.054
6000	1.800
5000	1.531
4000	1.257
3000	0.971
2000	0.668
1000	0.350

Non-significant groupings at 0.05 level connected by brackets

The analysis of variance (Table 4) showed that the second order interaction of sample by weathering had a significant effect on weight loss. The results of the Least Significant Difference Test which was performed on the weight loss means for the interaction of sample by weathering are presented in Table 7. There were no significant differences between the weight loss means of the following groupings: sample 2 at 4000 clock hours and sample 2 at 3500 clock hours; sample 2 at 3000 clock hours and sample 1 at 2000 clock hours; and sample 1 at 1000 clock hours and sample 2 at 1000 clock hours. All of the other groupings were significantly different in this analysis.

Table 7: Weight Loss Means for the Interaction of Sample X Weathering

Sample	Clock Hours	Means
1	3500	1.874
1	4000	1.839
1	3000	1.750
2	4000	1.700┐
2	3500	1.692┘
2	3000	1.663 ┐
1	2000	1.652 ┘
2	2000	1.583
2	1000	1.474 ┐
1	1000	1.470 ┘
2	500	1.329
1	500	1.270
2	0	0.956
1	0	0.561

Non-significant groupings at 0.05 level connected by brackets

The analysis of variance (Table 4) revealed that significant interactions were established for the weight loss means of weathering by abrasion. Presented in Table 8 are the results of the Least Significant Difference Test for the non-significant difference groupings for the combinations of weathering and abrasion that were computed on the weight loss means. It can be observed that there were no significant differences between the samples exposed 2000 clock hours

Table 8: Weight Loss Means for the Interaction of Weathering X Abrasion

	1,000 cycles	2,000 cycles	3,000 cycles	4,000 cycles	5,000 cycles	6,000 cycles	7,000 cycles	8,000 cycles	9,000 cycles
0 clock hrs.	0.055	0.106	0.249	0.469	0.679	0.938	1.231	1.436	1.664
500 clock hrs.	0.254	0.550	0.829	1.080	1.311	1.579	1.826	2.036	2.233
1,000 clock hrs.	0.360	0.666	0.976	1.261	1.539	1.797	2.045	2.203	2.403
2,000 clock hrs.	0.422	0.788	1.113	1.400	1.679	1.952	2.184	2.400	2.618
3,000 clock hrs.	0.438	0.837	1.186	1.502	1.790	2.057	2.301	2.528	2.719
3,500 clock hrs.	0.447	0.861	1.226	1.560	1.865	2.144	2.407	2.647	2.886
4,000 clock hrs.	0.477	0.868	1.218	1.531	1.855	2.133	2.386	2.615	2.841

Non-significant groupings at 0.05 level connected by brackets

after 1000 and 2000 cycles of abrasion; or between the samples exposed 3000 clock hours after 1000, 2000, 3000, and 4000 cycles of abrasion; or the samples exposed to 3500 and 4000 clock hours after 1000, 2000, 3000, 4000, 5000, 6000, 7000, 8000 and 9000 cycles. The results of the Least Significant Difference Test in Table 9 shows the non-significant difference groupings for the combinations of abrasion and weathering, computed on the weight loss means. As can be seen all of the rotation cycles, except 1000 and 2000 at 0 clock hours, were significant at the 0.05 level.

The analysis of variance (Table 4) revealed that significant interactions of abrasion by sample by weathering were established for the weight loss means. The results of the Least Significant Difference Test in Tables 10 to 13 present the non-significant differences groupings of sample 1 and sample 2 for the combinations of abrasion and weathering, computed on the weight loss means. In order to more thoroughly examine the interaction between the samples, weathering, and abrasion, the weight loss means were subdivided into two groups (sample 1 and sample 2).

Table 10 shows the non-significant groupings of weight loss means between cycles of abrasion and clock hours of exposure for sample 1. It can be seen that there were no significant differences between 1000, 2000, and 3000 cycles of abrasion at 0 clock hours of exposure to carbon-arc light source at a 0.05 level.

The non-significant groupings of weight loss means between clock hours of exposure and cycles of abrasion for sample 1 are shown in Table 11. In general, there was a progressive increase in the mean significant difference in weight loss between the levels of clock hours

Table 9: Weight Loss Means for the Interaction of Abrasion X Weathering

	0 clock hrs.	500 clock hrs.	1,000 clock hrs.	2,000 clock hrs.	3,000 clock hrs.	3,500 clock hrs.	4,000 clock hrs.
1,000 cycles	0.055	0.254	0.360	0.422	0.438	0.447	0.477
2,000 cycles	0.105	0.550	0.666	0.787	0.837	0.861	0.868
3,000 cycles	0.248	0.829	0.976	1.113	1.186	1.226	1.218
4,000 cycles	0.469	1.080	1.261	1.400	1.502	1.560	1.531
5,000 cycles	0.679	1.311	1.539	1.678	1.790	1.865	1.855
6,000 cycles	0.938	1.579	1.797	1.952	2.057	2.144	2.133
7,000 cycles	1.231	1.826	2.045	2.184	2.301	2.407	2.386
8,000 cycles	1.436	2.036	2.203	2,400	2.528	2.647	2.615
9,000 cycles	1.664	2.233	2.403	2.617	2.719	2.886	2.841

Non-significant groupings at 0.05 level connected by brackets

Table 10: **Weight Loss Means for the Interaction of Abrasion X Weathering of Sample 1**

	0 clock hrs.	500 clock hrs.	1,000 clock hrs.	2,000 clock hrs.	3,000 clock hrs.	3,500 clock hrs.	4,000 clock hrs.
1,000 cycles	0.086	0.208	0.352	0.430	0.432	0.483	0.497
2,000 cycles	0.119	0.497	0.628	0.804	0.857	0.916	0.907
3,000 cycles	0.150	0.780	0.953	1.131	1.227	1.295	1.278
4,000 cycles	0.285	1.013	1.251	1.420	1.540	1.652	1.608
5,000 cycles	0.424	1.266	1.549	1.718	1.853	1.970	1.920
6,000 cycles	0.659	1.555	1.815	2.002	2.131	2.252	2.203
7,000 cycles	0.892	1.814	2.073	2.230	2.356	2.530	2.471
8,000 cycles	1.107	2.043	2.212	2.451	2.590	2.775	2.712
9,000 cycles	1.333	2.255	2.401	2.680	2.760	2.991	2.949

Non-significant groupings at 0.05 level connected by brackets

Table 11: **Weight Loss Means for the Interaction of Weathering X Abrasion of Sample 1**

	1,000 cycles	2,000 cycles	3,000 cycles	4,000 cycles	5,000 cycles	6,000 cycles	7,000 cycles	8,000 cycles	9,000 cycles
0 clock hrs.	0.086	0.119	0.150	0.285	0.424	0.659	0.892	1.107	1.333
500 clock hrs.	0.208	0.497	0.780	1.013	1.266	1.555	1.814	2.043	2.255
1,000 clock hrs.	0.352	0.628	0.953	1.251	1.549	1.815	2.073	2.212	2.401
2,000 clock hrs.	0.430	0.804	1.131	1.420	1.718	2.002	2.230	2.451	2.680
3,000 clock hrs.	0.432	0.857	1.227	1.540	1.853	2.131	2.356	2.590	2.760
3,500 clock hrs.	0.483	0.916	1.295	1.652	1.969	2.252	2.530	2.775	2.991
4,000 clock hrs.	0.497	0.907	1.278	1.608	1.920	2.203	2.471	2.712	2.949

Non-significant Groupings at 0.05 level connected by brackets

with increasing cycles.

The non-significant groupings of weight loss means between cycles of abrasion and clock hours of exposure of sample are given in Table 12. There was no significant difference between 1000 (0.025 g) and 2000 cycles (0.093 g) after 0 clock hours of exposure, but all of the other paired grouping showed significant difference.

Table 13 presents the non-significant groupings of weight loss means between clock hours of exposure and cycles of abrasion of sample 2. There was a progressive increase in the mean significant difference between the 0, 500, 1000, 2000, and 3000 clock hours of exposure with increasing abrasional cycles.

In summary, weathering and abrasion had a significant effect on the amount of weight loss. The following two way interactions were significant in the weight loss analysis: sample by weathering, abrasion by weathering, and abrasion by sample. The weight loss means of the unexposed and exposed (500, 1000, 2000, and 3000 clock hours) samples after abrasion were significantly different. The weight loss means for the abraded synthetic turf showed a significant difference for all levels of abrasion. In general, there was a progressive increase in the mean significant difference in weight loss between the levels of clock hours with increasing abrasional cycles for the interaction of sample by weathering. For the combinations of abrasion and weathering, all of the rotation cycles, except 1000 and 2000 at 0 clock hours, were significant.

Analysis of Thickness

An analysis of variance of split-split-plot experiment was

Table 12: **Weight Loss Means for the Interaction of Abrasion X Weathering of Sample 2**

	0 clock hrs.	500 clock hrs.	1,000 clock hrs.	2,000 clock hrs.	3,000 clock hrs.	3,500 clock hrs.	4,000 clock hrs.
1,000 cycles	0.025	0.300	0.367	0.415	0.443	0.412	0.456
2,000 cycles	0.093	0.603	0.704	0.772	0.817	0.806	0.829
3,000 cycles	0.348	0.879	0.999	1.094	1.146	1.156	1.158
4,000 cycles	0.653	1.146	1.270	1.381	1.465	1.468	1.453
5,000 cycles	0.934	1.356	1.529	1.639	1.726	1.761	1.789
6,000 cycles	1.218	1.603	1.779	1.903	1.983	2.037	2.063
7,000 cycles	1.570	1.837	2.017	2.138	2.246	2.283	2.300
8,000 cycles	1.765	2.029	2.194	2.350	2.467	2.519	2.518
9,000 cycles	1.995	2.212	2.405	2.555	2.678	2.782	2.732

Non-significant groupings at 0.05 level connected by brackets

Table 13: **Weight Loss Means for the Interaction of Weathering X Abrasion of Sample 2**

	1,000 cycles	2,000 cycles	3,000 cycles	4,000 cycles	5,000 cycles	6,000 cycles	7,000 cycles	8,000 cycles	9,000 cycles
0 clock hrs.	0.025	0.093	0.348	0.653	0.934	1.218	1.570	1.765	1.995
500 clock hrs.	0.300	0.603	0.879	1.146	1.356	1.603	1.837	2.029	2.212
1,000 clock hrs.	0.367	0.704	0.999	1.270	1.529	1.779	2.017	2.194	2.405
2,000 clock hrs.	0.415	0.772	1.094	1.381	1.639	1.903	2.138	2.350	2.555
3,000 clock hrs.	0.443	0.817	1.146	1.465	1.726	1.983	2.246	2.467	2.678
3,500 clock hrs.	0.412	0.806	1.156	1.468	1.761	2.037	2.283	2.519	2.782
4,000 clock hrs.	0.456	0.829	1.158	1.453	1.789	2.063	2.300	2.518	2.732

Non-significant groupings at 0.05 level connected by brackets

performed on the thickness readings obtained for the abraded samples. The results are presented in Table 14. The independent variables or main effects in analysis were replica, weathering, sample, and abrasion. The only significant main effect was abrasion. Replica, weathering, and sample variables did not have significant over-all effects on the thickness.

The sub-sub-plots in Table 14 contain the second and third interactions of abrasion by weathering, abrasion by sample, and abrasion by sample by weathering. All interactions were significantly different at the 0.05 level.

Table 15 presents the results of the Least Significant Difference Test which was performed on the thickness means for the abraded samples. The rank order of the thickness means established for the cycles of abrasion was 9000 cycles (highest mean), 8000 cycles, 7000 cycles, 6000 cycles, 5000 cycles, 4000 cycles, 3000 cycles, 2000 cycles, and 1000 cycles (lowest mean). As is evidenced in Table 15, all the thickness means were significantly different at all cycle levels of abrasion at the 0.05 level.

Table 14: Analysis of Variance of Split-Split-Plot Experiment on Thickness of Abraded Synthetic Turf

Source of Variation	Sums of Squares	Degrees of Freedom	Means Squares	F
Main Plots:				
Replica (R)	0.001	1	0.001	0.062
Weathering (W)	0.064	6	0.011	1.204
Error (R X W)	0.053	6	0.009	
Sub-plots:				
Samples (S)	0.026	1	0.026	2.642
S X W	0.104	6	0.017	1.766
Error ((R X S) + (R X S X W))	0.068	7	0.010	
Sub-sub-plots:				
Abrasion (A)	2.605	8	0.326	1192.323**
A X W	0.071	48	0.001	5.414**
A X S	0.032	8	0.004	14.543**
A X S X W	0.051	48	0.001	3.906**
Error	0.031	112	0.000	

**Denotes significant at 0.05 level

Table 15: Thickness Means for Abraded Synthetic Turf

Cycles	Means
9000	0.381
8000	0.356
7000	0.327
6000	0.297
5000	0.262
4000	0.221
3000	0.172
2000	0.125
1000	0.066

Non-significant groupings at 0.05 level connected by brackets

The analysis of variance (Table 14) revealed that the significant interactions of weathering by abrasion were established for the thickness means. The results of the Least Significant Difference Test given in Table 16 shows the non-significant difference groupings for the combinations of abrasion and weathering, computed on the thickness means. There were no significant differences between the samples abraded 8000 and 9000 cycles at 1000 clock hours of exposure and 8000 and 9000 cycles at 4000 clock hours of exposure.

