

THE DURABILITY OF POLYPROPYLENE NONWOVEN GEOTEXTILES FOR WASTE CONTAINMENT APPLICATIONS

Polypropylene is a durable polymer used in many aggressive environments because of its excellent resistance to degradation in these environments. Currently, nonwoven polypropylene fibers are used in more than 80% of waste containment applications.

Potential mechanisms for degradation of polypropylene fibers include oxidation, hydrolysis and environmental stress cracking. As most polypropylene fibers are buried in landfills where elevated temperatures will exist, thermally activated oxidation is of most interest. In soil, oxygen concentration can vary from 21% in gravels to 1% in fine grained soils.

To study the durability of polypropylene in waste containment applications, a number of parameters were analyzed. They include: Moisture Resistance, Chemical Resistance, Leachate Compatibility, Biological Resistance, Temperature stability, Ultraviolet Resistance, Installation Survivability and Lifetime Prediction.

The results of the study indicate that the durability of polypropylene is not adversely affected by any of the parameter listed above. Furthermore, it has been concluded that polypropylene can be exposed to sunlight for up to 14 days between installation and cover and will have an expected lifetime of up to 200 years. In summary, it is evident that polypropylene geotextiles are not susceptible to biological or physical degradation under normal conditions of soil burial or contact with landfill leachate.



Smart Solutions®

Technical Note

SM-404

The Durability of Polypropylene Nonwoven Geotextiles for Waste Containment Applications



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SUMMARY OF BENEFITS

Polypropylene is a very durable polymer commonly used in aggressive environments including automotive battery casings, fuel containers and the like. Because of its excellent resistance to harmful chemical environments, the use of polypropylene to manufacture nonwoven geotextiles for waste containment systems is a beneficial use of this versatile polyolefin. Presently, nonwoven polypropylene geotextiles are used in more than 80% of all waste containment applications.

Moisture Resistance

Unlike nonwoven polyester geotextiles, polypropylene does not absorb water nor does the presence of water have any effect whatsoever on tensile strength or other mechanical properties.

Chemical Resistance (pH) Extensive research has shown polypropylene is very resistant to certain concentrations of aggressive chemicals such as nitric acid, hydrochloric acid, sulfuric acid, sodium hydroxide and potassium hydroxide. Therefore, polypropylene geotextiles have been found acceptable in most solid and hazardous waste landfills.

Leachate Compatibility

Many independent leachate immersion tests conducted in accordance with EPA Method 9090 have shown no significant reduction in mechanical properties of our nonwoven polypropylene geotextiles.

Biological Resistance

Since polypropylene does not support, attract or deteriorate from fungal growths, SI Geosolutions nonwoven geotextiles are rot and mildew resistant.

Temperature Stability

Polypropylene can withstand temperatures of at least 150 degrees Celsius (300°F) without melting.

Ultraviolet Resistance (Sunlight)

Because polypropylene degrades during extended exposure to sunlight, SI Geosolutions nonwoven polypropylene geotextiles are produced with carbon black and other UV inhibitors. These additives allow our nonwoven polypropylene geotextiles to be exposed for up to 14 days between laydown and cover.

Installation Survivability

Nonwoven polypropylene geotextiles have superior puncture and mullen burst strength, which increase their installation survivability.

Lifetime Prediction

When properly stabilized and buried, nonwoven polypropylene geotextiles have been expected to last for up to 200 years.

INTRODUCTION

By virtue of its chemical composition, molecular structure, and thermodynamic properties, polypropylene is one of the most resistant organic raw materials known today. This is one of the reasons that over 80 percent of all geosynthetics are made from the polypropylene (Schneider 1989).

METHODS OF DEGRADATION

Chemical degradation of geotextiles is a result of environmental and polymer compositional factors. Regarding environmental factors, one can expect the greatest amount of degradation to occur, in general; (1) at relatively high temperatures (i.e. $>100^{\circ}\text{C}$), (2) in soils which are chemically active; (3) and when the geosynthetic is under stress. Key chemical degradation mechanisms that can be found in some soil and waste environments include oxidation, hydrolysis, and environmental stress cracking.

An oxidation reaction can either be initiated by ultraviolet radiation or thermal energy, but must have sufficient oxygen present. Since the geosynthetic will be buried in most applications, thermally activated oxidation is of most interest. Polypropylene oxidation is the reaction of free radicals within polymer with oxygen, resulting in breakdown and/or degradation of the molecular chains and embrittlement of the polymer.

