

THE EFFECT OF AFTERMARKET CARPET PROTECTOR
TREATMENTS ON THE SOILING PROPENSITY OF
NYLON 6 CARPETING

by

Shailendra Dusaj

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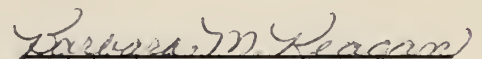
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Approved by:


Major Professor

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INTRODUCTION

Soil and stain repellent finishes are applied to a variety of textile products to enhance their resistance to soiling and staining caused by dirt, dust, food spills, grease and oils, and perspiration. Functionally, soil and stain repellent finishes, should be both water and oil repellent. In addition, they should be durable, compatible with other finishes and dyes, non-toxic, and economical.

Textile products that are commonly treated with soil and stain repellent finishes include apparel, upholstery, and carpeting which vary in fiber content and construction. These finishes may be applied at various stages during processing or after manufacturing (i.e., aftermarket treatments). Most of the antisoiling agents work by forming a film on the fiber, thus making the fiber non-receptive to soils. Some of these finishes are water-based and others are petrochemical-based. The water-based finishes are not durable, whereas the petrochemical-based finishes attract oily soils. In addition, some of these finishes give the surface a harder hand after treatment. Aftermarket topical finishes usually are air-curable, whereas those applied to textile products during manufacturing are usually heat-curable.

About 70% of the carpets produced in the U.S. have nylon pile because of its many advantages over other generic classes of fibers such as resiliency and abrasion resistance.

However, nylon as well as other synthetic fibers are both oleophilic and hydrophobic. Thus, they have a greater affinity for soils, and soil removal is more difficult, compared to natural fibers.

Carpeting is exposed to many different types of soils and stains because of its diversity of use in hospitals, schools, offices, homes, and other institutions. Furthermore, carpeting tends to be more heavily soiled and is more difficult to clean than apparel fabrics, because foot traffic forces soil into the carpet surface. Also, carpets are not cleaned as frequently as are apparel fabrics due to the relative inconvenience and cost of taking up carpets for cleaning or shampooing in place (68).

Because of consumer interest in the performance of carpeting, there has been a progressive increase in the use of soil repellent finishes on both residential and commercial carpeting during manufacturing and also after manufacturing. Aftermarket topical sprays for improving soil resistance are widely promoted by retailers, furniture stores, carpet cleaners, etc. In many instances, depending on the product, these treatments increase the cost of the carpeting without substantially improving its performance. Furthermore, some aftermarket topical sprays may actually increase soiling.

Thus this study examined the effects of various classes of aftermarket carpet protector treatments at two different application rates (1 gallon/800 sq. ft. and three times this

amount) on the soiling propensity of nylon carpeting at two different moisture levels (dry and wet (after cleaning)).

REVIEW OF LITERATURE

Historically, a variety of finishing agents have been used to improve the resistance of a textile to soiling and staining and to facilitate cleaning. Numerous compounds are available for imparting resistance to waterborne stains, but only a few repel oil (12, 13, 51, 52, and 53). In addition, many of the finishes used to impart resistance to waterborne stains often are used for imparting water repellency. One disadvantage of many water repellents (i.e. hydrocarbons and silicones), however, was that oily substances could eventually penetrate the fabric surface and often were held more tenaciously, compared to untreated fabrics. In the mid 1950s The 3M Company developed fluorochemical stain repellents that resisted oil and water-borne stains, but they often made it more difficult to clean soiled textile because the fluorinated groups packed tightly and resisted wetting. As a result, dual action fluorochemicals were developed with alternating hydrophobic and oleophobic units along the polymer backbone. These finishes enhance soil removal, in addition to resisting the absorption of oily soils (52).

The first stain and soil repellent finishes were applied to apparel fabrics. Similar products also were developed for carpeting containing nylon or other synthetic fibers because of their hydrophilicity and inherent affinity for soils. Today, 70% of the carpets produced in the U.S. contain nylon 6 or 66 face fibers, and the majority are either fiber

producer and/or mill treated with finishes to reduce soiling.

Nylon

Nylons are polyamide macromolecules whose structural units are interlinked by amide linkages $(-NHCO-)$ (46). Based on the FTC definition for nylon, less than 85% of the amide $(-NHCO-)$ linkage are attached directly to two aromatic rings. The important commercial fibers in this class are nylon 6 (polycaprolactum) and nylon 66 (condensation polymer of adipic acid and hexamethylene diamine). Both nylon 6 and nylon 66 fibers that are derived from polyamides that melt below the range of 280-290 C are produced by the melt spinning processes. The molten polyamide obtained either directly from the polymerization reactor system or by melting of polyamide chips is extruded through a die or spinneret (44, 45).

The orifices of the spinnerets are normally circular, thus producing filaments with circular cross-section. However, other orifice shapes are being used rather extensively for the production of filaments with non-circular cross-sections to achieve special effects such as luster, opacity, air permeability, insulation, and resistance to soiling. The filaments emerging from the spinneret are cooled in quench ducts by cross currents of air, wetted with a finish, and wound on bobbins at take-up speeds up to 6000 m/min. The spin finish applied is usually in the form of an aqueous emulsion or solution of lubricants (natural or

synthetic oils), emulsifiers, wetting agents, antistatic agents, bactericides, antioxidants, and antisoil agents. Flow in the spinneret system, velocities of extrusion, quenching, and takeup are process parameters that influence the structure and physical properties of the fiber (45, 46).

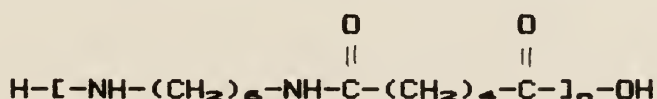
Chemistry

Nylon 6 (polycaprolactum) is made by addition polymerization of caprolactum $\text{HNCH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CO}$. The general structure of nylon 6 polymer is:



The synthesis of caprolactum is easier than that of hexamethylene diamine. The polymerization process is conducted either in a batch or in a continuous operation using equipment ranging from simple autoclave reactor to a multistage flow reactor system. The process is carried out at temperature in the range of 250-280 C for periods of about 12 to more than 24 hours. It results in a polymer melt that is either transferred directly to spinning units for filament formation or extruded in form of ribbon that are subsequently cut into chips (43).

Nylon 66 (polyhexamethylene adipamide) is made by condensation polymerization of adipic acid ($\text{HOOC}(\text{CH}_2)_4\text{COOH}$) and hexamethylene diamine ($\text{H}_2\text{N}(\text{CH}_2)_6\text{NH}_2$). The general structure for the nylon 66 polymer is (44, 46, 55):



Nylon salt (hexamethylene diamonium adipate), an intermediate in the polymerization process of nylon 66, may be prepared by either reacting an aqueous dispersion of the diacid with an aqueous solution of the diamine or by mixing alcoholic (in methanol) solutions of the two components. For polymerization, a stabilizer usually is added, and the salt is melted under an atmosphere of nitrogen. Water is split off from nylon salt as polymerization proceeds. Polymerization is allowed to take place at 280 C for 4 hours, then the polymer is either transferred directly to spinning units for filament formation or extruded in form of ribbons that are subsequently cut into chips (45, 46).

Physical Properties

Since nylon is a man-made fiber, its diameter, cross-sectional shape, and physical properties can be controlled during manufacturing. Typical deniers for carpet fibers are usually in the range of 13-18 dpf. (4, 56). Nylon generally is produced in medium to high tenacities ranging from 4.5-5.8 g/denier for nylon 6,6 and 5.6-7.0 for nylon 6 (37, 44). Nylon 6 also has much lower melting point (215 C) as compared to nylon 66 (250 C). It also has high elongation of 22 percent at break and high elasticity which varies from 100 percent at 8 percent stretch to 91 percent at 16 percent stretch. The most significant factors contributing to the success of nylon as a major carpet fiber are its high abrasion resistance and resiliency which are related to its

inherent strength and elongation properties. The moisture regain for both nylon 6 and nylon 66 is about 4.2% (44). Moisture has less influence on the mechanical properties of nylon 6 and nylon 66 due to their high crystallinity and relatively high hydrophobicity as compared to some synthetic (i.e., acrylics) or natural fibers. Because of low moisture content, nylon is a good insulator, but because of this property they are also subject to the accumulation of static electricity which increase the soiling propensity.

The cross-sectional shape of nylon fibers, which affects soil retention, appearance, hand, surface texture, and luster, is determined by the spinnerette shape, extrusion conditions, and method of spinning. Common cross-sectional shapes for fibers include circular or oval, triangular, dog bone, U shape, and hollow (44). In nylon carpeting, the fiber cross-sections are usually trilobal or Y shaped. Trilobal fibers generally have increased covering power, a more silk like feel, and decreased luster compared to other cross-sectional shapes (29). The decreased luster is due to light being reflected from one lobe to another, as well as from the surface of the fiber in different directions. This reduces "apparent soiling". Light is deflected or scattered from the fiber surface by the lobes reducing fiber transparency (29).

Nylon also has a good chemical resistance and is not affected by alkalies and most organic solvents. However,

various phenols which are found frequently in household disinfectants do damage nylon. Nylons also are damaged by mineral acids such as hydrochloric, nitric, and sulfuric acids (46). These acids cause nylon to disintegrated or dissolve almost immediately. Acid fumes in the air of industrial regions have been known to weaken the fiber to the point of disintegration.

Nylon, like other synthetic fibers, is resistant to damage from most insects and microorganisms. However, some insects, such as ants, carpet beetles, and roaches will cut or eat away nylon if trapped beneath it (37). Microorganisms do not damage nylon textiles but they may be made unserviceable by staining and odors which accompany microbial growth on adjacent natural fibers. In addition, nylon fibers like most synthetic fibers have a greater retentivity for microorganisms than natural fibers (33).

Carpeting

Carpeting is the most widely used floor covering material in the home because of its many advantages, including warmth and beauty, thermal and noise insulation, durability, price, and ease of maintenance. Hence, the majority of homes in the United States have carpeting in major living areas, and it represents one of the largest consumer expenditure for an individual item in the home (49). Commercial lines of carpeting also are available and are used widely in public buildings such as hospitals, schools,

office buildings, etc.

Carpeting was traditionally made from wool because of its serviceability, good resiliency, warmth, comfort, and dyeability. However, in the last twenty-five years, traditional woven wool carpeting has been replaced by tufted carpeting containing man-made fibers. Nylon 6 and 66 are the major carpet fibers, followed by polypropylene, polyester, acrylic, and wool. The commercial importance of nylon in carpeting is attributed to its easy dyeability, good crush resistance, high abrasion resistance and durability, ease of care properties, compressional resiliency, and low cost. Some undesirable characteristics of nylon fibers include easy soiling due to its oleophilic nature, discoloration by ultra-violet light, and non-dissipation of electrostatic charges (55).

Today, advanced generation carpet fibers are engineered to maximize appearance retention and performance. A variety of additives or finishing agents are incorporated into the fiber prior to or immediately following extrusion and/or are applied topically to the carpeting during manufacturing to improve luster, reduce soiling and staining, facilitate the dissipation of static charges, retard the growth of microorganisms, or increase flame resistance, depending on the intended end-use.

The first nylon carpet fibers, designated generation I, were clear, round fibers without any additives to improve

performance. Generation II nylon carpet fibers contained delustrants (e.g., TiO₂) and had unsymmetrical cross-sections to impart soil hiding properties. Because of the adverse effects of static electricity on computers and other electronic equipment, consumer comfort, and safety in hospital operating rooms, generation III carpets with improved antistat properties came into the market. In the early 1980's soiling became the major concern, hence, fluorochemical soil repellents for increasing the oil and water resistance were added during manufacturing in the nylon fibers to produce IV generation carpets. In 1986, three major carpet fiber producers (Allied Signal Inc., E. I. Du Pont De Nemours & Company, and Monsanto Company) introduced their V generation nylons with stain blockers that increased the carpet fiber's resistance to colored stains produced by many foodstuff (fruit drinks, wine, pet food etc.).

Carpet Construction

Presently, 85% of the carpeting produced in the United States is tufted, followed by woven, and to a much lesser extent fusion bonded, knitted, and needle-punched constructions (3). Tufting is the fastest and most economical method of manufacturing carpets. The tufted carpets are produced by needles that insert loops of yarns into a backing material, usually made of polypropylene or jute (58). If a cut pile is desired, a knife is used in conjunction with the needles. In order to hold the loops in

place, a layer of liquid latex is applied to the underside of the backing material (58).

Two carpet types prepared by weaving are Axminster and Wilton. Wilton carpets are produced on a Wilton loom which has a Jacquard attachment and can utilize up to six different colors. (29). These carpets are known for their durability and intricate patterns (29). Axminster carpets are formed by drawing pile yarns from small spools and weaving them into the background fabric. This method offers the advantage of limitless color use and design possibilities (3).

Fusion bonding, a newer method of carpet construction, embeds the pile yarn into a liquid backing which usually is a vinyl compound. As the backing solidifies, the tufts become fused or bonded. The main advantage of this technique is the degree of tuft-bind achieved between the pile and backing (3). In the needle punching process, pile fibers are entangled in a loosely woven carrier fabric by barbed needles. This method was originally developed for the production of indoor/outdoor carpets (3).

Carpet Finishing

The main functions of finishing in carpet manufacturing are to repair defects and to enhance the appearance or properties of the carpet (58). After tufting or weaving, carpets usually undergo several mechanical finishing processes, including brushing, shearing, steaming, and

inspection and mending. Brushing reduces pilling and removes loose fibers from the carpet pile. Shearing is done to give a more uniform pile height, while steaming removes wrinkles and creases and causes the yarn to untwist or "bloom". During inspection knots are removed and missing tufts are sewn by hand.

Next, backing is applied to the carpet in order to impart adequate tuft-bind (i.e., the measure of force required to pull one tuft of the pile out of the carpet) and strength (3). Generally the primary back-coating consists of latex or resin which locks the tufts into place. Some common backing materials include polyvinyl alcohol, rubber, and polyacrylate. A secondary backing also may be applied to the carpeting to enhance strength and dimensional stability (58).

After backing, other chemical finishes, such as antistats, flame retardants, antimicrobial agents, and soil repellents may be applied to carpeting by spraying. This technique consists of spraying the finish onto the carpet through jets spaced across the width of the carpeting. Many manufacturers prefer to add these agents at the fiber stage because of the disadvantage of spray finishing (i.e., resistance to penetration by the pile, and clogging of spray nozzles causing skips in application) (3). However, many finishes still are applied topically to carpeting at the mill.

With the increase of computer use in homes and offices, more attention has been directed towards the static propensity of carpeting (3). The three levels of static control carpeting available are: 1) residential and non-electronic carpeting, 2) carpeting for areas where electronic equipment will be used, and 3) carpeting for production areas. Static propensity of carpeting is affected by many factors, including fiber type and construction characteristics, environmental conditions (temperature and relative humidity), and use conditions (age, amount of soil, and wear, etc.).

Most antistatic agents function by improving the rate of charge dissipation. This can be accomplished by the use of electrically conductive fibers (i.e., metal or carbon containing fibers), conductive latex backings, and hygroscopic fibers and finishes (62). Hygroscopic finishes which are becoming increasingly important include organic salts, ammonium compounds, and polyethylene glycols. These compounds will differ in durability and performance. The static propensity of the carpet fibers also affects soiling characteristics by attracting or repelling soil particles.

Flammability is an important parameter in both residential and commercial carpets. Flame retardant finishes on textiles generally promote complex char formation and/or prevent further degradation and production of volatiles (21). Generally, flame retardant compounds contain

antimony, phosphorus, nitrogen, chlorine, or bromine. Presently, the two most important durable flame retardants are halogen/antimony systems and phosphorus based compounds.

Antimicrobial finishes are becoming increasingly important in carpet production and marketing. These agents can work by leaching and diffusing into the surrounding area, or they may be permanently bonded to the fiber, killing the microorganism by interruption of the cell wall. The major classes of antimicrobial agents used on textiles are the organosilanes, organometallics, organophenols, and quaternary ammonium compounds.

