Bull. Environ. Contam. Toxicol. (2002) 69:164–172

DOI: 10.1007/s00128-002-0043-4

Bulletin of Environmental Contamination and Toxicology

Viability of Textile Systems for Hand and Body Protection: Effects of Chemical Interaction, Wear, and Storage Conditions

M. Raheel, G. X. Dai

Department of Natural Resources and Environmental Sciences, University of Illinois at Urbana-Champaign, 905 South Goodwin Avenue, Urbana, IL 61801, USA

Received: 7 November 2001/Accepted: 7 March 2002

Hand protection is recognized as the first line of defense against chemicals or biological fluids for workers who handle these agents. Several million people annually are exposed to a variety of hazardous liquid chemicals such as pesticides or other toxic chemicals (NIOSH, 1979). Hands are especially prone to attack by chemicals since many industrial operations may involve prolonged contact of a gloved hand with toxic chemicals. Protective gloves must exhibit chemical barrier characteristics, physical and chemical integrity under use conditions, and not hinder dexterity. By the same token, full body protection is crucial for individuals who are occupationally exposed to chemicals. Many agriculturists, structural pesticide applicators, and lawn care workers prefer their everyday clothing. It is important that their clothing retain the initial level of protective efficacy after abrasion that may occur due to repeated wear and launderings.

Selection of chemical protective clothing (CPC) presents intricate problems because many parameters are involved. Chemical permeation tests (Jencen and Hardy, 1988; ASTM, 1991a) provide the most rigorous of all chemical resistance tests and measure the diffusion of chemical vapor on a molecular level through the polymeric material over a relatively short period of time. This characterization technique applies to any film-based material or adsorbent-based material. However, it does not adequately take degradation of the material into account. Liquid penetration testing (ASTM, 1991b) provides information on wetting or repellency property of materials. This type of testing is appropriate for the evaluation of material performance against liquid chemicals.

Some physical/mechanical property changes that determine material degradation include weight, thickness, strength, toughness, flexibility, puncture and abrasion resistance. Thus, a material's resistance to degradation when exposed to a target chemical or other environmental exposure conditions, as well as its resistance to chemical penetration and permeation will determine the degree of chemical protection it will provide. Material degradation testing is most useful when retention of specific physical properties is desired for multiple use items or as a screening technique for other chemical barrier testing techniques. Indeed the CPC material's chemical composition, thickness, interaction time with the target chemical and its concentration, as well as temperature are all capable of

Correspondence to: M. Raheel

influencing the degree of protection it can provide. Earlier, we have reported the effects of pesticide chemicals, sunlight and concomitant heat on structural integrity of various glove materials (Raheel and Dai, 1997a , and b). This study focuses on the effects of chemical interaction and low temperature on various glove materials; as well as the effects of abrasion that may occur due to repeated wear and laundering, on barrier efficacy of a number of fabrics used as full body protective clothing.

MATERIALS AND METHODS

The glove materials and their characteristics are given in Table 1. Also, apparel fabrics of various fiber contents, weights, geometries, and applied finishes were evaluated for pesticide retention and transport on secondary surface before and after abrasion. Fabric characteristics are given in Table 2.

The pesticide chemicals included carbaryl, a carbamate insecticide, and atrazine, a chlorinated triazine herbicide. Both pesticides were in flowable liquid formation. A 5% solution of each was prepared using distilled water.

To determine the resistance of glove materials to degradative effects of pesticide chemicals, we used a modified ASTM Test Method for Rubber Property - Effect of Liquids D471-79 (ASTM, 2001). Glove samples were exposed to pesticide solutions for 8 hr. The effects of chemical exposure were assessed in terms of weight and thickness change, effect on tensile strength and elongation, flexural rigidity, and puncture resistance. Standard methods of the ASTM (2001) were used for testing tensile, elongation, and flexural rigidity properties. Puncture resistance was assessed according to the method described by Lara et al. (1992). All tests were performed in triplicate except thickness change for which an average of ten tests performed at difference areas of the test sample are reported. Student's *t*- tests were performed to discriminate significant changes in properties between the control and treated samples. Statistical significance of data are reported at $\alpha \leq 0.05$.