The non-significant differences groupings of the Least Significant Difference Test for the combinations of weathering and abrasion are given in Table 17. As can be observed from Table 17, a significant change in thickness occurred at 0 clock hours and 500 clock

Table 16: Thickness Means for the Interaction of Abrasion X Weathering

	0 clock hrs.	500 clock hrs.	1,000 clock hrs.	2,000 clock hrs.	3,000 clock hrs.	3,500 clock hrs.	4,000 clock hrs.
1,000 cycles	0.040	0.040	0.064	0.074	0.089	0.079	0.080
2,000 cycles	0.088	0.098	0.122	0.139	0.151	0.137	0.139
3,000 cycles	0.137	0.145	0.172	0.187	0.201	0.180	0.183
4,000 cycles	0.231	0.185	0.218	0.229	0.242	0.221	0.223
5,000 cycles	0.299	0.224	0.253	0.259	0.275	0.260	0.266
6,000 cycles	0.348	0.260	0.282	0.291	0.306	0.297	0.298
7,000 cycles	0.379	0.296	0.310	0.319	0.335	0.328	0.321
8,000 cycles	0.413	0.328	0.336	0.345	0.369	0.355	0.348
9,000 cycles	0.449	0.353	0.353	0.372	0.393	0.380	0.371

Non-significant groupings at 0.05 level connected by brackets

Table 17: Thickness Means for the Interaction of Weathering X Abrasion

	1,000 cycles	2,000 cycles	3,000 cycles	4,000 cycles	5,000 cycles	6,000 cycles	7,000 cycles	8,000 cycles	9,000 cycles
0 clock hrs.	0.040	0.088	0.137	0.231	0.299	0.348	0.379	0.413	0.449
500 clock hrs.	0.040	0.098	0.145	0.185	0.224	0.260	0.296	0.328	0.353
1,000 clock hrs.	0.064	0.122	0.172	0.218	0.253	0.282	0.310	0.336	0.353
2,000 clock hrs.	0.074	0.139	0.187	0.229	0.259	0.291	0.319	0.345	0.372
3,000 clock hrs.	0.089	0.151	0.201	0.242	0.275	0.306	0.335	0.369	0.393
3,500 clock hrs.	0.079	0.137	0.180	0.221	0.260	0.297	0.328	0.355	0.380
4,000 clock hrs.	0.080	0.139	0.183	0.223	0.266	0.298	0.321	0.348	0.371

Non-significant groupings at 0.05 level connected by brackets

hours between 5000 to 9000 cycles of abrasion and at 500 clock hours and 1000 clock hours between 1000 to 3000 cycles of abrasion. All other groupings were significantly different in this analysis.

The analysis of variance (Table 14) showed that significant interactions of sample by abrasion were established for the thickness means. The results of the Least Significant Difference Test which was performed on the thickness means for the interaction of sample and abrasion are presented in Table 18. As can be seen from the Table 18, the non-significant pairs of groupings consisted of
sample 2 at 9000 cycles and sample 1 at 7000 cycles;
sample 1 at 7000 cycles and sample 2 at 8000 cycles;
sample 1 at 6000 cycles and sample 2 at 7000 cycles;
sample 2 at 6000 cycles and sample 1 at 5000 cycles;
sample 2 at 3000 cycles and sample 1 at 3000 cycles; and
sample 2 at 2000 cycles and sample 1 at 2000 cycles.

Table 18: Thickness Means for the Interaction of Sample X Weathering

Sample	Cycles	Means
1	9000	0.404
1	8000	0.378
2	9000	0.359
1	7000	0.347
2	8000	0.335
1	6000	0.314
2	7000	0.307
2	6000	0.280
1	5000	0.277
2	5000	0.247
1	4000	0.231
2	4000	0.212
2	3000	0.173
1	3000	0.170
2	2000	0.130
1	2000	0.119
2	1000	0.074
1	1000	0.059

Non-significant groupings at 0.05 level connected by bracktes

The analysis of variance (Table 14) revealed that significant interactions of abrasion by sample by weathering were established for the thickness means. The results of the Least Significant Difference

Test in Tables 19 to 22 present the non-significant differences groupings of sample 1 and sample 2 for the combinations of abrasion and weathering, computed on the thickness means. In order to more thoroughly examine the interactions between and within the samples, weathering, and abrasion the thickness means were subdivided into two groups (sample 1 and sample 2).

Table 19 shows the non-significant groupings of thickness means between cycles of abrasion and clock hours of exposure for sample 1. In general, there was a progressive decrease in the significance between the levels of cycles with increasing clock hours of exposure to the carbon-arc light source.

Table 20 presents the non-significant groupings of thickness means between clock hours of exposure and cycles of abrasion for sample 1. Significant differences in thickness occurred between 0 and 500 clock hours of exposure at 4000, 5000, 6000, 7000, 8000, and 9000 cycles of abrasion.

The non-significant groupings of thickness means between cycles of abrasion and clock hours of exposure of sample 2 can be observed in Table 21. Generally, a significant change in thickness occurred with 1000, 2000, 3000, and 4000 cycles at all levels of clock hours of exposure. After 4000 cycles, pairs of non-significant difference groupings increased (Table 21).

Sample 2's, thickness means with pairs of non-significant groupings for the interaction of weather and abrasion are presented in Table 22. As can be seen, a significant change in thickness occurred from 500 to 1000 clock hours of exposure with 1000, 2000, 3000, 4000, and 5000 cycles of abrasion.

Table 19: Thickness Means for the Interaction of Abrasion X Weathering of Sample 1

	0 clock hrs.	500 clock hrs.	1,000 clock hrs.	2,000 clock hrs.	3,000 clock hrs.	3,500 clock hrs.	4,000 clock hrs.
1,000 cycles	0.034	0.037	0.047	0.059	0.075	0.079	0.084
2,000 cycles	0.088	0.096	0.108	0.123	0.141	0.136	0.145
3,000 cycles	0.135	0.152	0.164	0.175	0.194	0.181	0.192
4,000 cycles	0.284	0.199	0.213	0.227	0.236	0.226	0.231
5,000 cycles	0.380	0.243	0.251	0.263	0.271	0.266	0.268
6,000 cycles	0.431	0.286	0.284	0.295	0.301	0.304	0.301
7,000 cycles	0.473	0.322	0.315	0.322	0.332	0.340	0.325
8,000 cycles	0.517	0.356	0.343	0.348	0.361	0.366	0.354
9,000 cycles	0.554	0.383	0.367	0.376	0.383	0.391	0.377

Non-significant groupings at 0.05 level connected by brackets

Table 20: Thickness Means for the Interaction of Weathering X Abrasion of Sample 1

	1,000 cycles	2,000 cycles	3,000 cycles	4,000 cycles	5,000 cycles	6,000 cycles	7,000 cycles	8,000 cycles	9,000 cycles
0 clock hrs.	0.034	0.088	0.135	0.284	0.380	0.431	0.473	0.517	0.554
500 clock hrs.	0.037	0.096	0.152	0.199	0.243	0.286	0.322	0.356	0.383
1,000 clock hrs.	0.047	0.108	0.164	0.213	0.251	0.284	0.315	0.343	0.367
2,000 clock hrs.	0.059	0.123	0.175	0.227	0.263	0.295	0.322	0.348	0.376
3,000 clock hrs.	0.075	0.141	0.194	0.236	0.271	0.301	0.332	0.361	0.383
3,500 clock hrs.	0.079	0.136	0.181	0.226	0.266	0.304	0.340	0.366	0.391
4,000 clock	0.084	0.145	0.192	0.231	0.268	0.301	0.325	0.354	0.377

Non-significant groupings at 0.05 level connected by brackets

Table 21: Thickness Means for the Interaction of Abrasion X Weathering of Sample 2

	0 clock hrs.	500 clock hrs.	1,000 clock hrs.	2,000 clock hrs.	3,000 clock hrs.	3,500 clock hrs.	4,000 clock hrs.
1,000 cycles	0.046	0.043	0.081	0.089	0.104	0.079	0.076
2,000 cycles	0.088	0.100	0.135	0.156	0.161	0.138	0.134
3,000 cycles	0.138	0.138	0.181	0.198	0.207	0.179	0.174
4,000 cycles	0.179	0.171	0.223	0.231	0.248	0.217	0.215
5,000 cycles	0.219	0.206	0.255	0.256	0.279	0.254	0.263
6,000 cycles	0.266	0.235	0.281	0.287	0.312	0.290	0.295
7,000 cycles	0.285	0.271	0.306	0.316	0.338	0.317	0.318
8,000 cycles	0.310	0.300	0.328	0.343	0.378	0.344	0.342
9,000 cycles	0.344	0.323	0.339	0.368	0.403	0.369	0.365

Non-significant groupings at 0.05 level connected by brackets

Table 22: Thickness Means for the Interaction of Weathering X Abrasion of Sample 2

	1,000 cycles	2,000 cycles	3,000 cycles	4,000 cycles	5,000 cycles	6,000 cycles	7,000 cycles	8,000 cycles	9,000 cycles
0 clock hrs.	0.046	0.088	0.138	0.179	0.219	0.266	0.285	0.310	0.344
500 clock hrs.	0.042	0.100	0.138	0.171	0.206	0.235	0.271	0.300	0.323
1,000 clock hrs.	0.081	0.135	0.181	0.223	0.255	0.281	0.306	0.328	0.339
2,000 clock hrs.	0.089	0.156	0.198	0.231	0.256	0.287	0.316	0.343	0.368
3,000 clock hrs.	0.104	0.161	0.207	0.248	0.279	0.312	0.338	0.378	0.403
3,500 clock hrs.	0.079	0.138	0.179	0.217	0.254	0.290	0.317	0.344	0.369
4,000 clock hrs.	0.076	0.134	0.174	0.215	0.263	0.295	0.318	0.342	0.365

Non-significant groupings at 0.05 level connected by brackets

In summary, the only significant main effect was abrasion on the thickness readings. The interaction of abrasion by weathering, abrasion by sample, and abrasion by sample by weathering were significantly different. As the abrasion cycles increased from 1000 to 9000, so there also an increase in thickness, with all the thickness means being significantly different. In general, for the combination of abrasion and weathering computed on the thickness means significant difference groupings occurred. For the combinations of weathering and abrasion a significant change in thickness occurred at 0 clock hours and 500 clock hours between 5000 to 9000 abrasion cycles and at 500 clock hours and 1000 clock hours between 1000 to 3000 abrasion cycles. Random significant and non-significant pairs of groupings occurred on the thickness means for the interaction of sample and abrasion with no trend observed.

Evaluation of Enclosed Carbon-Arc Weather-Ometer Calibration with NBS Standard Light-Sensitive Paper

The enclosed carbon-arc Weather-Ometer was calibrated with NBS Light-Sensitive Paper (NBS Standard Reference Material 700c) and the NBS Booklet of Standard Faded Strips (NBS Standard Reference Material 701c) in terms of NBS Standard Fading Hours (SFH). (40) Although the paper and booklets were originally designed for simple visual estimation of the fading of test strips, greated precision can be obtained by using instrumental reflectance measurements. (50)

The reflectance factor Rd was measured on each of the six standard faded strips using the Model D25M-3 Hunterlab Colorimeter. The reflectance values found with the instrument were plotted as a function of the exposure of the standard strips in SFH (obtained from the reflectance marked on each strip) to obtain a six-point calibration curve for the reflectance measured.

An arithmetic straight-line trend curve was fitted to the six standard faded strips Rd reflectance measurements. The general equation of an arithmetic straight line calculated from the sample data used was $\overline{Y}x = a + bX$. (37) The results of the basic calculations were $a = -92.034$ and $b = 8.054$. The trend equation was $SFH = -92.034 + (8.054)(Rd)$. The trend curve was plotted by calculating SFH for several transformed values of Rd, plotting the appropriate points, and connecting points with a straight line. (36)

The Rd reflectance values recorded in this study for calibrating of the carbon-arc with the NBS Standard Light-Sensitive Papers are presented in Figure 3. The samples of NBS Light-Sensitive Paper were exposed continuously for 20 hours during the initial cycle of the test and thereafter every 500 clock hours of exposure. The average predicted SFH for 4000 carbon-arc Weather-Ometer clock hours was 16.78 SFH for twenty hours of operation of the lamp, which was lower than operating conditions recommended by the manufacturer. The highest two values were obtained when the Weather-Ometer arc voltage was increased due to malfunctioning of the instrument during the last 1000 clock hours of operation.