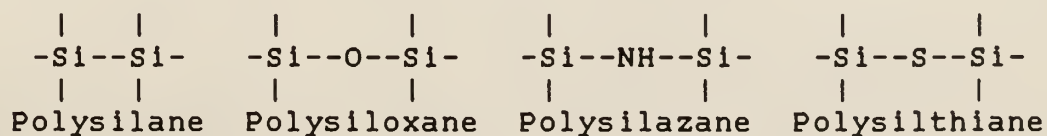
Soil repellent and soil release topical finishes are numerous and vary in quality and price. Chemical compounds commonly used as soil repellent finishes include fluorocarbons, silicones, acrylic copolymers, pyridiniums, and triazine compounds. These finishes can work by coating the surface of the fiber to prevent soil from imbedding in cracks or convolutions or by enhancing the soil release properties of the fiber (14 and 54). Other methods for producing soil repellent textiles include modifying the fiber surface by transesterification, partial hydrolysis, or grafting a soil repellent compound to the surface and blockage of dye sites. The fluorocarbon compounds are the most effective, but also the costliest. The most widely used fiber producer or mill applied soil repellent finishes for carpeting are 3M's Scotchguard and DuPont's Teflon, both of

which are fluorocarbons. In addition, commercial aftermarket (post-treatment) anti-soiling carpet protectors are available which contain fluorocarbons, siloxanes, fluorocarbon/siloxane mixtures, acrylic copolymers, and colloidal metal particles or silica.

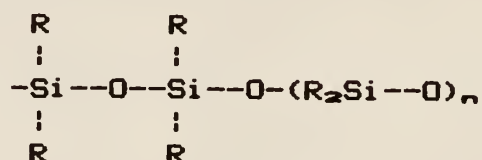
Silicones

Silicones, particularly the class of silicone polymers known as organo functional polysiloxanes, have become increasingly important in the last several years for treating fibers, yarns, threads, and fabrics (4). In particular, they are used as fabric softeners, lubricants, water repellents, and soil release agents. As engineering material, they are used in electric insulation, rubber, hydraulic oils, heat transfer media, and lubricants for ball bearings in machinery. Silicones also are copolymerized with fluorocarbons to produce fluorosiloxanes which are used as soil release agents (51).

Organosilicones are monomeric and polymeric compounds containing Si-C bonds. If the silicon atoms are linked directly with one another, the compounds are classified as polysilanes. Polymers with oxygen bridges between the silicon atoms are polysiloxanes, those with NH bridges are polysilazanes, and those with S bridges are polysilthianes (51).



The majority of organosilicones used in the textile industry are polysiloxanes. The silicon valences not taken up by oxygen are saturated with at least one organic group. The general structure for a simple linear siloxane or polysiloxane is as follows (13):



Where:

R = H, OH, or alkyl group

Polysiloxanes possess structural features typical of organic macromolecules. Because they contain hydrocarbon radicals combined directly with silicon, they have chemical properties similar to other organic compounds and, in particular, organometallics (51).

Silicon occupies an intermediate position between organic and inorganic compounds. The silicon atom in polyorganosiloxanes can be combined with one, two, or three organic groups with the remaining valences being satisfied by oxygen as illustrated in Table 1 (51).

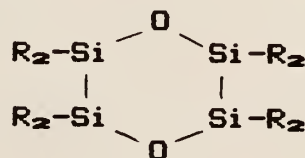
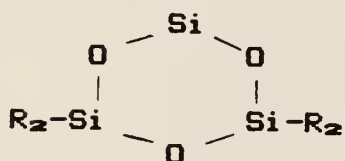
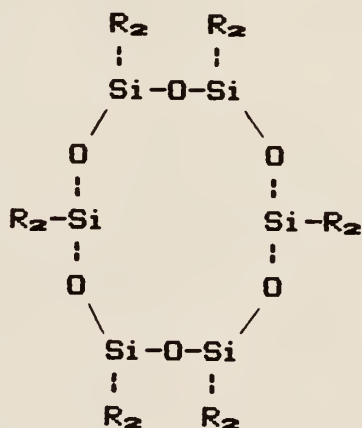
The non-functional molecule R_4Si cannot be used as a structural unit in polymers. Monofunctional molecules usually yield only dimers or serve as a terminal groups in polymer chains. Those that are tetrafunctional may occasionally be used with other silicon monomers of the di- and tri-functional types in the synthesis of organosiloxane

Table 1. Structural Units of Silicon

Structural Formula	Functionality
$\begin{array}{c} \text{R} \\ \\ \text{R--Si--R} \\ \\ \text{R} \end{array}$	Nonfunctional
$\begin{array}{c} \text{R} \\ \\ \text{R--Si--O--} \\ \\ \text{R} \end{array}$	Monofunctional
$\begin{array}{c} \text{R} \\ \\ \text{--O--Si--O--} \\ \\ \text{R} \end{array}$	Difunctional
$\begin{array}{c} \text{R} \\ \\ \text{--O--Si--O--} \\ \\ \text{O} \\ \end{array}$	Trifunctional
$\begin{array}{c} \\ \text{O} \\ \\ \text{--O--Si--O--} \\ \\ \text{O} \\ \end{array}$	Tetrafunctional

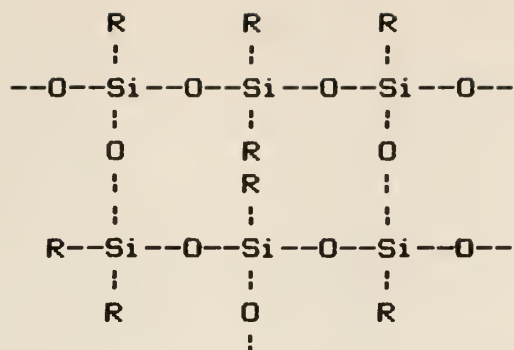
polymers. The great diversity in the types of compounds found in polyorganosiloxanes is attributed to the different siloxane units that can be combined with one another in the same molecule. Mono- and difunctional siloxane units can combine to form simple linear polymers.

Difunctional siloxanes also can produce closed-ring structures. The smallest known ring contains three siloxane units, however, rings with four or five siloxane units are readily available.



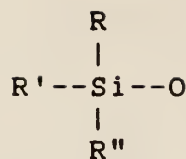
Cross-linked organosiloxanes compounds and resins can be obtained from trifunctional and tetrafunctional siloxanes monomers with the later being more common.

Combinations of mono-, di-, tri-, and tetrafunctional siloxanes are used to produce a variety of polyorganosiloxanes. The length of the polymer chain as well

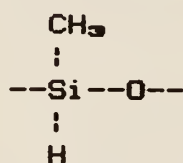


as the amount of cross-linking are influenced by the ratio of the siloxane units and reaction conditions. For example, a combination of mono- and difunctional siloxane units yield linear siloxane of various chain lengths, depending on the ratio of the mono- to difunctional units. A combination of mono- and tri- or tetrafunctional siloxanes units are used to produce low molecular weight compounds; and in general, di- and trifunctional siloxane units yield cross-linked macromolecules. Given the same number of silicon atoms, it is possible to obtain molecules of quite different types, depending on the nature of the siloxane units.

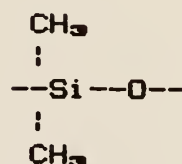
The properties of the organosilicones compounds also are influenced by the chemical structure of the organic radicals covalently bonded to the silicone atoms, yielding an inexhaustible number of compounds. The organic group may be saturated or unsaturated hydrocarbon radicals. They also may be substituted in various ways, and different organic groups may be attached to the same silicone atom as shown (51):



Polyorganosiloxanes that are important in textile finishing are often a mixture of methyl hydrogen siloxanes and dimethylsiloxane (51).

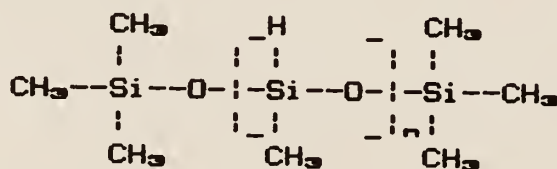


Methyl hydrogen siloxane

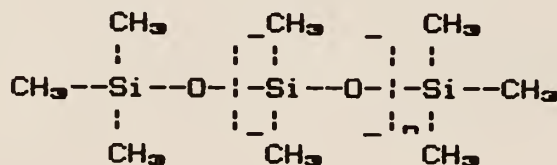


Dimethyl siloxane

Conventional reactive silicones are polydimethylsiloxane polymers containing either silanic hydrogen or silanol functional groups and may react with the substrate in the presence of water and a suitable organometallic catalyst. Other reactive functional groups that have been explored include amines, epoxides and alcohols (51).



Polydimethylsiloxane with silanic hydrogen



Polydimethylsiloxane with silanol functional group

The organo groups on polyorganosiloxanes influences their ability to react with a given substrate. Non-reactive organometallic catalyst (i.e., metallic zinc compounds) are used to facilitate cross-linking. Silicone resins frequently are applied to textiles by pad application or spraying, then dried, and cured. Spraying methods also are used to apply polyorganosiloxanes to carpeting and upholstery fabrics after manufacturing, but the curing step is eliminated.

Fluorocarbons

Fluorocarbons are compounds containing carbon and fluorine and are analogous to the familiar hydrocarbons. Fluorocarbons are becoming increasingly important. These are used as aerosol propellents, refrigerants, foam blowing agents, plastics, water and oil repellents for textiles, etc. and in some industrial processes (5 and 70).

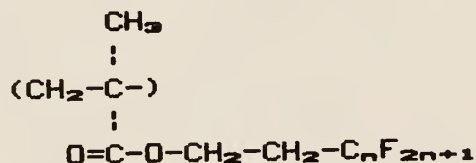
The only fluorocarbons reported in the literature before the 1940's were carbon tetrafluoride, CF_4 , hexafluoroethane C_2F_6 , and tetrafluoroethylene, CF_2CF_2 . The early years of fluorine chemistry were impeded by the difficulties and dangers associated with the preparation and use of fluorine.

The biggest boost to fluorocarbon chemistry came during World War II, when materials were needed for buffer gases, coolants, lubricants, and sealants in chemical plants handling highly reactive uranium hexafluoride which, incidently, was the only volatile uranium compound available

for use in a gaseous diffusion process for concentrating the ^{235}U isotope required for the development of atomic bomb. American chemists and technologists developed the commercial method of preparing saturated highly inert fluorocarbons such as polytetrafluoroethylene and polychlorotrifluoroethylene (5).

Fluorocarbon soil repellent finishes lower the surface energy of the treated substrate (12 and 13). They provide essentially a non-reversible fluorinated surface in all environments (i.e. the same non polar surface in water during laundering as well as in air). The low surface energy, characteristic of oil repellent fluorocarbon finishes, is obtained by the close packing of the perfluoro side groups (18).

A number of fluorocarbon soil repellents that are used on carpeting contain polyfunctional perfluoroalkyl esters having the following general structure:



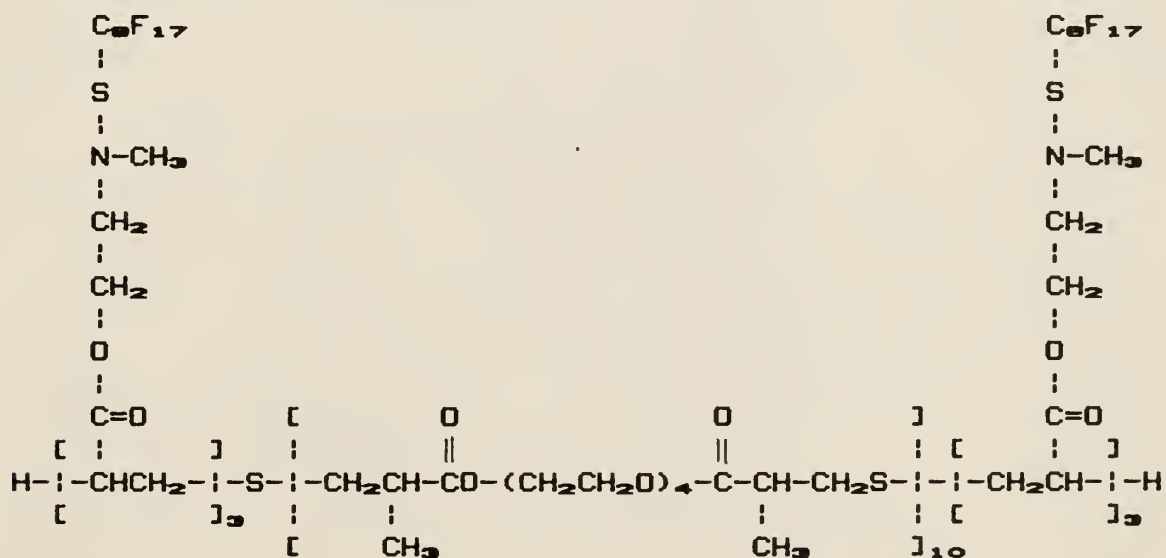
Where:

$n = 6, 8, \text{ or } 10$ (depends on the end use of product).

Some fluorochemical finishes, in addition to performing as stain repellents, are also soil releasing agents. These finishes function by virtue of their ability to expose

alternatively high- or low-energy surfaces in response to changes in the polarity of the environment. The preparation of these dual purpose finishing agent is accomplished by incorporating within a single hybrid molecule both fluorochemical and hydrophilic segments, each present in a sufficient quantity to confer the desired surface energy in either air or aqueous environments.

In these finishes, a fluorochemical or F segment is used to supply the fluorinated surface configuration in air. A hydrophilic or H segment is required to supply the hydrophilic surface in water for soil release properties. The H segment, on the other hand, must have polar groups capable of strong interaction with water, preferably by hydrogen bonding, such as the ethoxylate shown in the following example.



Structure of F-H-F block copolymer

When F and H segments are combined in a single molecule,

as a block copolymer, the compound has particularly effective performance as both a stain repellent and soil release finish (18, 65, and 66). The close packed fluorochemical groups dominate the surface in air, while the hydrophilic groups are collapsed below the surface. The hydrophilic groups dominate the surface in water with the attendant collapse of the fluorochemical groups below the surface.

The conventional and hybrid fluorocarbons differ in their ability to repel oily stains in the wet state. The conventional fluorocarbon oil repellent finish is able to repel a drop of hexadecane in air. However, it does not provide repellency to the hexadecane in water, thus demonstrating that the treated surfaces have a preference for oil compared to water in an aqueous environment. The hybrid fluorochemical soil release agent, on the other hand, repels the drop of hexadecane in both dry and aqueous environments. Hybrid fluorochemicals are oleophobic in air and hydrophilic in water. This dual function is attributed to the different orientation of the oleophobic and hydrophobic segments of the molecule in air and in water (18).

Fluorine-containing soil release/repellent compounds are applied to cotton, cotton/polyester blends, polyester, and nylon fibers fabrics by padding, spraying and exhaust procedures as a separate treatment or simultaneously during dyeing or scouring. They also are applied as spin finish to

nylon fibers used for carpeting. It is claimed that sufficient amounts of the fluorocarbon are retained by the fiber, even after dyeing, to give soil release properties to the carpeting (18).

Fluorosiloxanes

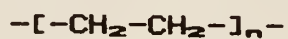
Fluorosiloxanes are fluorine-containing siloxane copolymers which are used as soil release agents and soil repellents. These siloxane copolymers are prepared by the hydrolytic copolymerization of a fluoroalkyl silane and a hydrophilic silane. Copolymers of fluorosilanes and hydrophilic silanes are prepared by solution copolymerization in a water miscible solvent such as tetrahydrofuran (53). In fluorosiloxane polymers which basically are siloxane polymers, fluorocarbons are substituted on secondary carbon chain.

Pittman et al (53) reported, however, that oil repellency is not necessarily increased with increasing quantities of fluoroalkyl silane in the copolymer. The difference in the oil repellency levels of these copolymers was attributed to the amount of cross linking after curing. The copolymers are effective in providing stain release and oil stain repellency with the proper ratio of fluoroalkyl silanes/hydrophilic silanes.

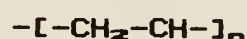
Acrylics

Acrylic compounds are a group of synthetic chemicals that form a sub-order of the parent group of vinyl-type

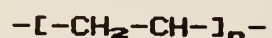
monomers, containing the vinyl grouping $\text{CH}_2=\text{C}$. This group combines with other radicals in various ways to yield some of our most common plastics and fibers (30). The substituents attached to the vinyl group influences the chemical and physical properties of compounds as well as the degree of crystallinity in vinyl polymers.



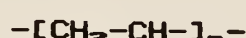
Polyethylene



Polypropylene

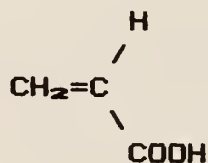


Polyvinyl chloride

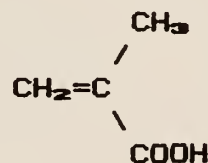


Polystyrene

When an acid or carboxyl group is joined to the vinyl radical together with an H or CH_3 the products are acrylic and methacrylic acids, respectively, which are the precursors for other acrylic compounds.