Glove materials, PVC, latex, natural rubber, neoprene, nitrile, and Viton® were kept at -3°C for ten days. After conditioning the samples at ambient temperature for 24 hr, their flexural rigidity, puncture resistance, and tensile properties were evaluated as per standard methods of the ASTM described earlier.

Fabrics of different fiber contents, weights, geometries, and applied finishes were subjected to 25 cycles of abrasion , using a Tabor abrader, according to ASTM D3884-80 method (ASTM, 2001). This level of abrasion was selected based on visual analysis of reusable garment surfaces of pesticide applicators clothing after 30 repeated wear and launderings.

Table 1. Characteristics of glove materials

Composition	Model	Thickness mm	Weight mg/cm^2	Flexural rigidity g-cm	Breaking load N	Elongation at break %	Puncture resistance N
Polyvinyl Chloride (PVC)	Pioneer, Stan Flex	0.11±0.005	14.2±0.54	0.75±0.0	33.8±5.3	370±73.3	6.6±1.0
Latex	Edmont	0.12±0.004	12.4±0.32	0.04±0.0	60.7±3.7	1278±42.7	0.9±0.2
Natural Rubber	Granet, 541	0.44±0.012	47.3±1.09	1.15±0.0	170.8±6.5	1083±37.1	13.7±2.3
Neoprene	Ansell	0.47±0.015	59.4±1.17	1.45±0.1	106.1±4.8	1078±81.7	35.7±3.4
Nitrile	Best, 727	0.29±0.009	30.7±0.63	1.08±0.1	168.5±5.1	369±21.7	19.8±4.6
Viton®	North, F-101	0.29±0.022	56.0±3.33	0.64±0.1	88.2±6.3	914±52.0	6.2±1.0

Table 2. Fabric characteristics

Fabrics	Fabric weight (g/m^2)	Fabric thickness (mm)	Yarns/cm W x F	Yarn twist turns/cm W x F
Cotton broad cloth #419A[a]	115	0.215	57 x 25	9 x 9
Cotton twill #423	295	0.495	33 x 24	7 x 5
Cotton poplin #407	222	0.363	44 x 23	7 x 5
P/C 50/50 poplin #7428	210	0.333	44 x 20	7 x 5
P/C 50/50, DP[b] #7428	210	0.337	44 x 20	7 x 5
P/C 50/50, SR[c] #7428	210	0.327	44 x 20	7 x 5
P/C 65/35 poplin #7402	180	0.274	44 x 23	7 x 5
P/C 65/35, DP #7402	183	0.274	44 x 23	7 x 5
P/C 65/35, SR #7402	183	0.274	44 x 23	7 x 5
P/C 65/35, Twill	257	0.451	20 x 23	5 x 4
P/C 50/50, Twill	216	0.420	28 x 21	7 x 6
P/C, 40/60, Twill	232	0.457	23 x 18	5 x 4
100% Cotton, Twill	265	0.532	37 x 21	6 x 4
Spun Dacron #767	116	0.236	25 x 19	8 x 7
Spun Nylon #361	150	0.325	21 x 23	6 x 8
Spun Orlon #864	140	0.325	19 x 15	5 x 5
100% Olefin, Tyvek	40	0.091	-	-

a - Testfabrics Inc., Middlesex, NJ, USA-Fabric numbers
b-DP = Durable-press finish
c- SR = Repellent finish

Liquid penetration tests on new and abraded specimens were conducted to assess the effect of abrasion on barrier effectiveness of protective materials. Liquid breakthrough (capillary transport) was measured using a TRI Liquid Breakthrough Tester Model CS-244 (Custom Scientific). The barrier fabric (top-layer), 6.0 cm wide, was placed over 100% knit cotton fabric (sub-layer receptor), and 1 kilogram weight was attached to each end of the barrier fabric pulley system to keep it in contact with knit cotton sub-layer in a reproducible fashion. The pressure applied on fabric can be calculated by the equation:

$$P = W / r.d \qquad [1]$$

where, W = weight in g, r is the radius of the anvil holding the fabric system, and d is the width of fabric in cm. Thus the pressure on fabric system was 37.0 g/cm^2 unless otherwise stated.