Evaluation of Photographs

The photographs of the abraded area in Figure 4 shows the effect of weathering and abrasion on esthetics and durability of synthetic turf. Samples were subjected to 0, 500, 1000, 2000, 3000, 3500, and

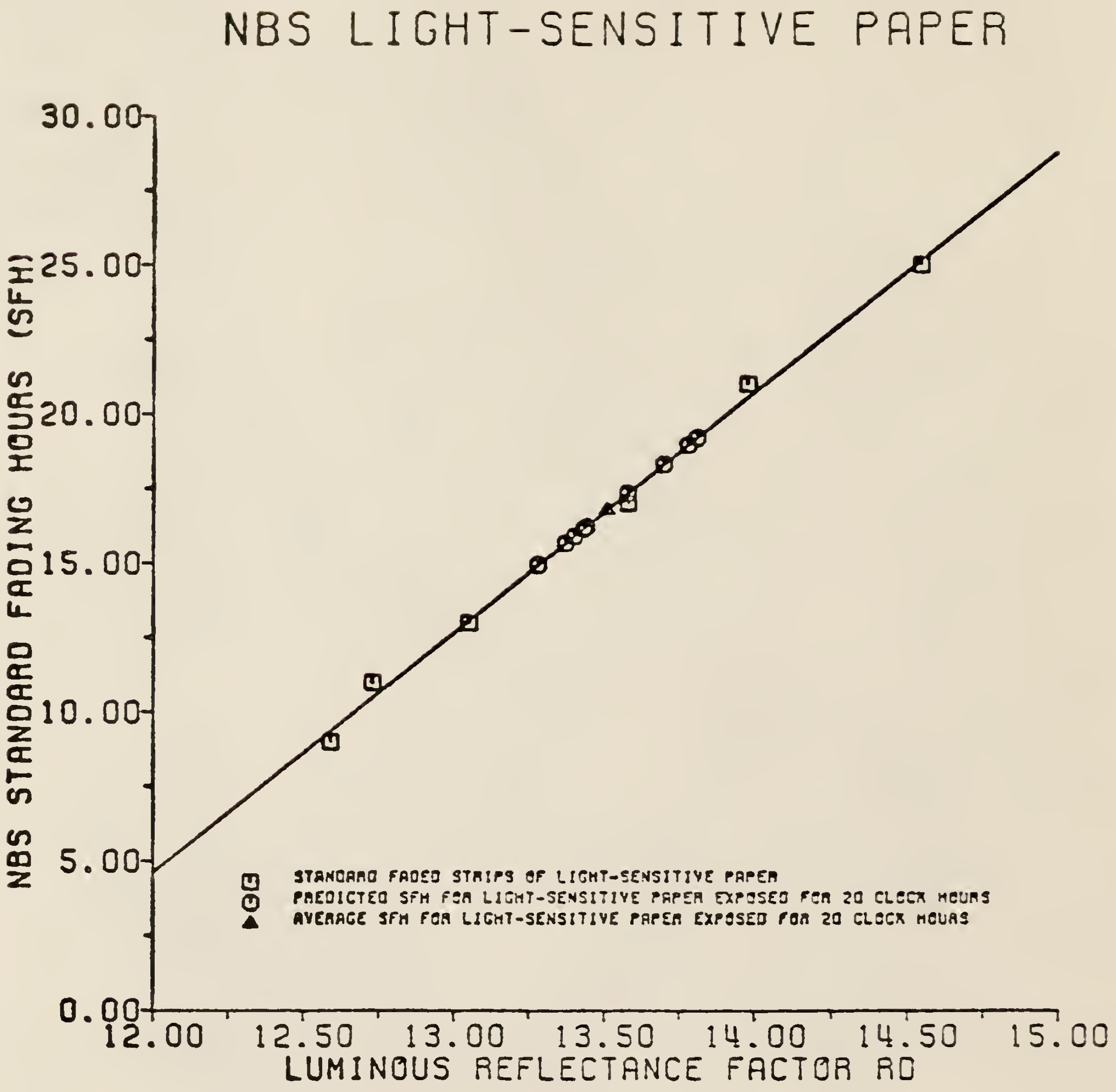

Figure 3: Evaluation of Carbon-Arc Weather-Ometer Calibration with NBS Standard Lignt-Sensitive Paper

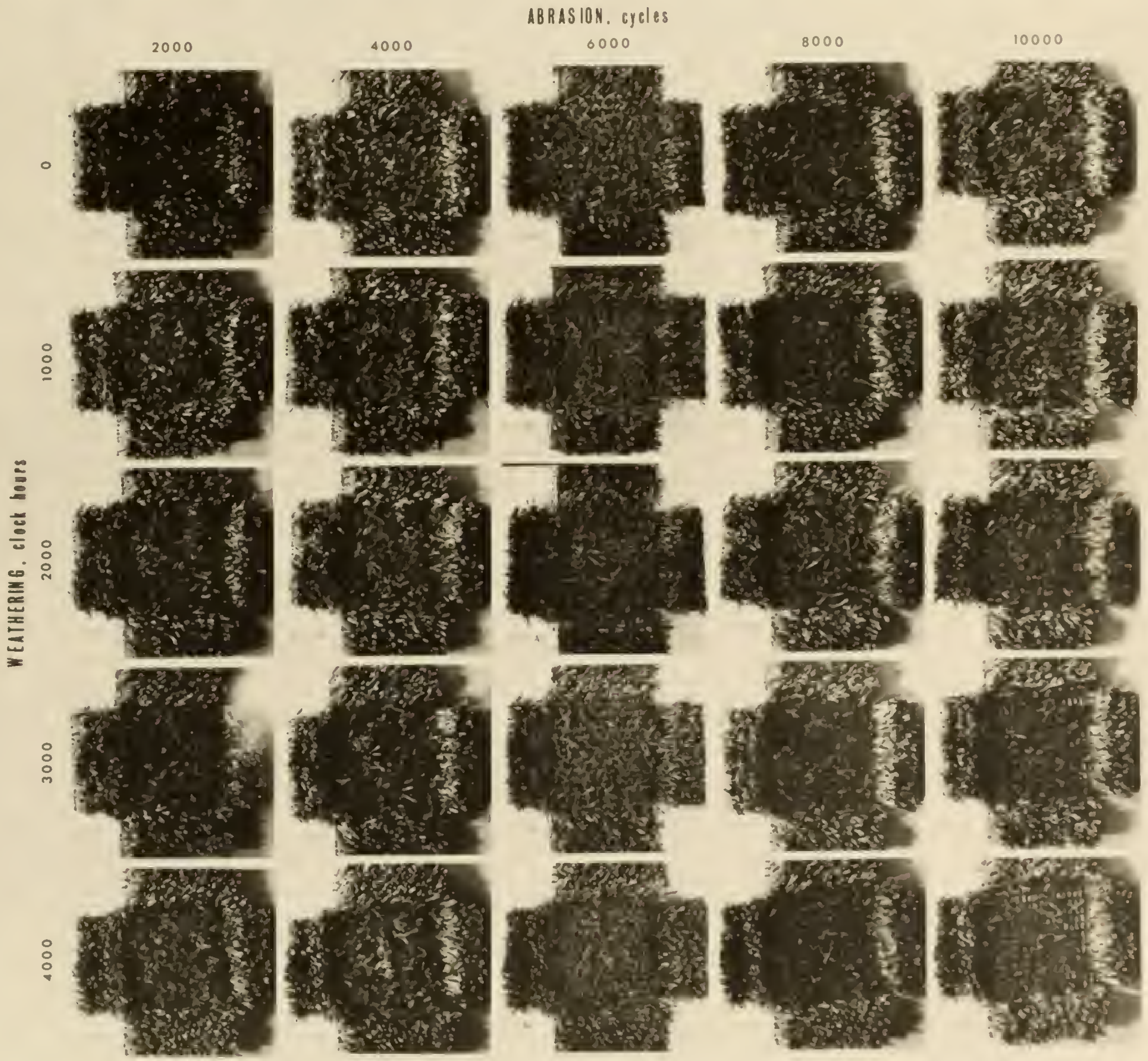

Figure 4: Effect of Weathering and Abrasion on Durability of Synthetic Turf

4000 clock hours of exposure with periodic wetting in the enclosed carbon-arc Weather-Ometer, followed by 1000, 2000, 3000, 4000, 5000, 6000, 7000, 8000, and 9000 abrasion cycles (Schiefer Abrader) using a 10-lb. load and carpet attachment. Punishment was inflicted only in the center of each sample, the outer areas show unpunished samples. Figure 4 represents only a selected portion of the abraded samples photographed, it was impossible to show all the different levels.

Knotting of the fibers occurred early in the abrasion cycles, which decreases the pile height and packed the fibers together, thereby preventing the filaments in the turf from returning to their original state. The discolored square areas in the center of sample indicate areas where brittle particles were removed. The breaking of fiber ends resulted in the formation of green dust particles.

Within a specific carbon-arc exposure period, the appearance of the turf's backing occurred more readily with increases in abrasion cycles. Within a specific rotation cycle, the appearance of the turf's backing also occurred more readily with increased exposure levels. This can be readily seen by comparing the unexposed sample abraded 10,000 cycles with the sample that was carbon-arc exposed for 4000 clock hours and abraded 10,000 cycles.

Evaluation of SEM Photomicrographs

Surface Damage after Exposure to Weathering

The surface damage on the fibers from the synthetic turf samples exposed in the carbon-arc Weather-Ometer for 0, 500, 1000, 2000, 3000, 3500, and 4000 clock hours was evaluated visually using the scanning electron microscope photomicrographs. The unexposed fiber surface was essentially smooth (Figures 5a, 5b, and 5c), although on some fibers minor flaws were observed. They were probably introduced either during filament extrusion or during the manufacturing processes. Figure 5d shows an unexposed fiber end cut during the manufacturing process, with characteristic serrated cross-section.

The surface of the nylon fibers which had been exposed to light with intermittent spraying for 500 clock hours (Figures 6a and 6b) exhibited a few cracks that formed in the depressed areas of the fiber. Figure 6c shows the splitting of the fiber along the depressed area of the fiber. Figure 6d shows the formation of a deposit at 500 clock hours of exposure to light with intermittent spraying.

After exposure of the nylon 66 fiber to light for 1000 clock hours, with intermittent spraying, pits were observed on the surface of the fibers (Figure 7a). Figure 7b shows the present of larger pits or cavities at the fiber end. Since the fiber surface was not eroded uniformly by the exposures, certain sites were apparently more susceptible to attack. It is possible that these sites might be near the delustrant in the fiber, as photoxidation of nylon 66 is accelerated by delustrants (51). Increased amount of cracks occurred along the fiber ends as showed in Figure 7c. Figure 7c and 7d also show a few deposits along the nylon surface.