Acrylic acid



Methacrylic acid

Esterification of the acrylic acids with various alcohol substituents gives the large group of acrylic esters with a wide range of properties, depending on the chain length of the alcohol used. Halogen substitution yields another large group of useful acrylics (30). The nitrogen-containing

acrylics like acrylonitrile also have wide spread use. Acrylamide, acrylaldehyde (aerolein), and many other derivatives also are available commercially.

Acrylic polymers cover a wide range of physical properties. Depending on the monomer selected and the method of polymerization, the product can be anything from a viscous, oily material to a tough and rigid sheet. Acrylics usually have good resistance to sunlight, heat, and weathering.

Emulsion polymerization is used to create an extensive series of acrylic polymers and copolymers used in textile finishing. For example, stiffeners of acrylic emulsions are used to replace natural starches. Other film forming emulsions have been used to increase the body of fabrics and/or give a soft, full hand. Emulsions also have been used as binders in non-woven fabrics and for adhering backings to upholstery, rugs, and pile fabrics (30). Acrylic copolymers consisting of an appreciable proportion of carboxylic acid, methacrylic acid, and ethyl acrylate are very effective soil release finishes for textiles (76).

In the past few years, acrylic soil release polymers have been used extensively to improve the soil release of various textile fabrics, particularly 50/50 and 65/35 polyester/cotton durable press fabrics. These polymers are hydrophilic, and consequently, coated fibers should have less affinity for hydrophobic oil. Acrylic soil release

polymers are anionic in basic wash solutions and, therefore, increase the zeta potential of the fabric surface. Particulate soil is negatively charged in aqueous solution because the dielectric constant of water is high. Hence, the negatively charged polymers repels particulate soil from the fabric's surface.

Colloids

Colloids are substances consisting of a homogeneous medium and of particles dispersed therein. Indian ink, the milky dispersions of sulphur, clays and humus, shaving cream, glue, and blood serum are all examples of colloids (34). Colloidal particles are smaller than filterable particles, but larger than atoms and small molecules, and range in diameter from 0.000001-0.0005 mm (i.e., 10-5000 Å) (34). Because of their small size, colloidal particles are invisible under ordinary microscopes, and they pass through the pores of ordinary filters.

Colloidals are becoming increasingly important in various branches of pure chemistry, industry, medicine, and many other fields. Colloid chemical approaches are very important in dealing with numerous technical and industrial problems. Solutions of such practically important materials such as starch, rayons, and rubber are colloids, as are many synthetic polymers including, nylons, acrylics, silicones, polymethacrylates, synthetic rubber, and polyvinylpropylene. Soaps, detergents, and other wetting agents dissolve in water

to form colloidal solutions, and surface activity and wetting of these compounds is important in textile dyeing and finishing.

Colloidal solutions are classified as either inorganic or organic. The colloids of inorganic substances can be further grouped into colloidal solutions of elements (metal and non-metal), oxides, hydroxides, and salts (34). The organic colloids are classified as homopolar, hydroxy, and hetropolar (34).

Many new compositions of silicones, including siloxane emulsions, epoxysilicone emulsions, and mixture of silicon with glycol and zirconium oxide have been developed. In general they are called colloidal silica compounds. All these compositions are water-dispersible as opposed to mineral oil or spirit soluble siloxanes. A typical aqueous emulsion of siloxane contain less than 80% of water in which the solids content is comprised of a mixture of methylhydropolysiloxane and methylpolysiloxane, an emulsifier, and a curable and water soluble condensate. Polyamide and polyester fibers also are made resistant to soiling by applying a finish comprised of a water soluble lubricating agent, a silicone, and a tin or zirconium compound (67).

Similar to silicone colloids, metal colloids also are used in increasing the soil resistance of polyamide and polyester fibers. The fibers are treated with an acidic

aqueous solution of a metal salt and a water soluble lubricating agent. Salts of different metals (Zr, Cu, Ti, Sn, etc.) are used to prepare the salt solution and are applied by different processes, depending on the fiber to be treated and its end use.

As previously mentioned, chemical finishes frequently are applied to carpeting to reduce soiling. One of the earliest methods involved the application of compounds called fillers (i.e., acrylate polymers or inorganic materials such as metal oxides) which occupy the sites of micro- and macro-occlusion. However, their use has been limited because of lack of durability. Today, a variety of soil retardant compounds are applied to carpeting, but the most widely used are fluorochemical compounds that are applied during fiber manufacturing as a compound in the spin finish or after tufting by exhaustion and pad-application methods. Many other chemical compositions, including fluorochemicals, siloxanes, fluorochemical/siloxane mixtures, acrylic copolymers, and colloidal compositions are sold in the market as aftermarket carpet protectors. Some of these finishes decrease the treated carpets affinity for oil and waterborne stains by reducing the sorption mechanism of soil retention, whereas, others have a deleterious effect, and soil retention increases (12, 13, 53, and 54). As compared to fluorochemicals, the siloxane and siloxane/fluorochemical mixtures increase soiling. Fluorocarbons applied topically

make the carpet surface or pile hard. Siloxanes and siloxane/fluorocarbon mixtures, on the other hand, attract oily soils and are more difficult to clean.

Soils and Soiling

The absorption and retention of soils by textile fibers occur by a variety of mechanisms, each contributing to the resultant greying, yellowing, and whiteness deterioration of a fabric (14). The soiling process consists of two steps: (a) the transport of soil to the fiber surface and (b) adsorption of soil on the fiber surface (39). Adhesion theories suggest that adsorption of particulate matter on fiber surfaces depends upon a large number of variables, including the size, shape, and relative hardness of the soil particle, its surface energy and polarity, and the magnitude and polarity of electrostatic charges present. The chemical composition of both the surface of the soil particle and the fiber determines the energy and the polarity of the contacting surfaces which can have a significant effect on soil adsorption. The hardness of the soil particle determines the surface deformation of fiber surface by the contacting particle. Strong adhesion results when a particle harder than the fiber surface deforms a viscoelastic fiber surface or when a particle softer than the fiber conforms to the fiber surface (41).

Most soils are mixtures consisting of two components: a fluid component, usually an oil or a grease, and a solid

component made up of small particles (73). Soils can be broadly classified into three general categories

1. Oily or greasy soils which are nonpolar and insoluble in polar solvents
2. Solid soils, vary in polarity, which may be coated with a film of oil
3. Staining agents such as perspiration, vegetable matter, food, or dye which may be readily or partially soluble in water (12 and 13).

Soiling of carpets from soil types 1 and 3 is generally referred to as liquid staining, whereas soiling from type 2 is due to dry accumulation (12 and 13). The two main processes by which soils are transferred to a carpet are a) direct contact and b) airborne or from the environment. Direct contact soiling includes contact with soiled objects, such as shoe soles, with or without oil being present. Airborne soiling includes deposition of particles by gravity, filtration, and electrostatic effects between a charged soiled particle and the fiber. Direct contact soiling accounts for approximately 80% of the soiling problem in carpeting, whereas airborne soiling and electrostatic effects are considered relatively minor factors. (12, 13, and 73)

The mechanisms by which soil binds to carpet fibers are called soil retention factors. These are classified into three general categories: i) geometric effects (micro- and

macro-occlusion), ii) oil bonding and sorptive forces, and iii) electrostatic charges. Geometric effects are the primary mode of binding of grease-free soil particles to many substrate and are strictly a physical form of bonding. The adhesion of soil via this mechanism is weak, and much of the soil can be removed by imparting sufficient energy in form of mechanical forces such as vacuuming. The geometric effects can be broken down into two main types: micro- and macro-occlusion. Micro-occlusion is dependent on physical entrapment of soil particles in the irregularities of carpet fibers. Macro-occlusion is the entrapment of soil in the intrayarn (fiber cross over points) and interyarn spaces (6, 12, 13, and 73)

Unlike the weak retention forces of geometric effects, the sorption of particulate soil sheathed in a layer of oil by Van der waal's or columbic forces at the surface or within pores and crevices can be very large. This sorption of soil takes place due to lower surface energy of the oil as compared to the surface energy of the fibers. In synthetic fibers, oil bonding of solid particles is the major cause of soil retention.

In addition to geometric and surface forces, electrostatic forces may be a contributing factor in soil retention. This mechanism is more prevalent at low humidities and with hydrophobic fibers. Because of relatively small forces with which the soil is brought into

contact with the fibers (by electrostatic attraction), little soil penetrates into the interior of a carpet.

The intensity of soiling in carpeting is influenced by the pile fiber content. For example carpets made of polypropylene pile soil less readily because of their low hygroscopicity, compared to nylon, acrylic, or wool. Intense soiling is characteristic of hydrophobic fibers in presence of oils because of their low surface energy (54).

Yarn and fabric characteristics also influence soil visibility. Dull fibers with trilobal cross-sections hide soils better than round, triangular, or square types; and soil is less visible on dark and multicolored carpets. Similarly, construction characteristics and finishing treatments influence the degree of soiling, low density constructions and higher pile heights also soil less. Soiling usually takes place less readily on carpets having a loop pile, compared to a cut pile construction (54). In a study by Benisek (6) carpet soiling on loop pile carpets show higher apparent soiling than did cut pile carpets because of higher light scattering coefficient of the later.

Since naturally occurring soil is a mixture of different particulate substances, multicomponent soils usually are used in soiling studies and soil resistance evaluation (41). However, their composition has varied considerably, depending on the study. A synthetic soil suggested by Florio and Merserean (64) had been used extensively in the past for

apparel and carpet soiling. This soil was based on the average composition of common street dirt in American cities. The only components of Florio-Merserean synthetic soil mixture that contribute substantially to visible soiling were iron oxide, carbon black, and humus (peat moss). (41).

Another soil used earlier in fabric soiling tests (64), had no oily component in it and was primarily a particulate soil. This disadvantage of not having an oily component did not make it very useful for research purposes.

Other studies have used vacuum cleaner soil which also is recommended in AATCC Test Method 123, Carpet Soiling: Accelerated Soiling Test. Vacuum cleaner sweepings from several vacuum cleaners were collected and passed through a 20 mesh screen, followed by a pass through a 100 mesh screen. The soil which passes through the 100 mesh screen is sterilized by heating for 30 minutes at 121 C (250 F) and ball milled to break up aggregates (41). This soil is used in both apparel and carpet soiling. The main disadvantage of using this soil are the hazards associated with being exposed to different bacteria and microorganisms.

Another soil, similar to the one suggested by Florio-Merserean, is produced by The 3M Company (Appendix B-2). Today, it is the most commonly used for carpet soiling research and is preferred over the Florio-Merserean soil which was criticized for being too oily.

The use of soil mixtures in laboratory soiling studies

present several problems. Firstly, a heterogeneous soil composition complicates interpretation of soiling data in quantitative terms. Secondly, the preparation of a multicomponent soil in a reproducible manner is difficult, especially when ingredients of variable quantity such as peat moss are used. Thirdly, the activity of a soil mixture can change with time if oily or fatty components are present due to aggregation of particles and diffusion. Furthermore, textiles in actual use come in contact with a great variety of soils which may be quite different from the common street soil or vacuum cleaner soil (41).

Soiling Tests

Various methods have been used to evaluate the soiling propensity and soil hiding characteristics of carpeting. In-service soiling tests are more widely used for carpeting than the accelerated tests which require laboratory-prepared soils. The components in the soil, particle size, the ratio of oily to particulate matter, and method of application are important variables that must be considered when conducting accelerated soiling tests. However, in-service soiling test methods are more time consuming and require a larger specimen (2). The American Association of Textile Chemist and Colorist has developed both an accelerated soiling method (AATCC Test Method 123) and a service soiling test (AATCC Test Method 122) for evaluating carpet soiling (2). In the accelerated soiling test, carpet specimens are exposed to

soil dispensed from a capsule with small holes and 60 1/2 inch steel balls in a rotating drum. After soiling the specimens may be evaluated visually and/or instrumentally. In another accelerated soiling method, the untreated (standard) and treated (evaluated) carpet samples were fixed in the testing drum of the tetrapod walker in the normal manner. Then 60 felt cubes (7/8 in. cube) cut from a 100% wool industrial sheet felt - 18 lb/yd², previously soiled with vacuum cleaner soil pass through a 90 mesh sieve (8g soil per 60 felt cubes), are placed in the drum. The drum is closed and rotated at a speed of 50 rpm for 2500 revolutions. In the service soiling test, carpet specimens are placed in a high traffic area and exposed to normal foot traffic. The carpet specimens are rotated and evaluated at prescribed time intervals. Visual and/or instrumental methods can be used to evaluate the specimens.

An indirect method that has been used to evaluate soil resistance is based on the oil wettability of the carpets. In this test method, samples are held between two flat aluminum plates coated with polytetrafluoroethylene to minimize capillary flow between the material and the plates. Test fluid (stored in a 100 ml bottle held about 10 cm above the apparatus) is drained into a horizontal buret, consisting of a 50 cm long glass tube (0.4 cm diameter). The test carpet (12.5 X 12.5 cm) is then centered over the orifice and covered with the upper aluminum plate, which is of

sufficient mass to produce good contact of the sample with minimum compression. As wetting is initiated, the flow rate can be accurately determined by recording elapsed time and volume absorbed.

Evaluation Methods

Various chemical, instrumental, and visual methods have been used to evaluate the amount of soil on carpeting or its ability to hide soil. However, K/S values are the most commonly used method in more recent soiling studies. (6, 11, 18, 19, 20, 39, 40, 41, and 77).

K/S or Kebulka-Munk values are calculated from reflectance (R) readings taken on the soiled and unsoiled carpet specimens, using a suitable spectrophotometer.

$$K/S = \frac{(1 - R)^2}{2R}$$

where:

R = reflectance

K = absorption coefficient

S = scattering coefficient

The degree of soiling ($\Delta K/S$) is found by subtracting the K/S value of soiled sample from the K/S value of unsoiled sample.

$$\text{Degree of soiling } \Delta K/S = (K/S)_{us} - (K/S)_s$$

This method has been criticized because K/S values often do not correlate well with visual ratings which may be attributed to the monochromatic light used for evaluation (6 and 73). The most common apparatus used is a photovolt

reflectance meter equipped with a tristimulus green filter (14 and 41).

In a similar method suggested by Mr. Richard Hunter of Hunter Associates Laboratory Inc., the Y tristimulus value is measured with a colorimeter and K/S values are calculated as follows:

$$K/S = \frac{(1 - Y/100)^2}{2 \times Y/100}$$

where:

Y = Y tristimulus value

K = absorption coefficient

S = scattering coefficient

The degree of soiling ($\Delta K/S$) is found by subtracting K/Ss value of soiled sample from the K/Sus value of unsoiled sample.

$$\text{Degree of soiling } (\Delta K/S) = (K/S)_{us} - (K/S)_s$$

According to Mr. Hunter, Y tristimulus value represents reflectance over complete visible range which provides a better method of measuring the amount of soil.

Evaluation of soiling is also done by using a color difference evaluation method. The X, Y, and Z tristimulus values are measured with a colorimeter. The color difference ΔC is then calculated as:

$$\Delta C = [(\Delta X)^2 + (\Delta Y)^2 + (\Delta Z)^2]^{1/2}$$

where ΔX , ΔY , and ΔZ represent the differences in X,

Y, and Z tristimulus values of soiled and unsoiled samples. These color difference values correlate well with visual assessment of carpet soiling (6, 73).

The degree of soiling is calculated by dividing the color difference of individual carpet samples (dCx) by the color difference of the carpet sample (dCy) which has the lowest color change during soiling, and multiplying by 100.

$$\text{Degree of soiling, \%} = \frac{dCx}{dCy} \times 100$$

where:

dCx = is the color difference of sample x

dCy = is the color difference of the sample showing the least amount of soiling.

Soiling propensity also may be expressed in total color difference units, ΔE , based on Hunter L, a, b or CIE L*, a*, and b* values. The total color difference is calculated as shown in the following equations:

$$\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$$

where:

$$\Delta L^* = L^*_{\text{before}} - L^*_{\text{after}}$$

$$\Delta a^* = a^*_{\text{before}} - a^*_{\text{after}}$$

$$\Delta b^* = b^*_{\text{before}} - b^*_{\text{after}}$$

Total color change is considered the most acceptable method of evaluating soiling on carpets. According to McKinnon and Mclaughlin (50), ΔE values are slightly more consistent with visual rankings than are $\Delta K/S$ values which,

in turn, are superior to ΔC . The one problem with ΔE is that the change in texture associated with wear and pile lay during soiling may influence the values resulting in some experimental error.