RESULTS AND DISCUSSION

Chemical Resistance of Protective Gloves: Among the gloves tested, two were disposable type (PVC and latex) and four were reusable. The reusable gloves are expected to receive prolonged exposure to chemicals and the detrimental effects

Table 3. Percent change in physical properties of glove materials due to pesticide solution exposure (8 hr)

Glove Composition	Pesticide 5% soln.	Thickness mm	Weight mg/cm2	Flexural Rigidity g-cm	Breaking Load N	Puncture Resistance N
Polyvinyl Chloride	Carbaryl	+5.0 ± 0.6	+0.8 ± 0.01	-10.0[a] ± 0.5	-14.2[a] ± 3.8	+9.3 [a] ± 1.7
(PVC)	Atrazine	-0.3 ±0.04	+0.4 ± 0.02	-23.6[a] ± 1.4	+9.4[a] ± 1.2	+30.5[a] ± 1.9
Latex	Carbaryl	-1.7 ±0.02	-5.1 ± 0.9	-22.3[a] ± 1.2	-7.3[a] ± 1.3	+38.1[a] ± 2.3
	Atrazine	-3.0 ±0.39	-5.7 ± 0.1	-17.3[a] ± 1.0	-4.0[a] ± 0.9	+58.2[a] ± 4.6
Natural	Carbaryl	-0.5 ±0.01	-0.2	-9.0[a] ± 0.4	+2.7 ± 0.1	-4.7[a] ± 1.2
Rubber	Atrazine	-0.9 ±0.01	-6.2 ± 0.17	-14.7[a] ± 0.7	-8.4[a] ± 1.2	-3.2[a] ± 1.1
Neoprene	Carbaryl	ND [b]	ND	-1.8 ± 0.7	-4.0[a] ± 1.0	-2.3 ± 0.9
	Atrazine	-0.5 ±0.01	+0.1	-7.6[a] ± 0.4	-7.5[a] ± 1.9	-1.1 ± 0.1
Nitrile	Carbaryl	+0.6 ±0.01	+0.4	-12.1[a] ± 0.6	+0.5	+5.0[a] ± 1.1
	Atrazine	+0.8 ±0.03	ND	-16.1[a] ± 0.9	-3.2 ±1.2	+14.1[a] ± 2.7
Viton®	Carbaryl	ND	ND	-1.1 ± 0.0	+0.3	+1.1 ± 0.2
	Atrazine	ND	ND	-2.0 ± 0.0	+1.0	+2.1 ± 0.7

a - significant at $\alpha \leq 0.05$ b - not detected of light and concomitant heat, or low temperature that may occur during use or storage. Earlier, we have reported the results of irradiation and heat (Raheel and Dai,1997, b). Results of chemical interaction as shown in Table 3, revealed that glove materials exhibited differential chemical resistance as indicated by changes in physical and mechanical properties. Latex and rubber glove materials showed reduction in weight due to exposure to both pesticides. This indicates chemical interaction between the pesticide chemicals and the glove polymer or filler, henceloss of weight and thickness. There was a slight gain in weight and thickness in PVC glove material indicating chemical diffusion and swelling. Neoprene and Viton® did not indicate interaction with chemicals based on physical property data. All glove materials showed reduction in flexural rigidity which was statistically significant in the case of PVC, latex, rubber neoprene and nitrile. The puncture resistance of PVC, latex, and nitrile gloves increased as a result of chemical exposure, this corresponds with the decrease in flexural rigidity of these glove polymers, hence increased flexibility and puncture resistance. Neoprene and Viton® did not reflect significant change. However, natural rubber did not show increased puncture resistance even though it had become limp due to pesticide exposure, this result suggests polymer degradation. Thus, the disposable gloves as well as natural rubber reusable gloves showed a much higher level of chemical degradation compared to neoprene, nitrile and Viton®.