Since the turf's pile was not degraded uniformly by the exposures, certain blades were apparently more susceptible to attack than others (Figures 8a, 8b, and 8c). Figures 8a and 8b show how a change can be seen from one side of the fiber compared with the other side of the same fiber. Increased amount of cracks (Figures 8a and 8b)

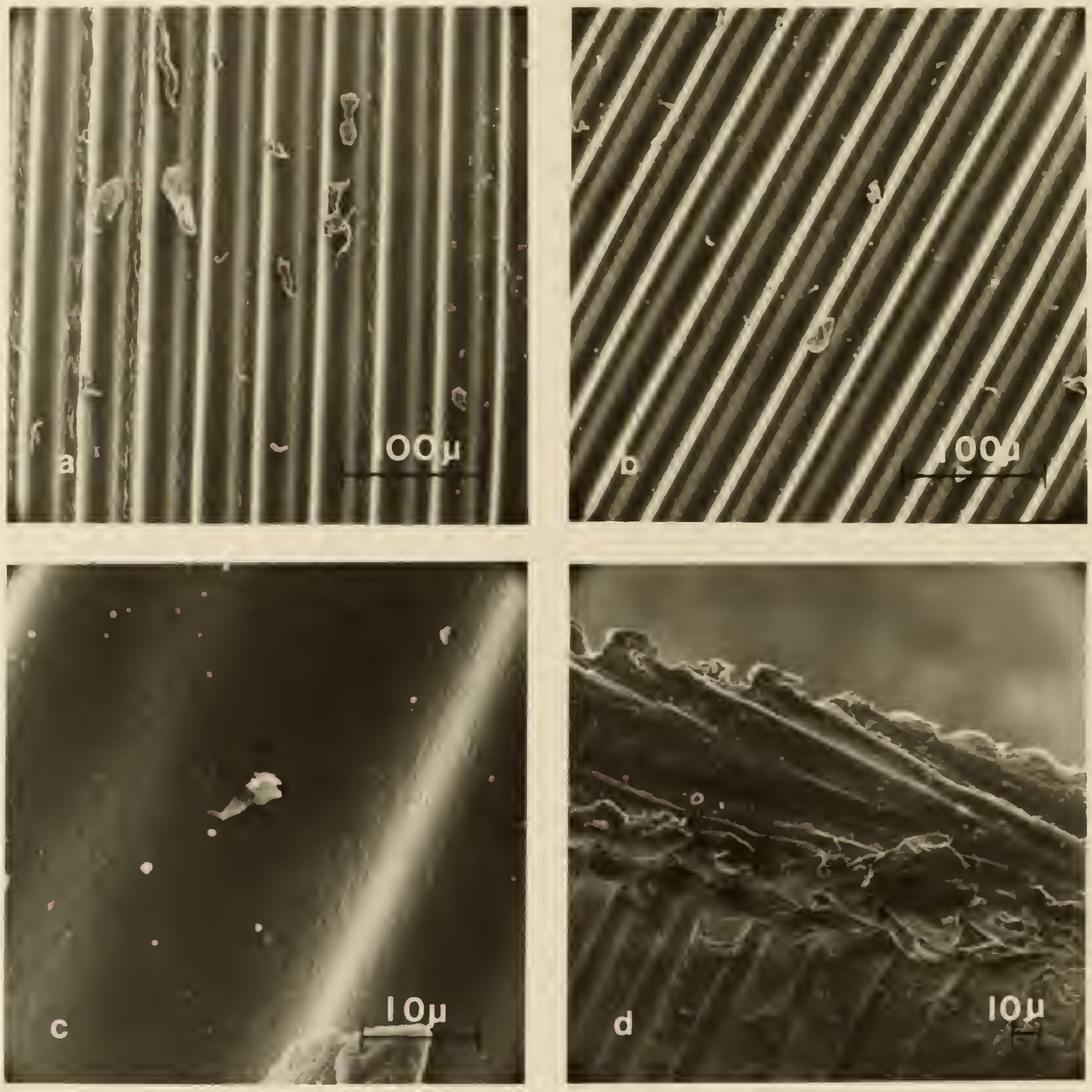

Figure 5: Synthetic Turf Fibers before Weathering

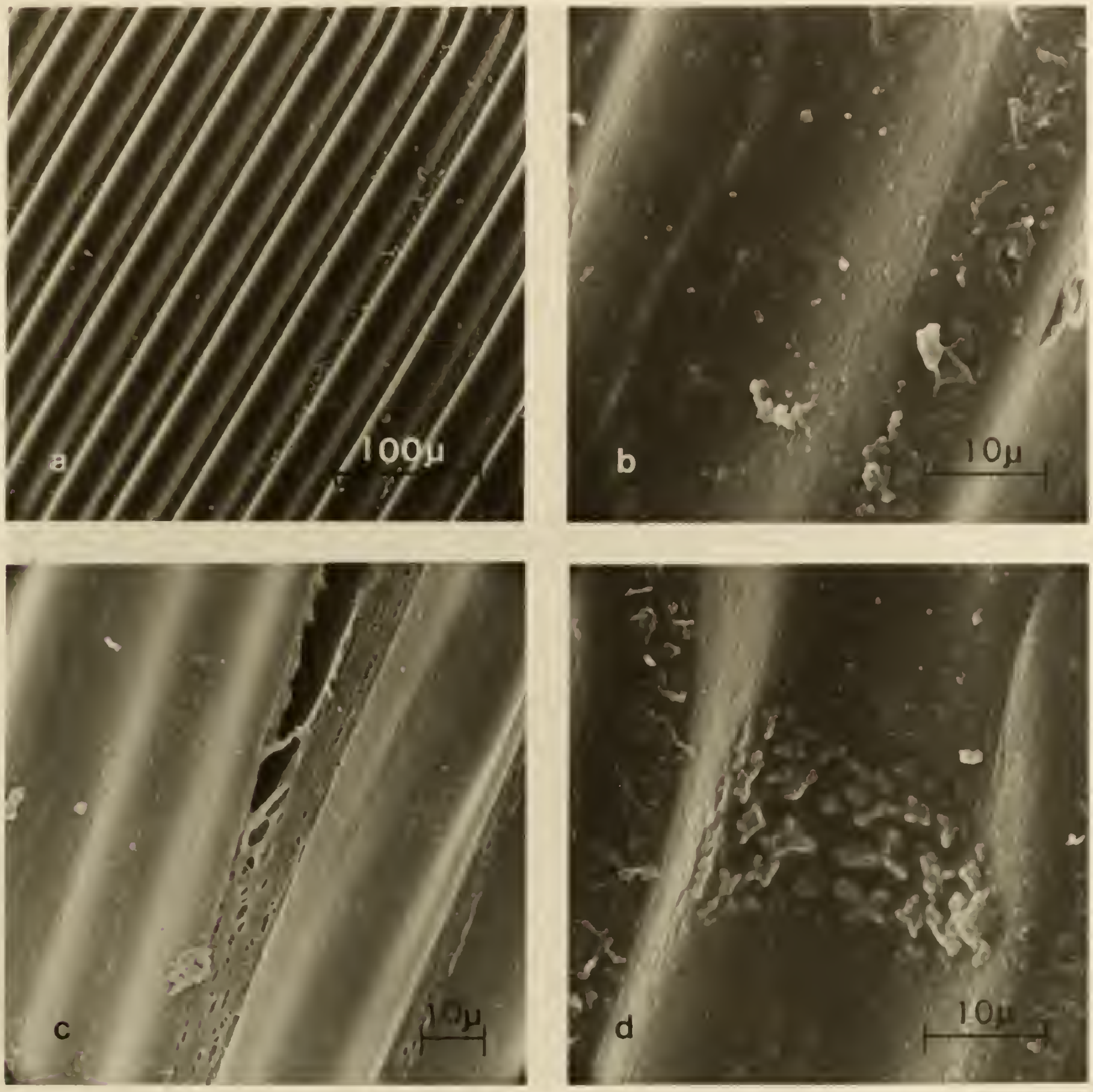

Figure 6: Synthetic Turf Fibers Weathered for 500 Clock Hours

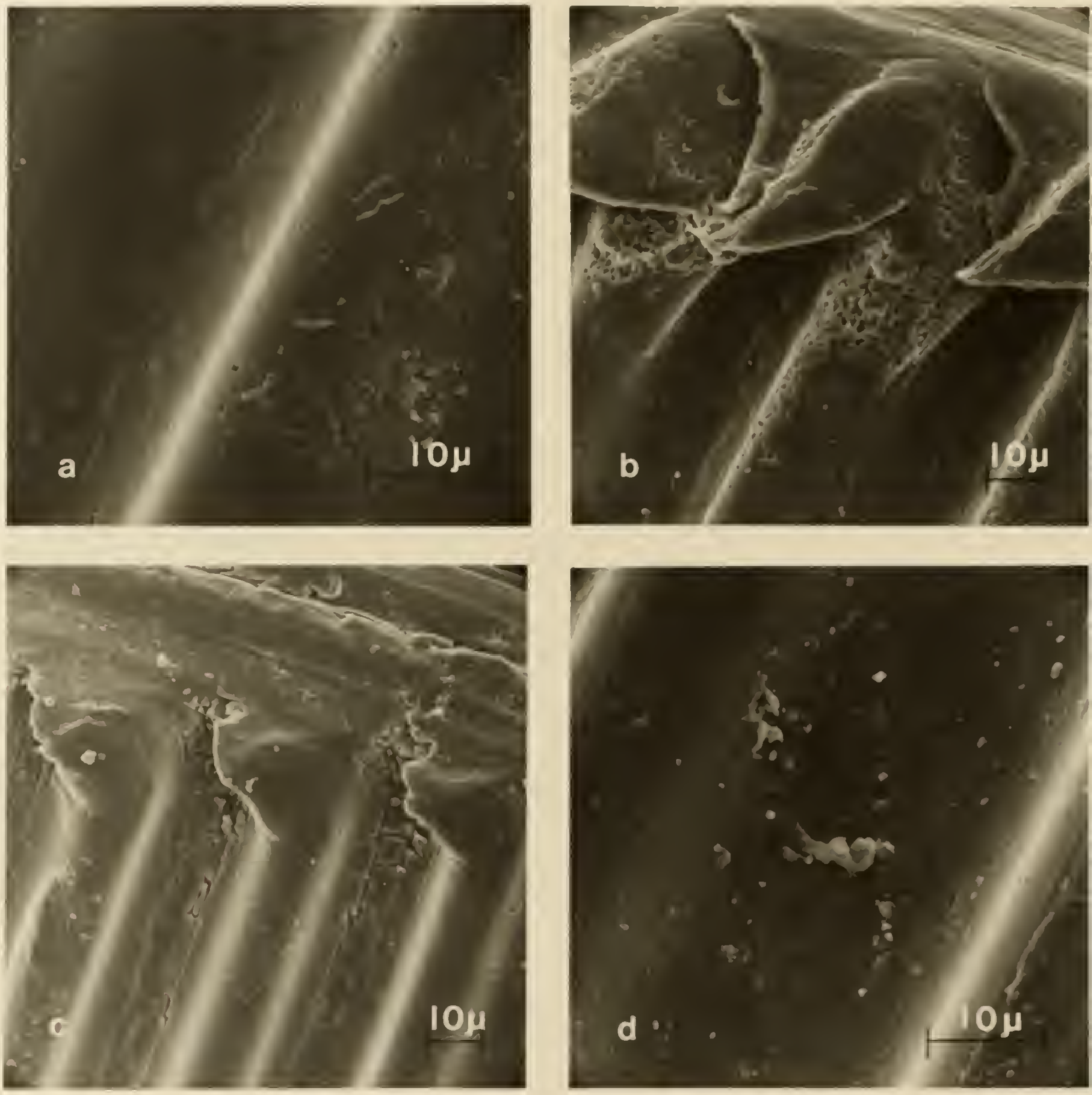

Figure 7: Synthetic Turf Fibers Weathered for 1000 Clock Hours

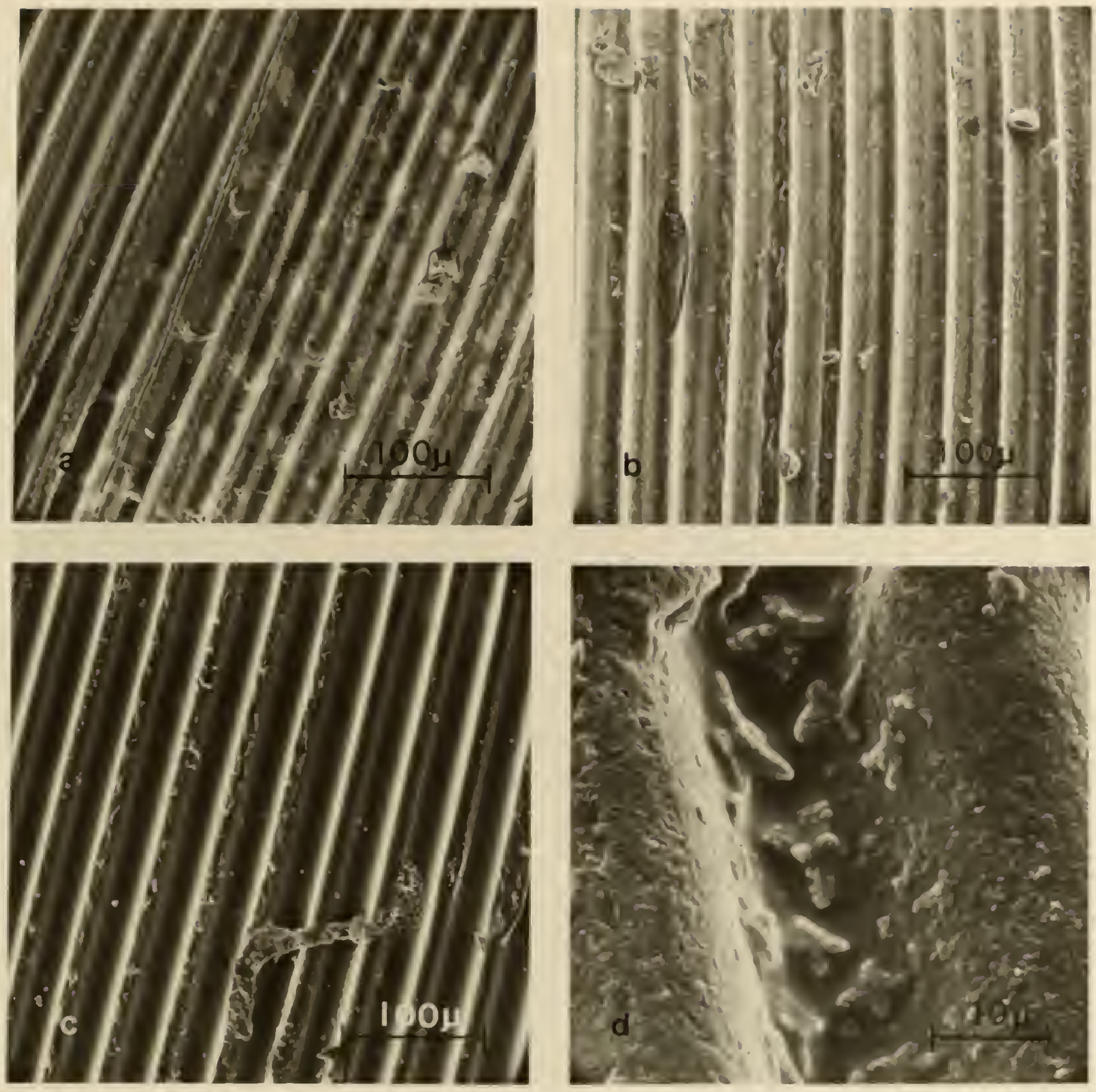

Figure 8: Synthetic Turf Fibers Weathered for 2000 Clock Hours

can be seen in nylon 66 exposed to 2000 clock hours with periodic spraying with water. Also a large amount of deposition occurred on the surface (Figures 8b and 8d).