Antioxidants are typically added to the polymer to prevent oxidation during processing and use. Broad classes of antioxidants often used in geosynthetic include phenolic and hindered amine light stabilizers (HALS). As the antioxidants are consumed, resistance of the polymer to oxidation will decrease. The rate of polymer oxidation is dependent on how much and what type of antioxidant is present initially, at what rate it is used, how well it is distributed within the polymer, and how fast it can be leached out by the flow of fluids, such as water, into and around the polymer. Environmental factors which affect the rate of oxidation include temperature and oxygen concentration. In soil, oxygen concentrations can vary from 21% in gravels at shallow depth to 1% in fine-grained soils at deeper depths. The presence of transition metal ions such as iron or copper may act as catalysts to accelerate the oxidation reaction. Thermal oxidation at typical in-soil temperatures appear to be quite slow. (Allen and Elias, 1996.)

TOXICOLOGY

Polypropylene is biologically inert and used for packaging food intended for human consumption (i.e., yogurt containers, Tupperware[®], etc.) To ensure that the

TOXICOLOGY (Cont.)

processing performed does not alter these characteristics, skin and mucous laboratory tests have shown that polypropylene does not cause irritating affects. An extensive series of repeat insult patch testing in humans and many years of extensive use in diverse products such as infant diapers, feminine hygiene products, and surgical fabrics have confirmed that adverse affects on the skin should not be expected. Furthermore, polypropylene is considered to be without significant oral toxicity. When tested by the Food and Drug Administration's specific methods, polypropylene is well below the specified limits of extractables. In addition, the United States Pharmacopoeia (U.S.P.) specifies oral toxicity testing on plastics intended for medical uses. Polypropylene materials have never caused toxicity when tested according to the U.S.P. method (MATAFAXX, 1992).

MOISTURE

Polypropylene is a paraffinic hydrocarbon and does not adsorb water like the polyamides polyester (PET) or nylon. The moisture gain of polypropylene fibers is insignificant and water has no affect on tensile strength and other mechanical properties. Therefore, water alone does not cause any noticeable degradation in polypropylene fibers. Fibers subjected to boiling water or steam for long periods show no loss of strength (Cook, 1984).

ULTRAVIOLET RESISTANCE (Sunlight)

Like polyethylene, polypropylene is attacked by atmospheric oxygen and the reaction is stimulated by sunlight. Polypropylene fibers will deteriorate on exposure to light, but may be effectively protected by stabilizers (Cook, 1984). Without site-specific environmental conditions, SI Geosolutions recommends a maximum exposure period of 14 days between laydown and cover of all of our nonwoven geotextiles. This is in compliance with guidelines issued by the US Environmental Protection Agency (EPA 1993). If the maximum exposure period will exceed these guidelines, we recommend that the installer either (1) utilize an economical, lightweight woven geotextile, such as SI Geosolutions 994GC as a temporary cover; or (2) install a test roll on the most northward facing slope and remove samples after 30 days of actual exposure to evaluate possible strength loss. Site personnel should carefully cut a representative roll-width by 5-foot sample (1.5m); label with contact name, address and telephone number; add a roll number, style and project name; place in a strong black wrap and send to a laboratory. It is the responsibility of the Construction Quality Assurance (CQA) engineer to identify the actual index tests required to determine the actual strength retention.

Three different nonwoven geotextiles were exposed in accordance with ASTM D5970-96, Deterioration of Geotextiles From Outdoor Exposure, starting June 15, through July 15, 1996 in Northwest Georgia, USA. Machine direction (MD) and cross-machine direction (CMD) coupons for each style were attached to a test frame oriented to 45° from horizontal and facing due south. Unexposed coupons were retained for control testing. After 30 days exposure, five specimens from each coupon were tested for tensile strength and elongation in accordance with ASTM D5035. The exposed results were then compared to the unexposed test results and the percent strength retained was calculated. The results are shown in Table 1 below:

Table 1. Results of 30-day Outdoor Exposure Tests

Product Style	Percent Strength Retained		
	MD	CMD	Average
801	96	85	91
1601	90	89	90
1751	94	91	93

TEMPERATURE STABILITY

High Temperatures

The mechanical properties of the fibers deteriorate as temperature increases, but polypropylene performs better than polyethylene in this respect. The softening point of polypropylene fibers is approximately 150° C (300° F), and the fibers “melt” at 165° C (330° F). The softening and melting points of polypropylene are determined in the way which crystallinity has been influenced during and after spinning. Shrinkage of polypropylene fibers depends greatly upon the treatment the fiber receives during processing. In boiling water, monofilament yarns may shrink as much as 15 percent after 20 minutes; multifilament and staple fibers only shrink between 0 and 10 percent (Cook, 1984). However, polypropylene exhibits a moisture regain of only 0.01 to 0.1 weight percent (Cox, 1994).

