

**A COMPARISON OF THE DEGRADATION
OF COTTON-BASED NONWOVENS
BY COMPOSTING AND
HEAT-MOISTURE TREATMENTS**

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Abstract

This research investigated the degradation of three nonwoven fabrics (fiberwebs) containing polypropylene and/or cotton. Physical and morphological properties, indicative of degradation, were compared for samples subjected to three different treatment conditions up to sixteen weeks in duration. The three treatments were: outdoor composting in a tumbler; heat and moisture in an oven; and, to provide control fabrics, a standard textile-testing environment. Changes in tensile strength and percent elongation were evaluated, in addition to fabric-surface discoloration and physical damage visible by light microscopy.

Introduction

Composites and nonwoven laminates are marketed for use in disposable protective apparel (Wuagneux, 1995). Some of the new barrier fabrics incorporate cotton and/or microporous films to improve the breathability. Noonan (1991) indicates that interest in using of cotton in nonwovens for agricultural workers' protective clothing is predicated on the assumed environmental advantages of such fabrics over commonly used synthetic nonwovens. Narayan (1991) notes that the increased use of single-use, short-lived nonwoven materials to make disposable protective clothing has added to waste disposal problems of the agricultural industry. The EPA has proposed to minimize landfilling by increasing source reduction, recycling, and waste-to-energy incineration (Van Volkenburgh and White, 1993). Degradability has become an important waste-disposal issue with the increased use of disposable protective clothing. The fungal biodeterioration of nonwoven fabrics containing cotton and polypropylene for short-use products has been investigated for the fabrics' feasibility in these disposable products (Goynes, Moreau, Delucca and Ingber, 1995). Biodegradation by soil burial of nonwovens for protective clothing has been evaluated (Warnock and Ferguson, 1996).

Environments such as soil, sewage, marine and compost provide active microorganisms to biodegrade materials.

Composting provides an environment for aerobic microorganisms to biodegrade materials. Compost is defined as "a group of organic residues or a mixture of organic residues and soil piled, moistened and undergone aerobic biological decomposition" (Rynk, 1992, p.170). The environmental degradation processes of photodegradation, chemical degradation, and biodegradation may operate in synergistic, concerted, or consecutive manner depending on the environment and the composition of the polymeric material (Narayan, 1989). Chemical changes caused by hydrolysis and oxidation mechanisms in a polymeric material can alter the molecular weight and the magnitude of interchain or secondary forces (hydrogen bonding, dipole interaction, and van der Waals forces) (Atkins and Batich, 1993). Procedures such as ASTM D 5509-94, Standard Practice for Exposing Plastics to Simulated Compost Environment use a laboratory-scale reactor to simulate a self-heating composting system and allow a controlled test environment. Small-scale compost systems (compost tumbler reactor systems) have been used to predict the fate and effects of whole products (diapers) during composting as would occur in a full scale system (King, Kain and Dorbin, 1992; Smith, Low and Herman, 1993). Nonwoven products such as disposable fiberwebs can be engineered to degrade. Little has been done to investigate composting as a means of disposal of barrier fabrics used in protective clothing (Crews, Baumert and Rich, 1995). Oxidation degradation, under heat and moisture, can cause physical and morphological changes in fiberwebs. Thermal oxidation, under elevated temperatures, results in weakening (embrittlement) or disintegration of the polymer material. Comparison of composting to heat and moisture can investigate the influence of the biotic or living factors (microbial population) to the abiotic or non-living factors (temperature and moisture) to determine which will enhance biodegradation.

Objectives

The objectives of this research as part of a larger study, were to determine a) the influence of cotton in a nonwoven structure on the degradability of the structure; and b) the relative contributions of temperature, moisture, and microbial activity on the progressive degradation of the fabrics investigated.

Procedures

The degradation of three selected fabrics exposed to a range of time-compost conditions were compared to temperature-time moisture conditions, with two fabrics being bi-laminates and the third a nonwoven. The three fiberwebs in this study are: a hydroentangled cotton (HEC); a polypropylene microporous film/hydroentangled cotton (MPF/HEC); and a polypropylene microporous film/spunbonded polypropylene (MPF/SBPP). The fabrics were cut into 9.5 in. X 10.5 in. samples, and colored flagging tape was sewn on the top edge of each sample for

identification. A total of 42 fabric samples was prepared for this part of the study providing two samples per fabric type for each of three treatments: out-door composting in a tumbler heat and moisture in an oven; and, to provide control fabrics, a standard textile-testing environment. All test fabric samples were conditioned in a standard environment (70 percent humidity at 72 degrees F) before being exposed to their selected treatments. Fabric samples were exposed to composting or to heat-moisture conditions for set time intervals of sixteen, twelve, eight, four, or two, weeks; or of one week. These exposure periods were effected through progressive insertions of the fabric samples, with removal of all samples at the end of the sixteen weeks.