In Figures 9a and 9b, the surface of nylon 66 fibers, which had been exposed to 3000 clock hours of weathering, contained a considerable increase in deposition. Whereas another nylon fiber exposed to the same conditions showed fewer deposits and a small number of cracks (Figure 9c). The photomicrograph in Figure 9b represents an enlargement of the area indicated by the arrow in Figure 9a. Figure 9d shows a lateral deposits forming in the depressed areas of the fiber surface. Figure 9d also represents an enlargement of the area indicated by the arrow in Figure 9c.

Production flaws were observed on the ridges of the nylon 66 fiber surface (Figures 10a and 10b). The photomicrograph in Figure 10b represents an enlargement of the area indicated by the arrow in Figure 10a. The fiber surface was exposed 3500 clock hours, with intermittent spraying. Figure 10c and 10d shows cracks along the depressed areas with a small amount of deposits.

Figures 11a, 11b, 11c, and 11d show the fiber surface of nylon 66 exposed to 4000 clock hours of light, with intermittent spraying of water. Figures 11a and 11b are the same fiber only the opposite side. One can see the differences obtained when the sample is not uniformly exposed. Larger cracks and an increased build-up of deposits were found on the surface of the nylon 66 which had been degraded more severely. The photomicrograph in Figure 11c represents an enlargement of the area indicated by the arrow in Figure 11b. Figure 11d shows production flaws on the ridges of the nylon 66 fiber surface. Figure