Effects of Low Temperature on Protective Gloves: The glove materials, PVC, latex, natural rubber, neoprene, nitrile, and Viton® were kept at -3°C for ten days. After the samples were conditioned at ambient temperature for 24 hr, their flexural rigidity, puncture resistance, and tensile properties were evaluated. As shown in Table 4, the flexural rigidity of latex, neoprene, nitrile, and Viton® glove polymers was reduced, that is, they became limp, especially nitrile glove material. Also, their puncture resistance decreased in the range of 2-38 %. As shown in Table 5, latex, rubber, neoprene, nitrile, and Viton® glove polymers

Table 4. Flexural rigidity of glove materials after freezing at -3 °C for 10 days[a]

Glove Material	Flexural Rigidity		
	Original g-cm	Treated g-cm	Change %
PVC	0.121	0.117	-2.91 ± 0.7
Latex	0.039	0.036	-8.00 ± 1.2^b
Natural Rubber	1.340	1.303	-2.92 ± 0.8
Neoprene	1.078	1.000	-5.62 ± 0.9^b
Nitrile	0.514	0.364	-29.19 ± 1.2^b
Viton F-101	0.960	0.873	-9.02 ± 0.9^b

a - Glove polymers conditioned for 24 hr at ambient temperature before testing.
b - significant at $\alpha \leq 0.05$

Table 6. Liquid retention and penetration in fabrics before and after abrasion

Fabrics	Atrazine[a], 32.87[b]				Carbaryl[a], 35.75[b]			
	unabraded		abraded[c]		unabraded		abraded[c]	
	% Liq. retention[d]	% Liq. penetration[d]	% Liq. retention	% Liq. penetration	% Liq. retention	% Liq. penetration	% Liq. retention	% Liq. penetration
Cotton Broad Cloth	41.55	58.46	49.26[e]	50.74[e]	39.02	60.98	37.05	62.95
Cotton Twill	82.08	17.92	96.56[e]	3.44[e]	88.73	11.27	98.98[e]	1.02[e]
Cotton Poplin	71.85	28.15	92.70[e]	7.30[e]	78.76	21.24	73.85[e]	26.15[e]
P/C 50/50 Poplin	62.49	37.51	82.10[e]	17.90[e]	54.12	45.88	62.35[e]	37.65[e]
P/C 50/50, DP	24.38	75.62	22.54	77.46	37.11	62.89	16.64[e]	83.36[e]
P/C 50/50, SR	<1.00	ND[f]	<1.00	ND	<1.00	0.65	<1.00	ND
P/C 65/35 Poplin	40.88	59.12	53.75[e]	46.25[e]	39.76	60.24	47.77[e]	52.23[e]
P/C 65/35, DP	36.56	63.44	40.76[e]	59.24[e]	35.66	64.34	40.80[e]	59.19[e]
P/C 65/35, SR	<1.00	ND	<1.00	ND	<1.00	0.30	<1.00	ND
P/C 65/35 Twill	52.60	47.40	56.64[e]	43.36[e]	45.11	54.89	47.83	52.17
P/C 50/50 Twill	98.71	1.29	77.28[e]	22.72[e]	99.30	0.70	96.07[e]	3.93[e]
P/C 40/60 Twill	98.71	1.29	98.95	1.05	99.31	0.69	99.97	ND
100% Cotton Twill	99.40	0.60	99.97	ND	99.27	0.73	99.98	ND
Spun Dacron	18.54	81.46	8.56[e]	91.44[e]	23.60	76.40	10.36[e]	89.64[e]
Spun Nylon	11.35	88.65	12.54	87.46	6.90	93.10	4.40	95.60
Spun Orlon	19.65	80.35	12.77[e]	87.23[e]	9.88	90.12	7.38[e]	92.62[e]
100% Olefin Tyvek	<1.00	ND	<1.00	ND	<1.00	ND	<1.00	ND

a -5.0% Atrazine,or Carbaryl
b - Surface tension (dynes/cm)
e - significant at $\alpha \leq 0.05$
c - 25 cycles of Tabor Abrader
d - Liq. contact time 1 min.
f - Not detected

Table 5. Puncture resistance of glove materials after freezing at -3 °C for 10 days[a]