A compost matrix was made to simulate a yard-waste stream consisting of grass, leaves, and shredded tree trimmings, as per ASTM D 5509-94, Standard Practice for Exposing Plastics to Simulated Compost Environment. Fabric samples were moistened at the time of insertion with an inorganic salts buffer solution, which also contained nutrients. The compost moisture level was maintained between fifty and sixty percent with the addition of distilled water. Moisture content, aeration space and pH were checked weekly, whereas temperature was monitored daily. Those three parameters were monitored due to their important impact on a compost environment amenable to microbial growth and thus fabric degradation (Cooke, 1990; Haung, Shetty & Wang, 1990). The monitoring showed favorable environmental conditions for promoting an increase in the microbial population. Moisture content ranged from 38.9% to 65.1%, with a general increase over the sixteen weeks. Aeration space, which varied inversely with moisture content as expected, had a range of 44% to 60% and generally decreased over the sixteen weeks. The pH profile was in the neutral range, varying from 6.34 to 7.42. Average measured temperature exceeded ambient throughout the sixteen weeks, indicating the expected self-heating due to microbial activity. The conditions just described show the achievement of a self-heating, high-moisture, aerobic, and thus effective compost system (Shrimp, 1991).

One week later, the remaining samples for heat- moisture exposure in an oven was started. Rectangles of light-weight 100% woven cotton print cloth were draped over each sample to maintain a moist immediate environment around them. First the suspended fabric samples were saturated with distilled water and then placed in a forced - air oven Model 625 Precision Scientific. The temperature was set at the average temperature of the previous week's composting. Daily saturation of the test fabric assemblies and refilling of pans with distilled water maintained the humid atmosphere. Oven temperature was changed weekly to reflect the previous week's average composting temperature. At each time interval additional fabric samples were saturated with distilled water and suspended in the oven.

The composted samples that were recoverable were removed from the compost tumbler; air-dried at room temperature; cleaned with filtered compressed air; and returned to the standard-environment room for reconditioning. The heat-moisture test samples were removed from the oven and returned to the standard environment for reconditioning.

The effects of the treatments were evaluated through measuring the percent loss in tensile strength and percent elongation at break; and visual microbiological damage to the fibers. From each exposed sample, two machine direction and four cross direction specimen, were cut in 25 mm. X 178 mm Strips. ASTM D1117-80, Standard Methods of Testing Nonwoven Fabrics, was followed for measuring breaking load and percent elongation. Visual images was produced with a 35mm camera; and greater magnification obtained with a Sony CCD/RGB color Video camera in conjunction with a Polarizing Light III Olympus microscope.

Results

Preliminary results of this study are available.

Heat-moisture

Tensile strength of the HEC in the MD peaked after two weeks (7875g/25mm), thereafter decreasing at each time interval; in the CD the pattern was the same (4538g/25mm), but without as much variation as in the MD. The MPF/HEC fabric delaminated during testing and had partial delamination at the twelve and sixteen week time interval. The first peak in the MD represents the HEC part of the specimen, while the second peak represents the MPF. The HEC in the MD increased through the exposure periods, peaking at one week; the MPF in the MD did not change much overall, peaking at eight weeks. In the CD, the first peak represents the MPF, while the second peak represents the HEC, except at the two week time interval where only one peak occurred. The second peak in the CD (HEC), initially peaked at one week with the lowest at twelve weeks increasing at sixteen weeks. The tensile strength of the MPF/SBPP fabric in the MD, peaking at eight weeks. In the CD, peaking at 4063 g/25mm .

Percent elongation for the HEC increased at four weeks in the MD; and in the CD increased at four weeks. In the MD of MPF/HEX, the first peak (HEC) had the greatest value at sixteen weeks. In the MD, the highest value for the 2nd peak (MPF) was at twelve weeks. In the CD, there was only one peak at the two week exposure, otherwise the 1st peak (MPF) highest value was at one week; the second peak highest value was at twelve weeks. For all exposures the percent elongation of the 1st peak was in MD. In the CD there was greater variation. MPF/SBPP percent elongation at break in the MD, increased at one week exposure then decreased with time over the 16 weeks. In the CD percent elongation decreased at one, two, four, and eight week

exposures, increasing at the twelve and sixteen week exposures.

Compost

Whole HEC samples were recovered only from the one week and two week exposures; fragments were still attached to the flagging tape at the four week exposure. HEC samples were not recoverable at the eight, twelve, and sixteen week exposures; only flagging tape was left. The HEC samples recovered were too fragile to test at the same conditions as the MPF/HEC and MPF/SBPP specimens.

The MPF/HEC fabric in the MD had two peaks for the one and two week exposures; at the other exposures only one peak occurred; while in the CD there was only one peak throughout all exposures. After one week the tensile strength greatly decreased in the MD; while in the CD tensile strength decreased after one week but not as much as in the MD. The MPF/SBPP fabric in the MD had a greater tensile strength at the twelve and sixteen week exposures than the control. The two week exposure was the only case to show a less than initial tensile strength. In the CD all values were less than the initial tensile strength.