Visual techniques also are used to evaluate the soiling of carpets. The AATCC Gray Scale for Color Change is used for visual evaluation of carpet soiling and is specified in AATCC Test Method 121, "Carpet Soiling; Visual Rating Method". The soiling is evaluated by comparing the unsoiled and soiled samples with the Gray Scale. This method is extensively used in soiling studies. In another visual evaluation method, a set of standards of the carpeting to be evaluated are prepared that represent 1/2 step difference from step 5 (no difference) to step 1 (largest difference). Soiled samples of the carpeting are compared with these standards. As compared to visual assessment, the instrumental evaluation gives more consistent results. However, it is not always possible to correlate reflectance measurements with observed soiling, and the change in texture associated with wear and pile lay during soiling may contribute to ΔE values.

EXPERIMENTAL PROCEDURE

The purpose of this study was to evaluate the effects of aftermarket topical soil-repellent finishes or carpet protectors on the soiling of three nylon 6 carpets which had 1) neither a fiber producer nor a mill applied fluorocarbon treatment, 2) a mill applied fluorocarbon treatment, and 3) both a fiber producer and mill applied fluorocarbon treatment.

The carpet specimens were treated individually with 14 commercial products, representing the major chemical classes of carpet protectors, at two different concentrations, conditioned in a standard atmosphere for testing, and then soiled in CSI Accelerated Soil Tester. The treatments were applied to both dry and wet (after cleaning) carpeting. Soiling propensity was evaluated visually with the AATCC Gray Scale for Color Change and instrumentally with a Hunter D25-M colorimeter and expressed in ΔE and $\Delta K/S$ units.

Carpeting

The three carpet types selected for this study were made of Anso IV nylon 6, 2-ply yarn tufted into polypropylene primary backing and a jute secondary backing. The untreated carpeting was obtained from Shaw Industries, whereas the carpets containing a fiber producer fluorocarbon treatment only or a fiber producer and mill fluorocarbon treatment were obtained from Galaxy Mills and the Mohasco Corporation,

respectively.

The carpeting was shipped to KSU in 250 lb. rolls. The three carpets were similar in construction to facilitate treatment, soiling, and subsequent color evaluation. All the carpets were beige in color, since it is preferred in soiling studies. A medium height, cut loop surface also was specified to reduce variability in visual and instrumental color evaluation.

Topical Finishes

In order to select the products for evaluation, letters were sent to all major companies that manufactured or sold carpet or upholstery fabric protectors. The criteria used to select were 1) chemical class, 2) formulation, 3) method of curing, 4) commercial importance, and 5) availability.

The fourteen topical treatments evaluated included four siloxane finishes, four fluorocarbon finishes, two fluorocarbon/ siloxane mixtures, two acrylic copolymer finishes, and two colloidal formulations (Table 2). Untreated carpeting was used as the control. A greater number of fluorocarbon and silicone products were evaluated because they are more commonly used in soil repellent finishes. All the products that were used were air-curable as opposed to the heat-curable types which usually are mill applied.

Sample Preparation

Carpet specimens measuring 11.5 X 11.5 cm were cut by

Table 2. Experimental Treatments Evaluated

Treat- ment code	Chemical class	Dilution	Solvent
1	Siloxane	none	Petroleum distillates
2	Siloxane	none	Hydrocarbons
3	Siloxane	none	Paraffins/ cycloparaffins
4	Siloxane	none	Hydrocarbons
5	Fluorocarbon	none	Water
6	Fluorocarbon	none	1,1,1, Tri- chloroethane
7	Fluorocarbon	1:16	Water
8	Fluorocarbon	1:8	Water
9	Siloxane/ fluorocarbon mixture	none	Mineral spirits
10	Siloxane/ fluorocarbon mixture	none	Petroleum spirits
11	Acrylic	none	Water
12	Acrylic	1:4	Water
13	Colloidal metal	none	Water
14	Colloidal silica	none	Water
15	Untreated		

using a metal template and mat knife. The loose protruding fibers were removed from the sides of specimens with electric clippers. To facilitate further preparation and treatment, the four specimens of each carpet type were affixed (with the pile lay in one direction) to polyester/cotton broadcloth (81 X 34.5 cm). For each treatment, four specimen sets were prepared (i.e., for two moisture levels (dry and wet) and at two application rates).

Topical Finish Application

The adhesive used to attach the specimens to the broadcloth was allowed to dry for 48 hours before further treatment. Each specimen set was then subjected to vacuum cleaning using a Jet Matic Model JM11 steam (jet and extraction machine), with five passes of vacuuming in each direction with last direction parallel to pile lay direction. Two sets of specimen, which were to be wet treated, were subjected to hot water extraction cleaning described below.

The recommended manufacturer's application rates for most of the products were given in volume per unit area. To simplify application procedures and to maintain accuracy, all the application rates were converted to weight per unit area by using the density of the product in application solution. The amount of solution applied was approximately equal to 1 liter per 19 m² (1 gal. per 800 ft²), which was the amount recommended on most products, and three times this quantity to evaluate the effect of overtreatment.

Commercial 1.9 liter (0.5 gallon) sprayers, manufactured by the B & G Company, were used to apply the topical finishes to the carpet specimens. Prior to each treatment, the sprayers were cleaned by rinsing in hot water thrice at 54 ± 3 C (130 ± 5 F) and spraying for 1 minute; treating with 0.5% detergent solution for 5 minutes, followed by three rinses; treating 15 minutes with acetone; and rinsing thrice with hot water and spraying for 2 minutes.

The majority of the products were of the ready-to-use form. Distilled water was used as the diluent for those requiring dilution. Approximately $3/4$ of the solution was transferred to the B & G sprayer, and the remaining portion was placed in a plastic spray bottle.

Prior to treatment, two specimen sets (one dry & one wet) which were to be treated at same application rate were placed on a $1/3$ cm thick cardboard (66 X 43 cm) that was covered with plastic. The broadcloth border was folded under so that only the specimens would be treated. After weighing the cardboard with two specimen sets, it was placed on a 2.5 cm (1 in.) thick wooden board covered with brown paper. At the beginning of each treatment, the finish was sprayed for 30 seconds in a large pan to ensure that the solution had replaced all water in the hose which may have remained during previous cleaning of the sprayer.

The finishes were sprayed onto the face of the carpet specimen sets with the B & G sprayer at 30 psi and a floor to

nozzle distance of about 30 cm. This was done to ensure that the average spray width, which was 23 cm through the dense portion of the spray pattern, covered two rows of the specimen (width of two rows = 23 cm). To maintain constant direction of spraying, the spraying was done across from the pile lay direction. After application the specimen sets with the cardboard were weighed again, and the wet pickup or the weight of the treatment solution applied was calculated. The hand sprayer was used to adjust the add-on weight if it was less than 3 g.

After drying for 24 hours in the ambient conditions, the specimen sets were transferred to the conditioning room (22 ± 1 C or 72 ± 2 F and 65 ± 5 % RH) for 48 hours, thus giving a total curing time of 72 hours. This curing time was selected because it represented the maximum cure time needed, even though for some of the products shorter curing times could be used.

Hot Water Extraction Cleaning

Half of the carpet specimen sets were cleaned immediately before the treatment, following the procedure in an AATCC proposed test method entitled "Carpet Cleaning: Hot Water Extraction", March 24, 1984. This test method was designed to simulate on location, hot water extraction cleaning of textile floor coverings.

The carpet specimen sets (46 X 34.5 cm) and a border carpet (77.5 X 57 cm with a 46 X 34.5 cm center removed) were

placed individually on a 1 cm thick exterior plywood mounting board. Each set was subjected to two passes or two cycles of cleaning using a Jet-Matic Model JM-11 steam (jet and extraction) machine which met the specifications in the AATCC proposed test method. The first cycle of cleaning was in a direction perpendicular to the pile lay direction and the second cycle was in the pile lay direction. The cleaning solution contained 56.6 g of AATCC carpet cleaning detergent (formulation given in Appendix B) per 5 gallons of water which was maintained at 60 ± 3 C (140 ± 5 F). Within five minutes after cleaning, the specimen sets were treated with the carpet protectors.

Soiling Procedure

Preparation and Coding of Specimens

The following sets of specimen were grouped together in sets of two (with same application rate) and treated with one finish simultaneously to ensure consistency of application:

Group 1:

- a. Normal application rate without hot water extraction cleaning.
- b. Normal application rate after hot water extraction cleaning.

Group 2:

- a. Three times normal application rate without hot water extraction cleaning.
- b. Three times normal application rate after hot water

extraction cleaning.

Subsequent to treatment, curing, and conditioning, the broadcloth fabric on each set was cut in order to separate the specimens. A seven-digit code number (following the coding procedure in Appendix C) and the pile lay direction were marked on the backs of each specimen. Each set was kept separated from the others by placing a sheet of Saran wrap between the specimen sets. This also prevented the unnecessary transfer of soil from one carpet specimen face to the back of another carpet specimen. A 2.5 cm (1 in.) wide piece of masking tape was placed on one side of the specimen face prior to conducting the soiling tests. This unsoiled strip was later used in the visual color evaluation with Gray Scale for Color Change.

Accelerated Soiling Tests

The untreated and treated carpet specimens were subjected to the accelerated soiling test following the AATCC Standard Test Method 123-1982, "Carpet Soiling: Accelerated Soiling Method" (2). The instrument used was a CSI (Custom Scientific Instruments) accelerated soil tester which consists of a soiling drum (with 4 port holes), which reverses every 3 minutes, a soiling capsule which dispensed the soil during testing, and 60 1.25 cm (1/2 inch) steel balls that were added to the drum to ensure an even distribution of soil in the carpet specimens during the soiling tests.

The soil used in this research was obtained from The 3M Company. The composition of this soil is given in Appendix B-2. The soil was prepared by passing 200 g through a 40 mesh standard U.S. sieve. It was then placed in a Pyrex glass dish, oven dried at 50 C for 8 hours, and desiccated until use.

Preliminary tests were conducted to determine the optimum amount of soil and time required to obtain the maximum differentiation among the specimen types with least amount of distortion on the carpet pile. Results showed a 5-minute cycle of soiling with 2 g of soil gave the best results.

To conduct the soiling tests, 2 g of the desiccated soil were weighed in the soiling capsule. Masking tape (2.5 cm wide) was placed across one end of the specimen to facilitate visual evaluating of soiling propensity. Next, three carpet specimens were placed in the port holes of the tester, and then the soil capsule, and 60 1.25 cm (1/2 inch) steel balls were placed in the drum, followed by the fourth specimen in the last port hole. After the 5-minute soiling cycle had been completed, the soiling capsule, steel balls, and carpet specimens were removed from the tester. The drum of the tester was thoroughly vacuumed to remove residual soil. The soiled carpet specimens were vacuumed with five strokes in each direction with the last direction parallel to the pile lay direction. The masking tape was removed, and then the

amount of soiling on the specimens was evaluated visually and instrumentally.

Color Evaluation

Soiling propensity was evaluated visually with an AATCC Gray Scale for Color Change and instrumentally with a Hunter D-25M colorimeter. Visual evaluations were conducted on each of the specimens by three trained observers. Evaluations were made in a MacBeth Lablight by comparing the degree of contrast between the soiled and unsoiled portions of the specimens with the pairs of neutral gray chips on the AATCC Gray Scale for Color Change. The unsoiled portion was covered with masking tape during soiling tests.

Instrumental parameters used to evaluate soiling propensity included total color difference, ΔE units, and the difference in the K/S values for the specimens before and after soiling, $\Delta K/S$. Three L^* , a^* , b^* , and Y readings were taken on each specimen and averaged together both before and after soiling to calculate total color difference in CIELAB ΔE units. Total color differences were calculated as follows:

$$\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$$

where:

ΔE = total color difference

$$\Delta L^* = L_2^* - L_1^*$$

$$\Delta a^* = a_2^* - a_1^*$$

$$\Delta b^* = b_2^* - b_1^*$$

L*, a*, and b* values correspond to the lightness/darkness, redness/greenness, and blueness/yellowness axes of a three dimensional color solid. Subscripts 2 designates the values after soiling and subscript 1 designates the values before soiling.

K/S values were calculated as shown:

$$\Delta K/S = K/S_2 - K/S_1$$

where:

$$K/S = \frac{(1 - Y/100)^2}{2 Y/100}$$

Statistical Analysis

The independent variables evaluated in this study included fifteen treatments, two application rates, two moisture levels (dry and wet), three carpet types, and two replications. Analysis of variance (ANOVA) and Duncan's Multiple Range Tests were used to elucidate which test variables had a significant effect on the soiling of carpeting.

RESULTS AND DISCUSSION

Evaluated in this study were the effects of fourteen aftermarket topical soil repellent finishes on the soiling propensity of nylon 6 carpeting. The treatments were evaluated at two application rates and at two moisture levels (i.e., to dry and wet (after cleaning) carpeting). Untreated carpeting also was subjected to same tests conditions. The topical treatments included four siloxane finishes, four fluorocarbon finishes, two fluorocarbon-siloxane mixtures, two acrylic finishes, and two colloidal products containing either metal or silica. Within the four siloxane treatments, two had hydrocarbons and one each had petroleum distillate and paraffins as the solvents. Among the fluorocarbons, three products were water based and one had trichloroethane as the solvent. One of the siloxane/fluorocarbon product had mineral spirit and other had petroleum naphtha as the solvent. All of the acrylic copolymers and colloidal compositions were water based.

Following the application of each topical treatment, the specimens were conditioned, cured, and then subjected to an accelerated soiling test (AATCC Test Method 123 "Carpet Soiling: Accelerated Soiling Method"), using a CSI (Custom Scientific Instruments) accelerated soil tester and a synthetic soil obtained from The 3M Company.

The degree of soiling in the test specimens was evaluated instrumentally as well as visually. Three

instrumental color readings (L^* , a^* , b^* , and Y) were taken (both before and after soiling) on each specimen and averaged together prior to calculating total color difference in ΔE units (Table 3). Also calculated were $\Delta K/S$ values (Table 4). To evaluate the soiling visually, AATCC Test Method 121, (Carpet Soiling: Visual Rating Method) was followed using the AATCC Gray Scale for Color Change. The ΔE and $\Delta K/S$ values presented in Table 3 and 4 respectively are the treatment means based on the data for the two replications.

Analysis of Variance and Duncan's Multiple Range Tests were performed on the data to determine the significant differences among the color difference values within each replication. In the following discussion the ΔE values obtained for the specimens after soiling will be presented, followed by the $\Delta K/S$ values. In general, similar results were obtained for the two instrumental methods of evaluating soiling. However, in certain instance the rank orders of the means differed slightly, and the magnitude of the change usually was less in $\Delta K/S$ values, as compared to the ΔE 's. This is understandable since $\Delta K/S$ values are only based on differences in the Y tristimulus values rather than total color change. The ΔE values appeared to be more discriminating because for a given amount of color change, the size of unit was larger, compared to the $\Delta K/S$ values. The ΔE values ranged from 1.5 to 19.5, whereas the $\Delta K/S$ values ranged from 0.2 to 4.3.

Table 3. Average Soiling Propensity (ΔE Units) of Nylon Carpeting Treated with Aftermarket Carpet Protectors.

Treatment Code	ΔE Units											
	Carpet I				Carpet II				Carpet III			
	1X Rate		3X Rate		1X Rate		3X Rate		1X Rate		3X Rate	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
1	15.2	12.6	16.7	14.2	13.7	10.9	13.1	12.2	10.6	11.2	12.8	12.3
2	15.0	14.0	18.8	19.4	11.4	12.2	16.6	16.0	10.6	11.1	16.8	16.8
3	14.6	14.4	17.4	15.3	10.4	10.1	13.7	12.7	9.5	10.4	12.0	14.2
4	13.6	13.5	16.2	15.7	10.1	10.3	12.7	12.6	10.2	10.5	12.3	12.6
5	7.5	6.9	7.0	6.1	3.5	3.3	2.8	2.7	3.1	3.0	2.9	2.7
6	8.9	7.9	7.4	6.1	4.8	4.8	5.1	5.3	5.7	6.5	8.1	7.7
7	8.4	7.8	7.5	6.4	6.2	4.1	5.3	3.1	4.2	4.7	2.9	3.4
8	7.0	6.9	6.3	5.3	3.8	5.1	2.6	4.4	3.6	4.6	3.1	3.2
9	15.1	15.0	17.6	15.2	13.0	12.4	15.2	15.2	11.2	11.9	14.6	14.4
10	11.0	9.2	11.7	9.6	9.1	7.1	8.3	6.6	5.7	6.9	6.9	7.9
11	10.9	7.6	10.6	7.1	7.0	4.4	6.7	4.5	4.8	4.5	5.2	4.5
12	10.9	7.7	10.8	7.1	7.7	3.3	5.6	3.6	4.4	4.6	4.3	4.4
13	8.2	6.3	7.3	5.4	3.8	3.1	3.4	3.9	3.5	3.2	4.2	3.2
14	8.0	4.3	3.5	2.0	3.9	3.1	3.1	2.1	4.0	4.1	2.1	1.7
15	9.8	9.5	11.5	9.1	5.6	6.7	7.1	5.9	4.5	5.8	5.1	5.5

Note: Carpet types: I (no fluorocarbon finish), II (fiber producer-applied fluorocarbon finish), and III (fiber producer and mill-applied fluorocarbon finish). Application rates 1X and 3X (1 L/19 sq. M) (1 gallon/800 sq. ft.). Treatments applied to dry and wet (after cleaning) carpeting.