Flammability

Polypropylene is a hydrocarbon and will burn. On being exposed to a flame, however, the fiber melts and draws away from the flame, extinguishing itself. When tested in accordance with BS2963, polypropylene fabrics are self-extinguishing and therefore of low flammability, (as defined in BS3121). Construction, additives, finishes, and

Flammability (Cont.)

the presence of other fibers have a considerable influence on the burning characteristics of any particular fabric or structure. For the purpose of fire insurance, polypropylene fabric is included in the same class as wool (Cook, 1984).

Low Temperature

The low temperature flexibility of polypropylene is excellent for most applications. SI's polypropylene geotextiles retain normal flexibility from -40C to 150C (-40F to 302F). Below -40F, polypropylene can become inflexible and not suitable for all applications.

BIOLOGICAL RESISTANCE

Insects

Polypropylene cannot be digested by insect and related pests, such as white ants, dermestid beetles, silverfish, and moth larvae. Polypropylene fiber is not liable to attack unless it becomes a barrier beyond which the insect must pass to reach an objective. In this case, the insect may cut through the fiber without ingesting it. Furthermore, polypropylene does not attract nor is it a food source for insects or rodents. As stated earlier, much like humans, it is believed that rodents would not be adversely affected by ingesting small quantities of polypropylene.

Micro-Organisms

Polypropylene fibers will not support the growth of mildew or fungi. Some micro-organisms, however, may even grow on the very small amount of contaminants which may develop on the surface of fibers or yarns in use. Such growth has no effect on the strength of any materials made from polypropylene fiber. Similarly, polypropylene is an inert resin which does not support or attract fungal growths and does not deteriorate due to fungal presence (Cox, 1994).

CHEMICAL RESISTANCE

Polypropylene is inert to a wide range of chemicals. Its resistance and susceptibilities are similar to those of polyethylene, but its higher crystallinity tends to make it more resistant than polyethylene to those chemicals which degrade polyolefin fibers. There is no known solvent for polypropylene at room temperature (Cook, 1994). Extensive information on the chemical resistance of polypropylene shows that it is very resistant to acids and alkalis at room temperatures (Ahmed, 1994). For example, polypropylene is acceptable at room temperature for use with:

Table 2. Chemical Resistance of Polypropylene at Various pH Levels

Chemical (Concentration)	pH Level
Nitric Acid—up to 39%	1
Hydrochloric Acid—up to 37%	1
Sulfuric Acid—up to 96%	1
Sodium Hydroxide—up to 70%	14
Potassium Hydroxide—10%, 25%	14

This covers the entire measurable pH range (Cox, 1994).

However, polypropylene is vulnerable to the following substances: highly oxidizing substances (peroxide), concentrated nitric acid (>40%), concentrated sulphuric acid, chlorosulphonate acid, pure halogen, certain chlorinated hydrocarbons (halogenated hydrocarbons), and certain aromatic hydrocarbons (Schneider, 1989).

Polypropylene does not show any tendency to develop surface cracks when subjected to stresses in the presence of detergents or other substances (Cook, 1994). Polypropylene is extremely stable chemically due to its structural properties as a hydrocarbon construction. Extensive studies testing the chemical stability of polypropylene when exposed to hundreds of organic and inorganic chemicals have shown it to be highly stable against: acids, alkalies, aqueous solutions of inorganic salts, detergents, oils and greases, and gasoline and lubricants.

CHEMICAL RESISTANCE (Cont.)