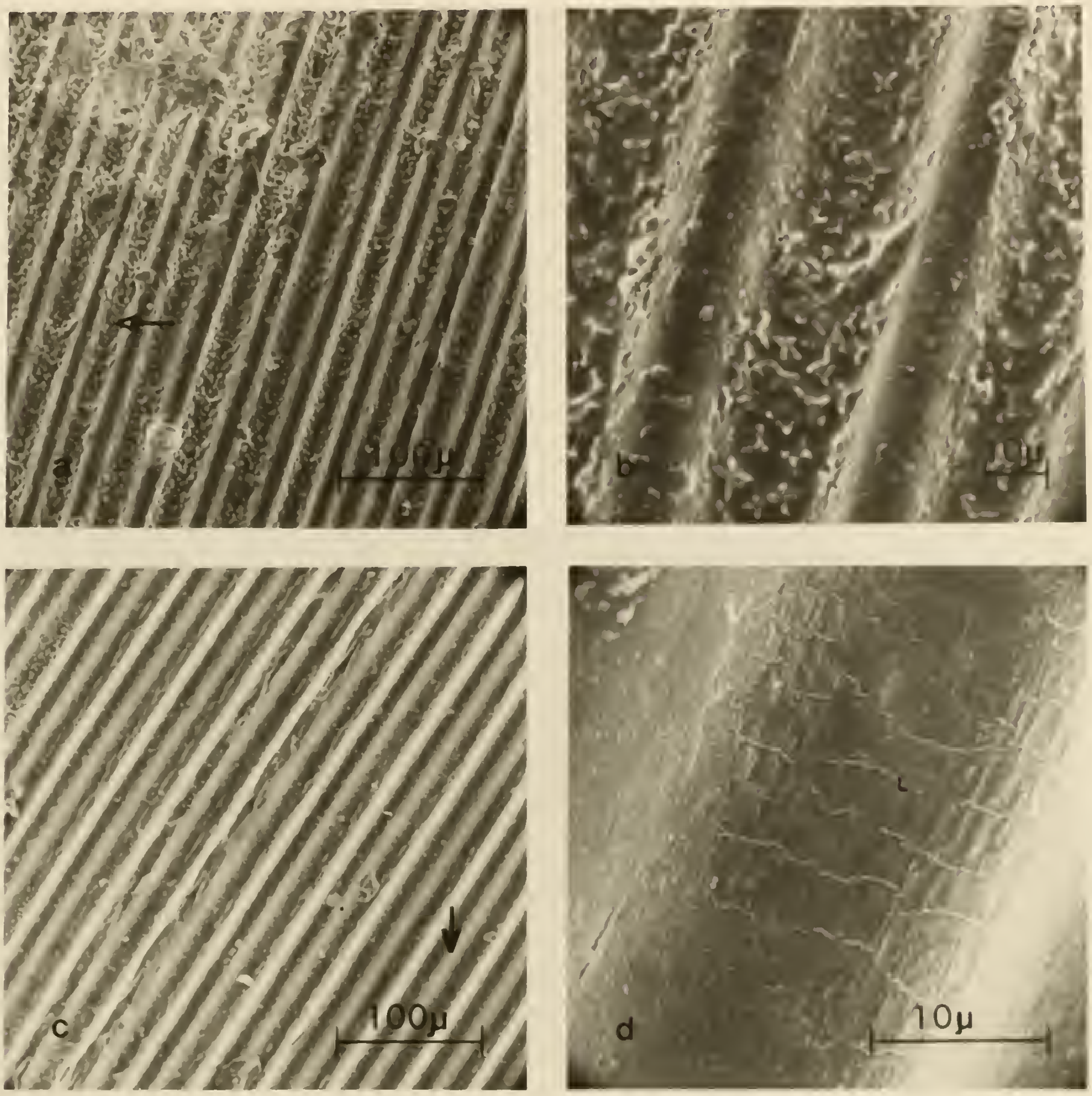

Figure 9: Synthetic Turf Fibers Weathered for 3000 Clock Hours

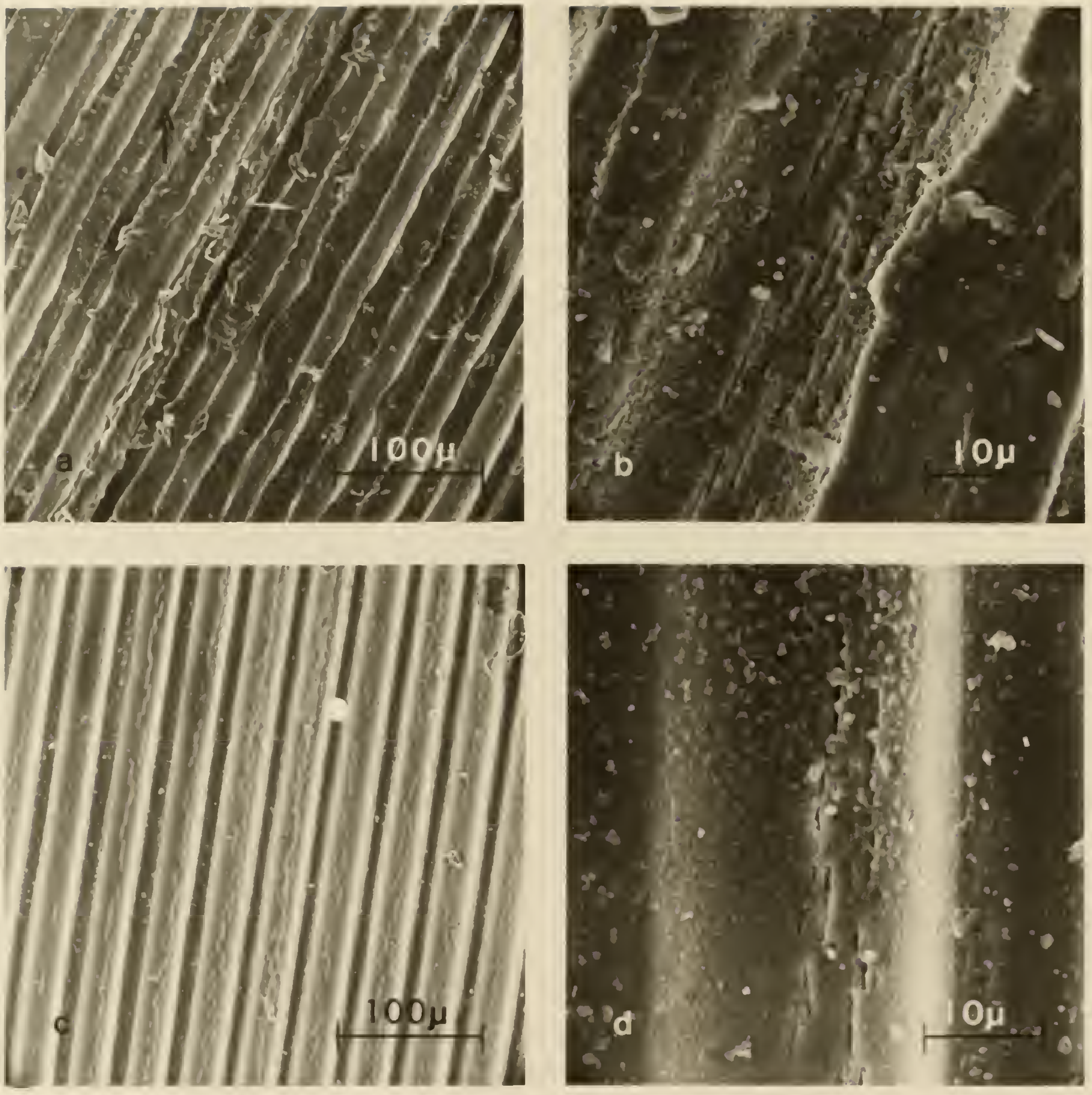

Figure 10: Synthetic Turf Fibers Weathered for 3500 Clock Hours

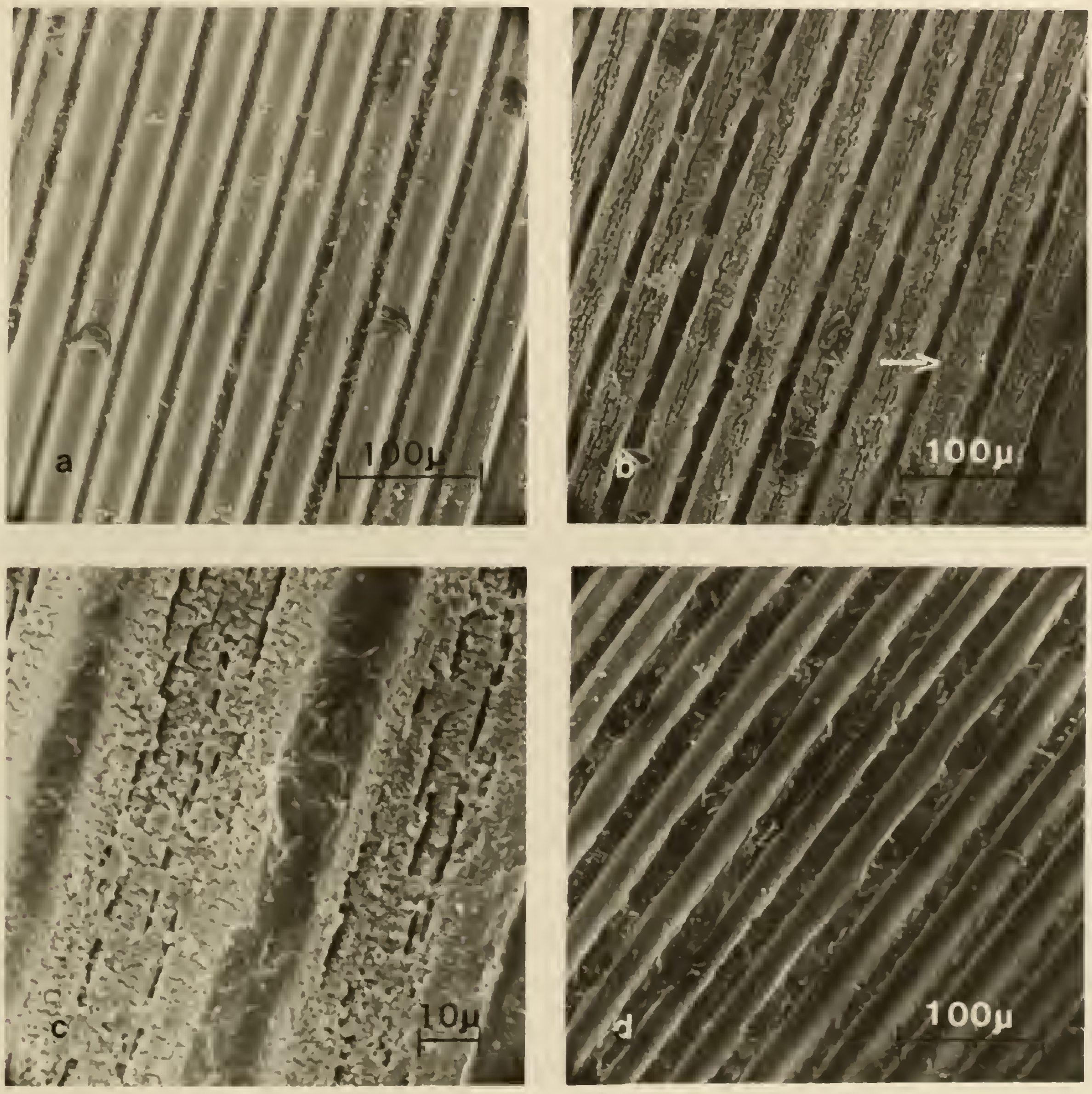

Figure 11: Synthetic Turf Fibers Weathered for 4000 Clock Hours

11d also shows fewer deposits and a small number of cracks than another nylon fiber (Figure 11b) exposed to the same weathering conditions.

Influence of Weathering upon Abrasion Damage

The surface damage on abraded synthetic turf fibers exposed to laboratory weathered conditions was evaluated visually using the scanning electron microscope photomicrographs. It was desirable when viewing the abraded fibers to make a series of photographs at a high magnification rather than one photograph showing the complete fiber. After printing the photographs were cut and fitted together in a montage. Most of the photographs in this section of the research project are made up of two or three separate pictures.

Figures 12 and 13 show the unexposed weathered synthetic turf fiber abraded for 4000 and 10,000 cycles, respectively. Figure 12 shows a nylon 66 fiber splitting longitudinally down the depressed areas of the fiber. The fiber surface has a very flattened and scraped appearance. In Figure 13, a finger-like appearance has resulted due to splitting during abrasion. Examination of the damaged fiber end shows the split, mashed, and scraped surface.

Figures 14 and 15 show the synthetic turf fibers that were exposed to accelerated light source for 500 clock hours and then subjected to 1000 and 4000 cycles of abrasion, respectively. The scanning electron micrograph (Figure 14) shows an abraded fiber relatively unaffected. Cracks can be seen at the tip of the ragged fiber edge creating a smoothing surface. Splitting also has occurred down the depressed areas.

Figures 16, 17, and 18 show the synthetic turf fibers that were

Figure 12: Unexposed Synthetic Turf Fiber after 4000 Abrasion Cycles

Figure 13: Unexposed Synthetic Turf Fiber after 10000 Abrasion Cycles

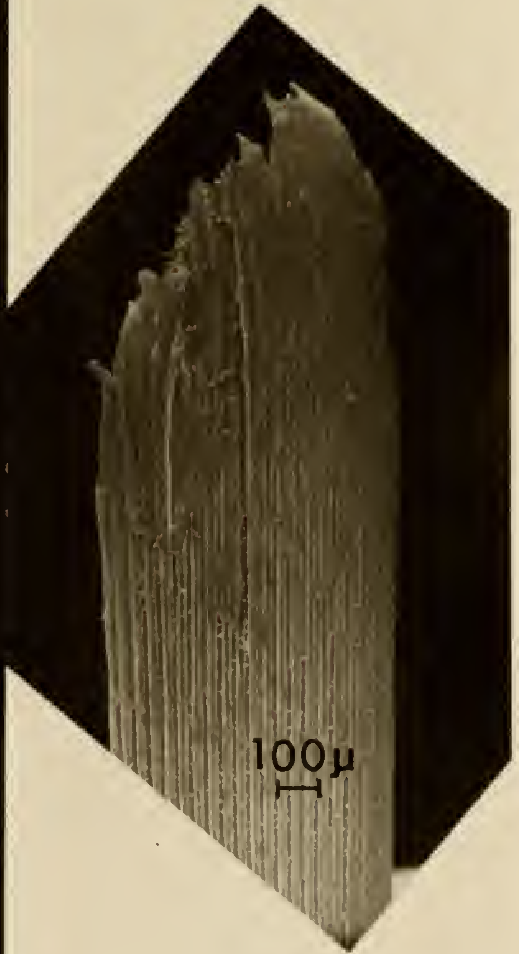

Figure 14: Synthetic Turf Fiber after 500 Clock Hours of Weathering and 1000 Abrasion Cycles

Figure 15: Synthetic Turf Fiber after 500 Clock Hours of Weathering and 4000 Abrasion Cycles

Figure 16: Synthetic Turf Fiber after 1000 Clock Hours of Weathering and 2000 Abrasion Cycles

Figure 17: Synthetic Turf Fiber after 1000 Clock Hours of Weathering and 8000 Abrasion Cycles

Figure 18: Synthetic Turf Fiber after 1000 Clock Hours of Weathering and 9000 Abrasion Cycles

exposed to 1000 clock hours in the accelerated light source and then abraded for 2000, 8000, and 9000 cycles, respectively. In Figure 16, the broken fiber ends tend to split into twisted ribbon-like strands with a loss of the surface ridges. Smashing of the split fiber end occurred in Figure 17 with the peeling back of the fiber surface. In Figure 18, the fiber ends have been sheared after 9000 cycles of abrasion.

The synthetic turf fibers in Figures 19, 20a, and 20b were exposed in the carbon-arc Weather-Ometer for 2000 clock hours and then abraded for 3000, 5000, and 5000 cycles, respectively. Figure 19 shows the fiber splitting into thin ribbon-like strips with evidence of wear on each strip. Abrasion has removed the top of the ridges on the fiber surface. Figures 20a and 20b shows three different fibers exposed to the same conditions (2000 clock hours and 5000 cycles). Longitudinal fiber splitting and a wearing away of ridges surfaces is evident on all fibers. Smashing of the fiber end in Figure 20b has resulted in the shearing off of the fiber.

Figures 21, 22, and 23 show the synthetic turf fibers that were exposed in the carbon-arc Weather-Ometer for 3000 clock hours and then abraded for 3000, 8000, and 9000 cycles of abrasion, respectively. In Figure 21 the split nylon 66 fiber shows more intense abrasion on the upper end of the fiber with the peeling and wearing away of the surface ridges. A finger-like appearance has resulted from the splitting of the turf fiber down the depressed areas of the fiber (Figure 22). Figure 23 shows smoothed fiber tips and excessive fiber splitting. An undetermined mass has occurred at the lower end of the fiber.

The synthetic turf fibers in Figures 24 and 25 were exposed in

Figure 19: Synthetic Turf Fiber after 2000 Clock Hours of Weathering and 3000 Abrasion Cycles

Figure 20: Synthetic Turf Fiber after 2000 Clock Hours of Weathering and 5000 Abrasion Cycles

Figure 21: Synthetic Turf Fiber after 3000 Clock Hours of Weathering and 3000 Abrasion Cycles

Figure 22: Synthetic Turf Fiber after 3000 Clock Hours of Weathering and 8000 Abrasion Cycles

Figure 23: Syntheti
Turf Fiber afte
3000 Clock Hour
of Weathering
and 9000
Abrasion Cycles

Figure 24: Synthetic Turf Fiber after 3500 Clock Hours of Weathering and 6000 Abrasion Cycles

Figure 25: Synthetic Turf Fiber after 3500 Clock Hours of Weathering and 7000 Abrasion Cycles

the carbon-arc Weather-Ometer for 3500 clock hours and then subjected to 6000 and 7000 cycles of abrasion, respectively. Examination of the damaged fiber in Figure 24 shows the split fiber, layers that are peeling back from the surface, and broken fiber ends bend which have further split apart into thin ribbon-like strips. Figure 25 shows the smashed end of the split fiber and layers that peeled back from the surface.

Synthetic turf fibers that were carbon-arc exposed for 4000 clock hours and abraded 3000, 10,000, and 7000 cycles, respectively, are shown in Figures 26, 27, and 28. Figure 26 shows a fiber which has split along the depress areas of the fiber and was then abraded so that the ridges were removed on the fiber end. Figure 27 shows the same characteristics which occurred at the 3000 cycles level in Figure 26. Figure 28 shows the shearing off of the fiber end and splitting of fiber.

The Schiefer abrasion tester degraded the surface of the synthetic turf damaging and weakening the pile fibers. Figures 29, 30, 31, and 32 show an enlarged view of the harsh effect caused by the steel blade abradant on the surface of the fibers. The photomicrograph in Figure 29 shows an abraded fiber slightly affected by the abrasion cycles. Cracks can be seen on the depressed areas of the fiber. Figure 30 shows the scraped ridges and the cracking and splitting that occurred in the depressed areas of the nylon 66 fibers. The fiber surface in Figure 31 has a very flattened and scraped appearance. Figure 32 shows the wrinkling of the synthetic turf filament when bent under a 10-lb. load on the Schiefer Abrader.

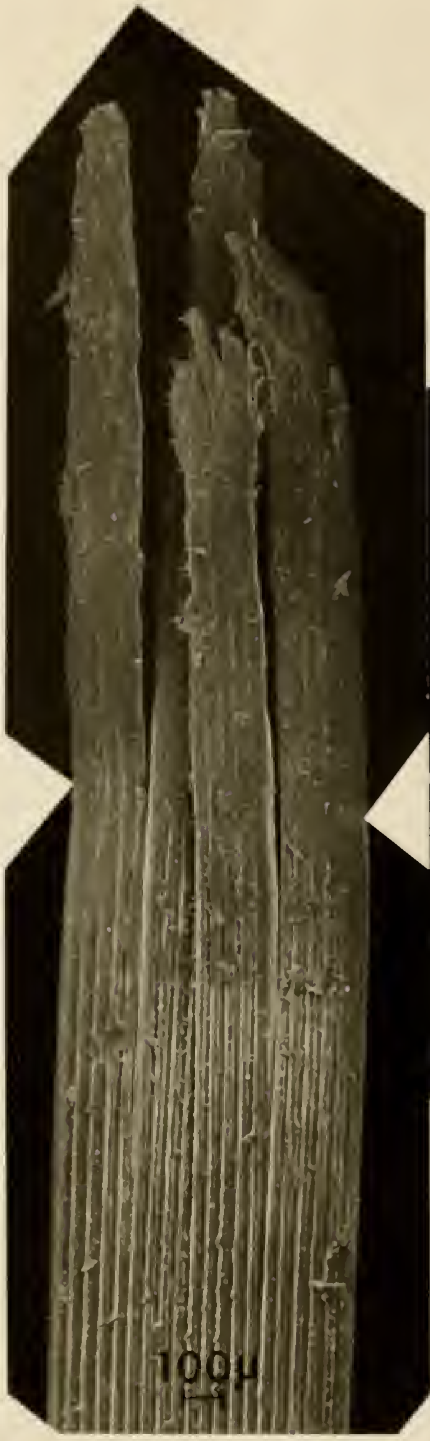

Figure 26: Synthetic Turf Fiber after 4000 Clock Hours of Weathering and 3000 Abrasion Cycles

Figure 27: Synthetic Turf Fiber after 4000 Clock Hours of Weathering and 10000 Abrasion Cycles

Figure 28: Synthetic Turf Fiber after 4000 Clock Hours of Weathering and 7000 Abrasion Cycles