Table 4. Average Soiling Propensity ($\Delta K/S$ Units) of Nylon Carpeting Treated with Aftermarket Carpet Protectors.

Treat- ment Code	$\Delta K/S$ Units											
	Carpet I				Carpet II				Carpet III			
	1X Rate		3X Rate		1X Rate		3X Rate		1X Rate		3X Rate	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
1	2.5	1.9	3.1	2.5	2.0	1.3	2.0	1.8	2.1	2.3	2.8	2.6
2	2.5	2.4	3.9	4.2	1.5	1.7	2.9	2.7	2.1	2.3	4.3	4.4
3	2.4	2.3	3.1	2.6	1.3	1.3	2.0	1.9	1.7	2.1	2.5	3.4
4	2.1	2.1	2.9	2.7	1.2	1.4	1.9	1.9	1.9	2.1	2.6	2.6
5	0.9	0.8	0.9	0.5	0.4	0.3	0.3	0.3	0.5	0.4	0.4	0.4
6	1.2	1.0	0.9	0.7	0.6	0.5	0.6	0.6	0.9	1.1	1.4	1.4
7	1.0	1.0	0.9	0.7	0.7	0.4	0.6	0.3	0.7	0.7	0.4	0.5
8	0.9	0.9	0.7	0.6	0.4	0.5	0.3	0.5	0.6	0.7	0.5	0.5
9	2.3	2.6	3.5	2.6	1.8	1.7	2.4	2.4	2.3	2.5	3.4	3.3
10	1.6	1.2	1.7	1.2	1.2	0.9	1.1	0.8	0.9	1.2	1.2	1.4
11	1.5	1.0	1.1	1.2	0.8	0.5	0.8	0.5	0.7	0.7	0.8	0.7
12	1.5	1.0	1.5	0.9	0.9	0.4	0.6	0.4	0.7	0.7	0.7	0.7
13	1.1	0.7	0.9	0.7	0.4	0.3	0.4	0.4	0.5	0.5	0.7	0.5
14	1.0	0.5	0.3	0.1	0.5	0.3	0.3	0.2	0.6	0.6	0.3	0.2
15	1.3	1.2	1.6	1.2	0.6	0.6	0.8	0.7	0.7	0.9	0.8	0.9

Note: Carpet types: I (no fluorocarbon finish), II (fiber producer-applied fluorocarbon finish), and III (fiber producer and mill-applied fluorocarbon finish). Application rates 1X and 3X (1 L/19 sq. M) (1 gallon/800 sq. ft.). Treatments applied to dry and wet (after cleaning) carpeting.

The results of analysis of variance test applied to the ΔE and $\Delta K/S$ data are given in Tables 5 and 6, respectively. In both analyses, all of the main variables (carpet type (C), treatment (T), application rate (A), and moisture level (M)) were significant at the 0.01 level, except replication (R) which was significant at 0.05 level for the ΔE data and not significant in the $\Delta K/S$ data (Tables 7 and 8). All but one (AXM) of the second order interactions were significant at 0.01 level. Two (CXTXA and CXTXM) of the four third order interactions were significant at the 0.01 level. The one fourth order interaction (CXTXAXM) also was significant at 0.01 level.

Effect of Carpet Type on Soiling

The three carpets used in this study were made from Anso IV nylon 6 fiber. One carpet type (I) was untreated, one was treated with a fluorocarbon finish by the fiber producer only (II), and one was treated with fluorocarbon finish by both the fiber producer and the carpet mill (III). The three types of carpeting were treated with the 14 aftermarket carpet protectors at two application rates and at two moisture levels (i.e., to dry and wet (after cleaning) carpeting).

The overall grand total color difference mean for carpet type I ($\Delta E = 10.3$) was significantly higher than those obtained for carpet type II ($\Delta E = 7.4$), or carpet type III ($\Delta E = 7.1$) (Table 9). This shows that, in general, carpet

Table 5. Analysis of Variance for Soiling Propensity
(ΔE Units).

Sources of Variation	Degrees of Freedom	Sum of Squares	F value	PR>F
Replication (R)	1	1.47	4.67	0.0321*
Carpet type (C)	2	778.93	1234.39	0.0001**
Treatment (T)	14	5411.83	1225.18	0.0001**
Application rate (A)	1	36.61	116.05	0.0001**
Moisture level (M)	1	46.52	147.44	0.0001**
C X T	28	97.29	11.01	0.0001**
C X A	2	9.34	14.81	0.0001**
C X M	2	50.12	79.42	0.0001**
T X A	14	279.48	63.27	0.0001**
T X M	14	49.92	11.30	0.0001**
A X M	1	0.81	2.58	0.1100
C X T X A	28	26.72	3.03	0.0001**
C X T X M	28	34.98	3.96	0.0001**
C X A X M	2	2.47	3.92	0.0216*
T X A X M	14	6.54	1.48	0.1217
C X T X A X M	28	17.78	2.01	0.0034**
Within groups	179	56.48		
Total	5969	6907.30		

* 0.05 level of significance
** 0.01 level of significance

Table 6. Analysis of Variance for Soiling Propensity
(Δ K/S Units).

Sources of Variation	Degrees of Freedom	Sum of Squares	F value	PR>F
Replication (R)	1	0.04	2.44	0.1204
Carpet type (C)	2	21.01	659.82	0.0001**
Treatment (T)	14	243.68	1093.04	0.0001**
Application rate (A)	1	4.90	307.77	0.0001**
Moisture level (M)	1	1.10	69.19	0.0001**
C X T	28	9.01	20.21	0.0001**
C X A	2	0.51	16.07	0.0001**
C X M	2	1.89	59.36	0.0001**
T X A	14	21.90	98.23	0.0001**
T X M	14	1.44	6.45	0.0001**
A X M	1	0.09	5.77	0.0173*
C X T X A	28	1.78	3.99	0.0001**
C X T X M	28	1.19	2.67	0.0001**
C X A X M	2	0.10	3.11	0.0469*
T X A X M	14	0.42	1.89	0.0305*
C X T X A X M	28	1.00	2.46	0.0002**
Within groups	179	2.85		
Total	359	313.01		

 * 0.05 level of significance
 ** 0.01 level of significance

Table 7. Duncan's Multiple Range Test on Soiling Propensity Means (ΔE Units) for Replications.

Replication	Mean ΔE	Grouping
2	8.3	A
1	8.2	B

Note: Means with same letter are not significantly different.

Table 8. Duncan's Multiple Range Test on Soiling Propensity Means ($\Delta K/S$ Units) for Replications.

Replication	Mean $\Delta K/S$	Grouping
2	1.3	A
		A
1	1.3	A

Note: Means with same letter are not significantly different.

Table 9. Duncan's Multiple Range Test on Soiling Propensity Means (ΔE Units) for Carpet Types.

Carpet Type	Mean ΔE	Grouping
I	10.3	A
II	7.4	B
III	7.1	C

Note: Means with same letter are not significantly different.

Table 10. Duncan's Multiple Range Test on Soiling Propensity Means ($\Delta K/S$ Units) for Carpet Types.

Carpet Type	Mean $\Delta K/S$	Grouping
I	1.5	A
III	1.3	B
II	1.0	C

Note: Means with same letter are not significantly different.

type I which did not contain a fiber producer or mill-applied finish exhibited the greatest amount of soiling, and carpet type III exhibited the least amount of soiling.

The overall $\Delta K/S$ grand mean for carpet type I was significantly higher (1.5) than those obtained for carpet types III (1.3) or II (1.0) (Table 10). However, the rank order of the means for carpet types III (with the fiber producer and mill applied fluorocarbon finish) and II (with only the fiber producer applied fluorocarbon finish) was opposite to that obtained in ΔE units. Based on change in reflectance, carpet type I exhibited the greatest amount of soiling, and carpet type II exhibited the least amount of soiling. Hence, method of evaluation influenced the apparent differences in the degree of soiling among the carpet specimens. Furthermore, the effects of carpet type were confounded by significant interactions (CXT, CXA, CXM, CXTXA, CXAXM, and CXTXAXM).

Effect of Treatment on Soiling

As mentioned earlier, the treatments evaluated in this study included 14 aftermarket carpet protectors plus an untreated control. These treatments were applied at two application rates to the dry and wet (after cleaning) specimens of the three carpet types which were then subjected to the accelerated soiling tests. Treatments #1-4 were siloxane products, #5-8 contained fluorocarbons, #9 and #10 were siloxane/fluorocarbon mixtures, #11 and #12 contained

acrylic copolymers, and #13 and #14 contained colloidal metal particles and colloidal silica, respectively. The untreated control carpeting was designated treatment #15.

The Duncan's Multiple Range Test results on the overall grand means for the 15 treatments based on total color difference (ΔE) are given in Table 11. Among the aftermarket carpet protectors evaluated, all of the products that contained siloxanes (#1-4) or were siloxane/fluorocarbon mixtures (#9 and #10) had mean ΔE values that were significantly higher than that obtained for the carpeting that was not laboratory treated (#15), thus indicating that these products caused an appreciable increase in soiling. Conversely, the mean ΔE 's for all of the products containing fluorocarbons (#5-8), acrylic copolymers (#11 and #12), or colloidal compositions (#13 and #14) were significantly lower than the mean for the untreated carpeting, indicating a reduction in soiling.

Presented in Table 12 are the Duncan's Multiple Range test results for the treatment means in $\Delta K/S$ units. The results were similar to the ΔE means in that all of the products that contained siloxanes (#1-4) or were siloxane/fluorocarbon mixtures (#9 and #10) had mean $\Delta K/S$ values that were significantly higher than the mean for untreated control (#15), thus indicating that these treatments caused an appreciable increase in soiling. Conversely, the mean $\Delta K/S$'s for all of the other aftermarket

Table 11. Duncan's Multiple Range Test on Soiling Propensity Means (ΔE Units) for Treatments

Treatment Code*	Mean ΔE	Grouping
2	14.9	A
9	14.2	B
3	12.9	C
1	12.8	C
4	12.5	D
10	8.3	E
15	7.0	F
6	6.6	G
11	6.4	G H
12	6.2	H
7	5.3	I
8	4.6	J
13	4.6	J K
5	4.3	K
14	3.5	L

*See Table .

Note: Means with same letter are not significantly different.

Table 12. Duncan's Multiple Range Test on Soiling Propensity Means ($\Delta K/S$ Units) for Treatments

Treatment Code*	Mean $\Delta K/S$	Grouping
2	2.9	A
9	2.5	B
1	2.2	C
3	2.2	C D
4	2.2	D
10	1.2	E
15	0.9	F
6	0.9	F G
11	0.8	G
12	0.8	G
7	0.6	H
13	0.6	H I
8	0.5	J I
5	0.5	J
14	0.4	K

*See Table .

Note: Means with same letter are not significantly different.

carpet protectors evaluated (fluorocarbons and colloidal compositions) were significantly lower than the mean for the untreated carpeting, except for fluorocarbon #6, indicating a decrease in soiling. The mean $\Delta K/S$ values for acrylic copolymers were not significantly different from the mean for the untreated control. Even though there were significant differences among the mean ΔE and $\Delta K/S$ values for the 15 treatments, their influence on soiling was confounded by significant second, third, and fourth order interactions which will be discussed following the main effects.

Effect of Application Rate on Soiling

The 14 aftermarket carpet protectors were applied to the three carpet types at two different application rates: 1 liter/19 m² (1 gallon/800 ft²), designated as 1X, and 3 liter/19 m² (3 gallon/800 ft²), designated as 3X. The 1X application rate used in the study represented the recommended label concentration for the majority of products, except for some fluorocarbons which specified higher application rates. (Note: the effects of applying the fluorocarbon at the recommended rate and 3X that amount are currently being evaluated at KSU).

The grand mean total color difference value for the 3X application rate ($\Delta E = 8.6$) was significantly higher than that obtained for the 1X application rate ($\Delta E = 7.9$), indicating that overall the higher application rates resulted in greater soiling (Table 13). Likewise, the grand $\Delta K/S$

Table 13. Duncan's Multiple Range test on Soiling Propensity Means (ΔE Units for Application Rates.

Application Rate	Mean ΔE	Grouping
3X	8.6	A
1X	7.9	B

Note: Means with same letter are not significantly different.

Table 14. Duncan's Multiple Range test on Soiling Propensity Means ($\Delta K/S$ Units) for Application Rates.

Application Rate	Mean $\Delta K/S$	Grouping
3X	1.4	A
1X	1.2	B

Note: Means with same letter are not significantly different.

mean for the higher (3X) application rate was significantly larger ($\Delta K/S = 1.4$) than value obtained for the lower application rate ($\Delta K/S = 1.2$) (Table 14). However, the difference between the mean ΔE 's and $\Delta K/S$ at the two application rates was attributed primarily to siloxane and siloxane/fluorocarbon products which caused more soiling at the higher application rate. However, less soiling occurred at the 3X rate for the specimens treated with other products (fluorocarbon, acrylic copolymers, and colloidal compositions). Since the influence of application rate was confounded by carpet type, type of finish, and moisture content of the carpeting, the following interactions were significant: CXA, TXA, CXTXA, CXAXM, and CXTXAXM.

Effect of Moisture Level on Soiling

Since some of the product manufacturers stated that the moisture content of the carpeting may influence the effectiveness of their products, all the carpet protectors were applied to both dry and wet (after cleaning) carpeting (i.e., at two carpet moisture levels). The dry carpeting was prepared by vacuuming only, whereas the wet carpeting was subjected to hot water extraction cleaning.

The grand mean for the carpet specimens that were treated dry was significantly higher ($\Delta E = 8.6$) than that obtained for the specimens treated wet ($\Delta E = 7.9$) (Table 15). Results from the Duncan's Multiple Range test on the grand mean $\Delta K/S$ values for the two carpet moisture levels

Table 15. Duncan's Multiple Range Test on Soiling Propensity Means (ΔE Units) for Moisture Levels.

Moisture Level	Mean ΔE	Grouping
Dry	8.6	A
Wet	7.9	B

Note: Means with same letter are not significantly different.

Table 16. Duncan's Multiple Range Test on Soiling Propensity Means ($\Delta K/S$ Units) for Moisture Levels.

Moisture Level	Mean $\Delta K/S$	Grouping
Dry	1.3	A
Wet	1.2	B

Note: Means with same letter are not significantly different.

also showed that, in general, the specimens treated dry exhibited greater soiling ($\Delta K/S = 1.3$) than did the specimens that were treated wet (after cleaning) ($\Delta K/S = 1.2$) (Table 16). Overall the treatments applied on dry carpeting exhibited greater soiling. Since the CXM, TXM, AXM, CXTXM, CXAXM, TXAXM, and CXTXAXM interactions were significant, the influence of moisture level was confounded by carpet type and aftermarket treatment.

Effect of Carpet Type and Treatment on Soiling

The soiling propensity means (ΔE 's) for the individual carpet protector treatments and the untreated control within each carpet type are presented in Table 17. The ΔE 's for the untreated controls (#15) reflect the inherent difference in the soil resistance of the three carpet types (I: $\Delta E = 9.9$, II: $\Delta E = 6.0$, and III: $\Delta E = 5.2$). The ΔE values for all of the carpet protector treatments on nylon carpet type I were higher than those obtained for carpet types II and III. As previously reported, the overall grand mean for carpet II was higher than carpet III. However, for many of the treatments, especially for the siloxanes (#1-4) and colloidal compositions (#13 and #14), little or no difference was observed between the ΔE 's obtained for carpet types II and III (i.e., the differences in the ΔE 's were ≤ 0.4). The greatest differences in soiling between carpet types II and III were observed for the siloxane/fluorocarbon mixtures (#9 and #10), the acrylic copolymers (#11 and #12), and

Table 17. Soiling Propensity Means (ΔE Units) for Treatments within Carpet Types

Treatment code	ΔE Units		
	Carpet type		
	I	II	III
1.	14.6	12.1	11.7
2.	16.8	14.1	13.8
3.	15.4	11.7	11.5
4.	14.7	11.4	11.4
5.	6.9	3.0	2.9
6.	7.6	5.0	7.2
7.	7.5	4.7	3.8
8.	6.4	3.9	3.6
9.	15.7	13.9	13.0
10.	10.4	7.7	6.8
11.	9.0	5.4	4.7
12.	9.1	5.0	4.4
13.	6.8	3.5	3.5
14.	4.4	3.1	2.9
15.	9.9	6.0	5.2

fluorocarbon treatment #7.