Actual test results are shown below:

Table 3. Physical Effects of Chemicals on Polypropylene (Schneider)

CHEMICAL	% Change in Mass Per Unit Area*	
	23° C	60° C
Sulfuric Acid (98%)	-0.2	-0.2
Nitric Acid, fuming	-0.1	--
Sodium hypochlorite (20%)	0.1	-2.1
Gasoline	4.8	6.6
Benzene	3.4	0.6
Xylene	7.0	0.3
Menthylene chloride	5.5	1.6
Carbon tetrachloride	13.5	0.9
Turpentine	9.5	10.5
Transformer oil	0.4	14.9

**The weight change as listed is due to the sum of the effects of swelling and dissolution.*

SI Geosolutions, in accordance with ASTM D543, has evaluated the chemical compatibility of our nonwoven geotextiles with JP4 jet fuel. A sample of our 451 (4.5 oz/yd² or 150 gr/m²) nonwoven geotextile was exposed to the fuel for 7 days at room temperature. It was then evaluated for retention of grab tensile properties in accordance with ASTM D4632. The results are as follows:

Table 4. Results of JP4 Jet Fuel Tests

Product Style	MD	Percent Strength Retained	
		CMD	Average
451	91.5	87%	89

LANDFILL LEACHATE

SI Geosolutions has performed several studies on the compatibility of our polypropylene nonwoven geotextiles with leachates and in various pH solutions commonly encountered in soil or solid waste applications. Since the evaluation of long-term chemical aging of nonwoven geotextiles is nearly impossible due to the inherent stability of the polymer, laboratory immersion tests were conducted at elevated temperatures (50° C) to accelerate behavior. Variables such as temperature, moisture, and oxygen content were controlled in the lab and samples were removed at 30-, 60-, 90-, and 120-day intervals. The results of these tests are shown in Table 5 (Boschuk, 1993 and Narejo, 1995).

LANDFILL LEACHATE (Cont.)

Table 5. Results of Chemical Compatibility Testing Conducted by SI Geosolutions, Inc.

Property	Test Method	% Change After 120 Days @ 50° C	
		451*	1601*
Grab Tensile	ASTM D4632	0.88	-1.14
Trapeziodal Tear	ASTM D4533	-23.79	54.82
		-16.28	-7.48
Puncture	ASTM D3786	-8.42	-6.6
Permittivity	ASTM D4491	-15.61	-7.46

*Typical 4.5 (150 gr/m²) and 16 oz/yd² (540 gr/m²) nonwoven needlepunched geotextiles, respectively.

LIFETIME PREDICTION

Using the assumption that kinetics double with every 10° C rise in temperature, polypropylene embrittlement would not take place for 45 years in a 30° C landfill under anaerobic conditions (Wheat, 1992). Since the first geotextile installation occurred in North America in 1958, it is not possible to demonstrate 100-year durability with “real-time” success stories. As a result, the Geosynthetic Research Institute (GRI) designed a series of four accelerated laboratory incubation protocols to demonstrate aging progression in polyethylene geomembranes. The “durability” (e.g. the prevention of aging) of polyethylene and polypropylene is typically extended by manufactures by adding antioxidants to the resin during processing. This prevents oxygen from attacking the polymer itself. Since it is well established that the engineering properties are not reduced until the antioxidants are completely depleted, tests were conducted at GRI to measure the amount of time to initiate polymer degradation.

Series III samples were exposed to water on top and air below with a compressive stress of 260 kPa (37.7 psi). This test series is intended to model leachate or surface water collection systems in a waste containment facility. Since polyethylene and polypropylene geotextiles behave similarly to the materials in this study, the predicted antioxidant lifetime at 25°C for the specimens evaluated is approximately 120 years, (Hsuan and Koerner, 1985).

In a separate study, properly stabilized polypropylene geotextiles have been estimated to have a functional longevity of nearly 200 years in an oceanic or marine application (Wisse & Birkenfeld, 1982).

INSTALLATION SURVIVABILITY

Nonwoven polypropylene geotextiles have higher puncture and mullen burst strength than polyester nonwoven geotextiles which make them very resistant to installation stresses and enhance their construction/installation survivability success.

Table 6. Selected Strengths of Typical Nonwoven Geotextiles

Properties	Test Method	MARV	
		PET	PP
Mass/Unit Area	ASTM D5261	8.0	8.0
Puncture Strength	ASTM D4833	100 lbs	140 lbs
Mullen Burst	ASTM D3786	380 psi	440 psi

CONCLUSIONS

As previously stated, polypropylene is a very durable polymer commonly used in aggressive environments including automotive battery casings, fuel containers and the like. Because of its excellent resistance to harmful chemical environments, the use of polypropylene to manufacture nonwoven geotextiles for waste containment systems is a beneficial use of this versatile polyolefin. Presently, nonwoven polypropylene geotextiles are used in more than 80% of all waste containment applications.

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