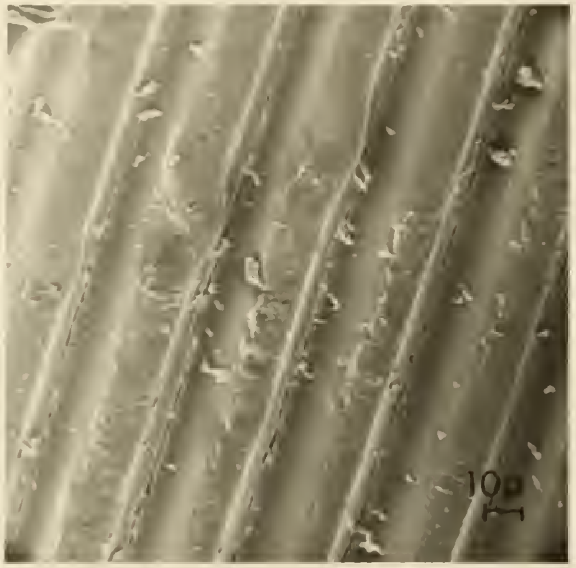

Figure 29: Unexposed Synthetic Turf Fiber after 2000 Abrasion Cycles

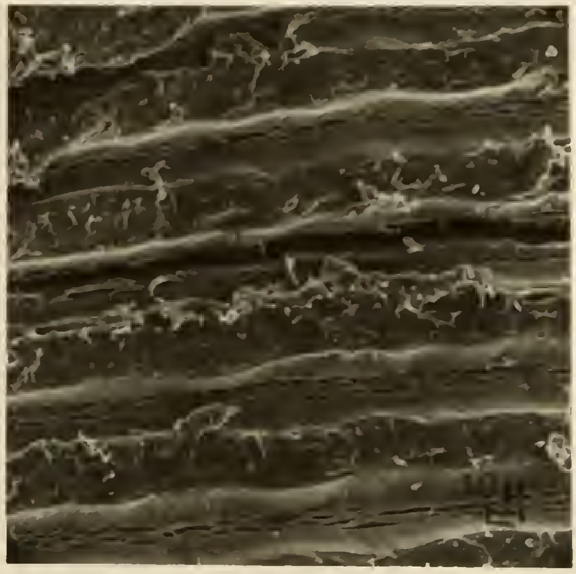

Figure 30: Turf Fiber after 1000 Clock Hours of Weathering and 1000 Abrasion Cycles

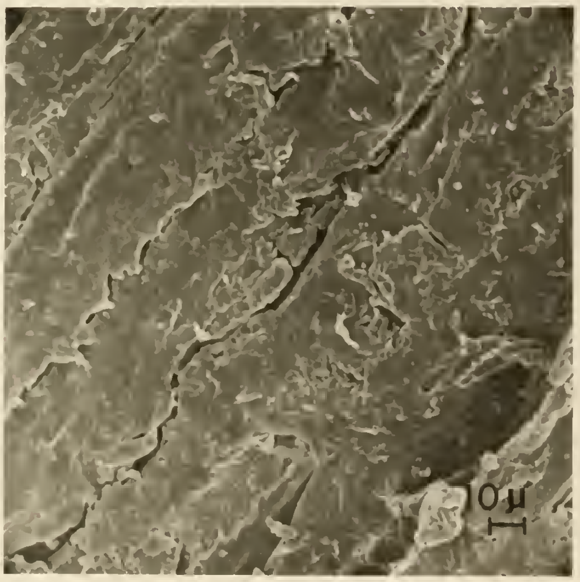

Figure 31: Synthetic Turf Fiber after 3000 Clock Hours of Weathering and 2000 Abrasion Cycles

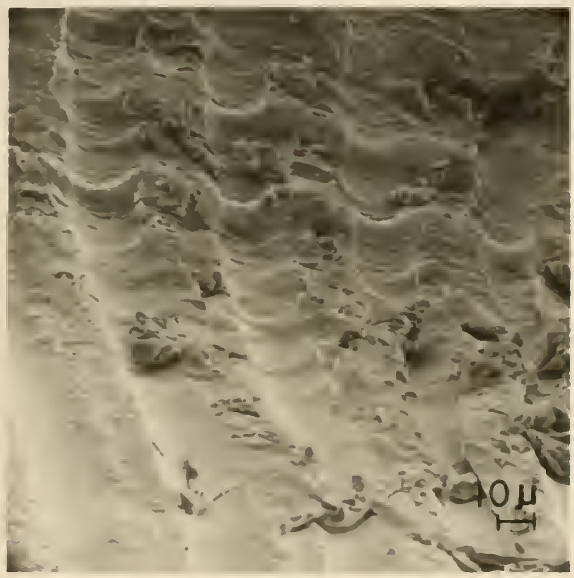

Figure 32: Synthetic Turf Fiber after 1000 Clock Hours of Weathering and 1000 Abrasion Cycles

Miscellaneous Observation

Figures 33, 34, 35a, and 35b show the fiber ends that appear to have melted sometime during testing. One can speculate that these melted ends may have been caused by a build up of heat under the spring steel blade abradant. The figures show that it has occurred randomly throughout the testing for 500 clock hours at 6000 cycles, 2000 clock hours at 4000 cycles, 2000 clock hours at 10,000 cycles, and 2000 clock hours at 10,000 cycles, respectively. Further research is needed to determine if the excessive heat build up is atypical to that encountered in normal wear and if this factor should be considered in evaluating the significance of accelerated abrasion testing.

Figure 33: Synthetic Turf Fiber after 500 Clock Hours of Weathering and 6000 Abrasion Cycles

Figure 34: Synthetic Turf Fiber after 2000 Clock Hours of Weathering and 4000 Abrasion Cycles

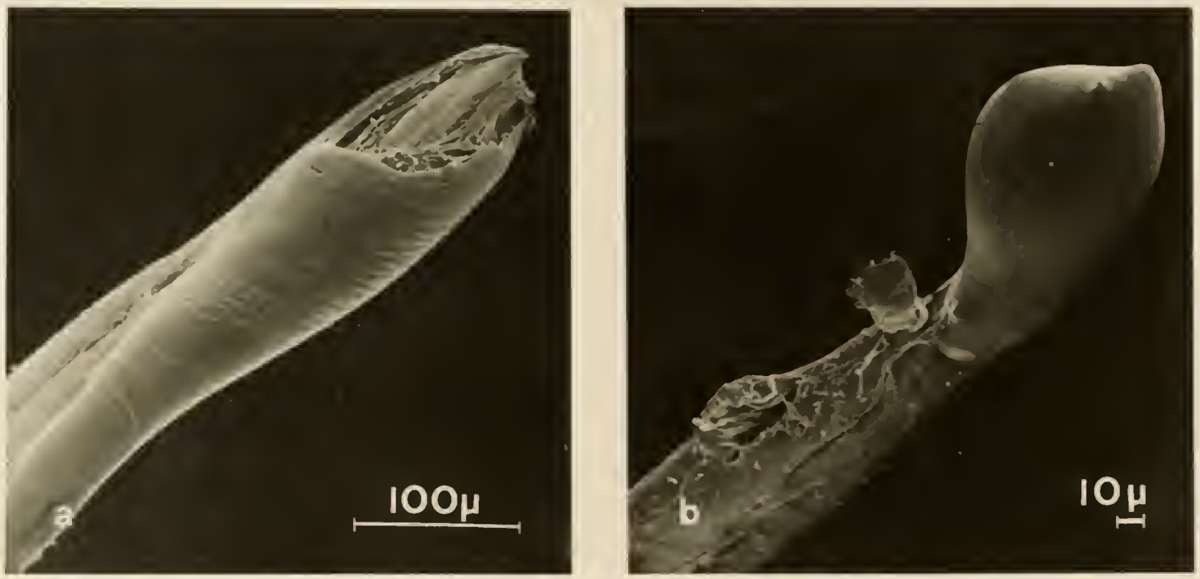

Figure 35: Synthetic Turf Fiber after 2000 Clock Hours of Weathering and 10000 Abrasion Cycles

SUMMARY AND CONCLUSIONS

The installation of synthetic recreational surfaces prospered during the late fall and winter of 1968-69. Their popularity has been attributed to greater emphasis on leisure activity and the needs of athletes and sportsmen for greater consistency in playing surfaces. (20, 49) The synthetic turf surfaces are designed to have durability, functionality similar to natural grass turf, and esthetic appeal based on traditional concepts. (47) The major justification for synthetic turf is the tremendous increase in usage it will permit on a given playing field. The three major factors which affect the life of synthetic turf installation are (1) exposure to ultraviolet radiation, (2) exposure to severe air pollution, and (3) wear from traffic. (30) There was no provisions made in this study for evaluating the effects of air pollutants. The purpose of this study was to evaluate the durability of synthetic turf after weathering and abrading.

In order to evaluate the effects of weathering the experimental synthetic turf was exposed in the carbon-arc Weather-Ometer with continuous light and periodic wetting. The samples were evaluated instrumentally for total color difference with a Hunterlab D25M-3 Tristimulus Colorimeter and visually for the type and extent of surface damage by means of the scanning electron photomicrographs. An unequal subclass analysis of variance was applied to the data obtained for total color difference in order to evaluate the effects of weathering on color loss. Exposure time had a significant effect on the amount of color change which occurred. Sample direction also was analyzed as a main source of variation but was found not to be significant.

After 0, 500, 1000, 2000, 3000, 3500, and 4000 clock hours of carbon-arc exposure, the weathered synthetic turf was evaluated for abrasion resistance by subjecting the test specimens to 0, 1000, 2000, 3000, 4000, 5000, 6000, 7000, 8000, 9000, and 10,000 abrasion cycles with the Schiefer Abrader using a spring steel blade abradant under a 10-lb. load according to ASTM Designation D 1175-71. After each 1000 cycles of abrasion, the weight loss and thickness readings were taken, and appearance was checked. The extent of surface damage was evaluated visually using scanning electron photomicrographs. An analysis of variance procedure of a split-split-plot experiment was applied to the data obtained from thickness and weight loss values of abrasion in order to determine the significant differences among the independent variables or main effects of replica, weathering, sample, and abrasion. The number of abrasion cycles had a significant effect on thickness and weight loss values obtained for the unexposed and exposed test specimens.

An over-all evaluation of the photodegradation data showed that the synthetic turf demonstrated a high resistance to accelerated exposure conditions. After exposing the synthetic turf in the carbon-arc Weather-Ometer for 4000 clock hours, which was a year of laboratory time, only a slight change in color was observed. Statistically, the weathering of synthetic turf had a significant effect on the total color difference. Significant difference in the total color difference occurred after every 1000 clock hours of exposure. It will be noted that the total color difference values of the weathered synthetic turf was very small from one level of exposure sample to another.

The results of the scanning electron photomicrographs taken at each exposure level showed that the serrated cross-section may have influenced surface damage. Pits or cavities and cracks formed in the depressed area of the fiber. Deposits were observed in the depressions along the serrated fiber surface. However, this deposition appears to be attributable to causes not readily explainable. Large cracks and increased deposition on the surface of the nylon 66 fibers was found to increase with the weathering. Also, the position of the fibers in the synthetic turf and the amount of surface area exposed to light influence the extent of photodegradation.

Accelerated abrasion testing was used to estimate the resistance of the synthetic turf to wear before and after carbon-arc exposure. The criteria used for measuring the effects of abrasion were: (1) weight loss, (2) thickness, (3) visual evaluation with photographs, and (4) microscopic study. Statistically, the only significant independent variable influencing the thickness of the abraded samples was the number of abrasion cycles. All the thickness means were significantly different at all cycle levels of abrasion. The rank order of the thickness means established for the cycles of abrasion was 1000 cycles with the lowest mean consecutive to 9000 cycles with the highest mean. The independent variables of weathering and abrasion had significant effect on the weight loss values obtained for the abraded samples. The weight loss means for the abraded synthetic turf showed a significant difference for all levels of abrasion. From 0 clock hours to 3000 clock hours of carbon-arc exposure no significant differences occurred in weight loss. From the examination of the scanning electron microscope pictures taken of the abraded fibers, the following specific damage patterns evolved: splitting of the fiber down the depressed areas of the fiber into thin ribbon-like strips, scraping and flattening of the ridges of the nylon 66 fiber, shredding, fraying, and fibrillation of the fiber surface, peeling back of layers from the fiber's surface, and shearing off of the fiber ends.

RECOMMENDATIONS

Some suggestions for further research include:

(1) A comparison of the weathering and abrasion characteristics of other types of synthetic turf products with the results obtained from the synthetic turf evaluated in this study.

(2) An evaluation of the effects of accelerated light exposure with and without periodic wetting on synthetic turf to determine effects of waterspray on weathering.

(3) A comparison of the fiber damage found in accelerated abrasion tests with fiber damage found in actual end-use.

(4) Further investigation of the deposition caused in weathered synthetic turf observed in the scanning electron photomicrographs.

(5) Further investigation of the melted fiber ends probably occurring during abrasion as seen in the scanning electron photomicrographs.

(6) Evaluate the photodegradation of the nylon 66 fiber with infrared spectroscopy.

REFERENCES CITED

1. AATCC Test Method 111A-1975, Weather Resistance: Carbon-Arc Lamp Exposure with Wetting. 1976 Technical Manual of the American Association of Textile Chemists and Colorists. Volume 52. Research Triangle Park, N.C.: American Association of Textile Chemists and Colorists, 1976.