As shown in Table 17, the siloxanes (treatments #1-4) and the siloxane/fluorocarbon mixtures (treatments #9 and #10) caused the greatest amount of soiling in all three carpet types which, unlike the other products evaluated, was higher than the untreated control (treatment #15). Conversely, lower ΔE values were obtained for all three carpet types treated with the fluorocarbons (treatments #5-8), acrylic copolymers (treatments #11 and #12), and colloidal compositions (treatments #13 and #14) as compared to the mean for untreated control. These results show that the soiling propensity in nylon carpeting is related to the carpet type and the treatment applied thereon. However, these generalization pertaining to specific treatments were confounded by significant CXTXA, CXTXM, and CXTXAXM interactions.

Differences also were observed in the magnitude of the color difference values associated with the products or treatments within a chemical class. Among the siloxane treatments, #2 exhibited an appreciably higher ΔE value for all carpet types, compared to treatment #1, #3, and #4 which had similar ΔE values. Likewise, the mean ΔE 's for siloxane/fluorocarbon mixture #9 was substantially higher than the ΔE 's for #10 which was more similar to the means for the untreated controls. Some differences were observed in the mean color difference values for the fluorocarbon

treatments (#5-8), however, the range was not as great. Fluorocarbon treatment #6 resulted in higher mean ΔE 's for carpet types I, II, and III, followed by #7, #8, and #5. Within the colloidal compositions, treatment #13 which was a metal colloid, resulted in higher ΔE 's for the three carpet types, indicating that it caused more soiling than did the product containing silica. Few difference were observed between the ΔE values for the acrylic copolymer treatments (#11 and #12) within carpet types.

The mean $\Delta K/S$ values for the 14 treatments and untreated controls within each carpet type ranged from 0.3 to 3.2 (Table 18). The mean for the untreated controls (#15) on carpet type I ($\Delta K/S = 1.3$) was somewhat higher than those associated with carpet type II ($\Delta K/S = 0.7$) or III ($\Delta K/S = 0.8$). Unlike the ΔE soiling data, the mean $\Delta K/s$ values for all of the carpet protector treatments within carpet type III were higher than those for carpet type II.

These data were similar to the ΔE means in that, overall, soiling was greater within all three carpet types for the siloxanes (#1-4) and the siloxane/fluorocarbon mixtures (#9 and #10), as compared to the untreated control (#15). All of the mean $\Delta K/S$ values for the siloxane were ≥ 1.6 with the greatest amount of soiling associated with treatment #2. Even though both siloxane/fluorocarbon mixtures had larger $\Delta K/S$ values than the untreated controls, treatment #9 resulted in substantially greater soiling than

Table 18. Soiling Propensity Means (Δ K/S Units) for Treatments within Carpet Types

Treatment code	Δ K/S Units		
	Carpet type		
	I	II	III
1	2.5	1.8	2.4
2	3.2	2.2	3.2
3	2.6	1.6	2.4
4	2.5	1.6	2.3
5	0.8	0.3	0.4
6	0.9	0.5	1.2
7	0.9	0.5	0.5
8	0.7	0.4	0.5
9	2.7	2.0	2.9
10	1.4	1.0	1.2
11	1.2	0.6	0.7
12	1.2	0.5	0.7
13	0.8	0.4	0.5
14	0.5	0.3	0.4
15	1.3	0.7	0.8

#10. The fluorocarbons (#5-8) and colloidal compositions (#13 and #14) resulted in a decrease in overall soiling, except for fluorocarbon treatment #6 applied to carpet type III. However, the acrylic copolymers had little or no influence on soiling, and the mean $\Delta K/S$ values for treatments #11 and #12 were slightly lower than those for the untreated controls.

Effect of Carpet Type and Application Rate on Soiling

The overall soiling propensity means in ΔE and $\Delta K/S$ units for the two application rates (1X and 3X) within carpet types (I, II, and III) are given in Tables 19 and 20. The magnitude of the difference between the mean ΔE 's for the 1X and 3X application rates was influenced by carpet type. Carpet type I (no fluorocarbon finish) had almost the same degree of overall soiling at the 1X and 3X application rates (ΔE 's = 10.2 and 10.4, respectively), whereas the differences between the application rate means were substantially greater for carpet types II and III. At both the 1X and 3X application rates, carpet type I had the highest mean ΔE values, whereas carpet type III had the lowest. Within each carpet type, the color difference means were greater at the 3X application rate. However, the mean ΔE 's for carpet types II and III for the two application rates were very similar, especially at the 3X rate.

Based on the overall $\Delta K/S$ means for the two application rates within each of the three carpet types, more soiling

Table 19. Soiling Propensity Means (ΔE Units) for Application Rates within Carpet Types

ΔE Units		
Carpet type	Application rate	
	1X	3X
I	10.2	10.4
II	7.0	7.7
III	6.6	7.6

Table 20. Soiling Propensity Means ($\Delta K/S$ Units) for Application Rates within Carpet Types

$\Delta K/S$ Units		
Carpet type	Application rate	
	1X	3X
I	1.5	1.6
II	0.9	1.1
III	1.2	1.5

occurred at 3X application rate, as compared to the 1X rate, and within the two application levels, carpet type I had more soiling than carpet types III or II (Table 20). However, within both application rates, slightly larger mean $\Delta K/S$ values were associated with carpet type III rather than II as was reported for the ΔE data.

However, the above generalizations are not all inclusive because of the significant third and fourth order interactions (CXTXA, CXAXM, and CXTXAXM). The overall increase in the soiling propensity at 3X rate in all of the carpet types was mainly due to siloxane and siloxane/fluorocarbon treatments which increased soiling at the higher application rate.

Effect of Carpet Type and Moisture on Soiling

The ΔE soiling propensity means for the two moisture levels (dry and wet) during specimen treatment within each carpet type are presented in Table 21. The greatest amount of soiling as well as the largest differences between the ΔE 's for two moisture levels was observed for carpet type I, followed by carpet types II and III. The mean ΔE 's associated with the specimens treated dry were higher than those treated wet for carpet types I and II. The reverse was observed for carpet type III, but the means were not significantly different. Since fluorocarbon treatments applied during manufacturing alter the wetting properties of carpeting, fewer differences in moisture levels were expected

Table 21. Soiling Propensity Means (ΔE Units) for
Moisture Levels within Carpet Types

ΔE Units		
Carpet type	Moisture level	
	Dry	Wet
I	11.1	9.6
II	7.8	6.9
III	7.0	7.2

Table 22. Soiling Propensity Means ($\Delta K/S$ Units) for
Moisture Levels within Carpet Types

$\Delta K/S$ Units		
Carpet type	Moisture level	
	Dry	Wet
I	1.7	1.4
II	1.0	0.9
III	1.3	1.4

for carpet types II and III.

The overall $\Delta K/S$ grand mean for the dry moisture level within carpet type I also was considerably greater than the mean for the specimens treated wet (after cleaning), whereas for carpet types II and III the moisture level means were more similar (Table 22). In particular, for carpet type II, the mean $\Delta K/S$ value for the dry treatments was slightly larger than the mean for the wet treatment, whereas in carpet type III there was no appreciable difference between the means for specimens treated dry and wet. The mean $\Delta K/S$ values also were the highest for carpet type I, within each moisture level, followed by carpet types III and II.

Since, overall, less soiling occurred in the specimens treated wet, perhaps moist or damp carpeting facilitates the absorption of the aftermarket topical treatments, thereby increasing their effectiveness. This is more thoroughly explained by examining the significant CXTXM, CXAXM, and CXAXTXM interactions.

Effect of Treatment and Application Rate on Soiling

The mean color difference values for the aftermarket carpet protector treatments at the two application rates (1X and 3X) are presented in Table 23. (Note: The means obtained for the controls reflect only the variability in the readings since these samples were untreated). Larger ΔE values were obtained for the siloxanes (treatments #1-4) at the 3X application rate, indicating an overall increase in soiling

Table 23. Soiling Propensity Means (ΔE Units) for Application Rates within Treatments

Treatment code	ΔE Units	
	Application rate	
	1X	3X
1	12.1	13.5
2	12.4	17.4
3	11.6	14.2
4	11.3	13.7
5	4.5	4.0
6	6.4	6.7
7	5.9	4.8
8	5.1	4.1
9	13.1	15.3
10	8.1	8.5
11	6.3	6.4
12	6.4	6.0
13	4.7	4.5
14	4.6	2.4
15	6.8	7.4

when an excess was applied. However, only siloxane/fluorocarbon treatment #9 exhibited an appreciable increase in soiling at the higher application rate. Conversely, two of the fluorocarbon treatments (#7 and #8) had mean ΔE 's that were notably lower at the higher application rate indicating less soiling, whereas for the other two fluorocarbons (#5 and #6), there was no significant difference. For the acrylic copolymers (treatments #11 and #12) no significance difference in soiling was observed between the two application rates. Similarly, for the colloidal metal composition (#13) the difference was not appreciable, but for colloidal silica composition (#14) the soiling was less at the 3X application rate as compared to 1X.

The $\Delta K/S$ soiling propensity means for the 15 treatments for the 1X and 3X application rates were similar to the ΔE means in that the siloxanes (#1-4) and siloxane/fluorocarbon mixtures (#9 and #10) exhibited greater soiling at the higher rate (Table 24). Conversely, somewhat less soiling occurred at 3X application rate for all of the fluorocarbons except for treatment #6. No appreciable differences in soiling were observed in the $\Delta K/S$ values for the acrylic copolymers (#11 and #12) for the two application rates. Similarly, for the colloidal metal composition (#13) the difference was not appreciable, but for colloidal silica composition (#14) the $\Delta K/S$ was less at the 3X application rate.

Table 24. Soiling Propensity Means (Δ K/S Units) for Application Rates within Treatments

Treatment code	Δ K/S Units	
	Application rate	
	1X	3X
1	2.0	2.4
2	2.0	3.7
3	1.8	2.5
4	1.8	2.4
5	0.5	0.4
6	0.9	0.9
7	0.7	0.5
8	0.6	0.5
9	2.2	2.9
10	1.1	1.2
11	0.8	0.8
12	0.8	0.8
13	0.6	0.6
14	0.6	0.2
15	0.9	1.0

In summary, when the siloxanes (#1-4) and one of the siloxane/fluorocarbon mixtures (#9) were applied at the 3X application rate, soiling appreciably increased, compared to the 1X application rate. Whereas, for the carpeting treated with two of the fluorocarbons (#7 and #8), and the colloidal silica composition (#14), less soiling occurred at the 3X application rate. However, these generalizations were confounded by significant CXTXA, CXAXM, and CXAXTXM interactions.

Effect of Treatment and Moisture Level on Soiling

As shown in Table 25, the effect of carpet moisture level during treatment on soiling was dependent on treatment. Soiling was greater for some of the treatments (#1, #10, #11, #12, #13, and #14) when they were applied on dry carpeting. The differences in soiling propensity for the other treatments within moisture level were not appreciable. Only one siloxane treatment (#1), one fluorocarbon treatment (#7), and one siloxane/fluorocarbon mixture (#9) resulted in appreciably less soiling when applied to wet (after cleaning) carpeting. However, moisture level was an important variable for all of the acrylic copolymers and colloidal compositions as demonstrated by the appreciably lower mean ΔE values obtained for the carpeting treated wet.

For the majority of treatments, few differences were observed between the mean $\Delta K/S$ values for carpet specimens treated dry and wet (after cleaning) (Table 26). Among the

Table 25. Soiling Propensity Means (ΔE Units) for
Moisture Levels within Treatments

Treatment code	ΔE Units	
	Moisture level	
	Dry	Wet
1	13.7	12.0
2	14.9	14.9
3	12.9	12.8
4	12.5	12.5
5	4.5	4.1
6	6.8	6.3
7	5.8	4.9
8	4.4	4.9
9	14.4	14.0
10	8.7	7.8
11	7.3	5.4
12	7.3	5.1
13	5.0	4.1
14	4.1	2.8
15	7.3	6.8

Table 26. Soiling Propensity Means ($\Delta K/S$ Units) for
Moisture Levels within Treatments

Treatment code	$\Delta K/S$ Units	
	Moisture level	
	Dry	Wet
1	2.4	2.0
2	2.9	2.9
3	2.2	2.2
4	2.1	2.1
5	0.5	0.4
6	0.9	0.9
7	0.7	0.6
8	0.5	0.6
9	2.6	2.5
10	1.3	1.1
11	1.0	0.7
12	1.0	0.7
13	0.6	0.5
14	0.5	0.3
15	0.9	0.9

siloxanes, only treatment #1 resulted in a slightly higher mean $\Delta K/S$ value when applied to dry carpeting. The greatest difference between the moisture level means was observed for the acrylic copolymers, both of which had a mean increase of 0.3 $\Delta K/S$ units when applied to dry carpeting, indicating slightly greater soiling. There was no significant difference between the means for the untreated control specimens soiled 'as received' and after cleaning. Similar results were obtained when soiling was evaluated on the basis of ΔE values. The effects of moisture level also were dependent on carpet type and application rate as reflected in the significant CXTXM, CXAXM, and CXTXAXM interactions.

Effect of Application Rate and Moisture Level on Soiling

No appreciable difference was observed in soiling propensity means for the two moisture levels at the 1X and 3X rates (Table 27), even though the ΔE values obtained for the carpeting treated dry were higher, indicating somewhat more soiling, compared to the means for the carpet specimens treated wet. At both the moisture levels, higher mean ΔE 's were obtained for the 3X application rate.

Similarly, the mean $\Delta K/S$ values at the 3X application rate were greater than the corresponding means for the 1X rate, however, no significant difference was observed in mean $\Delta K/S$ values for moisture levels within the two application rates (Table 28). The increase in the mean $\Delta K/S$ values at the 3X application rate was attributed to the siloxanes and

Table 27. Soiling Propensity Means (ΔE Units) for Moisture Levels within Application Rates

ΔE Units		
Application rate	Moisture level	
	Dry	Wet
1X	8.3	7.6
3X	9.0	8.2

Table 28. Soiling Propensity Means ($\Delta K/S$ Units) for Moisture Levels within Application Rates

$\Delta K/S$ Units		
Application rate	Moisture level	
	Dry	Wet
1X	1.2	1.1
3X	1.5	1.3

siloxane/fluorocarbon mixtures which caused greater soiling at the higher concentration, hence these findings are confounded by significant CXAXM, TXAXM, and CXTXAXM interactions.

Effect of Carpet type, Treatment and Application Rate on Soiling

The soiling propensity means expressed in ΔE and $\Delta K/S$ units for the untreated controls (#15) and the aftermarket carpet protector treatments (#1-14) within each carpet type and application rate are given in Tables 29 and 30. (Note: The data reported for the controls (#15) at the two application rates represents only replication means since the samples were not treated.) The siloxanes (#1-4) and siloxane/fluorocarbon mixtures (#9 and #10) resulted in greater soiling on all three carpet types when applied at the 3X rate as compared to 1X rate. The only other treatment that exhibited similar results was fluorocarbon treatment #6 which also had greater soiling when applied to carpet types II and III at the 3X rate. The soiling propensity means for the other fluorocarbons (#5, #7 and #8), the acrylic copolymers (#11 and #12) and the colloidal compositions (#13 and #14) were slightly less or not significantly different from those obtained at the 1X rate.