Glove Material	Puncture Resistance Original N	Treated N	Change %
PVC	1.82	1.84	-2.06 ± 0.16
Latex	2.76	1.71	-38.27 ± 2.1 [b]
Natural Rubber	6.29	4.98	-20.74 ± 7.7 [b]
Neoprene	13.50	9.41	-30.43 ± 2.8 [b]
Nitrile	13.29	10.86	-18.29 ± 1.9 [b]
Viton F-101	6.03	5.74	-5.34 ± 0.6 [b]

a - Glove polymers conditioned for 24 hr at ambient temperature before testing.
b - significant at $\alpha \leq 0.05$

showed a highly significant reduction in puncture resistance. However, there were no significant changes in tensile property of the materials.

Effect of Abrasion on Barrier Properties of Protective Clothing: Pesticide solution retention and penetration in fabrics was assessed before and after abrasion. Results are shown in Table 6. In general, as expected, the woven fabrics allowed much greater penetration of liquids than non-woven (Tyvek®) and repellent finished fabrics. Also, significant differences existed due to fiber content, weight, and geometry. Abrasion increased surface fuzziness in fabrics containing staple fibers, especially cellulose fibers hence, there was an increase in liquid holding capacity and less liquid penetration in cotton, and high cotton containing fabrics. However, there was a much higher level of liquid penetration and transport on secondary surface in synthetic fiber containing new and abraded woven fabrics compared to cotton fabrics. This is due to their high wicking property. Durable press (DP) finish imparted some hydrophobicity to cellulose fabrics, thus reducing their liquid holding capacity which resulted in somewhat higher liquid penetration compared to similar fabrics without DP finish. Repellent finished (SR) fabrics maintained their excellent barrier property even after low level of abrasion in this study, as did the non-woven Tyvek® fabric. Nevertheless, fabric weight, geometry and repellent finishes were the overriding factors affecting liquid retention and penetration.

Acknowledgments. This research was funded by the Illinois Agricultural Experiment Station, under Project # 60-0383.

REFERENCES

American Society for Testing and Materials (1991a) Test Method F739, resistance of protective clothing materials to permeation by liquids and gases. ASTM Standards on Protective Clothing, American Society for Testing and Materials, Philadelphia, PA.

American Society for Testing and Materials (1991b)Test Method F905, resistance of protective clothing materials to penetration by liquids. ASTM Standards on Protective Clothing. American Society for Testing and Materials, Philadelphia, PA.

American Society for Testing and Materials (2001) , ASTM Standards , 7.02: American Society for Testing and Materials, Philadelphia, PA.

Jencen DA, Hardy, J K (1988) Method for the evaluation of the permeation characteristics of protective glove materials. American Ind Hyg Assoc 49: 293-300

Lara J, Nelisse NF, Cote S, Nelisse HJ (1992) Development of a method to evaluate the puncture resistance of protective clothing materials. In: McBriarty J P, Henry, NW (eds), Performance of Protective Clothing: Fourth Volume, ASTM STP 1133, American Society for Testing and Materials, Philadelphia, PA. 26-37

National Institute for Occupational Safety and Health (1979) Development of performance criteria for protective clothing used against carcinogenic liquids (DHEW/NIOSH Pub. No. 79-106). Arthur D. Little, Cambridge, Mass.

Raheel M, and Dai GX(1997a) Chemical resistance and structural integrity of protective glove materials. J Environ Sci Health A32: 567-579

Raheel M, and Dai GX. (1997b) Effects of chemical, sunlight and heat exposure on barrier properties and structural integrity of protective gloves. In: Gatewood BM, Lewis AM, Robinson AC, (eds). Proceedings of the Third International Symposium on Consumer and Environmental Issues pp. 244-255.

Stull J O, White DF, and Greimel T C (1992) A comparison of the liquid penetration test with other chemical resistance tests and its application in determining the performance of protective clothing. In: McBriarty JP, Henry NW (eds.), Performance of Protective Clothing: Fourth Volume, ASTM STP 1133, American Society for Testing and Materials, Philadelphia, PA.123-138.