2. "A Farewell to Grass", Newsweek, Vol. 75, (May 11, 1970), pp. 73-74.

3. Appleby, Dorothy K. "The Action of Light on Textile Materials: A Review of Literature", American Dyestuff Reporter, Vol. 38, No. 4, (February 21, 1949), pp. 149-156, 189-192.

4. ASTM Designation: D 1175-71, Standard Test Methods for Abrasion Resistance of Textile Fabrics. 1976 Annual Book of ASTM Standards. Part 32. Philadelphia, Pa.: American Society for Testing and Materials, 1976.

5. "AstroTurf Stadium Surfaces Specifications", Consumer and Recreational Products by Monsanto Company, St. Louis, Missouri, May 15, 1975, pp. 1-3.

6. Atlas Electric Devices Company. Atlas Weather-Ometer Operation Instruction Book No. FW-110WR. Chicago, Illinois: Atlas Electric Devices Company.

7. "A Very Rough Season for Synthetic Turf", Business Week, (November 6, 1971), p. 35.

8. Baker, F. L. and Princen, L. H. "Scanning Electron Microscopy", Encyclopedia of Polymer Science and Technology, Vol. 15, (1971), pp. 498-507.

9. Booth, J. E. Principles of Textile Testing. 3rd ed. New York: Chemical Publishing Company, Inc., 1969.

10. Cady, William. "The Tendering Action of Light on Textile Fibers", American Dyestuff Reporter, Vol. 27, No. 12, (June 13, 1938), pp. P235-P327.

11. Carry, Peter. "A Surface Case of Bugs in the Rugs", Sports Illustrated, Vol. 33, No. 11, (September 14, 1970), pp. 40-45.

12. Casper, M. S. Synthetic Turf and Sporting Surfaces. Park Ridge, New Jersey: Noyes Data Corporation, 1972.

13. Cohen, I. "Carpets: Commercial Testing, Evaluation, Control of Delivered Quality (I)", Textile Institute and Industry, Vol 6, No. 6, (June 1968), pp. 147-150.

14. Coleman, R. A., and Peacock, W. H. "Ultraviolet Absorbers", Textile Research Journal, Vol. 25, (September, 1958), pp. 784-791.

15. Elbert, D. L. "Synthetic Turf Products Having Variable Blade Widths", United States Patent 3,573,147, March 30, 1971. Appl. January 24, 1968.

16. Elbert, D. L., and Wright, R. T. "Heat and Light Resistant Pigmented Nylon Fibers", United States Patent 3,565,910, February 23, 1971. Appl. February 18, 1969.

17. Everhart, Thomas E. and Hayes, Thomas L. "The Scanning Electron Microscope", Scientific American, Vol. 226, No. 1, (January, 1972), pp. 55-69.

18. Gardner Laboratory Inc. Technical Information on Gardner Color Difference Meters. Technical Information PH 260-Z2. Bethesda 14, Maryland: Gardner Laboratory Inc., January 19, 1959.

19. Giles, Charles H. and McKay, Robert B. "A Lightfastness of Dyes: A Review", Textile Research Journal, Vol 33, No. 7, (July, 1963), pp. 527-577.

20. Goldberg, Ivan J. "Synthetic Sports Surfaces", Textiles, Vol. 3, No. 2, (June, 1974), pp. 41-44.

21. Hearle, J. W. S. "An Atlas of Fiber Fracture 1-15", Textile Manufacturer, Vol. 99-100, No. 1164-1165, 1167-1175, 1177-1180, (January/February, March/April, May, June, July, August, September, October, November, December, January, March, April, May, June, 1972-1973), pp. 14-15, 12-13, 20-21, 26-27, 42-43, 40-41, 16-17 40-41, 12-13, 36-37, 24-25, 24-25, 34-35, 54-55, 44-45.

22. Hearle, J. W. S. and Cross, P. M. "The Fractography of Thermoplastic Textile Fibers", Journal of Materials Science, Vol. 5, No. 6, (June, 1970), pp. 507-516.

23. Hearle, J. W. S., and Peters, R. H. Fiber Structure. London and Manchester: Butterworth and Co. Ltd. and the Textile Institute, 1963.

24. Hearle, J. W. S. and Sparrow, J. T. "The Fractography of Cotton Fibers", Textile Research Journal, Vol. 41, No. 9, (September, 1971), pp. 736-749.

25. Johnson, William. "Goodby to Three Yards and a Cloud of Dust", Sports Illustrated, Vol. 30, (January 27, 1969), pp. 37-39.

26. Kirkwood, Barbara Hodam. "Microscopical Observations of the Abrasive and Ultraviolet Deterioration of Nomex Aramid Fiber", Textile Research Journal, Vol. 47, No. 3, (March, 1977), pp. 171-177.

27. Laughlin, Kenneth C. "Carpet Weathering: Effect on Compression and Recovery Properties and on Wear Performance", Journal of the American Association of Textile Chemists and Colorists, Vol. 3, No. 4, (April, 1971), pp. 92-94.

28. Light and Weather Resistance of Fibers. Bulletin X-203 (April, 1966), Wilmington, Delaware: E. I. Du Pont De Nemours and Company, Inc.

29. Linton, George E. The Modern Textile and Apparel Dictionary. 4th ed. Plainfield, New Jersey: Textile Book Service, 1973.

30. "Longevity of Synthetic Turf Surfaces", St. Louis Missouri: Monsanto Company, (Mimeographed).

31. McLaren, K. "The Use of Fading Lamps for Determining Light Fastness", Journal of the Society of Dryers and Colourists, Vol. 70, No. 12, (1954), pp. 553-556.

32. Milner, Ed M., Director, Products Technology Consumer and Recreational Products. Personal correspondence. Monsanto Commercial Products Company, St. Louis, Missouri, December 5, 1975.

33. Milner, Ed M., Director, Products Technology Consumer and Recreational Products. Personal correspondence. Monsanto Commercial Products Company, St. Louis, Missouri, March 11, 1976.

34. "Mod Sod", Time, Vol. 89, (May 12, 1967), p. 57.

35. Monsanto Company. AstroTurf® Stadium Surface Specifications. St. Louis, Missouri: Consumer and Recreational Products, Monsanto Company, May 15, 1975.

36. Neta, John, Wasserman, William, and Whitmore, G. A. Fundamental Statistics for Business and Economics. 4th ed., Boston: Allyn and Bacon, Inc., 1973.

37. Ranby, B., and Rabek, J. F. Photodegradation, Photo-oxidation, and Photostabilization of Polymers, New York: John Wiley and Sons, Inc., 1975.

38. Rollins, M. L., DeGruy, I. V., Hensarling, T. P., and Carra, J. H. "Abrasion Phenomena in Durable-Press Cotton Fabrics, A Microscopical View", Textile Research Journal, Vol. 40, No. 10, (October, 1970), pp. 903-916.

39. Schick, M. J. Surface Characteristics of Fibers and Textiles, Part 1, New York: Marcel Dekker., 1975.

40. Shouse, P. J. and Wood, L. A. National Bureau of Standards Certificate of Calibration Standard Reference Material 701c Booklet of Faded Strips of Light-Sensitive Paper. Washington, D.C.: U.S. Department of Commerce, October 1, 1971.

41. Singleton, R. W., Kunkel, R. K., and Spraque, B. S. "Factors Influencing the Evaluation of Actinic Degradation of Fibers", Textile Research Journal, Vol. 35, No. 3, (March, 1965), pp. 228-237.

42. Skinkle, John H. Textile Testing. 2nd ed. Brooklyn, New York: Chemical Publishing Company, Inc., 1949.

43. "Textile Grass is Set to Grow", Textile World, Vol. 119, No. 3, (March, 1969), pp. 52-55.

44. The AstroTurf® Field. St. Louis, Missouri: AstroTurf® Surfaces by Monsanto Company.

45. "The Grass is Greener", Daily News Record, Vol. 5, No. 170, (Tuesday, September 2, 1975), p. 9.

46. Tweedie, A. S., Mitton, M. T., and Sturgeon, P. Z. "How Reliable are Artifical Light Sources for Predicting Degradation of Textiles by Daylight?", Journal of the American Association of Textile Chemists and Colorists, Vol. 3, No. 2, (February, 1971), pp. 22-40.

47. Vinicki, John. "Synthetic Turflike Surfaces", Encyclopedia of Polymer Science and Technology, Vol. 15, (1971), pp. 481-490.

48. "Where's the Real Market in Sports Surfaces? Underneath", Modern Plastics, Vol. 49, (February, 1972), pp. 44-45.

49. Whitaker, H. R. "Magic Carpet for all Outdoors", Science Digest, Vol. 66, (July, 1969), pp. 33-37.

50. Wood, Lawrence A. and Shouse, Paul J. "Standard Reference Materials: Use of Standard Light-Sensitive Paper for Calibrating Carbon-Arcs used in Testing Textile for Colorfastness to Light", National Bureau of Standards Special Publication 260-41. Washington, D.C.: U.S. Government Printing Office, August 1972.

51. Zeronian, S. H. "The Effect of Light and Air Contaminated with Sulfur Dioxide on the Surface of Nylon 66 Fibers", Textile Research Journal, Vol. 41, No. 2, (February, 1971), pp. 184-185.

52. Zook, Margaret Harris. "Historical Background of Abrasion Testing", American Dyestuff Reporter, Vol. 39, No. 19, (September 18, 1950), pp. 625-630.

WEATHERING AND ABRASION RESISTANCE
OF SYNTHETIC TURF

by

ANDREA TIMM NISLEY

B.S., University of Nebraska, 1974

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Clothing, Textiles, and Interior Design

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1978

The major justification for synthetic turf is the tremendous increase in usage it will permit on a given playing field. The three major factors which affect the life of synthetic turf installation are (1) exposure to ultraviolet radiation, (2) exposure to severe air pollution, and (3) wear from traffic. (30) The purpose of this study was to evaluate the durability of synthetic turf after weathering and abrading.

In order to evaluate the effects of weathering the experimental synthetic turf was exposed in the carbon-arc Weather-Ometer with continuous light and periodic wetting. The samples were evaluated instrumentally for total color difference with a Hunterlab D25M-3 Tristimulus Colorimeter and visually for the type and extent of surface damage by means of the scanning electron photomicrographs. An unequal subclass analysis of variance was applied to the data obtained for total color difference in order to evaluate the effects of weathering on color loss. Exposure time had a significant effect on the amount of color change which occurred.

After 0, 500, 1000, 2000, 3000, 3500, and 4000 clock hours of carbon-arc exposure, the weathered synthetic turf was evaluated for abrasion resistance by subjecting the test specimens to 0, 1000, 2000, 3000, 4000, 5000, 6000, 7000, 8000, 9000, and 10,000, abrasion cycles with Schiefer Abrader using a spring steel blade abradant under a 10-lb. load according to ASTM Designation D 1175-71. After each 1000 cycles of abrasion, the weight loss and thickness readings were taken, and appearance checked. The extent of surface damage was evaluated visually using scanning electron photomicrographs. An analysis of variance procedure of a split-split-plot experiment was applied to the data obtained from thickness and weight loss values of abrasion in order to determine the significant differences among the independent variables of replica, weathering, sample, and abrasion. The number of abrasion cycles had a significant effect on the thickness and weight loss values obtained for the unexposed and exposed test specimens.

An over-all evaluation of the photodegradation data showed that the synthetic turf demonstrated a high resistance to accelerated exposure conditions. After exposing the synthetic turf in the carbon-arc Weather-Ometer for 4000 clock hours, which was a year of laboratory time, only a slight change in color was observed. Statistically, the weathering of synthetic turf had a significant effect on the total color difference.

The results of the scanning electron photomicrographs taken at each exposure level showed that the serrated cross-section may have influenced surface damage. Pits or cavities and cracks formed in the depressed area of the fiber. Deposits were observed in the depressions along the serrated fiber surface. Large cracks and increased deposition on the surface of the nylon 66 fibers was found to increase with weathering. Also, the position of the fibers in the synthetic turf and the amount of surface area exposed to light influenced the extent of photodegradation.

Accelerated abrasion testing was used to estimate the wear of synthetic turf fibers. The criteria used for measuring the effects of abrasion were weight loss, thickness, visual evaluation with photographs, and microscopic study. Statistically, the only significant independent variable influencing the thickness of the abraded samples was the number of abrasion cycles. Exposure time had no significant effect on thickness after abrasion. The independent variables of weathering and abrasion and a significant effect on the weight loss values obtained for the abraded samples. From the examination of the scanning electron microscope pictures taken of the abraded fibers, the following specific damage patterns evolved: splitting of the fiber down the depressed areas of the fiber into thin ribbon-like strips, scraping and flattening of the ridges of the nylon 66 fiber, shredding, fraying, and fibrillation of the fiber surface, peeling back of layers from the fiber's surface, and shearing off of the fiber ends.