All of the mean ΔE and $\Delta K/S$ values for fluorocarbon treatments (#5-8) within each carpet type and application were appreciably lower than the corresponding values for the

Table 29. Soiling Propensity Means (ΔE Units) for Treatments and Carpet Types within Application Rates

ΔE Units						
Carpet type						
Treatment code	I		II		III	
	Application rate					
	1X	3X	1X	3X	1X	3X
1.	13.9	15.4	11.6	12.6	10.9	12.5
2.	14.5	19.1	11.8	16.3	10.8	16.8
3.	14.5	16.3	10.2	13.2	10.0	13.1
4.	13.5	15.9	10.2	12.6	10.3	12.5
5.	7.2	6.5	3.4	2.7	3.0	2.8
6.	8.3	6.8	4.8	5.2	6.1	8.3
7.	8.1	6.9	5.2	4.2	4.4	3.2
8.	7.0	5.8	4.4	3.5	4.1	3.1
9.	15.0	16.3	12.7	15.2	11.5	14.5
10.	10.1	10.7	8.1	7.4	6.2	7.3
11.	9.2	8.8	5.2	5.6	4.6	4.8
12.	9.2	8.9	5.4	4.6	4.5	4.3
13.	7.2	6.3	3.4	3.6	3.3	3.7
14.	6.1	2.7	3.5	2.6	4.0	1.9
15.	9.6	10.3	5.5	6.5	5.2	5.3

Table 30. Soiling Propensity Means (Δ K/S Units) for Treatments and Carpet Types within Application Rates

Δ K/S Units						
Carpet type						
Treatment code	I		II		III	
	Application rate					
	1X	3X	1X	3X	1X	3X
1	2.2	2.8	1.6	1.9	2.2	2.7
2	2.4	4.0	1.6	2.8	2.2	4.3
3	2.3	2.8	1.3	1.9	1.9	2.9
4	2.1	2.8	1.3	1.8	2.0	2.6
5	0.9	0.7	0.3	0.3	0.4	0.4
6	1.1	0.8	0.5	0.6	1.0	1.3
7	1.0	0.8	0.6	0.4	0.6	0.4
8	0.8	0.6	0.5	0.3	0.6	0.4
9	2.4	3.0	1.7	2.3	2.4	3.3
10	1.4	1.4	1.0	0.9	1.0	1.3
11	1.2	1.1	0.6	0.6	0.7	0.7
12	1.2	1.2	0.6	0.5	0.7	0.6
13	0.9	0.8	0.3	0.4	0.5	0.6
14	0.7	0.2	0.4	0.3	0.6	0.2
15	1.2	1.4	0.6	0.7	0.8	0.8

untreated controls, except for fluorocarbon treatment #6 applied to carpet type III, indicating a decrease in soiling. The colloidal compositions (#13 and #14) also resulted in a significant decrease in soiling on all three carpet types. However, the mean ΔE 's and $\Delta K/S$ for the acrylic copolymers (#11 and #12) were only slightly lower, reflecting a minimal influence on soiling.

Effect of Carpet type, Treatment, and Moisture level on Soiling

The soiling propensity means for the aftermarket carpet protectors applied to three carpet types at two moisture levels are given in Table 31. The moisture level of the carpeting during treatment had a minimal influence on the soiling for many of treatments applied to the three carpet types. The highest soiling propensity means for all treatments applied at both moisture levels (dry and wet) were associated with carpet type I, followed by carpet types II and III. Within treatments, the siloxanes (#1-4) and siloxane/fluorocarbon mixtures (#9 and #10) increased soiling as compared to the untreated carpeting (#15) for all three carpet types and at both moisture levels. Conversely the fluorocarbons (#5-8), and colloidal compositions (#13 and #14) reduced soiling in all three carpet types when applied to both the dry and wet specimens. The acrylic copolymers (#11 and #12) reduced soiling somewhat when applied to wet carpet, but had little or no effect when applied to dry

Table 31. Soiling Propensity Means (ΔE Units) for Treatments and Carpet Types within Moisture Levels

ΔE Units						
Carpet type						
Treatment code	I		II		III	
	Moisture level					
	Dry	Wet	Dry	Wet	Dry	Wet
1	15.9	13.4	13.4	10.9	11.7	11.7
2	16.9	16.7	14.0	14.1	13.7	13.9
3	16.0	14.8	12.0	11.4	10.8	12.3
4	14.9	14.6	11.3	11.4	11.2	11.5
5	7.3	6.5	3.1	3.0	3.0	2.8
6	8.1	7.0	4.9	5.0	7.3	7.1
7	7.9	7.1	5.7	3.6	3.6	4.0
8	6.6	6.1	3.1	4.7	3.3	3.9
9	16.3	15.1	14.1	13.8	12.9	13.1
10	11.3	9.4	8.6	6.8	6.2	7.3
11	10.7	7.3	6.4	4.4	5.0	4.5
12	10.8	7.4	6.6	3.4	4.3	4.5
13	7.7	5.8	3.6	3.4	3.8	3.2
14	5.7	3.1	3.5	2.6	3.0	2.9
15	10.6	9.3	6.3	5.6	4.8	5.6

carpeting. The difference in soiling due to treatments applied on dry and wet carpeting differed from treatment to treatment and from carpet type to carpet type and, in some instances, the difference in soiling due to moisture level was not appreciable. On carpet type I, all mean ΔE values were slightly lower for the treatments applied to the wet (after cleaning) specimens, especially for treatment #'s 1, 3, 6, 9, 10, 11, 12, 13, and 14. The siloxane/fluorocarbon mixtures (#9 and #10), the acrylic copolymers (#11 and #12) and the colloidal metal (#14) also resulted in slightly less soiling on carpet type II when applied to wet carpeting. Contrary to that suggested by company representatives, no particular class of treatments appeared to perform better when applied to wet carpeting.

Similar results as discussed above were observed in the mean $\Delta K/S$ for the treatments applied at two application rates within carpet types (Table 32). However, the influence of moisture level was not as apparent when soiling propensity was based on $\Delta K/S$. For the majority of the treatment combinations, few differences were observed between the mean $\Delta K/S$ for the carpeting treated dry and wet (after cleaning).

Effect of Treatment, Application rate, and Moisture level on Soiling

The soiling propensity means for the treatments within application rate and moisture level are given in Table 33. Within treatments, the ΔE values for the siloxanes (#1-4)

Table 32. Soiling Propensity Means ($\Delta K/S$ Units) for Treatments and Carpet Types within Moisture Levels

Treatment code	$\Delta K/S$ Units					
	Carpet type					
	I		II		III	
	Moisture level					
	Dry	Wet	Dry	Wet	Dry	Wet
1	2.8	2.2	2.0	1.5	2.4	2.4
2	3.2	3.3	2.2	2.2	3.2	3.3
3	2.7	2.4	1.7	1.5	2.1	2.7
4	2.5	2.4	1.6	1.6	2.3	2.3
5	0.9	0.7	0.3	0.3	0.4	0.4
6	1.0	0.8	0.6	0.5	1.1	1.2
7	0.9	0.8	0.6	0.4	0.5	0.6
8	0.8	0.7	0.3	0.5	0.5	0.6
9	2.8	2.6	2.1	2.0	2.8	2.9
10	1.6	1.2	1.1	0.8	1.0	1.3
11	1.5	0.9	0.7	0.5	0.8	0.7
12	1.5	0.9	0.7	0.4	0.7	0.7
13	1.0	0.7	0.4	0.4	0.6	0.5
14	0.6	0.3	0.4	0.3	0.4	0.4
15	1.4	1.2	0.7	0.6	0.7	0.9

Table 33. Soiling Propensity Means (ΔE Units) for Treatments and Application Rates within Moisture Levels

ΔE Units				
Application rate				
Treatment code	1X		3X	
	Moisture level			
	Dry	Wet	Dry	Wet
1	13.1	11.1	14.2	12.9
2	12.3	12.4	17.4	17.4
3	11.5	11.6	14.4	14.0
4	11.2	11.4	13.7	13.6
5	4.7	4.4	4.2	3.8
6	6.4	6.4	7.2	6.3
7	6.3	5.5	5.2	4.3
8	4.8	5.5	4.0	4.3
9	13.1	13.1	15.8	14.9
10	8.6	7.7	8.9	8.0
11	7.2	5.5	7.5	5.4
12	7.6	5.2	6.9	5.0
13	5.1	4.2	4.9	4.1
14	5.3	3.8	2.9	1.9
15	6.6	6.9	7.9	6.8

and the siloxane/fluorocarbon mixtures (#9 and #10) were greater than those for the untreated controls (#15). All of the mean ΔE 's for the fluorocarbon treatments were lower but not always significantly different from those for the untreated controls, especially for treatment #6. When applied to dry carpeting, the acrylic copolymers had little effect on soiling, however, their effectiveness was increased when applied to wet carpeting. Some of the lowest soiling propensity means were associated with the colloidal compositions, in particular, treatment #14 containing colloidal metal which was more effective when applied to wet carpeting.

Few differences also were observed between the $\Delta K/S$ treatment means for the two moisture levels within the 1X and 3X application rates (Table 34). For the majority of the treatment combination, the difference between the $\Delta K/S$ means for the dry and wet application conditions was ≤ 0.2 .

In summary, fewer differences were observed among the specimens when the degree of soiling was expressed in $\Delta K/S$ units, calculated by using Y-tristimulus value, as compared to ΔE values which are based on total color difference. Since soiling may result in both a change in hue as well as a loss in reflectance, ΔE values appear to be more indicative of the magnitude of soiling. The results from the visual color evaluation are not discussed, because there was too much variation within three evaluators and the Gray Scale

Table 34. Soiling Propensity Means ($\Delta K/S$ Units) for Treatments and Application Rates within Moisture Levels

ΔE Units				
Application rate				
Treatment code	1X		3X	
	Moisture level			
	Dry	Wet	Dry	Wet
1	2.2	1.8	2.6	2.3
2	2.0	2.1	3.7	3.7
3	1.8	1.9	2.5	2.6
4	1.8	1.8	2.5	2.4
5	0.6	0.5	0.5	0.4
6	0.9	0.9	0.9	0.9
7	0.8	0.7	0.6	0.5
8	0.6	0.7	0.5	0.5
9	2.1	2.2	3.1	2.7
10	1.2	1.1	1.3	1.2
11	1.0	0.7	1.0	0.7
12	1.0	0.7	0.9	0.6
13	0.6	0.5	0.6	0.5
14	0.6	0.4	0.3	0.2
15	0.8	0.9	1.0	0.9

values did not correlate well with instrumental color results. Additional studies are needed to compare colorimetric methods with visual assessment. However, the influence of treatment type, application rate, carpet type, and moisture level on soiling propensity was similar in the two methods of analysis. The most noticeable difference between the data for ΔE and $\Delta K/S$ was in the rank order of the carpet type II (with fiber producer applied fluorocarbon finish) and III (with fiber producer and mill applied fluorocarbon finish). In both methods of analysis, the greatest soiling was observed on carpet type I (no fluorocarbon finish) as compared to carpet types II and III. These findings show the relative effectiveness of the fluorocarbon soil and stain repellent finishes applied during manufacturing in reducing soiling. Overall, greater difference were observed in the amount of soiling that occurred on carpet type I, compared to carpet type II or III. Based on total color difference (ΔE units), carpet type III had less soiling than carpet type II for some of the treatments, thus indicating mill applied fluorocarbon finishes may further enhance the soil resistance of carpeting treated by the fiber producer.

Fourteen aftermarket topical treatments were evaluated which represented five important chemical classes of soil and stain repellents. Among these the siloxanes (#1-4) and fluorocarbon/siloxane mixtures (#9 and #10) exhibited greater

soiling as compared to untreated control (#15). However, differences in soiling were observed within a particular class. For example, the siloxane/fluorocarbon treatment #10 exhibited substantially less soiling than did #9. Overall these finishes increased soiling when applied at higher application rate (3X). Conversely, the fluorocarbons (#5-8), and the colloidal compositions (#13 and #14) reduced soiling at both application rates and carpet treatment moisture levels, except for fluorocarbon treatment #6 which exhibited an increase in soiling at 3X application rate on carpet types II and III only. The other treatments exhibited either a decrease or no appreciable change in soiling at 3X application rate as compared to 1X rate. The acrylic copolymers had minimal influence on soiling with ΔE values only slightly lower than the untreated controls.

The differences in soiling among the classes of soil and stain repellents may be partially attributed to changes in the surface energy of the substrate after treatment. In order to overcome Van der Waal's attractive forces so that wetting of a liquid on a solid surface can be accomplished, the surface tension of the liquid must be approximately equal to or less than the surface energy of the solid. The surface energy of nylon is approximately 45 dynes/cm. Fluorochemicals have a lower surface energy (10-12 dynes/cm) than acrylic copolymers (about 25 dynes/cm), colloidal compositions (20 dynes/cm), or siloxanes (27 dynes/cm) (12,

13, and 34). The fluorochemicals cause the greatest reduction in the surface energy of the carpet required for wetting.

The application of siloxanes and fluorochemical/siloxane mixtures (#1-4, #9 and #10) on untreated nylon carpet also result in the reduction of the surface energy of the carpet required for wetting, but the reduction was not enough to repel the soil which has a surface tension less than that of the carpet surface (due to oily component in the soil). For the same reason the surface energy required for wetting of the carpet types II and III (with fluorocarbon finishes applied during manufacturing) increased on application of siloxane and fluorocarbon/siloxane mixtures and, hence, these finishes caused an increase in soiling compared to the untreated controls (#15). When applied at the higher application rate, these finishes caused a additional increase in the soiling because of the excess of hydrocarbon solvent on the surface of the carpet which attract soil.

The application of fluorochemicals and colloidal compositions caused a reduction in the surface energy of the carpet required for wetting, resulting in less soiling when compared to the untreated controls. Similarly, the higher application rate resulted in a further lowering of the surface energy of the carpet required for wetting, thus, a reduction in soiling was observed.

On a carpet that is already wet with water, consequent

wetting and capillary movement of the finish into carpet pile is relatively easy to achieve (12, 13). Hence, on a wet carpet a more uniform distribution and lesser (for soil reducing finishes) or greater (for soil increasing finishes) soiling were to be expected. Soiling increased for some of the treatments and decreased for others, when they were applied on wet carpeting. Residual detergent on the surface of the carpet after hot water extraction cleaning also may have influenced test results.

SUMMARY AND CONCLUSIONS

Carpeting is the most popular floor covering used in the United States, and about 70% of the carpets produced today contain nylon (6 and 66) as the pile or face fiber. Even though nylon has very good functional properties (resiliency, crush resistance, elasticity, etc.) as a carpet fiber, its oleophilic and hydrophobic nature makes it easier to soil and more difficult to clean.

To overcome the soiling problems in carpets, both fiber producers and carpet mills apply antisoil finishes at various stages of processing. Also available are aftermarket topical finishes which are applied after manufacturing to enhance the resistance of carpeting to soiling and staining caused by dirt, dust, food spills, grease and oils, etc. These finishes vary in chemical compositions and efficiency as soil inhibitors. Furthermore, depending on product, these treatments increase the expenditure of carpet maintenance without substantially improving its performance, and some treatments may actually increase soiling.

Evaluated in this study were the effects of 14 aftermarket carpet protectors, representing five chemical classes, on the soiling propensity of three types of nylon 6 carpeting when applied at two application rates and at two carpeting moisture levels. Specifically, the treatments included, four siloxanes, four fluorocarbons, two siloxane/fluorocarbon mixtures, two acrylic copolymers and

two colloidal compositions. Untreated carpeting was used as control. Commercial formulations were used for treatment, and they were applied at two application rates (1 liter/19 m² or 1 gal/800 ft² and three times this application rate) and at two carpet moisture levels (dry and wet). The three carpet types were similar in color and construction, but differed in that one had no fluorocarbon finish, one had a fiber producer applied fluorocarbon finish, and one had both a fiber producer and mill applied fluorocarbon finish. In total, there were 1,440 specimens in this study (3 carpet types X 15 treatments X 2 application rates X 2 moisture levels X 2 replications X 4 specimens/replication). After treatment application, air-curing, and conditioning of the specimens, they were subjected to an accelerated soiling test (AATCC Test Method 123, Carpet Soiling: Accelerated Soiling Method) using a synthetic soil made by The 3M Company. A CSI (Custom Scientific Instruments) accelerated soil tester was used for these tests.

Three instrumental readings of Y, L*, a*, and b* were taken on each specimen before and after soiling test. The values were averaged prior to calculating ΔE or $\Delta K/S$ values. Analysis of variance statistical tests were conducted on the ΔE and $\Delta K/S$ values to determine which variables had a significant effect on soiling propensity of the nylon carpeting. Duncan's Multiple Range Tests were used to determine the significant differences between the means

associated with all the main variables.