Elongation at break in the MD increased dramatically at the four week exposures, and continued to be greater than the initial percent elongation. In the CD, the percent elongation at break decreased at sixteen, four, two and one week exposures; only greater than control at eight weeks.

Conclusions

The unexpected greater variation of tensile strength in the MD of the HEC and MPF/HEC fabrics did not occur in the MPF/SBPP in the heat-moisture treatment; tensile strength varied more in the CD for the MPF/SBPP fabric. Tensile strength increased at two weeks (HEC); one week and two weeks (MPF/HEC); one, four, eight, and twelve weeks influenced by thermoplastic components. The MPF/SBPP had greater tensile strength than the MPF/HEC, even though the HEC was the strongest of the three fabrics. However, the increase in tensile strength after the heat-moisture exposure was greater for the MPF/HEC fabric than the MPF/SBPP. The heat and moisture had less of an effect on the HEC the synthetic components. The HEC fabric by itself also increased in tensile strength and percent elongation.

Composting decreased the tensile strength of the MPF/HEC fabric, however, the elongation increased dramatically in the MD as compared to the MPF/SBPP. The HEC and HEC component of the MPF/HEC was biodegraded more than the MPF/SBPP. Also, the compost exposure increased the tensile strength and elongation in the ME for the MPF/SBPP fabric, as compared to the heat-moisture exposures. The debris still left on the fabric may be influencing the trend.

Composting biodegraded the cotton containing nonwoven more than the polypropylene nonwoven, as compared to the heat-moisture exposure. Microbial activity greatly affected the tensile strength and elongation of these fabrics. The addition of the HEC enhanced the biodegradability of the nonwovens.

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Table 1. Heat-Moisture-average tensile strength. G/25mm

Fabric type	Time interval	MD	CD
HEC	control	6800	4013
	t1 - 16 weeks	5325	3113
	t2 - 12 weeks	6575	3463
	t3 - 8 weeks	6900	4063
	t4 - 4 weeks	7175	4038
	t5 - 2 weeks	7875	4538
	t6 - 1 week	6775	3763
MPF/HEC	control	3250	4025
	t1 - 16 weeks	4050	3550
	t2 - 12 weeks	4075	3650
	t3 - 8 weeks	4875	3300
	t4 - 4 weeks	3850	3463
	t5 - 2 weeks	4625	4763
	t6 - 1 week	4975	4338
MPF/SBPP	control	5100	4925
	t1 - 16 weeks	4225	3763
	t2 - 12 weeks	5275	4063
	t3 - 8 weeks	5325	3675
	t4 - 4 weeks	5200	3800
	t5 - 2 weeks	5050	3713
	t6 - 1 week	5250	3050

Table 2. Heat-Moisture-average % elongation at break

Fabric type	Time interval	MD	CD
HEC	control	38	66
	t1 - 16 weeks	38	78
	t2 - 12 weeks	38	77
	t3 - 8 weeks	37	68
	t4 - 4 weeks	42	84
	t5 - 2 weeks	39	79
	t6 - 1 week	34	81
MPF/HEC	control	42	81
	t1 - 16 weeks	47	64
	t2 - 12 weeks	44	70
	t3 - 8 weeks	51	67
	t4 - 4 weeks	41	73
	t5 - 2 weeks	47	92
	t6 - 1 week	52	89
MPF/SBPP	control	45	42
	t1 - 16 weeks	37	43
	t2 - 12 weeks	46	45
	t3 - 8 weeks	45	39
	t4 - 4 weeks	44	40
	t5 - 2 weeks	44	40
	t6 - 1 week	51	36

Table 3. Compost - tensile strength g/25mm

Fabric type	Time interval	MD	CD
MPF/HEC	control	3250	4025
	t1 - 16 weeks	525	2663
	t2 - 12 weeks	700	2875
	t3 - 8 weeks	475	2563
	t4 - 4 weeks	675	2400
	t5 - 2 weeks	1550	3113
	t6 - 1 week	3325	3313
MPF/SBPP	control	5100	4925
	t1 - 16 weeks	6050	3688
	t2 - 12 weeks	6050	3825
	t3 - 8 weeks	5675	3675
	t4 - 4 weeks	5775	3575
	t5 - 2 weeks	4900	3788
	t6 - 1 week	5500	3775

Table 4. Compost - Average % elongation at break

Fabric type	Time interval	MD	CD
MPF/HEC	control	42	81
	t1 - 16 weeks	285	80
	t2 - 12 weeks	316	82
	t3 - 8 weeks	230	58
	t4 - 4 weeks	338	38
	t5 - 2 weeks	28	63
	t6 - 1 week	39	57
MPF/SBPP	control	45	42
	t1 - 16 weeks	58	40
	t2 - 12 weeks	50	44
	t3 - 8 weeks	46	43
	t4 - 4 weeks	51	40
	t5 - 2 weeks	48	35
	t6 - 1 week	45	39

(data for second peak not included in tables)