In general, carpet type I (no fluorocarbon treatment) exhibited the greatest soiling, followed by carpet type II (fluorocarbon treatment applied by fiber producer only), and carpet type III (fluorocarbon treatment applied by both fiber producer and carpet mill), when evaluated on the basis of ΔE values, whereas, when evaluated on the basis of $\Delta K/S$ values carpet type I exhibited greatest amount of soiling, followed by carpet types III and II. The overall ΔE values for all the siloxane treatments, two fluorocarbon treatments, and both colloidal compositions were not appreciably different ($\leq 0.4 \Delta E$ units) for carpet types II and III. Furthermore, one fluorocarbon treatment resulted in greater soiling on carpet type III, compared to carpet type II. The greater soiling in carpet type I as compared to carpet types II and III was attributed to absence of fluorocarbon finish during manufacturing. The presence of mill applied fluorocarbon finish on carpet type III further enhanced the soil resistance.

Among the aftermarket carpet protectors evaluated, all of the products that contained siloxane and one product that contained siloxane/fluorocarbon mixture had mean ΔE and $\Delta K/S$ values (amount of soiling) significantly higher for all three carpet types than that obtained for the carpeting that was not laboratory treated, thus indicating these products caused an appreciable increase in the soiling. The other

siloxane/fluorocarbon had a minimal influence on soiling. On the other hand, the mean ΔE and $\Delta K/S$ values for the products containing fluorocarbons, and colloidal compositions were significantly lower than that for untreated carpeting, indicating a reduction in soiling. One fluorocarbon treatment exhibited greater soiling on carpet types II and III. Few differences were observed in the amount of soiling that occurred on the specimens treated with the acrylic copolymer products compared to the untreated carpeting.

Overall the higher application rate (3X), resulted in greater soiling as compared to the lower application rate, However, this was attributed primarily to siloxane and siloxane/fluorocarbon products which exhibited more soiling at the higher application rate, whereas less soiling was observed at the 3X rate with products containing fluorocarbons and colloidal compositions. One fluorocarbon treatment caused greater soiling at higher application rate for carpet types II and III, and the amount of soiling did not change appreciably for specimens applied with acrylic copolymer treatments.

In general, the carpeting treated dry exhibited greater soiling as compared to the carpeting treated wet. Moisture level was an important variable only for acrylic copolymers and colloidal compositions, where appreciably lower soiling was observed on the carpeting treated wet. In other treatments, the effect of moisture level on soiling was not

significant. In general, the difference in soiling due to treatments applied on dry and wet carpeting differed from treatment to treatment and from carpet type to carpet type.

All the treatments that contain hydrocarbons, mineral spirit, or other petroleum distillates as solvents caused more soiling, except for fluorocarbon treatment #6, which resulted in less soiling as compared to untreated carpeting. However, treatments containing water as solvent exhibited lower soiling as compared to untreated carpeting. A number of chemical finishing operations are done on carpeting during manufacturing. These chemicals may be interacting with the aftermarket treatments applied on carpeting, hence, the evaluation of these finishes on the soiling of carpet fiber in fiber form may give a better insight about the variables responsible for soiling. Also, different results may be obtained if the same study is repeated with a soil that does not contain an oily component.

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APPENDIX A

Table A-1. Soiling Propensity (ΔE Units) of Nylon Carpeting Treated with Aftermarket Carpet Protectors for Replication 1.

Treatment Code	ΔE Units											
	Carpet I				Carpet II				Carpet III			
	1X Rate		3X Rate		1X Rate		3X Rate		1X Rate		3X Rate	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
1	14.7	12.2	16.6	14.6	13.5	9.4	13.2	12.2	10.7	11.4	13.0	12.0
2	15.5	13.5	18.7	19.5	11.2	12.4	16.7	15.0	11.0	11.4	16.6	17.1
3	14.5	14.5	17.8	15.3	10.7	9.5	14.0	13.3	9.2	9.9	11.8	14.1
4	14.3	13.6	16.9	15.9	9.9	9.5	12.5	11.8	10.1	10.9	12.1	12.3
5	7.0	7.4	6.6	5.7	3.3	3.3	2.0	1.9	2.8	2.4	3.4	2.8
6	9.2	7.2	7.2	6.4	4.4	4.3	4.3	5.6	5.1	6.1	6.7	7.4
7	9.1	7.7	7.0	6.7	6.2	4.2	4.9	3.3	4.9	5.0	2.7	4.1
8	6.8	6.5	5.8	4.8	3.6	4.9	2.3	3.7	3.2	4.1	2.8	2.9
9	15.8	14.5	16.7	15.2	13.5	11.9	15.5	15.2	11.2	11.8	14.9	13.9
10	10.2	9.1	11.5	9.0	9.5	7.1	8.0	6.0	5.3	6.6	7.1	7.4
11	10.1	7.1	10.8	7.0	5.8	3.7	6.5	4.8	4.6	4.0	5.3	3.9
12	11.4	7.2	10.9	7.7	7.1	3.6	5.6	3.6	4.4	4.4	4.6	4.2
13	7.9	5.6	7.3	5.3	3.8	2.9	2.9	3.6	3.6	3.1	4.1	3.4
14	7.8	3.7	3.6	1.8	4.0	3.2	3.8	2.4	3.3	4.0	1.9	1.5
15	10.6	10.3	11.7	8.7	6.2	7.7	7.2	6.0	5.0	6.3	5.5	6.0

Note: Carpet types: I (no fluorocarbon finish), II (fiber producer-applied fluorocarbon finish), and III (fiber producer and mill-applied fluorocarbon finish). Application rates 1X and 3X (1 L/19 sq. M) (1 gallon/800 sq. ft.). Treatments applied to dry and wet (after cleaning) carpeting.

Table A-2. Soiling Propensity (ΔE Units) of Nylon Carpeting Treated with Aftermarket Carpet Protectors for Replication 2.

Treatment Code	ΔE Units											
	Carpet I				Carpet II				Carpet III			
	1X Rate		3X Rate		1X Rate		3X Rate		1X Rate		3X Rate	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
1	15.7	13.0	16.7	13.7	13.8	12.3	13.0	12.1	10.5	10.9	12.5	12.6
2	14.4	14.4	18.9	19.2	11.6	12.0	16.5	16.0	10.2	10.8	16.9	16.5
3	14.7	14.2	17.0	15.3	10.0	10.7	13.4	12.0	9.8	10.9	12.2	14.3
4	12.9	13.4	15.5	15.4	10.2	11.1	12.8	13.4	10.2	10.0	12.6	12.9
5	8.0	6.4	7.4	6.4	3.6	3.2	3.5	3.5	3.4	3.6	2.4	2.5
6	8.5	8.5	7.6	5.8	5.1	5.3	5.8	4.9	6.3	6.8	9.4	7.9
7	7.7	7.9	7.9	6.1	6.2	4.0	5.6	2.8	3.5	4.3	3.1	2.7
8	7.2	7.3	6.8	5.7	3.9	5.2	2.8	5.1	3.9	5.1	3.4	3.4
9	14.3	15.5	18.4	15.1	12.4	12.0	14.8	15.2	11.2	12.0	14.3	14.8
10	11.8	9.2	11.8	10.2	8.6	7.0	8.5	7.1	6.0	7.1	6.6	8.3
11	11.6	8.0	10.4	7.2	8.2	5.0	6.9	4.2	4.9	4.9	5.0	5.1
12	10.3	8.1	10.7	6.5	8.2	2.9	5.6	3.6	4.4	4.8	3.9	4.5
13	8.5	6.9	7.3	5.4	3.7	3.2	3.9	4.1	3.4	3.3	4.2	3.0
14	8.2	4.8	3.3	2.1	3.8	3.0	2.4	1.7	4.6	4.1	2.2	1.9
15	9.0	8.6	11.2	9.4	5.0	5.6	7.0	5.8	4.0	5.3	4.6	5.0

Note: Carpet types: I (no fluorocarbon finish), II (fiber producer-applied fluorocarbon finish), and III (fiber producer and mill-applied fluorocarbon finish). Application rates 1X and 3X (1 L/19 sq. M) (1 gallon/800 sq. ft.). Treatments applied to dry and wet (after cleaning) carpeting.

Table A-3. Soiling Propensity ($\Delta K/S$ Units) of Nylon Carpeting Treated with Aftermarket Carpet Protectors for Replication 1.

Treatment Code	$\Delta K/S$ Units											
	Carpet I				Carpet II				Carpet III			
	1X Rate		3X Rate		1X Rate		3X Rate		1X Rate		3X Rate	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
1	2.0	1.8	3.0	2.5	2.0	1.3	2.1	1.7	2.2	2.4	2.8	2.4
2	2.6	2.2	3.9	4.2	1.5	1.7	2.8	2.8	2.2	2.3	4.2	4.4
3	2.4	2.3	3.0	2.6	1.4	1.2	2.1	2.0	1.7	1.9	2.4	3.2
4	2.3	2.1	3.2	2.7	1.2	1.2	1.8	1.7	1.9	2.2	2.5	2.5
5	0.8	0.9	0.8	0.6	0.3	0.3	0.2	0.2	0.4	0.3	0.5	0.4
6	1.2	0.9	0.8	0.7	0.5	0.4	0.5	0.6	0.8	1.0	1.5	1.3
7	1.1	0.9	0.8	0.7	0.7	0.4	0.5	0.3	0.8	0.8	0.4	0.6
8	0.8	0.8	0.6	0.5	0.4	0.5	0.2	0.4	0.5	0.6	0.4	0.4
9	2.2	2.3	3.2	2.6	1.9	1.6	2.4	2.4	2.3	2.5	3.5	3.1
10	1.4	1.2	1.6	1.1	1.3	0.8	1.0	0.7	0.8	1.1	1.2	1.3
11	1.3	0.9	0.8	1.5	0.8	0.4	0.7	0.5	0.7	0.6	0.8	0.6
12	1.6	0.9	1.5	0.9	0.8	0.4	0.6	0.4	0.7	0.7	0.7	0.6
13	1.0	0.6	0.9	0.6	0.4	0.3	0.3	0.4	0.5	0.5	0.6	0.5
14	0.9	0.4	0.3	0.1	0.5	0.3	0.4	0.2	0.5	0.6	0.2	0.2
15	1.4	1.4	1.6	1.1	0.6	0.5	0.8	0.7	0.8	1.0	0.8	0.9

Note: Carpet types: I (no fluorocarbon finish), II (fiber producer-applied fluorocarbon finish), and III (fiber producer and mill-applied fluorocarbon finish). Application rates 1X and 3X (1 L/19 sq. M) (1 gallon/800 sq. ft.). Treatments applied to dry and wet (after cleaning) carpeting.

Table A-4. Soiling Propensity ($\Delta K/S$ Units) of Nylon Carpeting Treated with Aftermarket Carpet Protectors for Replication 2.

Treatment Code	$\Delta K/S$ Units											
	Carpet I				Carpet II				Carpet III			
	1X Rate		3X Rate		1X Rate		3X Rate		1X Rate		3X Rate	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
1	2.9	2.0	3.2	2.4	2.0	1.2	1.9	1.9	2.0	2.1	2.7	2.0
2	2.4	2.5	3.9	4.1	1.5	1.6	2.9	2.5	2.0	2.2	4.4	4.3
3	2.4	2.2	3.1	2.5	1.2	1.3	1.9	1.7	1.7	2.2	2.5	3.5
4	1.9	2.1	2.6	2.7	1.2	1.5	1.9	2.0	1.9	1.9	2.7	2.7
5	1.0	0.7	0.9	0.4	0.4	0.3	0.4	0.4	0.5	0.5	0.3	0.3
6	1.1	1.1	0.9	0.6	0.6	0.6	0.7	0.5	1.0	1.1	1.2	1.4
7	0.9	1.0	0.9	0.6	0.7	0.4	0.6	0.3	0.5	0.6	0.4	0.3
8	0.9	0.9	0.8	0.6	0.4	0.5	0.3	0.5	0.6	0.8	0.5	0.5
9	2.3	2.8	3.7	2.6	1.6	1.8	2.3	2.3	2.3	2.5	3.3	3.4
10	1.7	1.2	1.7	1.3	1.1	0.9	1.1	0.9	1.0	1.2	1.1	1.5
11	1.7	1.0	1.4	0.9	0.7	0.5	0.8	0.5	0.7	0.8	0.7	0.8
12	1.4	1.1	1.5	0.8	0.9	0.3	0.6	0.4	0.7	0.7	0.6	0.7
13	1.1	0.8	0.9	0.7	0.4	0.3	0.4	0.4	0.5	0.5	0.7	0.4
14	1.0	0.5	0.3	0.1	0.4	0.3	0.2	0.2	0.7	0.6	0.3	0.2
15	1.1	1.0	1.5	1.2	0.5	0.6	0.8	0.6	0.6	0.8	0.7	0.8

Note: Carpet types: I (no fluorocarbon finish), II (fiber producer-applied fluorocarbon finish), and III (fiber producer and mill-applied fluorocarbon finish). Application rates 1X and 3X (1 L/19 sq. M) (1 gallon/800 sq. ft.). Treatments applied to dry and wet (after cleaning) carpeting.

APPENDIX B

Table B-1. Composition of Soil Suggested by Florio and Merserean.

Component	Percent
Peat moss	38.00
Cement	17.00
Kaolin clay	17.00
Silica	17.00
Mineral oil	8.75
Carbon black	1.75
Iron oxide	0.50

	100.00

Table B-2. Composition of Soil Manufactured by
The 3M Company.

Component	Percent
Peat moss	38.40
Portland cement	18.00
Kaolin clay	18.00
Silica	18.00
Mineral oil	6.25
Carbon black	1.05
Iron oxide	0.30
	<u>100.00</u>

Table B-3. Composition of Proposed AATCC Carpet
Cleaning Detergent for Hot Water
Extraction Cleaning

Component	Parts by Weight
Sodium metasilicate pentahydrate	10
Sodium stearate	5
Dodecylbenzene sulfonate (Sulframin-90)	5
Sodium bicarbonate	10
Sodium tripolyphosphate, light density	70
Optical brightner (cumerine or stylbene type)	0.05

Appendix C

Table C-1. Coding Procedure for Specimens

 | a | b | c | d | e | f |

Code	Variables	Numeral Assigned
a	Carpet type	
	I	1
	II	2
	III	3
b	Treatments	
	Siloxanes	1-4
	Fluorocarbons	5-8
	Siloxane/Fluorocarbon	9-10
	Acrylic copolymers	11-12
	Colloidal compositions	13-14
	Untreated	15
c	Application rate	
	3X	1
	1X	2
d	Moisture level	
	Dry	1
	Wet	2
e	Replication	
	1st	1
	2nd	2
f	Specimen number	1-4

THE EFFECT OF AFTERMARKET CARPET PROTECTOR
TREATMENTS ON THE SOILING PROPENSITY OF
NYLON 6 CARPETING

by

Shailendra Dusaj

B.Tech., Indian Institute of Technology, Delhi, 1985

AN ABSTRACT OF A MASTER'S THESIS

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MASTER OF SCIENCE

Department of Clothing, Textiles, and Interior Design

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1988

ABSTRACT

This study evaluated the effects of aftermarket topical finishes on the soiling propensity of nylon carpeting. Fourteen aftermarket carpet protectors (representing five major chemical classes) were applied at two application rates (1 liter/19 m² or 1 gal/800 ft². and three times this rate) on dry and wet (after cleaning) carpeting. The carpet types included 1) untreated carpeting, 2) carpeting containing a fiber producer applied fluorocarbon finish, and 3) carpeting containing a fiber producer and mill applied fluorocarbon finish.

After air drying (24 hrs), the specimens were conditioned (48 hrs) and subjected to accelerated soiling test (AATCC test method 123, Carpet Soiling: Accelerated Test Method), using a CSI (Custom Scientific Instruments) accelerated soil tester, two grams of a standard soil (made by The 3M Company), and 60-1.25 cm (0.5 inch) diameter steel balls for a 5-minute soiling cycle. Soiling propensity was evaluated instrumentally with Hunter Lab colorimeter and visually with an AATCC Gray Scale for Color Change.

In general, less differences were observed among the specimens, when the soiling was expressed in $\Delta K/S$ values compared to ΔE values. Greater soiling occurred on the siloxane and siloxane/fluorocarbon mixtures compared to untreated control and soiling increased when these products were applied at the higher application rate. Fluorocarbons

and colloidal compositions reduced soiling at both application rates compared to untreated and soiling either reduced or did not change appreciably at higher application rate. The acrylic copolymers had a minimal influence on soiling with degree of soiling slightly lower than untreated controls. Greater amount of soiling was observed on carpet type I (no fluorocarbon finish) as compared to carpet types II and III (fluorocarbon finish applied during manufacturing) and few differences were observed between specimens treated dry and wet.

